USING LEAN TECHNIQUES TO REDUCE WASTE AND IMPROVE PERFORMANCE IN MUNICIPAL CONSTRUCTION PROJECT DELIVERY

by

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I would like to express my gratitude to my mom for her love and support throughout my life. Thank you for giving me strength to reach the stars and chase my dreams. My wife, brothers, sisters, and friends deserve my wholehearted thanks as well.

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Abstract

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The basic concepts of lean thinking in construction projects are to reduce waste, improve communication, and promote teamwork integration through a common set of tools and techniques. With increased demand for public works projects, there is a need to focus attention on the efficient delivery of construction project services in the public sector, and in particular, on municipal project delivery. Municipal projects are a part of the public works which include a broad category of infrastructure projects, financed and constructed by the local government, for uses in the greater community. Municipal construction projects have special challenges that may differ from other construction projects. These projects include a vast area and scatter around the city and local government region. The objectives of this thesis are to analyze how lean construction techniques improve performance and productivity in municipal project delivery, and provide a new knowledge of how lean techniques can reduce non-physical waste related to project delivery process. The scope of the thesis is limited to use of lean construction techniques to overcome problems, facilitate project progress, and offer recommendations for better municipal construction project processes. This study adapts and extends a non-physical controllable waste classification using the Analytical Hierarchy Process (AHP).

Utilizing AHP, this thesis determines a goal, identifies and categorizes the waste, and takes the action by applying the appropriate lean techniques. A comparison-based survey was conducted to quantify relative priorities for a given set of alternatives on a ratio scale based on the judgment of the construction professionals' experience. Through the AHP approach, the thesis identified and prioritized parameters to reach the optimum goal of waste reduction and performance improvement.

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Chapter 1

INTRODUCTION

Reducing the time from start to delivery by eliminating the source of waste in the work flow is one of the basic concepts of lean enterprise. In construction, lean techniques are used to reduce waste and increase productivity. Lean enterprise is to achieve owner expectations through the use of the absolute minimum amount of man, machine, and material. This is achieved by continuous pursuit, identification and elimination of waste through a systematic approach that relies on team-integration and effective communication (Odomirok, 2015). Improper information and communication process in the construction industry leads to change orders, rework, decreased constructability, cost overruns, and delays, making it one of the biggest causes of waste, especially in the public sector. The municipal construction projects is one of the sectors where improvement is very much needed due to the frequent incompatibility and discrepancy between the design information provided and the actual site conditions, especially for the improvement and renovation projects in the old urban areas. To improve these projects, the concept of lean techniques offers new insight into the dynamics of innovation and provides a clear vision of what these projects are trying to achieve in regards to the impact of the work method governing these projects. Some of the lean techniques used in this thesis include, detection of incompatibility and discrepancy, look-ahead planning, percentage of planned completed, root cause analysis, process evaluation, constraint analysis, concurrent engineering, standardization of work process, and others that will be defined later in the following chapters.

1.1 Motivation

In August 2014, City of A (a City with 200,000 people in North Texas) decided to suspend construction of a $600,000 project of a sidewalk, hardscaping[1] and landscape improvement in its downtown area due to improper design. The problem had arisen after detection of incompatibility and discrepancy between the design information provided and the site actual conditions. The poor level of communication between the three parties, owner, designer, and contractor, contributed to the failure of the construction process and led in project suspension.

The project appeared to be simple, but several constraints beyond the contractor's control had severely impacted the construction schedule and caused delays. Initial issues with condition survey, drainage, gas line, old and deteriorated water pipe leaks, underground electrical conduit, differing surface conditions, and restriction with project sequencing due to limited access to shopping center parking areas all affected construction efficiency, and impacted the construction activities.

This case is an example of the necessity for improvement with the information and communication processes within traditional contract practices that are used in these types of projects. Moreover, communicating with general contractors indicated similar situations in previous projects within North Texas, which give these problems a redundancy feature that might continue affecting contractors in similar projects in the future.

1.2 Need Statement

As per Aziz and Hafez (2013), several partial studies from various countries have confirmed that waste in the construction industry represents a relatively large percentage

[1] The placement of non-plant elements such as fences, walkways, paving, and lighting in a planned outdoor area (www.en.wikipedia.org).

of production costs. Furthermore, they argued that "the existence of significant number of waste types in the construction industry has depleted overall performance and productivity in the industry, and certain serious measures have to be taken to rectify the current situation." Literature review investigation does not show specific research in applying lean concepts in municipal project delivery. Furthermore, it shows similar situations and issues facing the construction projects regarding this subject, and the previous researchers acknowledged that improvement is needed, for example Jones (2009), Hosseini et al. (2012), and Aziz & Hafez (2013).

1.3 Thesis Statement and Question

It is hypothesized that the implementation of lean techniques is directly related to the improvement of performance and productivity in municipal construction projects. The main purpose of lean techniques is to find the waste in each process and isolate them. Waste does not improve the value; it only increases the cost, at the same time decreasing the quality, productivity, and satisfaction of the project owner. Waste can be removed by adequate planning, proper supervision, right decision making, quality standards, accurate information and methods, better resource use, and effective execution led by the construction team. Hence the careful elimination of waste leads, foremost, to cost reductions and performance improvement. Generally, all the construction companies aim for high quality projects, on-time, and within budget completions. Construction companies implementing lean techniques in their work-sites will have improved performance due to the inherent characteristics of lean construction.

These characteristics, such as the stabilization of work process, the use of concurrent engineering[2], and the last planer system[3], encourage waste reduction in the

[2] Parallel execution of various tasks by multidisciplinary project teams with equal goal and vision

work process, an orderly work performance, and overall increased task predictability and flow reliability. The research conducted for this thesis addresses the existing synergy between the implementation of lean construction techniques and process practices and how these results are prioritized to reduce waste and improve performance and productivity. Figure 1.1 demonstrates the concept of research being applied in order to eliminate the waste in the project process to reach better project outcome. From the left to the right, eliminating the waste in the construction project process is possible through adopting lean principles and using lean techniques to improve performance and obtain better outcome.

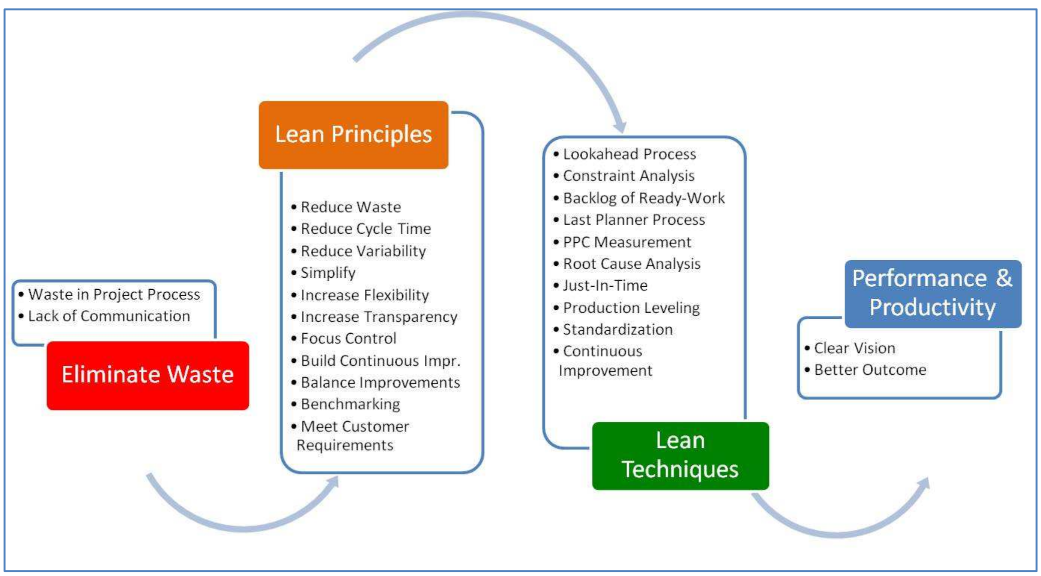

Figure 1.1 Thesis Statement

1.4 Thesis Objectives

The key question this thesis presents is: How does the implementation of lean techniques affect project performance? This question was further narrowed down into the

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[3] An effective methodology that advantageously improves workflow efficiency by stabilizing the workflow in construction sites while protecting it from variability.

following sub-questions: (a) what specific techniques and methods of lean construction reduce waste and improve performance efforts? (b) what is the correlation, if any, between the implementation of lean construction techniques, controllable waste, and performance? And (c) what are the priorities and consistency measurements to evaluate lean alternatives to find out the best criteria to attain their goal?

As a response to above questions and the construction problems previously discussed, the objectives of this thesis are:

(1) To analyze how lean construction techniques improve performance and productivity in municipal project delivery.

(2) To provide a new knowledge to the existing literature on the topic of how lean techniques can reduce waste in municipal project delivery process.

(3) To gain a better understanding of the nature of information and communication process between the construction firms and their clients through the eyes of those directly involved in the industry.

Figure 1.2 demonstrates the thesis objective as a set of toothed wheels that work together, where application of lean techniques clockwise will gear up to reduces the waste counter-clockwise, which in turn drives up the wheel of performance and productivity improvement in construction project process.

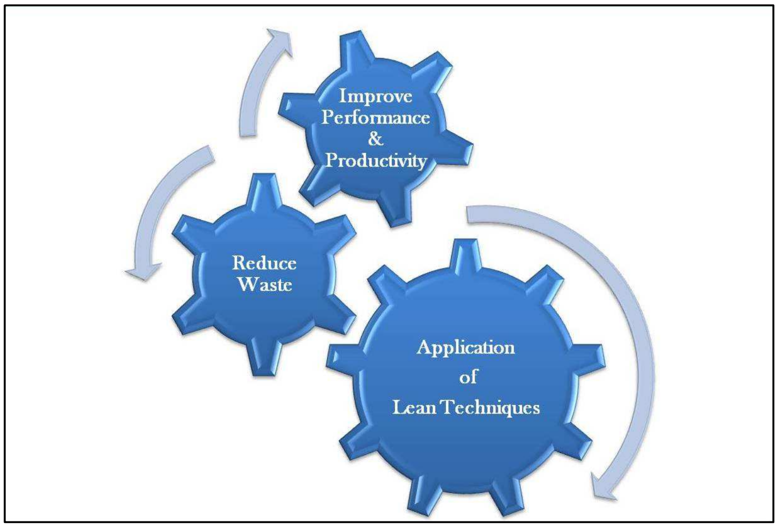


Figure 1.2 Thesis Objectives

1.5 Thesis Methodology

A research methodology approach known as The Analytic Hierarchy Process (AHP) was applied in this thesis. AHP is a method for the mathematical treatment of decision problems, and it is recommended for stakeholder's decision-makers. This research approach is utilized to prioritize lean techniques and how they reduce waste, obtain required results, and look for continuous construction improvement. The thesis methodology is conducted through the following steps:

1) Identify the waste associated with the municipal construction projects process
2) Specify waste in certain categories
3) Structure the decision factors in a hierarchy
4) Conduct survey of industry professionals
5) Analyze the data and discuss the results

Figure 1.3 illustrates the overall thesis methodology starting from the top left quarter where problem observation sparks motivation. This helps to establish the given point of departure in the next right quarter by reviewing the literature and determining the thesis method. Research task followed in the bottom right quarter, and it was generated through data collection, analysis and result. The methodology ends in the bottom left quarter as predicted improvement outcome and recommendations offer for future research.

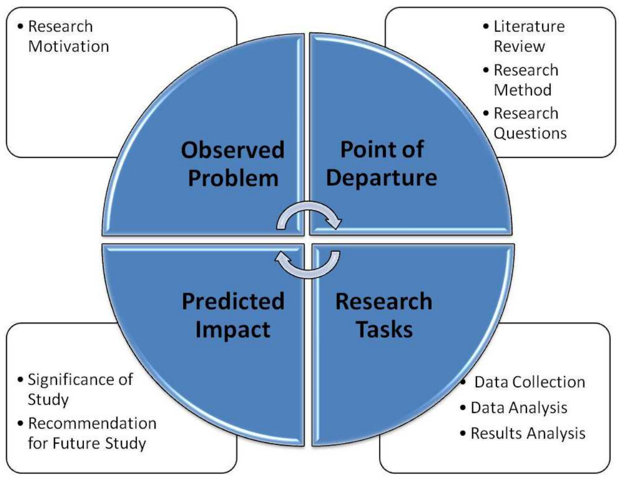


Figure 1.3 The Overall Research Methodology

1.6 Thesis Organization

Chapter 1 presents background, motivation, need statement, research statement and question, objective, methodology, and expected outcome of this thesis. Chapter 2 provides background and a literature review on the municipal project delivery methods, lean construction, waste in construction, information system and communication, and productivity and performance measurement. Chapter 3 outlines in details a methodology behind this thesis by giving a step by step narrative on the research performed. Chapter 4 outlines results of the thesis. Chapter 5 draws conclusions and offers recommendations for implementation and further research. References and appendices are provided at the end of this thesis.

1.7 Expected Outcome

This thesis is expected to provide more efficient information on methods, better communication processes, and to facilitate project team-integration by using lean techniques. This integration will help entrepreneurs, owners, designers, and stakeholders, especially in the municipal construction projects to reduce waste, increase productivity, and open the door for more application in public work projects in the United States. This research will discuss principles, methods, techniques, and implementation phases of lean construction showing the waste in construction and how it could be minimized. Improvements using lean techniques are considered to overcome these problems and offer recommendation for better performance, improvement, and project success.

1.8 Chapter Summary

Waste reduction in order to improve performance and productivity is one of the basic concepts of lean thinking. A case sparks a concern of the necessity for improvement with the construction delivery process within traditional method practices in municipal construction project. The main research objective is to analyze how lean construction techniques can improve performance and productivity in municipal project delivery. Lean techniques provide a clear vision of what these projects are trying to achieve in regards to the impact of the work method. The research method used in this thesis will discuss principles, methods, techniques, and implementation phases of lean construction showing the waste in construction. This chapter presented motivation, need statement, objectives, methodology, and expected outcome for this thesis.

Chapter 2

BACKGROUND AND LITERATURE REVIEW

Chapter one discussed the motivation behind the thesis, need statement, objectives, methodology, and the expected outcome. This chapter provides background and a literature review on the subject of improving performance and productivity in municipal projects. It covers research that has been previously conducted on methods used by municipal construction projects as well as lean construction, waste in construction, productivity and performance measurement, and information system and communication.

2.1 Municipal Construction Project Methods

Municipalities as a public work sector or local government have a variety of choices in project delivery methods available for construction projects. Design-Bid-Build (DBB), Design-Build (DB), Construction Manager at Risk (CMR), and Competitive Sealed Proposal (CSP) are most often used on municipal construction projects. Public works projects (as historically recognized in the United States) include public buildings (municipal buildings, schools, hospitals), transport infrastructure (roads, railroads, bridges, pipelines, canals, ports, airports), public spaces (public squares, parks, beaches), public services (water supply, sewage, electrical grid, dams), and other, usually long-term, physical assets and facilities. Maurer (2001) stated that “almost all of its work is completed with the traditional design, bid and build mode used in municipal engineering as required by state statute.” In addition, Ahmed and Forbes (2011) stated the following:

> “DBB has many well-known shortcomings: there is [a] greatly protected process [for] programming, design, bidding and bid award, followed by construction. Oftentimes, delay[s] further extend the [duration of project] and may result in cost

inflation as the time extends. Litigation and dispute are very common with this method of construction delivery because of dissonance between the expectations of the three parties—owners, designers, and contractors. Furthermore, the lack of communication and the fragility of the information process connecting all those three parties during the construction phase result in frequent failure." (p. 10)

Figure 2.1 illustrates the relationship between the parties involved in the Design-Bid-Build process where the owner engages an engineer to prepare the design and presented to contractors who bid for the work and possibly engage subcontractors to provide specialty construction of the project (Hasan, 2010).

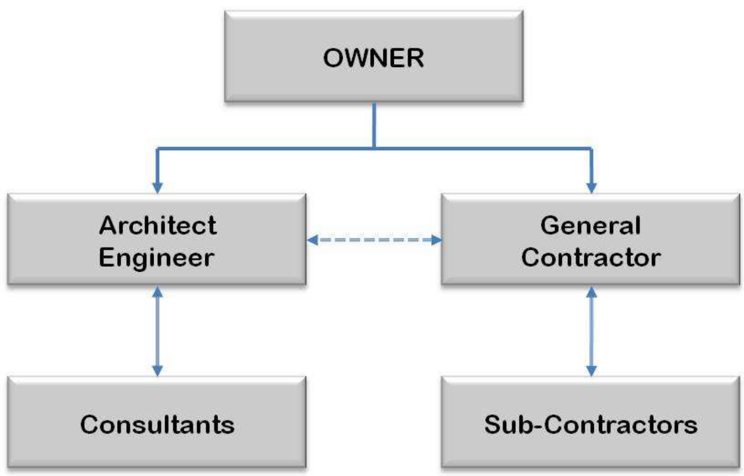


Figure 2.1 Design-Bid-Build Method

2.1.1 Limitations in Traditional Construction Method

The traditional Design-Bid-Build (DBB) method has been used by construction industry for several decades. DBB requires an architectural consulting team to develop the project documents for the owner, after which the owner sends the plans out for competitive pricing from contractors and then selects a contractor to build the project. In this case, the owner is at risk to contractor for design errors. Design and construction are sequential, typically resulting in longer schedules, and construction cost is unknown until contract award. Figure 2.2 demonstrates the Design-Bid-Build construction phases from top to bottom, where traditional project management is very limited in its ability to reduce project variability.

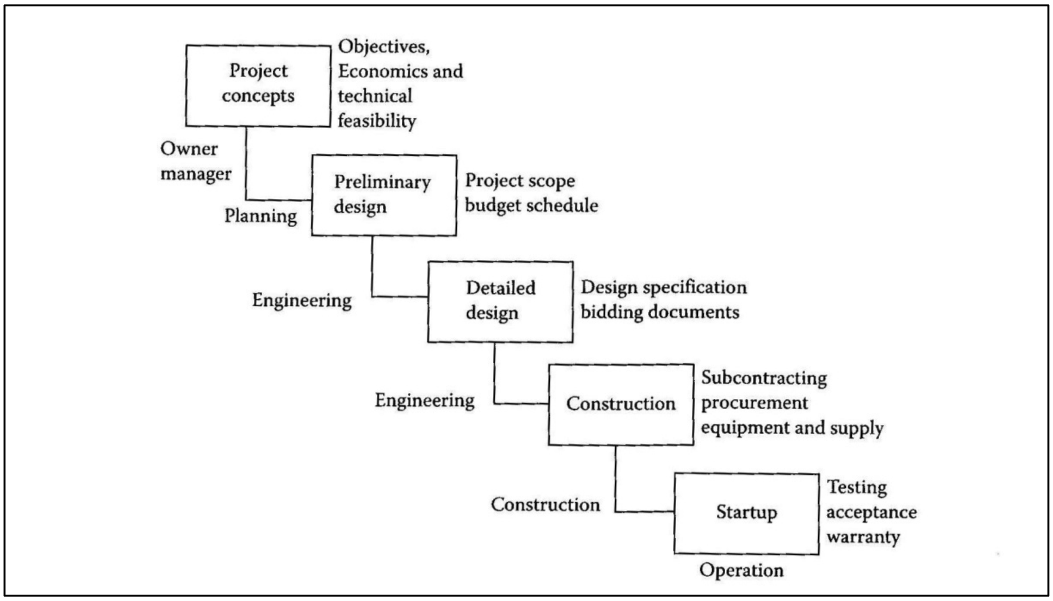


Figure 2.2 Traditional Design-Bid-Build Construction Phases (Ahmed & Forbes, 2011)

2.1.2 Process Methodology in Traditional Construction Method

Figure 2.3 illustartes the serial iteration process in the manufacturing industry, which depends on a methodical process from organization to organization until a project is finally delivered. However, the construction industry follows the same process methodology in its traditional delivery method in which organizational barriers (fences) prevent contractor and designer relationships from developing. One result of this is that errors usually are not detected until after the work has been passed on. In the end, this process leads to costly rework. Although the project eventually gets delivered, the process usually takes too long and costs too much, and the end project may be of questionable quality. Traditional project management also involves a culture of "pushing" work assignment to subcontractors in order to meet the master schedule, whether or not these procedures have all the needed resources to complete those assignments in the given week (Ahmed and Forbes, 2011).

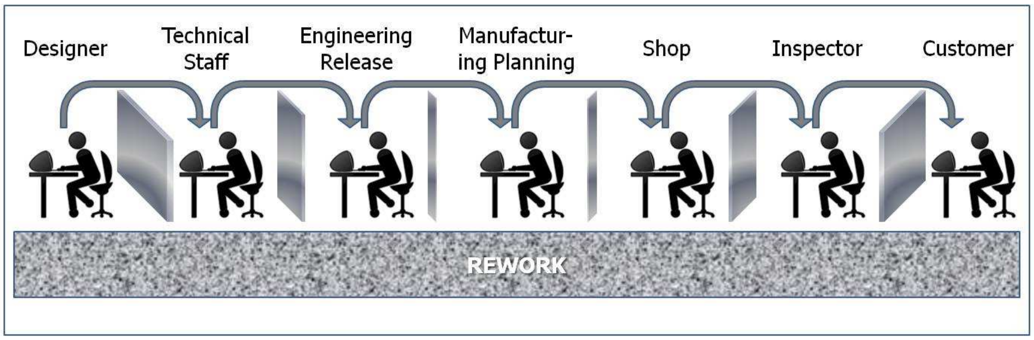


Figure 2.3 Serial Iteration Process

2.1.3 Limitations of Traditional Contracting Contracts

Traditional contracts have many disadvantages which need to be considered upon selection. In Ahmed and Forbes (2011), the authors pointed to four systemic problems presented by Matthew and Howell (2005) with traditional contracting that can be addressed with a relational contracting approach: (1) Design ideas often lack field input, (2) cooperation and innovation are inhibited, (3) planning systems are not coordinated, and (4) self-preservation is the subcontractors' mantra. Ahmed and Forbes (2011) argued that "the traditional contracts provide little incentive for subcontractors to collaborate or cooperate with each other, as each is driven by contract language to selfishly focus on [timely] completion of their portion of the project within budget."

2.1.4 Philosophical Differences between Lean Construction and Traditional Construction

The application of DBB and lean construction method in construction project process is widely different, where each method emphasizes a specific performance concept. According to Ahmed and Forbes (2011):

“Lean construction departs significantly from traditional project management practices. Processes are actively controlled, and metrics are used in planning system performance to assure reliable workflow and predict project outcome. Lean methods attempt to optimize performance at the project level, whereas current project management approaches reduce total performance by attempting to optimize each activity. Traditional construction approaches reward [each] individual crews’ performance; crews may focus on their tasks to the detriment of the other crews.” (p. 59)

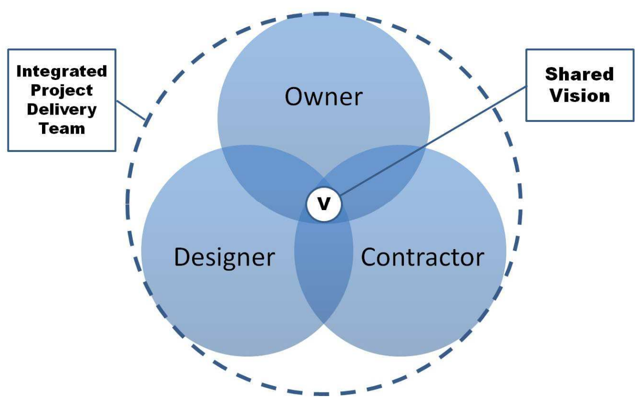


Figure 2.4 Lean Concept of Integration System

In the lean approach (Figure 2.4), all involved disciplines work as integrated project team with a shared vision, and they are rewarded for completing major sections of the project. Lean construction succeeds by optimizing at the project level, as opposed to the local optimization of an individual subcontractor.

2.2 Lean Construction

According to Antillon (2010), lean construction refers to the application and adaptation of the underlying concepts and techniques of lean production as a new philosophy of production for construction. The industry has adapted this production model as a means for improving its performance and reducing the waste that tends to exist in the construction industry. Lean production focuses on the reduction of waste, increase of value to the owners, and continuous improvement. Several of these lean production concepts and techniques have been successfully implemented in the construction industry from which effective lean construction tools, such as the Last Planner System, have been developed (Antillon, 2010).

2.2.1 Defining Lean Construction

Lean construction has been defined in several ways as the concept continues to evolve. The Construction Industry Institute (CII) has defined lean construction as “the continuous process of eliminating waste, meeting or exceeding all owner requirements, focusing on the entire value stream, and pursuing perfection in the execution of a constructed project” (CII Lean Principles in Construction Project Team, PT 191). As per Ahmed and Forbes (2011), Koskela (2002) described lean construction as “a way to design production systems to minimize waste of materials, time, and effort in order to generate the maximum possible amount of value for the customer (both internal and external).” (p. 45).

2.2.2 Lean Principles

Lean thinking has been summarized in the following five principles, which are the core concepts of lean production as presented by Ahmed and Forbes (2011) according to Womack and Jones (1996): (1) Precisely specify value by specific product, (2) Identify the value stream for each, (3) Make value flow without interruptions, (4) Let the customer pull value from the producer (use a pull logistic), and (5) Pursue perfection. As per Antillon (2010), Womack and Jones (1996, p. 15) also concisely summarized these principles of lean production in lean thinking in which the authors stated that “a lean way of thinking allows companies to specify value, line up value-creating actions in the best sequence, conduct these activities without interruption whenever someone requests them, and perform them more and more effectively."

2.2.3 Lean Construction Tools and Techniques

Lean production has several tools and techniques that have evolved since the beginning of it is application in the construction industry. These tools and techniques continue to develope as more understanding and experience develops. Lean construction has been identified as trying to develop a list of the most prominent and exhaustive tools and techniques that are being implemented in today's construction industry and that might also impact performance practices. Some of the tools related to the topic of study are: [Constraint analysis, look-ahead planning, the Percent Plan Complete (PPC) measurement, concurrent engineering, just-in-time, resources managing, immediate problem detection, standardization, detection of incompatibility and discrepancy, process evaluation, team integration, use of visual indicators and continuous improvement][4]. The implementation of such lean tools and techniques had significantly reduced waste and improved performance in construction projects.

2.2.4 Systems Perspective of Lean

The system perspective of lean, as presented by Ahmed and Forbes (2011), stated that the time a product spends in a production system is an important measure of efficiency. Figure 2.5 demonstrates the impact of value-added (process time) versus non-value added time (move, wait, and setup time) in construction project activity.

Ahmed and Forbes listed three assumptions for the systems perspective of lean, the cost of a product related to the length of time in the system, the shorter the time in the

[4] These terms are defined in Appendix A, page 67 & 68.

system, the better the producer can meet the owner's delivery requirement, and the shorter the time in the system, the smaller the probability of operational problems.

Ahmed and Forbes (2011) described the system components in four time zones, move time, wait time, setup time, and process time, and they desribed it as follows:

> "Move time represent the time required to move a product or service from one work station to another or from a queue to a processing activity. Move time does not add value. Wait time which is the sum of all phases in a system in which a product or service is waiting to be transformed. Efficiency is negatively impacted the longer the wait time, as it does not add value. This wait time is directly influenced by such issues as equipment downtime, material shortages, and unbalanced lines. Setup time is the time where preparations are made for a process by adjusting equipment, material, procedures, and so forth in anticipation of processing activities. No value is added in this phase. And finally process time which is represent the only value-added phase; that is, the time a product is actually undergoing transformation by equipment and/or operators. It is the sum total of all processing activities." (p. 63)

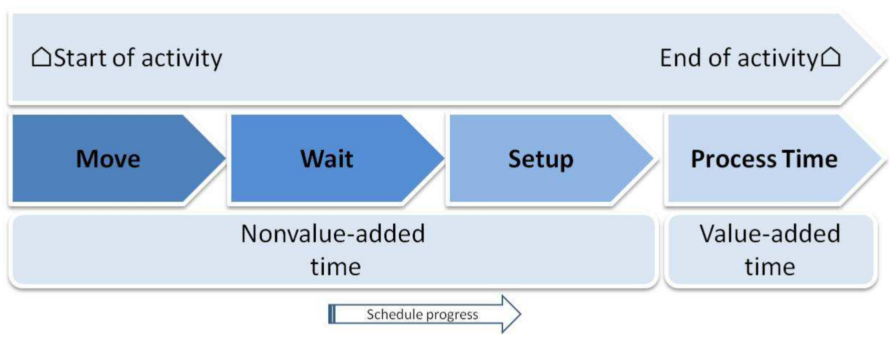


Figure 2.5 Impact of Value-added vs. Non-value added Time in a Typical Construction Process

2.2.5 Lean Construction Fundamentals and Opportunities

The Construction Industry Institute (CII) identified five lean construction principles in their study PT 191: (1) Customer focus, (2) culture and people, (3) workplace organization and standardization, (4) elimination waste, and (5) continuous improvement and built-in quality. Ahmed and Forbes (2011, p. 67) illustrated three connected opportunities in design and construction projects as a foundation for lean construction quoted as follows:

1) Impeccable coordination seeks to overcome the unpredictability that is typical of traditional construction projects; lack of coordination results in an average of only 55% or fewer of promised tasks being completed in a specific week as promised. Project success depends on the predictability of workflow that results when commitments are met between various disciplines and trades involved in a project.
2) Organizing projects as production systems align the roles of the parties in the project to maximize overall performance. It emphasizes productions system design to meet the owner's value proposition; conversations between contractors and designers inform the process of translating design to the built environment. Project executions strategies take advantage of technology or best practices such as prefabrication, modularization, and concurrent multi-trade coordination.
3) Projects are a collective enterprise. Aligning financial incentives with project-wide optimization motivates project team members to adopt an investment mindset for improving performance. Sharing resources avoids expensive duplication and waste—the savings derived benefit both the team and the owner/client. Team orientation and trust are essential for mobilizing creativity and reducing waste.

2.3 Waste in Construction

Construction waste is normally described as physical construction waste generated as a result of construction work. As per lean construction theory, there are noticeable wastes in the construction processes which are named “non value-adding activities or non-physical waste.” In recent decades, various methods are utilized in order to reduce construction waste and mitigate its effects. Hosseini et al. (2012) argued that “many research efforts have been done in order to classify construction waste according to different attributes such as kind, quantity, [location, among others]. In spite of different classifications, all of them follow the same basic concept.” Waste could be referred to several connotations, and clarification of what intended in this research will be illustrated in the following sections.

2.3.1 Definition of Waste in Construction

Waste was defined by researches in different ways in which it could be classified and recognized. Excess materials, delays, rework and defects are some of those waste commonly mentioned by researchers (Senaratne and Wijesiri, 2008). Hosseini et al. (2012) stated that “Formoso et al. (2002) recommended a broader definition of waste to include not only material waste, but also waste generated in a construction project such as waiting times, transportation times, [and setup time].” This reveals the production of non-physical waste within the construction processes, which is the basis of waste concept adopted by lean construction approach and by this research as well. Koskela (1992) also states that a systematic attempt for identifying waste in construction processes (flow wastes in lean thinking terms) has not been done by the construction management practitioners until the lean construction concept was introduced (Hosseini et al., 2012).

2.3.2 Classification of Waste in Construction

Formoso, et al. (1999) proposed the main classification of waste based on an analysis of several Brazilian building sites; using the following categories: Overproduction, substitution, waiting time, transportation, processing, inventories, movement, production, and others. Overproduction was related to the production of a quantity greater than required or earlier than necessary, while monetary referred to the waste caused by the substitution of a material by a more expensive one (with unnecessary better performance). Waiting time was related to the idle time caused by lack of synchronization and leveling of material flows and pace of work by different groups or equipment. Transportation was concerned with the internal movement of materials on site, while processing was related to the nature of the processing (conversion) activity which could only be avoided by changing construction technology. On other hand, inventories was related to excessive or unnecessary inventories which lead to material waste (by deterioration, losses due to inadequate stock conditions on site, robbery, and vandalism) and monetary losses due to the capital that is tied up. Movement was concerned with unnecessary or inefficient movements made by workers during their job. Furthermore, Formoso et al. (1999) related the production of defective products to the waste occurs when the final or intermediate product does not fit the quality specifications, and other waste to any other nature than the previous ones, such as burglary, vandalism, inclement weather, and accidents (Aziz and Hafez, 2013).

2.3.3 Controllable Waste in Construction

According to Aziz and Hafez (2013), a research by (Alarcon, 1994, 1997) divided the controllable waste into three different activities as follows:

1) Controllable Causes Associated with Flows
    a) Resources

i) Materials: lack of materials at the work place; materials are not well distributed; inadequate transportation means

ii) Equipment: non-availability; inefficient utilization; inadequate equipment for work needs

iii) Labor: personal attitudes of workers; rebellion of workers

b) Information

i) Lack of information

ii) Poor information quality

iii) Timing of delivery is inadequate

2) Controllable Causes Associated with Conversions

a) Method

i) Deficient design of work crews

ii) Inadequate procedures

iii) Inadequate support to work activities

b) Planning

i) Lack of work space

ii) Too much people working in reduced space

iii) Poor work conditions

c) Quality

i) Poor execution of work

ii) Damages to work already finished

3) Controllable Causes Associated with Management Activities

a) Decision-Making

i) Poor allocation of work to labor

ii) Poor distribution of personnel

b) Ineffective Supervision/Control: Poor or lack of supervision

2.3.4 Waste in Lean Construction Thinking

Lean thinking pay lots of attentions to the waste produced over a construction process. Hosseini et al. (2012) argued that “although the construction industry witnesses [a] noticeable share of waste in [the] construction process, effective practices for reducing [this waste] are performed rarely.” However, lean construction thinking through a consideration of an integrated view of production and shared vision, attempts to reveals the importance in neglected concepts of designing and engineering in the construction processes. Through their study of reinforcement operations of a six-floor building construction, Hosseini et al. (2012) affirmed that there is great potentiality for such principles in improving construction processes and also reducing waste generated during these processes. Furthermore, they argued that the construction operations have a high potential for optimizing efficiency through application of lean principles and simulation which will finally lead to a drastic promotion in construction industry.

2.4 Information System and Communication

Each effective project team will proactively work towards identification of project requirements while demonstrating the needs of planning and maintaining effective communication, information, and collaboration. Ahmed and Forbes (2011) argued that:

> “New approaches to construction management such as relational contracting and lean design and construction are built on a foundation of team integration and open sharing of project-related information. With the use of lean techniques and relational contracting, it is possible to use improved information and communication methods for potential problems and concerns and maintaining the involvement of shareholders in a project, which is vital for project success.

Thus, organizational leaders in the construction industry need to have a strong foundation in information processing to effectively communicate." (p. 203)

Furthermore, Jones (2009) presented an argument by Rowlinson and Cheung (2004) in which the authors stated "the problem often occurs when information is not shared, or misrepresented, and one of the many groups involved in a project is not aware of what is taking place in other areas." Figure 2.6 describes a crucial aspect of communications among the project team members upon project starting where information is often missed in the handoff.

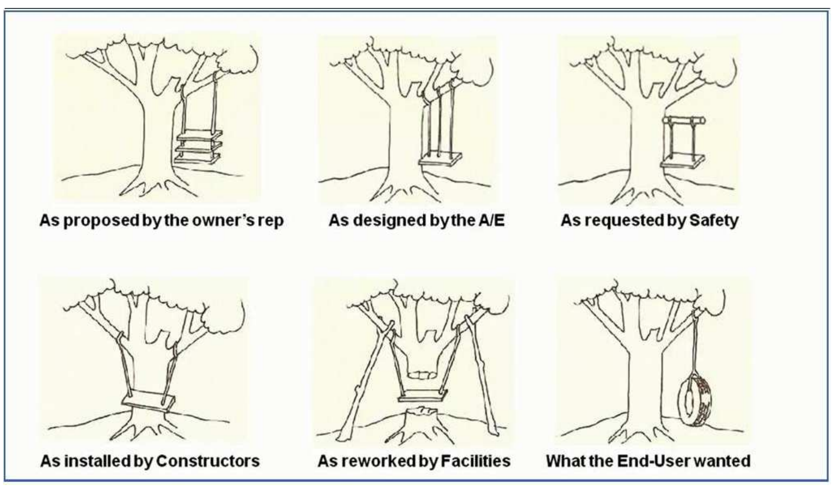


Figure 2.6 Common Understanding of Project Information
(Adapted from businessballs, 2014)

2.4.1 Communication Failures in Projects

Communication in projects is a critical factor in a project's success, and many times, it fails if project team doesn't communicate effectively during the construction process. Cervone (2014) stated that:

"While communication failures in projects are caused by many factors, the project team ultimately bears the burden for ensuring successful communication within a project. The realm of mistakes that can be made related to communication is

> boundless. Too often, unsuccessful project communication is due to the project team emphasizing communication status updates and expectations of project participants in an outward, unidirectional manner."

Furthermore, Cervone illustrated his argument by stating that "this manner of communicating provides neither the project team nor the stakeholders with a complete understanding of the issues and challenges within a project. It is rare for a stakeholder group to have the same level or type of engagement with a project as does the project team." With emphasizing the mean of effective communication between project team and their stakeholders, communication will generally lead to better outcomes and for overall project success.

2.4.2 Mutual Trust Relationships

Many successful stakeholders' relationship was built on trust, and thus played a significant role in the project performance and success. Jones (2009) stated that there is general agreement that the level of success in major projects is well below expectations due to mistrust. A review of the construction industry and the interests of the stakeholders can assist in alleviating this problem, especially from the viewpoint of trust. The exact nature and extent of mistrust in the construction industry, as well as the role that an improved information system and communication process might play in building trust, have not been effectively recognized and developed. The result of Jones' study indicates that improving communications via information technologies offers potential for significant improvement of industry efficiency and business attitudes between the major stakeholders. Moreover, Ahmed and Forbes (2011) stated that "one of the explanations for distrust [and/or] conflict between construction firms and clients may be the fault in the integrative approach necessitating complex communication systems in the generation and transfer of information required in construction projects."

2.5 Productivity and Performance Measurement

In June 2014, the National Society of Professional Engineers published a chart created by Matt Stevens (University of Melbourne Senior Lecturer in Construction) with data from the US Department of Labor and the US Bureau of Economic and Analysis, showing construction productivity in decline (Figure 2.7). Stevens likewise found that, with the exception of a productivity surge in 2008 and 2009, the construction industry's productivity is in decline, lower now than it was in 1993. Stevens (2014) argued that "Generally, the negative changes over the last three decades have outpaced the positive changes. Lack of consistent engagement by construction project stakeholders to each other has made project information flow unevenly, causing chaos. The contracts continue to be draconian, so each party acts with as much legal insulation as possible." This declination in productivity sparks the necessity for more improvement efforts and measurement. Productivity and performance measurement provide a foundation for improving design and construction delivery, regardless of the methods utilized in each respective project. This foundation is especially helpful with lean construction methods, as they are based on a culture of learning and continuous improvement (Ahmed and Forbes, 2011).

To improve the implementation of lean construction, Aziz and Hafez (2013) stated that "Miller et al. (2002) proposed the harmonization between main contractors and subcontractors as a prerequisite, while Thomas et al. (2004) proposed reducing variability to improve performance and labor flow reliability for better productivity presented as lean construction principles."

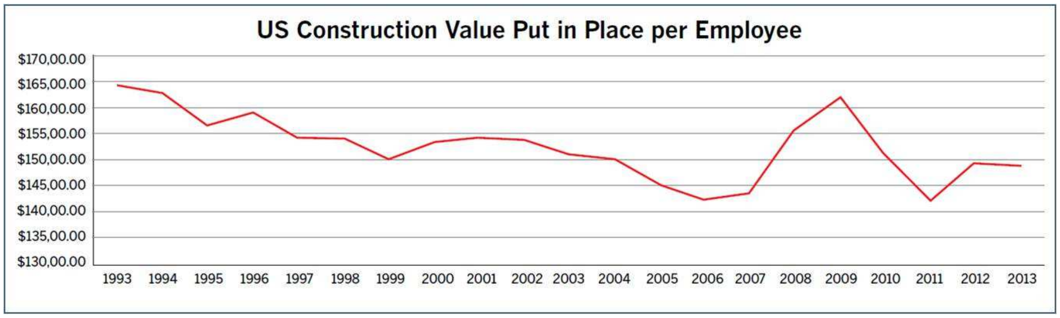


Figure 2.7 Construction Productivity in Decline (Stevens, 2014)

2.6 Chapter Summary

This chapter provided a literature review of several aspects related to the research objectives. These aspects include the traditional delivery method of municipal project, lean construction, waste definition and classification, and measurement of construction productivity. Moreover, the literature review demonstrated the significant role of the information system and communication to improve construction process.

Chapter 3

RESEARCH METHODOLOGY

Chapter 2 provided backgrounds and literature review covering several aspects of the thesis objective. This chapter presents the research methodology, which includes method, approach, and survey used in this thesis.

3.1 Introduction

A research approach known as a The Analytic Hierarchy Process (AHP) was applied in this thesis. The research identified a group of controllable waste associated with the municipal construction project process. A controllable waste classification presented by Aziz and Hafez (2013) presented by Alarcon (1994, 1997) has been adapted and extended, and lean techniques have been hypothesized to develop significant improvement upon application. To further gather data on the application of lean techniques, the decision factors were structured in a hierarchy, and a survey was sent to industry professionals. AHP process was then applied and analyzed to prioritize these techniques in each level of the process in order to examine the relationship between lean construction techniques and its objective.

3.2 Research Method

3.2.1 The Analytical Hierarchy Process (AHP)

The Analytical Hierarchy Process (AHP) is a decision-aiding method aimed at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision-maker, and stresses the importance of the intuitive judgments of a decision-maker as well as the consistency of the comparison of alternatives in the decision-making process (Saaty, 1980). As per Perera and Sutrisna (2011), AHP philosophy is based on the intention to provide a comprehensive and rational framework for structuring a decision problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. It is based on mathematics and psychology, but more specifically matrixes and processes. Also, AHP is a ‘normative’ model of decision making. Opposed to a ‘descriptive’ model which allows for describing the way a decision-makers actually makes decision, a normative model enables a decision-maker to defend his choice over competing alternatives in specific steps. Figure 3.1 shows decompose of a decision-making problem into a hierarchy of criteria and alternatives. On the top is the goal of the analysis. Level 1 is multi-criteria that consist of several criterions; also several other levels of sub-criteria could be added, and the last level is the alternative choices.

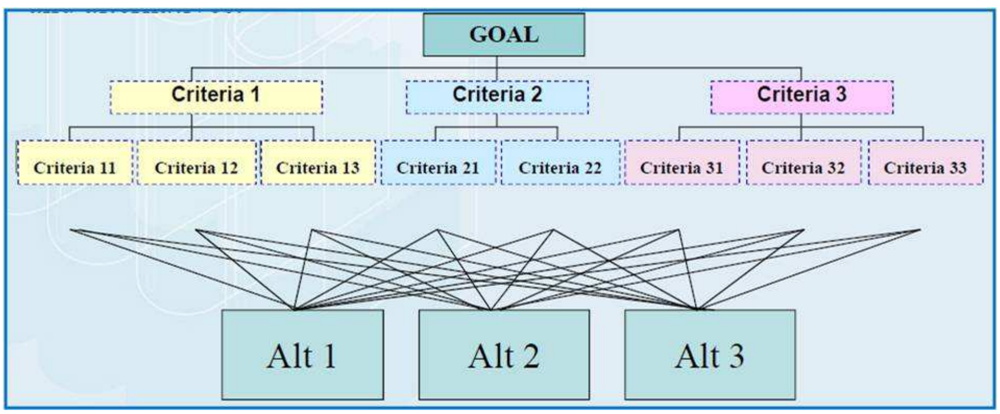


Figure 3.1 Example of the Hierarchy Structure (Bunruamkaew, 2012)

3.2.2 The Basic Approach of AHP

Saaty (1982) stated that the fundamental problem of decision theory is how to derive weights for a set of activities according to importance. Importance is usually judged by several criteria that may be shared by some or all of the activities. Weighing of activities with respect to importance is a process of multi-criterion decision making. The objective of this approach is to use the weights, also known as priorities, to allocate a resource among the activities, or if precise weights cannot be obtained, to simply implement the most important activities by rank. The problem then, is to find the relative strength or priority of each activity with respect to each objective and then compose the results to obtain a single overall priority for all the activities. Frequently, the objectives themselves must be prioritized or ranked in terms of yet another set of higher-level objectives. These priorities are then used as weighted factors for the priorities derived for the activities.

3.2.3 The AHP Method Procedures

The basic steps in determining a solution for problem solving using AHP are summarized by Goepel (2013) it in the following steps:

(1) Define the goal of the decision – what do I want to decide, for what purpose, and what are my alternatives?

(2) Structure the decision problem in a hierarchy – what are the categories and criteria that Figure into my decision?

(3) Pair comparison of criteria in each category – e.g., blue or green? Which do I prefer, and by how much do I prefer one or the other color?

(4) Calculate the priorities and a consistency index – were my comparisons logical and consistent?

(5) Evaluate alternatives according to the priorities identified – what alternative optimum solution is there to the decision problem?

3.2.4 The Core of AHP Method

As per Goepel (2013), the core of AHP is the comparison of pairs instead of sorting (ranking), voting (assigning points), or the free assignment of priorities. Validation of the method in practical testing shows surprisingly good agreement with actual measured values. Furthermore, Goepel (2013) stated that “AHP has been used successfully in many institutions and companies. One of AHP’s great advantages is the ability to use it for group decisions in which all participants evaluate pairs and the group result is mathematically determined as the optimum consensus. In practice the solutions arrived at by the method are well accepted since the results are objective and free of political influence."

3.2.5 The Advantages of the AHP Method

Figure 3.2 illustrates a summarization of the advantages of the AHP method as presented by Saaty (1982).

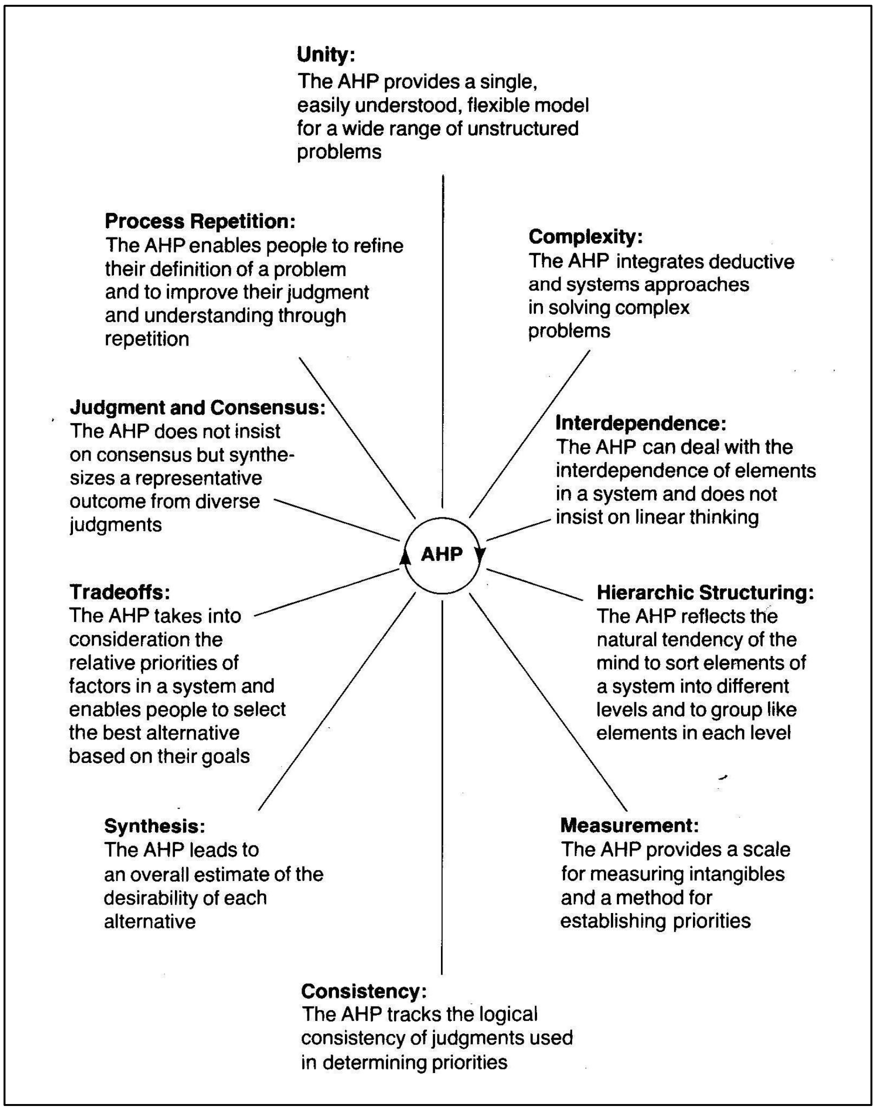


Figure 3.2 The Advantages of the AHP Method (Saaty, 1982)

3.3 Research Approach

As shown in Figure 3.3, the research approach used in this thesis includes the following steps: (1) set a goal, (2) identify type of waste, (3) categorize waste, (4) take action for the appropriate lean techniques suggested, and (5) prioritize the alternatives for best improvement.

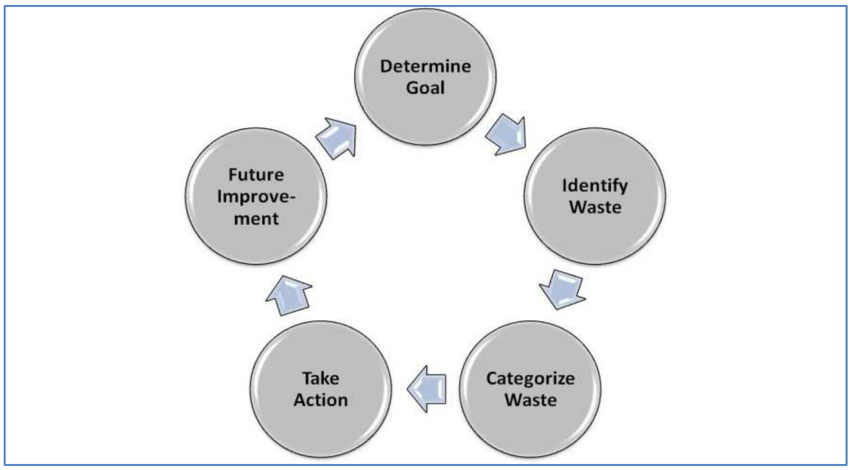


Figure 3.3 Research Approach

3.4 Construction Project Waste Classification

Many problems (waste) within a municipal construction project were identified previously in chapter 1 and 2 of this thesis These problems can be summarized as follows: Lack of design specification, false or missed information, inaccurate existence of utilities, inspection and restriction, city limitation in project, community impact during construction, lack of management support, non-disclosure of information, resistance to change, and Lack of shared vision. Using the waste classification presented by Aziz and Hafez adopted from Alarcon (1994, 1997), waste has been decomposed into a hierarchy in order to reach the decision-making. The waste has been categorized to comply with a set of alternatives of lean techniques, and the lean techniques are then prioritized for decision-making. The waste categorization and lean techniques application could be described as follows:

1) Controllable Causes Associated with Flows include:

   (a) Resources; could be improved by:

      (i) Resources availability

      (ii) Resources leveling

   (b) Information; could be improved by:

      (iii) Accurate information

      (iv) Clear specifications

      (v) Effective communication

      (vi) Detection of incompatibility and discrepancy

2) Controllable Causes Associated with Conversions include:

   (a) Method; could be improved by:

      (i) Team integration

      (ii) Concurrent engineering

      (iii) Standardization of work process

   (b) Planning; could be improved by:

      (i) Constraint analysis

      (ii) Root cause analysis

      (iii) Look-ahead planning

      (iv) Percentage of planned completed

   (c) Quality; could be improved by:

      (i) Process evaluation

      (ii) Immediate problem detection

      (iii) Systematic procedures

(iv) Inspection and enforcement

2) Controllable Causes Associated with Management Activities include:

   (a) Decision-Making; could be improved by:

      (i) Use of visual indicators

      (ii) Take decisions slowly, implement them quickly

      (iii) Take decision at construction site

   (b) Ineffective Supervision/Control; could be improved by:

      (i) Management support

      (ii) Transparency

Figure 3.4 demonstrates the decision-making problem as a hierarchy of criteria and alternatives. On top is the goal that each level works toward reaching in the municipal construction project. Level 1 illustrates the categories of controllable waste, while level 2 shows the sub-level of the controllable waste, and level 3 shows where implementation of lean techniques were considered for improving performance and productivity.

3.5 Research Survey

The survey was conducted based on comparison that relies upon AHP for its methodology. The survey objective is to quantify relative priorities for a given set of factors and alternatives on a ratio scale, based on the judgment of the construction professionals' experience. A pair-wise comparison matrix has been constructed for all elements within the same level, and for each of the lower levels with one matrix for each element in the level immediately above. The pair-wise comparisons are done in terms of which element dominates the other using the relative scale measurement shown in Figure 3.5.

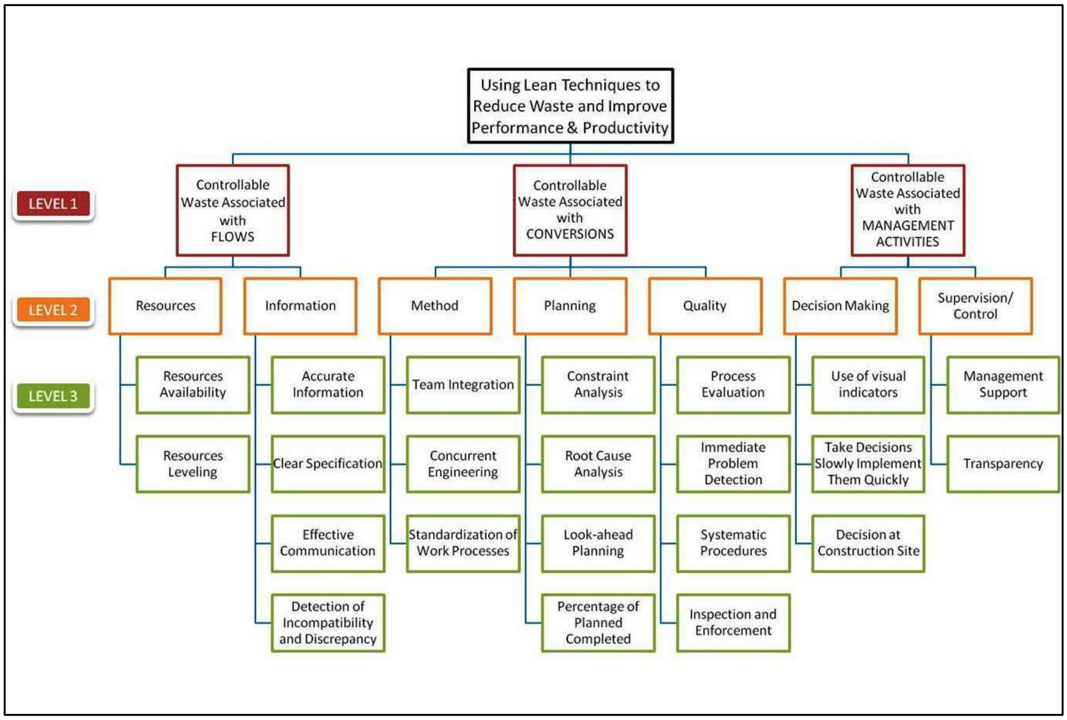


Figure 3.4 The Decision-Making Problem into a Hierarchy of Criteria and Alternatives

Level of Preference of Each Factor	1. Significantly Less Important 2. Less Important 3. Equally Important 4. More Important 5. Significantly More Important

Figure 3.5 Pair-wise Comparison Scale for AHP Preferences

For more understanding of the main concept of the various parameters, a table of definitions has been attached in the survey. A description of these definitions is shown in Appendix A.

Figure 3.6 provides an example of the survey where pair-wise comparison matrix constructed for all elements within level 2.

AHP Level 2

FACTOR		Level of Preference		FACTOR
Decision Making	IS	Please click here to Select one		Quality
		1. Significanty Less Important 2. Less Important		Planning
		3. Equally Important 4. More Important		Method
		5. Significanty More Important		Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Quality	IS	Please click here to Select one	TO	Planning
		Please click here to Select one	TO	Method
		Please click here to Select one	TO	Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Planning	IS	Please click here to Select one	TO	Method
		Please click here to Select one	TO	Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Method	IS	Please click here to Select one	TO	Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Information	IS	Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Resources	IS	Please click here to Select one	TO	Supervision/Control

Figure 3.6 Pair-wise Comparison Matrix for Level 2

3.5.1 Survey Population and Techniques

The survey was sent to construction professionals who were actively engaged in a major public construction project. Geographically, the survey attempted to focus in Texas entities as a targeted region, and to include both private and public sectors. The survey was selected to be in standardized format and targeting decision-makers (Directors/Principals), Process Managers (Project Managers/Engineers), and related Disciplines. The fact that all participants received the survey in the same manner was an important aspect for the standardization of research methods. The survey targeted more than 300 participants, and they were picked in accordance to their participation in public work or local government projects in Texas. The reason for choosing Texas construction professionals was because of familiarity with the Texas municipal projects and involvement of survey respondents with these projects. Although the majority of survey respondents were from Texas, the result is generic and can be applied to other states. However, only 18 responded and 2 were found to be relocated out of Texas at the time of the survey sent, and were included in the survey analysis since they were familiar with the municipal's construction project method. The survey was emailed to the participants in an excel file format in such a way that it was easy for the participants to select out their responses. Once the participants had selected out their responses, the participants were able to email their responses back to the sender for archival and analysis.

3.6 Chapter Summary

A decision-making method quantifying relative priorities for a given set of alternatives was used in this thesis. The Analytical Hierarchy Process (AHP) provides a comprehensive and rational framework for structuring a decision problem, representing and quantifying its elements, relating those elements to overall goals, and for evaluating alternative solutions. This research approach determined a goal, categorized the waste, and took into action by applying the appropriate lean techniques. A comparison-based survey was conducted to quantify relative priorities for a given set of alternatives on a ratio scale based on the judgment of the construction professionals' experience.

Chapter 4

DATA ANALYSIS AND RESULTS

Chapter 3 discussed the research methodology, method, approach, and survey used in this thesis. This chapter demonstrates data collection process, analysis, validation, and the final results obtained. This chapter explains utilization of AHP method and presents the results of this thesis.

4.1 Data Collected

4.1.1 Distribution of Survey Respondents

The Data from the 18 respondents of the survey were analyzed according to the location (In Texas/Other States), sector (Private/Public), and position (Director/Principal, Project Manager/Engineer, and Others) as illustrated in Figure 4.1, 4.2, 4.3, and 4.4 respectively.

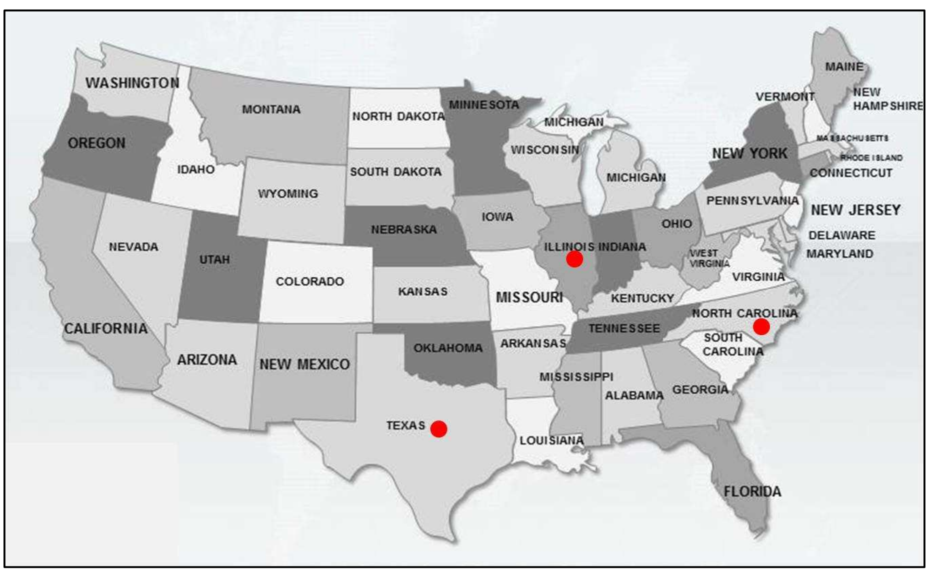


Figure 4.1 Map of United States Depicting Areas of Survey Response

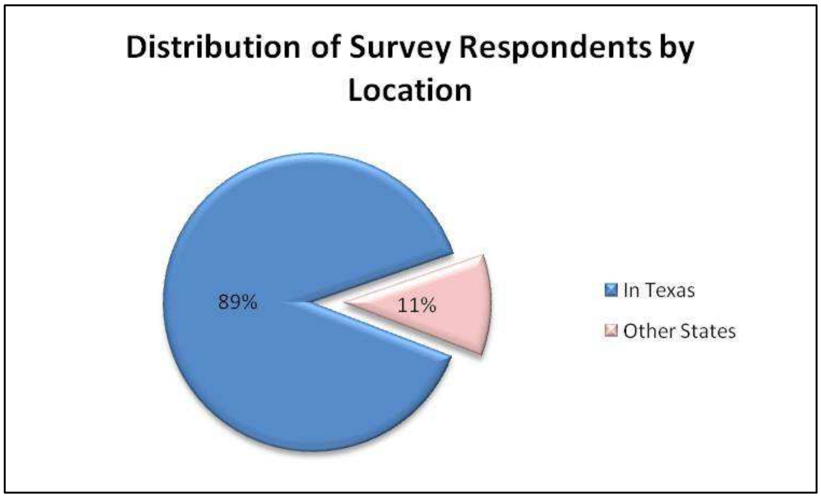


Figure 4.2 Distribution of Survey Respondents by Location

Based on 18 Respondents

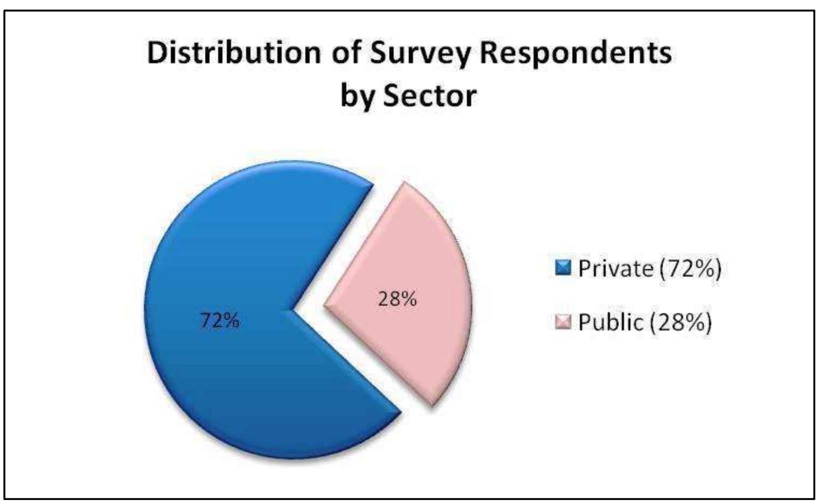


Figure 4.3 Distribution of Survey Respondents by Sector

Based on 18 Respondents

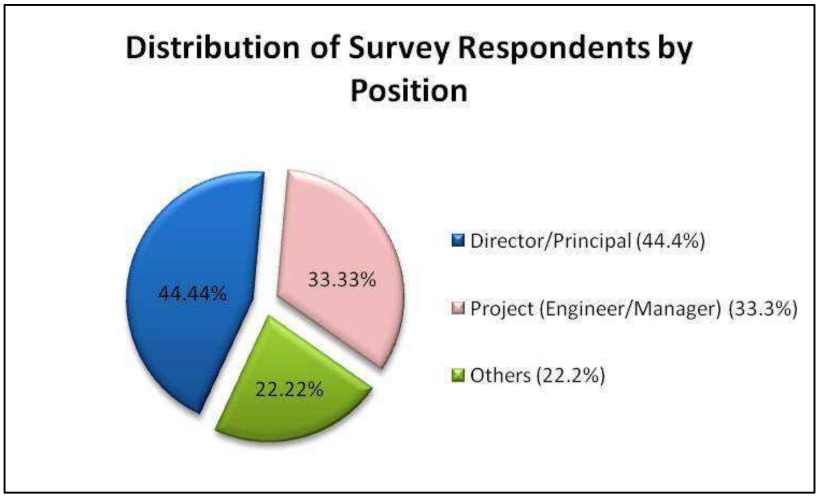


Figure 4.4 Distribution of Survey Respondents by Position
Based on 18 Respondents

4.1.2 Perfection of Responses

There were 50 comparison questions included in the survey with response rate of 96.3%. The responses were received within 3 weeks from the date of sending.

4.2 Data Analysis

4.2.1 Preferences Analysis

To evaluate the pair-wise comparison questions judged by the construction professionals' experience, first the most dominant preference has to be determined for every pair-wise in each level. Figure 4.5 shows an example for comparison 1.2 preferences analysis. Appendix B illustrates the preferences calculations and results for all 50 pair-wise comparisons used in this research.

Comparison 1.2

Controllable Waste Associated with Management Activities
Vs.
Controllable Waste Associated with Flows

Total responses 16 **Out of** 18 **Response rate** 88.89%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	3	16.67%	18.75%
3. Equally Important	7	38.89%	43.75%
4. More Important	4	22.22%	25.00%
5. Significantly More Important	2	11.11%	12.50%
	16		1

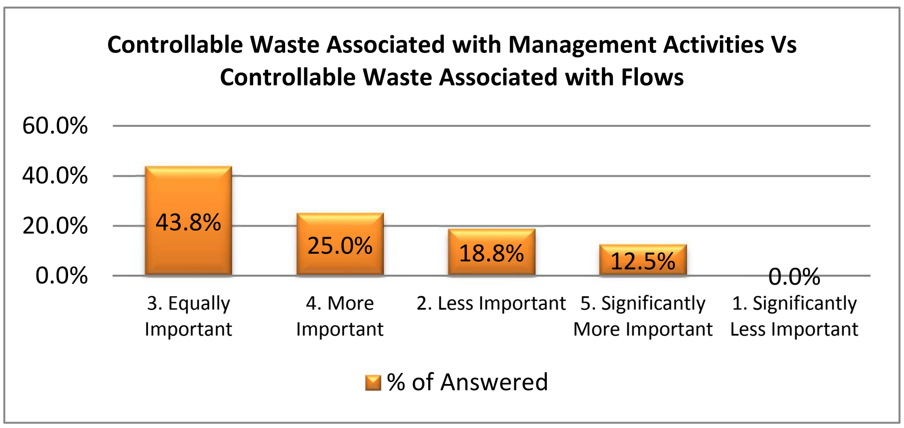


Figure 4.5 Preferences Analysis Example for Comparison 1.2

4.2.2 Preferences Weighing

According to Saaty (2009) "the fundamental scale of the AHP is a scale of absolute numbers used to answer the basic question in all pair wise comparisons: how many times more dominant is one element than the other with respect to a certain criterion or attribute?" Based on this principle, to obtain the set of overall priorities for a decision problem, synthesize the judgment was made in the pair-wise comparison. However, following this synthesis, the data is weighed and added in order to give a single number to indicate the priority of each element. Saaty (1980, p. 54) based the pair-wise comparison on a scale of 1 to 9 as per the definition of weights given in Table 4.1.

Table 4.1 Pair-wise Comparison Scale (Saaty, 1980)

Weight	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgment slightly favor one activity over another
5	Essential or strong importance	Experience and judgment strongly favor one activity over another
7	Very strong or demonstrated importance	An activity is favored very strongly over another; its dominance demonstrated in practice
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent scale values	When compromise is needed
Reciprocals of above nonzero	If factor *i* has one of the above nonzero numbers assigned to it when compared to factor *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
Rationales	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Suggested numbers expressing the degree of preference or importance as assigned by participants was established in the matrix for each level within the hierarchy. Figure 4.6 shows the weight scale suggested and the way it was applied for each preference.

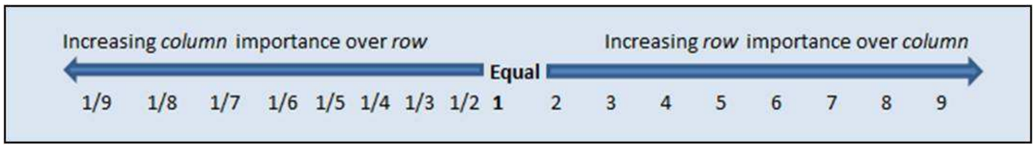


Figure 4.6 Weighing Scale

4.2.3 Comparison Matrix

To evaluate the pair-wise comparison, a comparison matrix was created for all levels of the hierarchy (level 1, 2, and 3). Figure 4.5 illustrated the matrix for level 2 as an example, where the remaining matrixes and calculations for the research were illustrated in Appendix C.

Table 4.2 Comparison Matrix for Level 2

Parameter	Decision-Making	Quality	Planning	Method	Information	Resources	Supervision/ Control
Decision-Making	1	1	0.667	1	1	1	1
Quality	1	1	1	3	1	1	1
Planning	1/3	1	1	3	1	1	1
Method	1	1/3	1/3	1	1/3	1/3	1
Information	1	1	1	1/3	1	3	1
Resources	1	1	1	1/3	1/3	1	1
Supervision/ Control	1	1	1	1	1	1	1
Total	**6.499**	**5.333**	**5.000**	**14.006**	**4.666**	**7.333**	**7.000**

The matrix was established by making rows and columns to have the same parameters. For example, if the first row is Decision-Making, the first column is also Decision-Making; if the second row is Quality, the second column is also Quality. The matrix was arranged and a score range of 1 to 9 was selected and allocated, where a maximum score implies that the row is more important than the column. The diagonal of the matrix was allocated at a score of 1. Proceeding column-wise, the value in the corresponding column just below the diagonal is reciprocal of the scores in the corresponding row. Likewise all the columns were calculated and added to arrive at the total.

4.2.4 Computation of Priorities

To compute the priorities, scores were normalized first. This step is to normalize the matrix by totaling the numbers in each column. Each entry in the column is then divided by the column sum to yield its normalized score. The sum of each column is 1. The mathematical normalization steps can be summarized as follows:

For the matrix of pair-wise elements:

$$\begin{bmatrix} C11 & C12 & C13 \\ C21 & C22 & C23 \\ C31 & C32 & C33 \end{bmatrix}$$

1) Sum the values in each column of the pair-wise matrix

$$\mathrm{C\ ij} = \sum_{i\,=\,1}^{n} = \mathrm{C\ ij}$$

2) Divide each element in the matrix by its column total to generate a normalized pair-wise matrix

$$\mathrm{X\ ij} = \frac{C\ ij}{\sum_{i=1}^{n} C\ ij} \quad \begin{bmatrix} W11 & W12 & W13 \\ W21 & W22 & W23 \\ W31 & W32 & W33 \end{bmatrix}$$

3) Divide the sum of the normalized column of matrix by the number of criteria used (n) to generate weighted matrix

$$\mathrm{W\ ij} = \frac{\sum_{i=1}^{n} W\ ij}{n} \quad \begin{bmatrix} W11 \\ W21 \\ W31 \end{bmatrix}$$

Table 4.3 illustrates an example for normalization and priorities calculation for level 2.

Table 4.3 Example of Normalization and Priorities Calculation for Level 2

Parameter	Decision-Making	Quality	Planning	Method	Information	Resources	Supervision/ Control	**Total**	**Priority**
Decision-Making	0.154	0.188	0.133	0.071	0.214	0.136	0.143	0.908	0.130
Quality	0.154	0.188	0.200	0.214	0.214	0.136	0.143	1.097	0.157
Planning	0.231	0.188	0.200	0.214	0.214	0.136	0.143	1.164	0.166
Method	0.154	0.063	0.067	0.071	0.071	0.045	0.143	0.550	0.079
Information	0.154	0.188	0.200	0.214	0.214	0.409	0.143	1.337	0.191
Resources	0.154	0.188	0.200	0.214	0.071	0.136	0.143	0.980	0.140
Supervision/Control	0.133	0.158	0.167	0.067	0.176	0.120	0.143	0.964	0.138
Total	1.00	1.00	1.00	1.00	1.00	1.00	1.00	Total	1.00

4.2.5 Percent Ratio of Priorities and Results

Through normalization and computation of all matrix scores in each level, prioritization was achieved. The obtained result could be discussed as follows:

4.2.5.1 Level 1

As shown in Figure 4.7, through comparing the three level factors to each other, the result demonstrates that Management Activities and Flows have the same priority level with 43%, while Conversion has a priority of 14%. This result very much supports

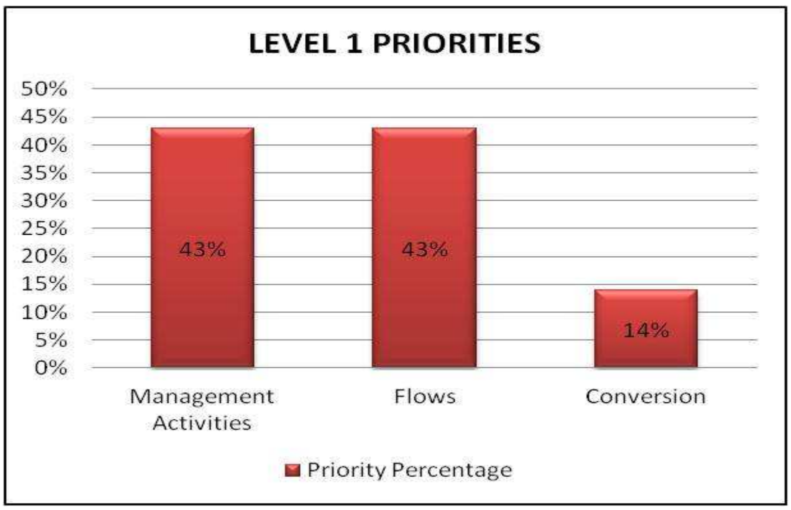


Figure 4.7 Level 1 Priority Rate

lean construction principles where management activities and process flows have a significant impact over the project performance.

4.2.5.2 Level 2

Figure 4.8 illustrates the priorities of level 2, where Information obtained the most importance rate with 19.1%, followed by Planning with 16.6%, Quality 15.7%, Resources 14%, Supervision/Control 13.8%, Decision-Making 13%, and Method with 7.9%. The construction professionals rated Information as the most important factor among the other level's factors to achieving the superior-goal (Level 1). These results confirm the significant contributing role of Information in project performance and productivity.

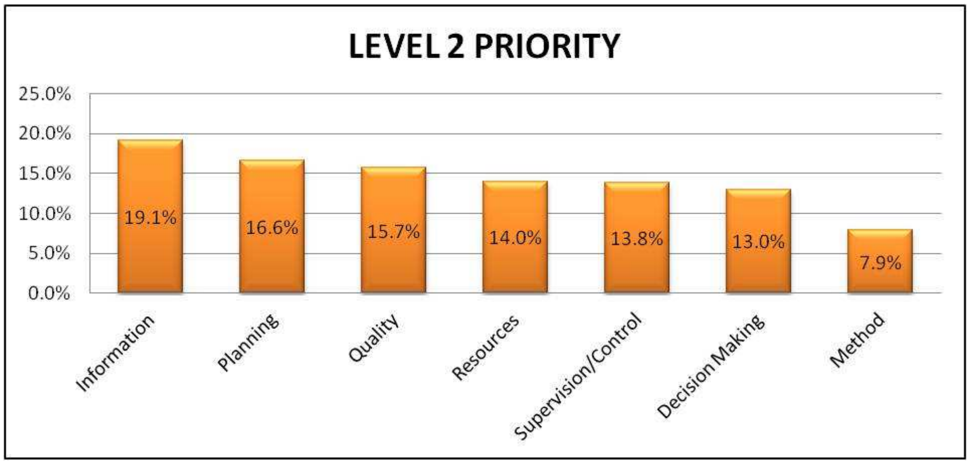


Figure 4.8 Level 2 Priority Rate

4.2.5.3 Level 3

Level 3 represents the sub of level 2, where each element in level 2 was factored, and all the factors within each sub level were compared to each other. Priorities in this level were illustrated as follows:

1) Supervision/Control:

   As Shown in Figure 4.9, two factors were compared to each other, Management Support and Transparency. Result demonstrates that both factors have the same level of importance, and they could be considered even.

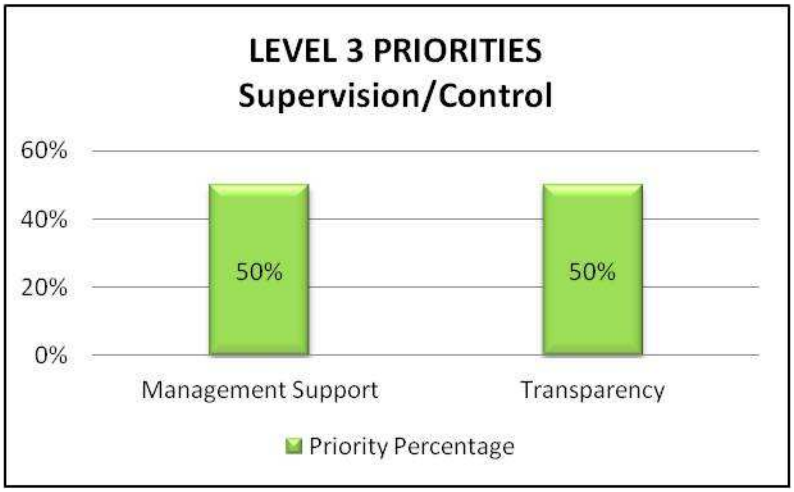


Figure 4.9 Supervision/Control Priority Rate

2) Decision-Making

Three factors were evaluated and compared under this element. Decision at Construction Site found to be more priorities with 49%, Taking Decision Slowly and Implement them Quickly comes next with 31%, and the Use of Visual Indicators has the least rate with 20% (Figure 4.10).

Figure 4.10 Decision-Making Priority Rate

3) Quality

Immediate Problem Detection was found dominant with 32%, Process Evaluation was next with rates of 29% followed by Inspection and Enforcement with 20%, and Systematic Procedures last with a rate of 19% (Figure 4.11).

Figure 4.11 Quality Priority Rate

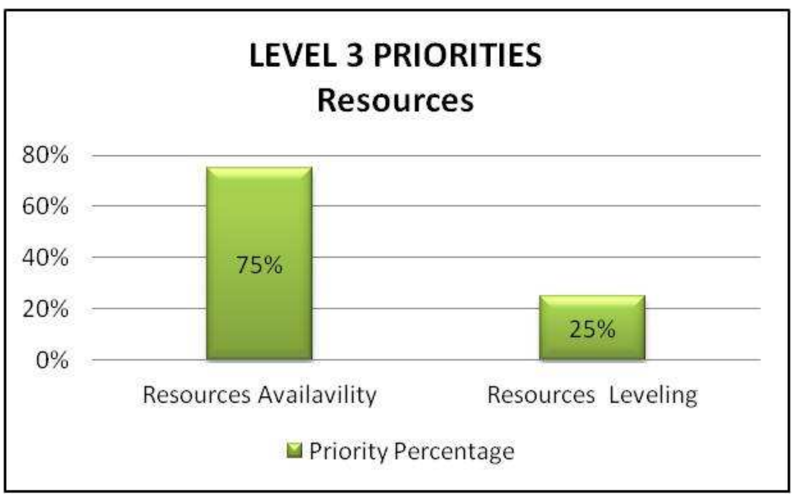


Figure 4.12 Resources Priority Rate

4) Resources

Resources have two factors compared to each other. Resources Availability with a rate of 75% has more priority than Resources Leveling with 25% (Figure 4.12).

5) Planning

Among four factors compared to each other, Look-ahead Planning was first with a rate of 34%. Root Cause Analysis, Constraint Analysis, and Percentage of Planned Completed were next with rate of 29%, 24%, and 14% respectively (Figure 4.13).

Figure 4.13 Planning Priority Rate

6) Method

Method's factors shared their priorities evenly, and each one obtained a rate of 33%. These results reflect the role of method elements and its equal importance in the project process (Figure 4.14).

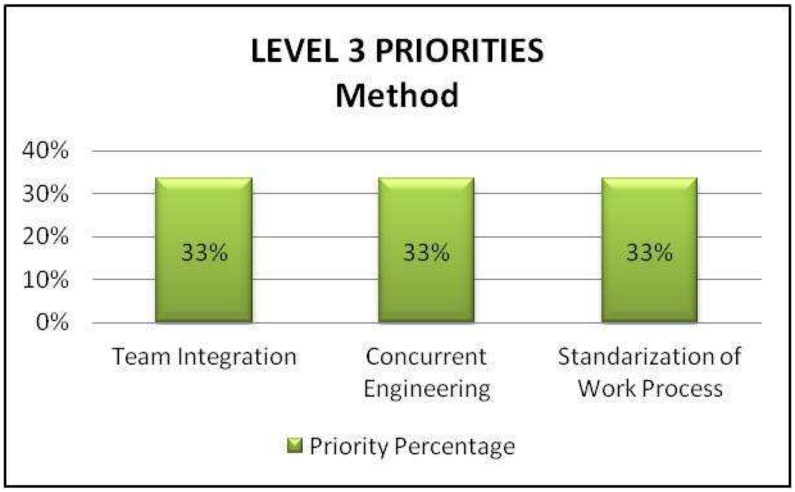


Figure 4.14 Method Priority Rate

7) Information

Information has four factors compared to each other. Clear Specification and Effective Communication were shared the most priority rates with 31% each. Accurate Information was next with 24%, and Detection of Incompatibility and Discrepancy were last with a rate of 14% (Figure 4.15).

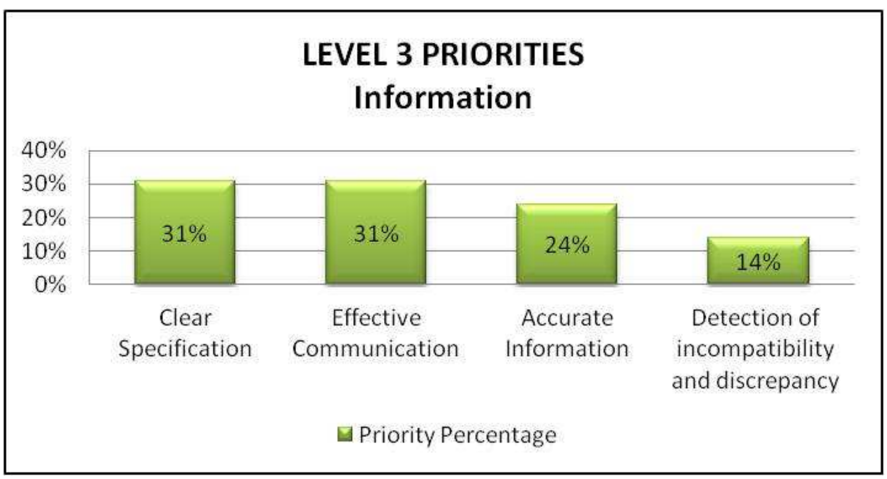


Figure 4.15 Information Priority Rate

4.3 Method Validation

To validate the results and methods used in these decision-making problems, it is important to know how good its consistency is. The importance of this step is to not base the decision on judgments that have such low consistency that they appear to be random.

4.3.1 Consistency Analysis

As per Saaty (1980), consistency means that "when we have a basic amount of row data, all other data can be logically deduced from it. In doing pair-wise comparison to relate *n* activities so that each one is represented in the data at least once, we do n-1 pair-wise comparison judgments. From them all other judgments can be deduced simply by using the following kind of relation." Consistency could be computed by calculating the consistency measure, index, and ratio for each level comparison.

4.3.2 Consistency Measure

Decision accuracy refers to the extent to which classifications based on test scores match those that would have been made if the scores did not contain any measurement error. Accuracy must be estimated because errorless test scores do not exist. As per Saaty (1980), "to get a crude estimate of consistency, we multiply the matrix of comparisons on the right by the estimated solution vector obtaining a new vector[5]. If we divide the first components of this vector by the first component of the estimated solution vector, the second component of the new vector by the second component of the estimated solution vector and so on, we obtain another vector. If we take the some of the components of this vector and divide by the number of components we have an

[5] Matrix consisting of one row or one column is called vector.

approximation to a number λ_{max} to use in estimating the consistency as reflected in the proportionality of preferences." The following steps illustrate the estimation process:

a) Consistency Vector was calculated by multiplying the pair-wise matrix by the weights vector

$$\begin{bmatrix} C11 & C12 & C13 \\ C21 & C22 & C23 \\ C31 & C32 & C33 \end{bmatrix} \text{x} \begin{bmatrix} W11 \\ W21 \\ W31 \end{bmatrix} = \begin{bmatrix} Cv11 \\ Cv21 \\ Cv31 \end{bmatrix}$$

b) Then it was accomplished by dividing the weighted sum vector with criterion weight

$$\text{Cv11} = \frac{1}{W11} \quad [C11W11 + \quad C12W21 + \quad C13W31]$$
$$\text{Cv21} = \frac{1}{W21} \quad [C21W11 + \quad C22W21 + \quad C23W31]$$
$$\text{Cv31} = \frac{1}{W31} \quad [C31W11 + \quad C32W21 + \quad C33W31]$$

c) λ was calculated by averaging the value of the Consistency Vector

$$\lambda = \sum_{i=1}^{n} \text{Cv ij}$$

4.3.3 Consistency Index (C.I.)

Deviation from consistency called Consistency Index and can be calculated using the following steps:

a) Multiply each column of the pair-wise comparison matrix by the corresponding weight
b) Divide sum of the row entries by the corresponding weight
c) Compute the average of the values from step b, denote it by λ_{max}
d) The approximate CI is:

$$\frac{(\lambda \max - n)}{(n-1)}$$

4.3.4 Random Index (R.I.)

The consistency index of a randomly generated reciprocal matrix from the scale 1 to 9, with reciprocal forced called Random Index (R.I.) (Saaty, 1980). An average of R.I. for matrixes of order 1-15 using a sample size of 100 was generated by Oak Ridge National Laboratory used in this research as presented by Saaty. Table 4.4 gives the order of the matrix (first row) and the average R.I. (second row) determined as described above.

Table 4.4 Random Index Scale

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48	1.56	1.57	1.59

4.3.5 Consistency Ratio (C.R.)

As per Saaty (1980), “the AHP measures the overall consistency of judgments by means of as Consistency Ratio. The value of the consistency ration should be 10 percent or less. If it is more that 10 percent, the judgments may be somewhat random and should be revised. The Consistency Ration was calculated by taking the ratio of C.I. to the average R.I. for the same order matrix.” A ration of 0.10 or less is considered acceptable.

Table 4.5 shows the consistency calculation example for level 2 which was illustrated earlier and the remaining calculations for the research were illustrated in Appendix C.

Table 4.5 Consistency Calculation for Level 2

Average (Priority)	Consistency
15%	6.251005
18%	6.275808
20%	6.246776
8%	6.178372
23%	6.432085
16%	6.252179
Total	37.63623

Table 4.5 Continued

λ_{max} = Total/n	6.272704
C.I. = (λ_{max}-n)/(n-1)	0.054541
R.I. (for n=6)	1.24
C.R.= C.I./R.I.	**0.043985**
0.0433985 < 0.1 (*Acceptable*)	

4.3.6 Consistency Results

Consistency ration was computed for level 1, 2, and 7 matrixes of level 3, and the results were found as follows:

a) 2 matrixes were less than (3x3) (Supervision/Control and Resources) where the ratio index is zero, and wasn't considered for computation

b) Consistency ratio for level 1, 2, and "3" matrixes of level 3 (Quality, Method, and Information) were found under 10 percent and were accepted

c) 2 matrixes within level 3 (Decision-Making and Planning) were resulted in consistency ration higher that 10 percent and were adjusted

4.3.7 Consistency Adjustment

As a clarification of inconsistency ration, Saaty (1982, p. 82) stated that "usually we cannot be so certain of our judgments that we would insist on forcing consistency in the pair-wise comparison matrix. Rather, we guess our feeling or judgments in all the positions except the diagonal ones (which are always 1) force the reciprocal in the transpose positions, and look for an answer, we may not be perfectly consistent, but that is the way we tend to work." Saaty suggested that one way to improve consistency when it turns out to be unsatisfactory is to rank the activities by a simple order based on the weights obtained in the first run of the problem. A second pair-wise comparison matrix is then developed with this knowledge of ranking in mind. The consistency generally is better (Saaty, 1982, p. 85). Based on Saaty's suggestion, a second pair-wise comparison was developed for Planning and Decision-Making matrixes as shown in table 4.6, 4.7, 4.8, and 4.9 respectively.

Table 4.6 Actual Result of Planning Matrix

Parameter	Constraint Analysis	Root C. Analysis	Look A. Planning	Inspection & Enforcement			
Constraint Analysis	1	0.333	1	3			
Root Cause Analysis	3.000	1	0.333	3			
Look-ahead Planning	1	3.000	1	3			
Inspection.& Enforcement	0.333	0.333	0.333	1			
Total	**5.333**	**4.667**	**2.667**	**10.000**			
Parameter	Const. Analysis	Root C. Analysis	Look A. Planning	Inspection & Enforcement .	**Total**	**Ave.**	**Consist.**
Const. Analysis	0.187	0.071	0.375	0.300	0.934	23%	4.194
Root C. Analysis	0.563	0.214	0.125	0.300	1.202	30%	4.645
Look-ahead Planning	0.187	0.643	0.375	0.300	1.505	38%	4.731
Inspection.& Enforcement	0.062	0.071	0.125	0.100	0.359	9%	4.381
Total	1.000	1.000	1.000	1.000	Total	100%	17.951
						λ_{max}	4.488
						C.I.	0.163
						R.I.	0.900
				CR > 0.1 (Not Acceptable)		**CR**	**0.181**

Table 4.7 Adjusted Result of Planning Matrix

Parameter	Constraint Analysis	Root C. Analysis	Look A. Planning	% of Planned Completed			
Const. Analysis	1	0.5	1	2			
Root C. Analysis	2	1	0.5	2			
Look-ahead Planning	1	2	1	2			
% of Planned Completed	0.5	0.5	0.5	1			
Total	**4.500**	**4.000**	**3.000**	**7.000**			
Parameter	Const. Analysis	Root C. Analysis	Look A. Planning	% of Planned Completed	**Total**	**Ave.**	**Consist.**
Const. Analysis	0.222	0.125	0.333	0.286	0.966	24%	4.111
Root C. Analysis	0.444	0.250	0.167	0.286	1.147	29%	4.221
Look-ahead Planning	0.222	0.500	0.333	0.286	1.341	34%	4.244
% of Planned Completed	0.111	0.125	0.167	0.143	0.546	14%	4.165
Total	1.000	1.000	1.000	1.000	Total	100%	16.742
						λ_{max}	4.185
						C.I.	0.062
						R.I.	0.900
					CR < 0.1 (Acceptable)	**CR**	**0.069**

Table 4.8 Actual Result of Decision-Making Matrix

Parameter	Use of Visual Indicators	Decision at Construction Site	Take Decision Slowly, Implement them Quickly			
Use of Visual Indicators	1	0.333	0.333			
Decision at Construction Site	3.003	1	3			
Take Decision Slowly, Implement them Quickly	3.003	0.333	1			
Total	**7.006**	**1.666**	**4.333**			
Parameter	Use of Visual Indicators	Decision at Construction Site	Take Decision Slowly, Implement them Quickly	**Total**	**Ave.**	**Consist.**
Use of Visual Indicators	0.143	0.200	0.077	0.419	14%	3.049
Decision at Construction Site	0.429	0.600	0.692	1.721	57%	3.230
Take Decision Slowly, Implement them Quickly	0.429	0.200	0.231	0.859	29%	3.133
Total	1.000	1.000	1.000	Total	100%	9.412
					λ_{max}	3.137
					CI	0.069
					RI	0.580
				CR > 0.1 (Not Acceptable)	**CR**	**0.118**

Table 4.9 Adjusted Result of Decision-Making Matrix

Parameter	Use of Visual Indicators	Decision at Construction Site	Take Decision Slowly, Implement Quickly
Use of Visual Indicators	1	0.5	0.5
Decision at Construction Site	2	1	2
Take Decision Slowly, Implement them Quickly	2	0.5	1
Total	**5.000**	**2.000**	**3.500**

Parameter	Use of Visual Indicators	Decision at Construction Site	Take Decision Slowly, Implement them Quickly	**Total**	**Ave.**	**Consist.**
Use of Visual Indicators	0.200	0.250	0.143	0.593	20%	3.030
Decision at Construction Site	0.400	0.500	0.571	1.471	49%	3.078
Take Decision Slowly, Implement them Quickly	0.400	0.250	0.286	0.936	31%	3.053
Total	1.000	1.000	1.000	Total	100%	9.161
					λ_{max}	3.053
					CI	0.027
					RI	0.58
				CR < 0.1 (Acceptable)	**CR**	**0.046**

4.4 Analysis of Results

The survey results previously described, not only helped in gaining an insight into the way of how lean construction techniques could improve construction process, but also provided the basis for prioritizing alternatives for the stakeholder's decision-making. Furthermore, it provided a reality check and consistency for the goal achieved, thus ensuring that the decision was based on sound logic. The overall analysis of results could be illustrated as shown in Figure 4.16.

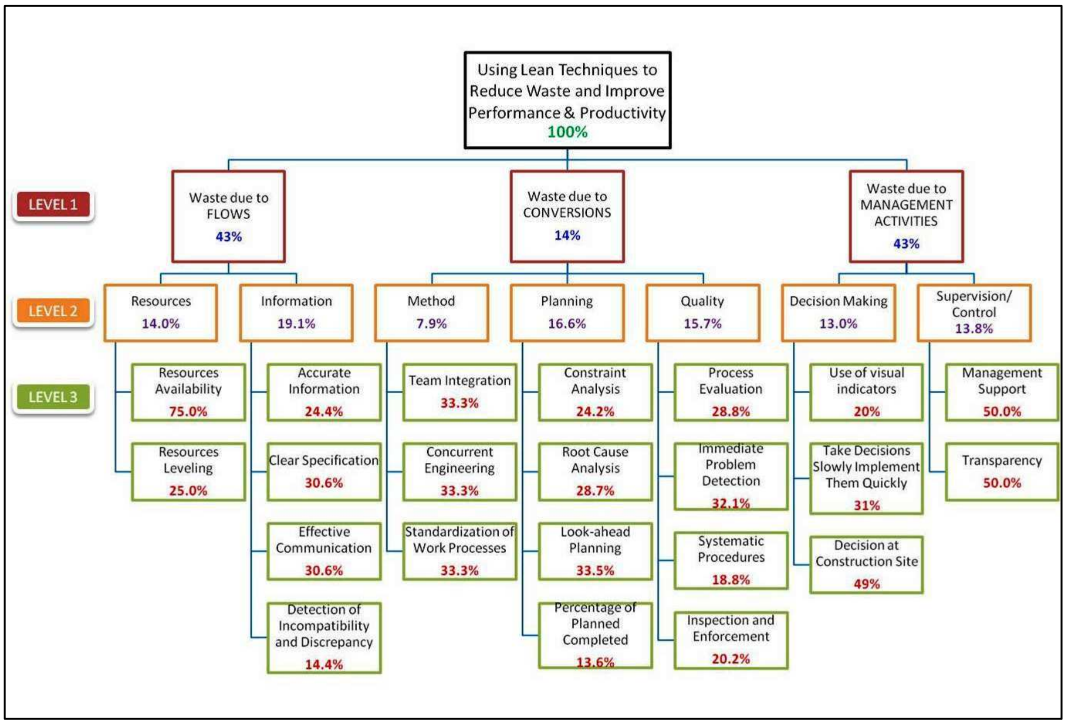


Figure 4.16 Overall Analysis of Results

4.5 Discussion of Results

As illustrated in Figure 4.16, the survey result assessed the importance of the waste factors and lean techniques in order to help decision-makers to make tradeoffs among them. To reach the optimum goal of improvement, the result demonstrates the following:

1) Controllable waste associated with Management Activities and Flows are the most important factors in reducing the process waste (Figure 4.7). This result demonstrates the necessity for giving the priority for waste reduction to activities associated with Management Activities (Supervision/Control and Decision-Making), and Flows (Information and Resources). Application of lean techniques should have more consideration and importance in these activities in order to improve performance and productivity.
2) While each controllable waste was subdivided to different factors, waste due to Information was found the most importance among the other six factors, and Method found to be the least; see Figure 4.8. Information then has to be considered through the suggested lean techniques which include: (Accurate information, clear specification, effective communication, and detection of incompatibility and discrepancy).
3) The result provides a set of priorities for how application of lean techniques (level 3) could be categorized, and it demonstrates the importance of the alternatives for reaching the superior goal (level 2); please refer to section 4.2.5.3, and see Figures 4.9 through 4.15.

4.6 Chapter Summary

A survey was sent out to professionals in the construction industry including both private and public sectors. The majority of the survey participants were from Texas, and they belonged to various areas of the construction including directors, project managers, and others. The survey approach was to use the weights, or priorities, to allocate a resource among the activities to simply implement the most important activities by rank. To validate the results and methods used in these decision-making problems, consistency was computed to determine its acceptability. To improve the consistency of some of the results obtained, activities have been re-ranked by a simple order based on the weights obtained in the first run of the problem, and the consistency obtained was better. To help decision-makers make tradeoffs, the survey results assessed the importance of the waste factors and lean techniques.

Chapter 5

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

Chapter 4 illustrated the data collection process, analysis, validation, and the final results obtained. This chapter includes the summary of this thesis and the conclusions drawn from the research conducted on applying lean techniques for municipal project delivery improvement. The limitations to the research and recommendations for implementation and future research were also discussed in this chapter.

5.1 Research Summary

A case sparked the necessity for improvement of the construction project process within traditional method practices used by municipal projects. This research aimed to propose the application of lean techniques to reduce waste and improve performance and productivity in municipal project delivery. A literature review on the existing body of knowledge pertaining to this thesis was concluded. This literature review covered methods used by municipal construction projects as well as lean construction, waste in construction, productivity and performance measurement, and information system and communication. This thesis developed a framework in which lean theory can be put into practical experiences through the Analytical Hierarchy Process approach (AHP). AHP is a decision-aiding method aimed at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the decision-maker. For this purpose, a comparison-based survey was conducted targeting the construction professionals' experience. The research approach aimed for optimum success that could be reached by applying the appropriate techniques to reduce the waste, obtain required results, and look for continuous improvement for future application. Many alternatives of lean techniques were identified and prioritized to support in reaching the optimum goal of waste reduction and performance improvement.

5.2 Conclusions

The following conclusions can be derived from this thesis:

1) Waste in the construction process were defined and isolated as a controllable waste in which it was classified, recognized, and controlled.
2) This thesis provided better understanding of lean techniques application as a waste controller and improvement provider.
3) Many alternatives of lean techniques were identified to support in reaching the optimum goal of waste reduction and performance and productivity improvement.
4) Through the AHP approach, the survey result helped the decision-makers to reach their goal through demonstrating the decision-making problem as a hierarchy of criteria and alternatives.
5) The survey result clearly assessed the importance of the waste factors and lean techniques alternatives in order to help decision-makers to make tradeoffs among them.
6) The analysis of the survey result was prioritized the controllable waste associated with Management Activities and Flows as the most important factors need to be focused on with a rate of 43% for each.
7) Waste associated with Information was found the most important factor among the controllable waste sub-factors with a rate of 19%, followed by Planning 16.6%, Quality 15.7, Resources 14%, Supervision/Control 13.8%, Decision-Making 13%, and Method found to be the least with 7.9%.

8) Lean techniques were specified as alternatives for each sub-level waste, and prioritized for better application; see Figures 4.9 through 4.15 in chapter 4.

5.3 Limitations

There are several limitations that need to be addressed in regards to the development of this thesis:

- This research investigated problems in the municipal construction project delivery in Texas region as a specimen sample, and assigned to a known construction method practices (Design-Bid-Build).
- This research selected specific lean techniques to be implemented to solve the research problems presented in this thesis.
- The results obtained from this research were related to a data collected according to construction professionals' experience and the research topic investigation, and further consideration might be needed for future research.
- In this research, respondents were selected in one geographic area, which may have influenced the results.

5.4 Recommendations for Implementation

The following topics are recommended on the subject of using lean techniques in construction industry:

- The results of this thesis could lead to improved relationships between owners, consultants, and contractors through the suggested techniques.
- Construction firms need to be aware of the intensity of the miscommunication that exist in the construction industry and encourage relations that build on team integration and transparency.

- In terms of social change, this thesis presented the opportunity to change the way in which the stakeholders interact with each others in construction industry for continuous improvement.
- Knowledge gained from this thesis could also be incorporated into training techniques for leaders in the construction industry to ensure successful project completion.
- The results of this study may also serve as an influence to members of the construction industry who are hesitant to implement lean techniques for waste reduction and performance improvement.
- This research can help to provide the construction industry increased knowledge that is needed to change its own public image, as well as to improve the performance through interactions between stakeholders.

5.5 Recommendations for Future Research

- It is hoped that this study will inspire future research regarding lean construction, and the use of lean techniques in many areas within the construction industry.
- Because this study focused on a specific sector and project delivery method, future research should be conducted to include more sectors and delivery methods used by the construction industry and other types of projects.
- Future research should also consider the construction industry on a national or even global scale; however, such an endeavor was outside the scope of this research.

Appendix A

RESEARCH SURVEY

Re: **Research Survey**

My name is Yasir Abdelrazig and I am a graduate student at University of Texas at Arlington (UTA) conducting a thesis research for my master degree evaluating: *“Using Lean Techniques to Reduce Waste and Improve Performance in Construction Project Delivery”*

Objective

- To analyze and gain a better understanding on the topic of how lean techniques could reduce waste and improve performance in of the traditional municipal project delivery based on construction professionals’ experience.

Methodology

- To conduct a pair-wise computation to identify the weight of several factors.
- To calculate an overall score of the factors using the Analytic Hierarchy Process (AHP).
- Figure 1: Provides a hierarchy chart of the rating factors (in the attached survey file).
- Table 1: Provide the definitions of the various rating factors.

Note:

The Analytical Hierarchy Process (AHP) is a decision-aiding method aims at quantifying relative priorities for a given set of alternatives on a ratio scale, based on the judgment of the Decision-Maker.

Confidentiality

- The information provided will be used only in support of this research project.
- Your completion of this survey is completely voluntary.
- No IP address from which you are responding will be tracked (names of participants to remain anonymous).
- All participants information collected will be kept confidential by the researcher, and you will receive a summary report describing the findings of the study upon request.

Please download the Excel file and select the appropriate level of preferences for each pair of comparison by clicking on the drop down arrow on the middle table on the attached survey, save the file and reply to the sender email.

Contact:

If you have any concern about this survey, please contact:

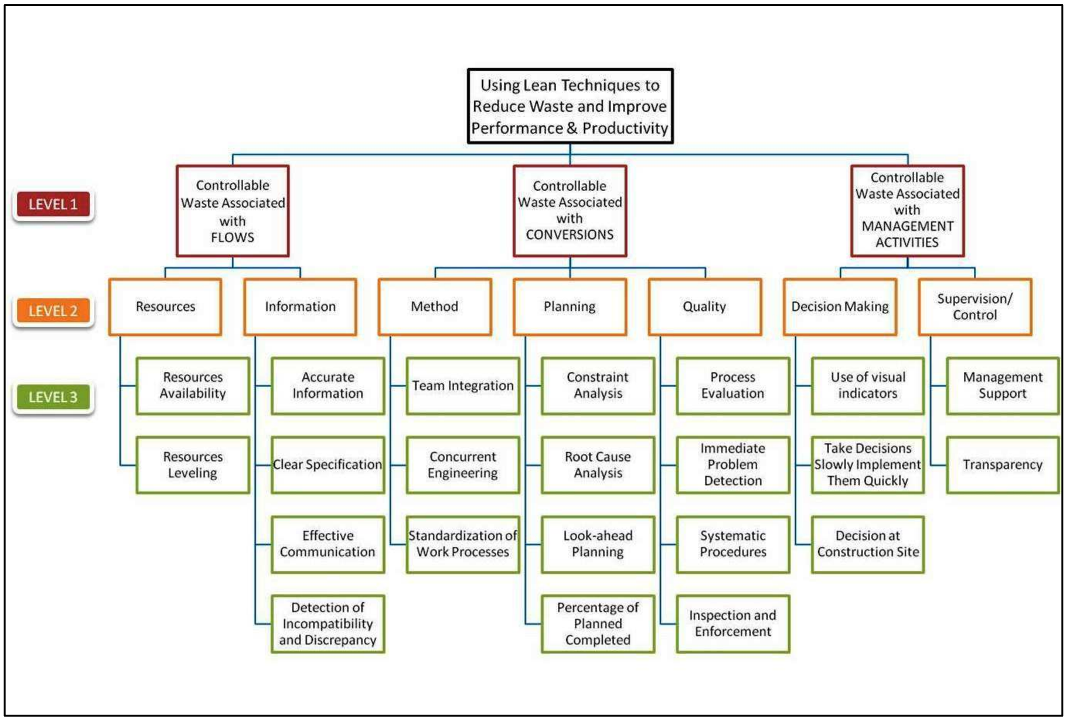
- Yasir Abdelrazig (yasir.bdelrazig@mavs.uta.edu); Graduate Student at UTA, (817) 987-7671.
- Dr. Mohammad Najafi (najafi@uta.edu); Professor and Director, Construction Engineering and Management, University of Texas at Arlington (UTA) at (817) 272-0507.

We would like to thank you in advance for your assistance.

Sincerely,

Yasir Abdelrazig
Graduate Student
College of Civil Engineering
University of Texas at Arlington

Three Level AHP Structure for Lean Techniques Rating



Title	Definition
Accurate Information	Provide a valid and accurate information required to complete the job
Clear Specification	Provide detailed requirement or characteristics of the product, service, outcome, or result of the project
Concurrent Engineering	Parallel execution of various tasks by multidisciplinary project teams with equal goal and vision
Constraint Analysis	Determine what must be done for a given work assignment before execution
Decision at Construction Site	Getting on the project site and see what the real problem is
Detection of Incompatibility and Discrepancy	Detection of a conflict or variation, as between the given facts and the actual condition
Effective Communication	Efficient and effective communication process among the stakeholders
Immediate Problem Detection	Create continuous process flow and review to bring problems to the surface on time
Inspection and Enforcement	Adding inspections, and increasing tracking of defects, rather than reducing waste by preventing defects

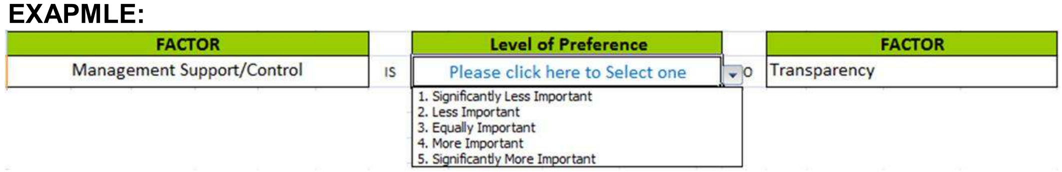
Look-ahead Planning	Expresses what CAN be done after the master plan defines what SHOULD be done
Management Support	Involvement of managers in the process at the project level
Percentage of Planned Completed	Systematically comparing the plans committed to the plans executed in a project
Process Evaluation	Evaluation of project performance and process efficiency at site and project level
Resources Availability	Availability of a resource that is committable, operable, or usable upon demand
Resources Leveling	The process allocate and smoothing out daily resources demands (Labor - Equipment - Material)
Root Cause Analysis	Tracking and analyzing for nonconformance with the plan in order to develop a future plan
Standardization of Work Process	Using stable, repeatable methods everywhere to maintain the predictability, regular timing, and regular output of processes
Systematic Procedures	Increase output value through systematic consideration of owner requirements
Take Decision Slowly, Implement them Quickly	Take decisions slowly after total consensus of all the stakeholders, implement them quickly on project
Team Integration	Members from all the organizations needed to develop, build, and deliver the project
Transparency	The availability of full information required for collaboration, cooperation, and collective decision making
Visual Indicators	Effective techniques such as the fishbone, cause and effect diagram, and A4 chart

Level of Preference of Each Factor

1. Significantly Less Important
2. Less Important
3. Equally Important
4. More Important
5. Significantly More Important

FROM THE MIDDLE TABLE, PLEASE SELECT THE APPROPRIATE LEVEL OF PREFERENCE OF EACH FACTOR ON THE LEFT TO THE FACTOR ON THE RIGHT BY CLICKING THE DROP DOWN ARROW

EXAPMLE:



AHP Level 2

FACTOR		Level of Preference		FACTOR
Decision-Making	IS	Please click here to Select one	TO	Quality
		Please click here to Select one	TO	Planning
		Please click here to Select one	TO	Method
		Please click here to Select one	TO	Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Quality	IS	Please click here to Select one	TO	Planning
		Please click here to Select one	TO	Method
		Please click here to Select one	TO	Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Planning	IS	Please click here to Select one	TO	Method
		Please click here to Select one	TO	Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Method	IS	Please click here to Select one	TO	Information
		Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Information	IS	Please click here to Select one	TO	Resources
		Please click here to Select one	TO	Supervision/Control
FACTOR		**Level of Preference**		**FACTOR**
Resources	IS	Please click here to Select one	TO	Supervision/Control

AHP Level 3

FACTOR		Level of Preference		FACTOR
Management Support/Control	IS	Please click here to Select one	TO	Transparency

AHP Level 3

FACTOR		Level of Preference		FACTOR
Use of visual indicators	IS	Please click here to Select one	TO	Take Decisions Slowly Implement Them Quickly
		Please click here to Select one	TO	Decision at Construction Site
Take Decisions Slowly Implement them Quickly	IS	Please click here to Select one	TO	Decision at Construction Site

AHP Level 3

FACTOR		Level of Preference		FACTOR
Process Evaluation	IS	Please click here to Select one	TO	Immediate Problem Detection
		Please click here to Select one	TO	Systematic Procedures
		Please click here to Select one	TO	Inspection and Enforcement
Immediate Problem Detection	IS	Please click here to Select one	TO	Systematic Procedures
		Please click here to Select one	TO	Inspection and Enforcement
Systematic Procedures	IS	Please click here to Select one	TO	Inspection and Enforcement

AHP Level 3

FACTOR		Level of Preference		FACTOR
Resources Availability	IS	Please click here to Select one	TO	Resources Leveling

AHP Level 3

FACTOR		Level of Preference		FACTOR
Constraint Analysis	IS	Please click here to Select one	TO	Root Cause Analysis
		Please click here to Select one	TO	Look-ahead Planning
		Please click here to Select one	TO	Percentage of Planned Completed
Root Cause Analysis	IS	Please click here to Select one	TO	Look-ahead Planning
		Please click here to Select one	TO	Percentage of Planned Completed
Look-ahead Planning	IS	Please click here to Select one	TO	Percentage of Planned Completed

AHP Level 3

FACTOR		Level of Preference		FACTOR
Team Integration	IS	Please click here to Select one	TO	Concurrent Engineering
		Please click here to Select one	TO	Standardization of Work Processes
Concurrent Engineering	IS	Please click here to Select one	TO	Standardization of Work Processes

AHP Level 3

FACTOR		Level of Preference		FACTOR
Accurate Information	IS	Please click here to Select one	TO	Clear Specification
		Please click here to Select one	TO	Effective Communication

		Please click here to Select one	TO	Detection of Incompatibility and Discrepancy
Clear Specification	IS	Please click here to Select one	TO	Effective Communication
		Please click here to Select one	TO	Detection of Incompatibility and Discrepancy
Effective Communication	IS	Please click here to Select one	TO	Detection of Incompatibility and Discrepancy

OPTIONAL:

Respondent's Agency:	
Respondent's Name:	
Job Title:	
Phone Number:	

NOTE

PLEASE:

- *SAVE YOUR WORK AFTER COMPLETION*
- *REPLY ATTACHING THIS FILE TO THE SENDER EMAIL (yasir.bdelrazig@mavs.uta.edu)*

Appendix B

DATA ANALYSIS

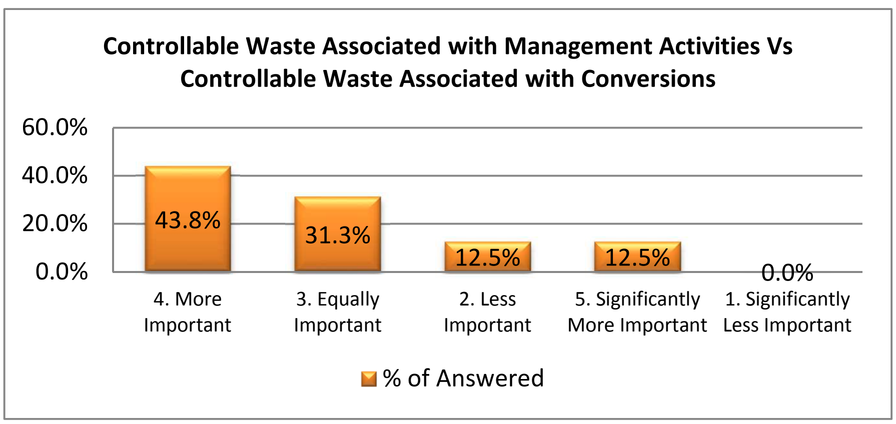
LEVEL 1

Comparison 1.1

Controllable Waste Associated with Management Activities
Vs.
Controllable Waste Associated with Conversions

Total responses 16 **Out of** 18 **Response rate** 88.89%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	2	11.11%	12.50%
3. Equally Important	5	27.78%	31.25%
4. More Important	7	38.89%	43.75%
5. Significantly More Important	2	11.11%	12.50%
	16		1

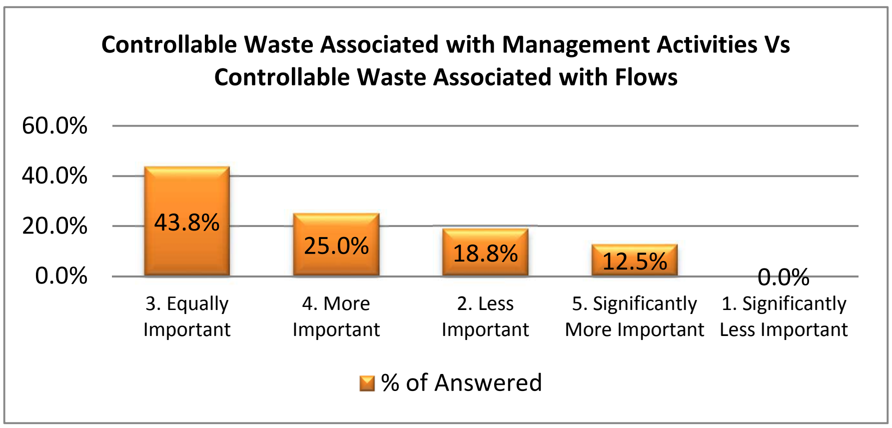


Comparison 1.2

Controllable Waste Associated with Management Activities
Vs.
Controllable Waste Associated with Flows

Total responses 16 **Out of** 18 **Response rate** 88.89%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	3	16.67%	18.75%
3. Equally Important	7	38.89%	43.75%
4. More Important	4	22.22%	25.00%
5. Significantly More Important	2	11.11%	12.50%
	16		1

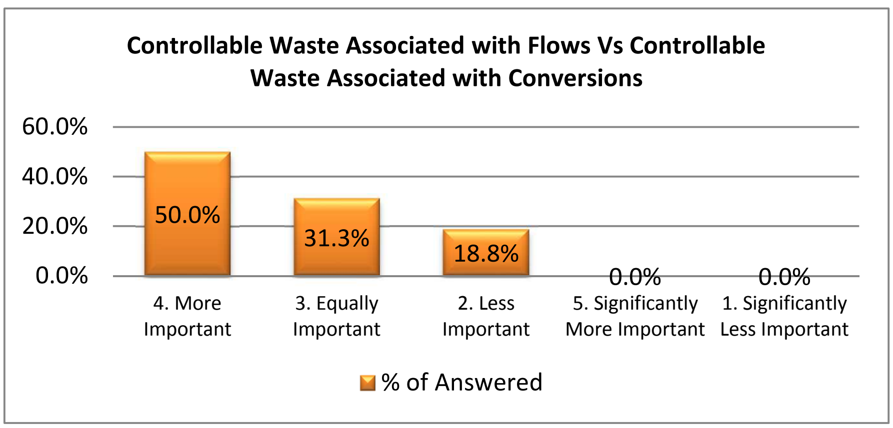


Comparison 1.3

Controllable Waste Associated with Flows
Vs.
Controllable Waste Associated with Conversions

Total responses 16 **Out of** 18 **Response rate** 88.89%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	3	16.67%	18.75%
3. Equally Important	5	27.78%	31.25%
4. More Important	8	44.44%	50.00%
5. Significantly More Important	0	0.00%	0.00%
	16		1



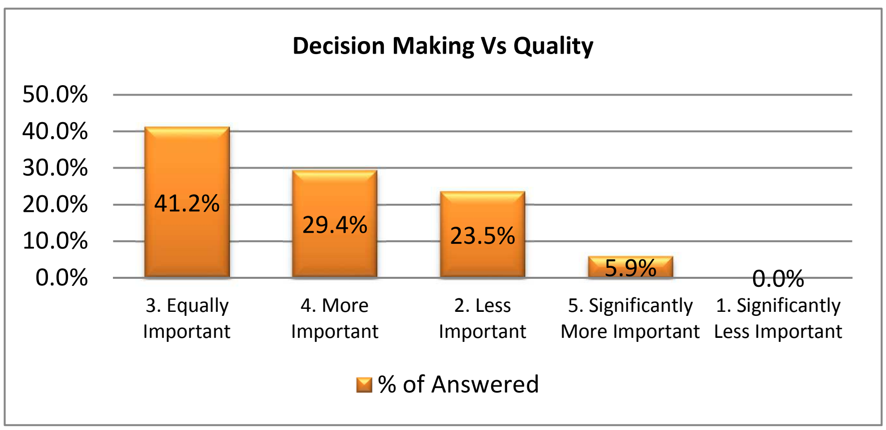
LEVEL 2

Comparison 2.1

Decision-Making
Vs.
Quality

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	4	22.22%	23.53%
3. Equally Important	7	38.89%	41.18%
4. More Important	5	27.78%	29.41%
5. Significantly More Important	1	5.56%	5.88%
	17		1

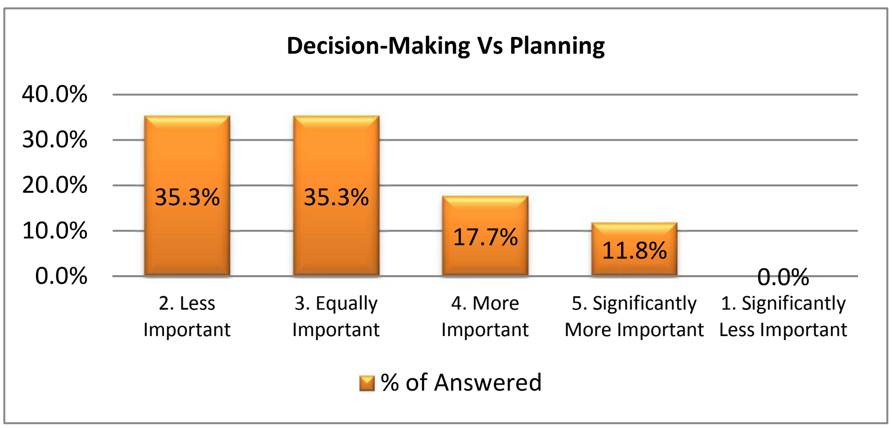


Comparison 2.2

Decision-Making
Vs.
Planning

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	6	33.33%	35.29%
3. Equally Important	6	33.33%	35.29%
4. More Important	3	16.67%	17.65%
5. Significantly More Important	2	11.11%	11.76%
	17		1

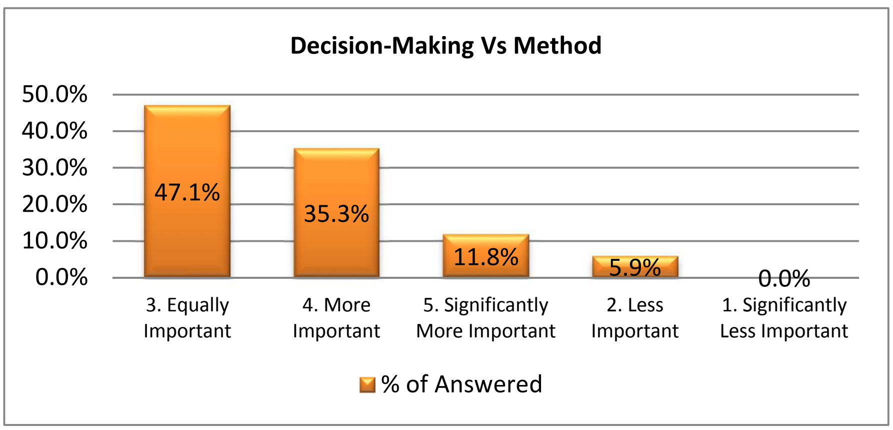


Comparison 2.3

Decision-Making
Vs.
Method

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.88%
3. Equally Important	8	44.44%	47.06%
4. More Important	6	33.33%	35.29%
5. Significantly More Important	2	11.11%	11.76%
	17		1

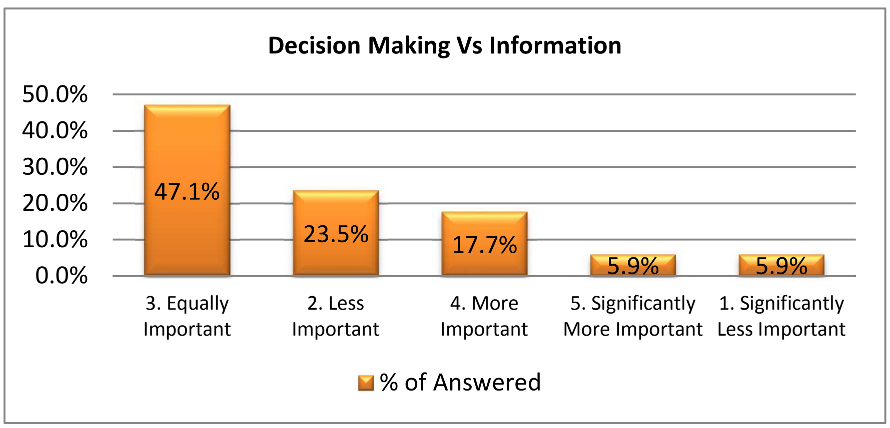


Comparison 2.4

Decision-Making
Vs.
Information

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	4	22.22%	23.53%
3. Equally Important	8	44.44%	47.06%
4. More Important	3	16.67%	17.65%
5. Significantly More Important	1	5.56%	5.88%
	17		1

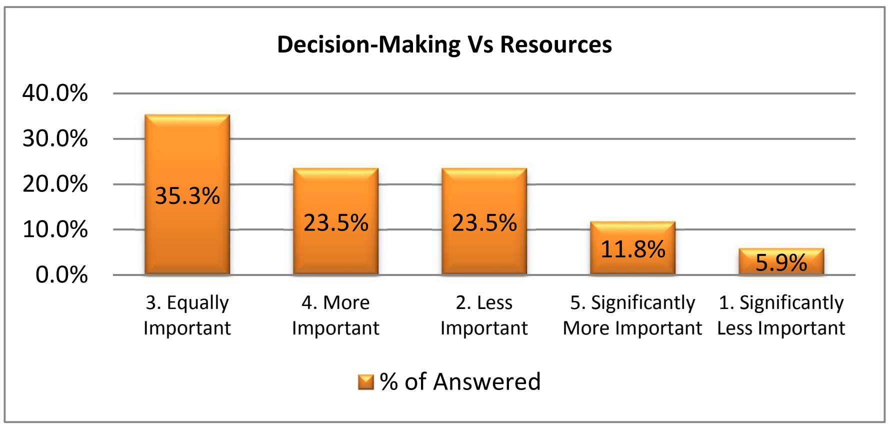


Comparison 2.5

Decision-Making
Vs.
Resources

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	4	22.22%	23.53%
3. Equally Important	6	33.33%	35.29%
4. More Important	4	22.22%	23.53%
5. Significantly More Important	2	11.11%	11.76%
	17		1

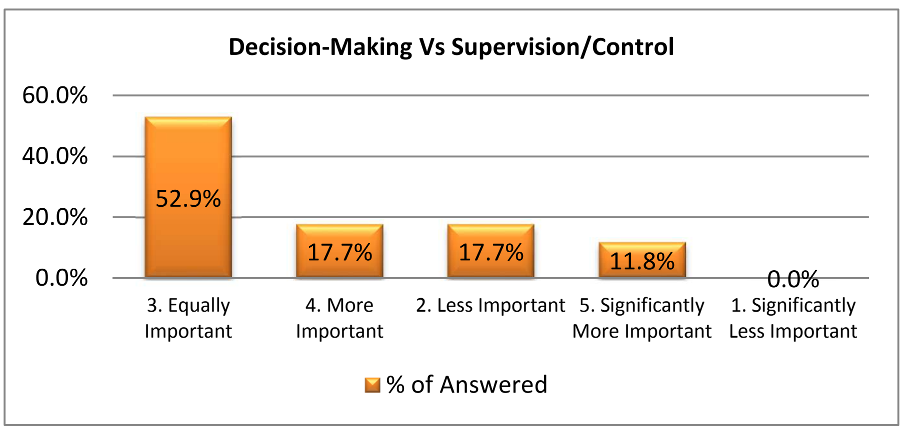


Comparison 2.6

Decision-Making
VS.
Supervision/Control

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	3	16.67%	17.65%
3. Equally Important	9	50.00%	52.94%
4. More Important	3	16.67%	17.65%
5. Significantly More Important	2	11.11%	11.76%
	17		1

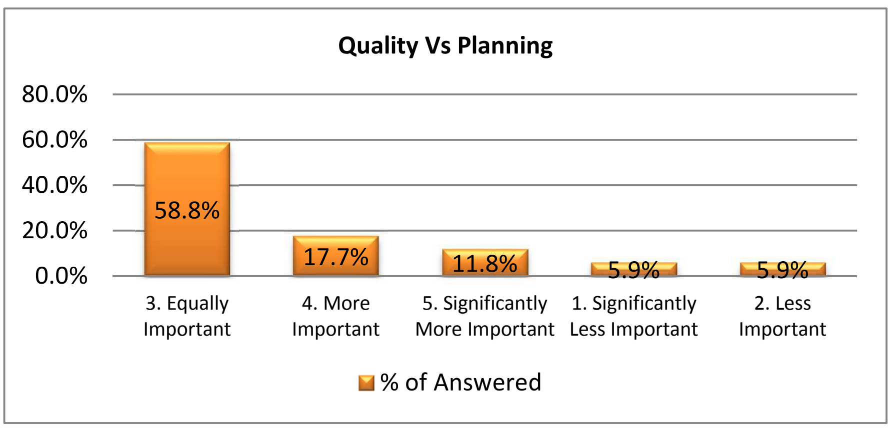


Comparison 2.7

Quality
Vs.
Planning

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	1	5.56%	5.88%
3. Equally Important	10	55.56%	58.82%
4. More Important	3	16.67%	17.65%
5. Significantly More Important	2	11.11%	11.76%
	17		1

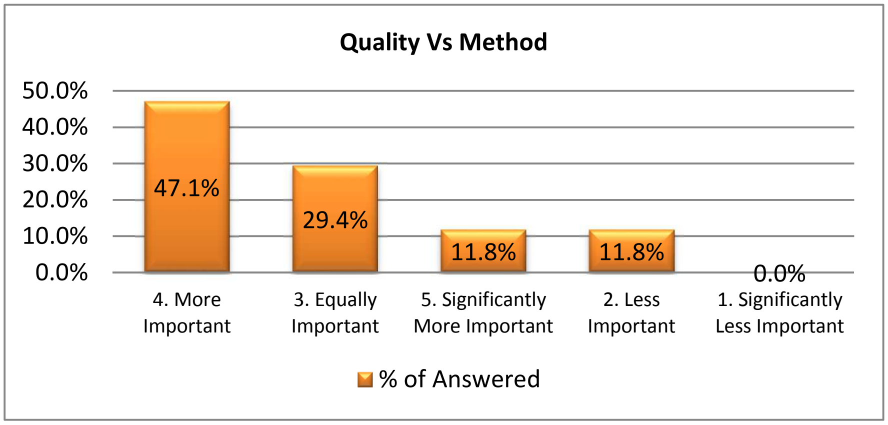


Comparison 2.8

Quality
Vs.
Method

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	2	11.11%	11.76%
3. Equally Important	5	27.78%	29.41%
4. More Important	8	44.44%	47.06%
5. Significantly More Important	2	11.11%	11.76%
	17		1

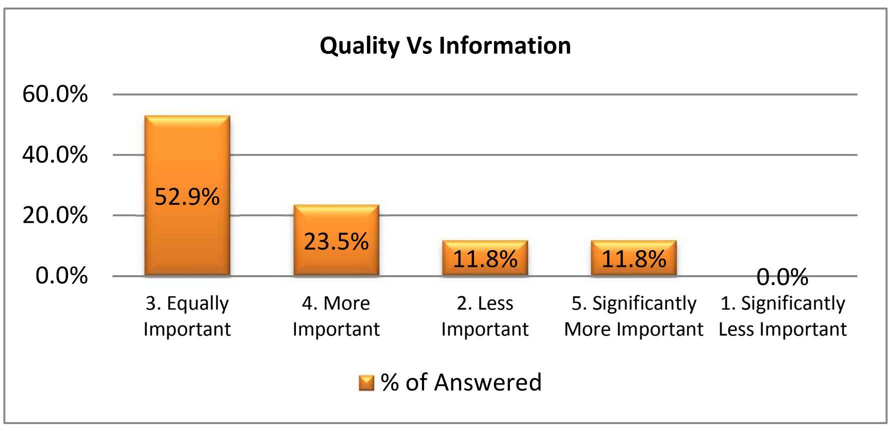


Comparison 2.9

Quality
Vs.
Information

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	2	11.11%	11.76%
3. Equally Important	9	50.00%	52.94%
4. More Important	4	22.22%	23.53%
5. Significantly More Important	2	11.11%	11.76%
	17		1

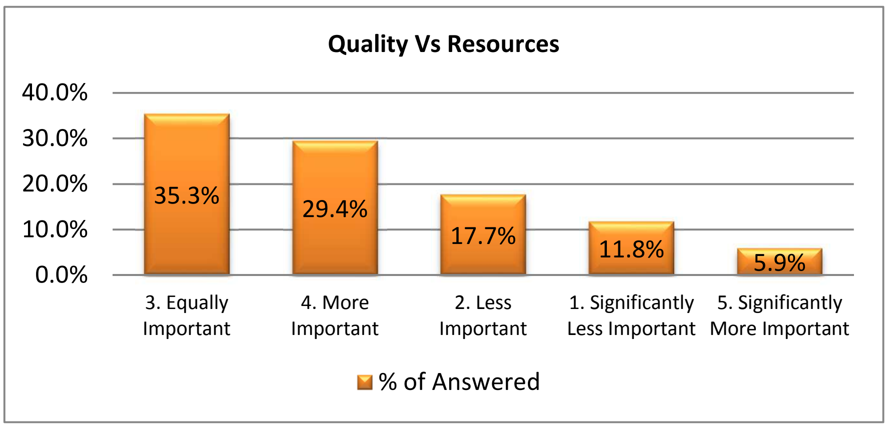


Comparison 2.10

Quality
Vs.
Resources

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	2	11.11%	11.76%
2. Less Important	3	16.67%	17.65%
3. Equally Important	6	33.33%	35.29%
4. More Important	5	27.78%	29.41%
5. Significantly More Important	1	5.56%	5.88%
	17		1

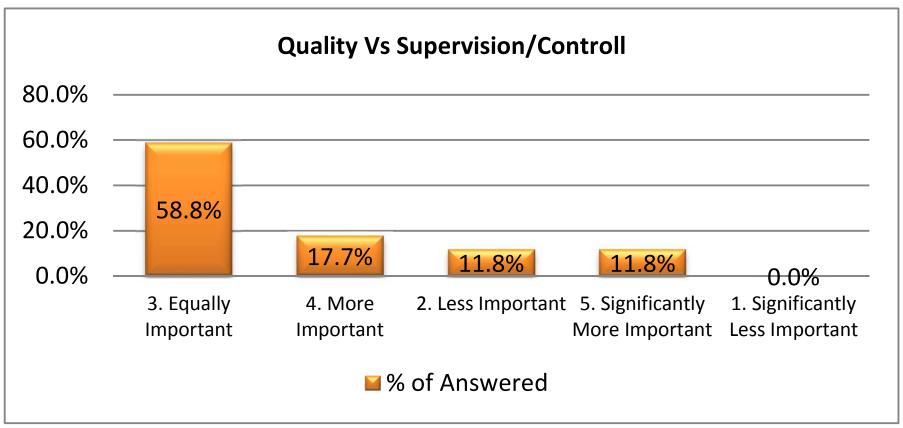


Comparison 2.11

Quality
Vs.
Supervision/Control

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	2	11.11%	11.76%
2. Less Important	2	11.11%	11.76%
3. Equally Important	10	55.56%	58.82%
4. More Important	3	16.67%	17.65%
5. Significantly More Important	0	0.00%	0.00%
	17		1

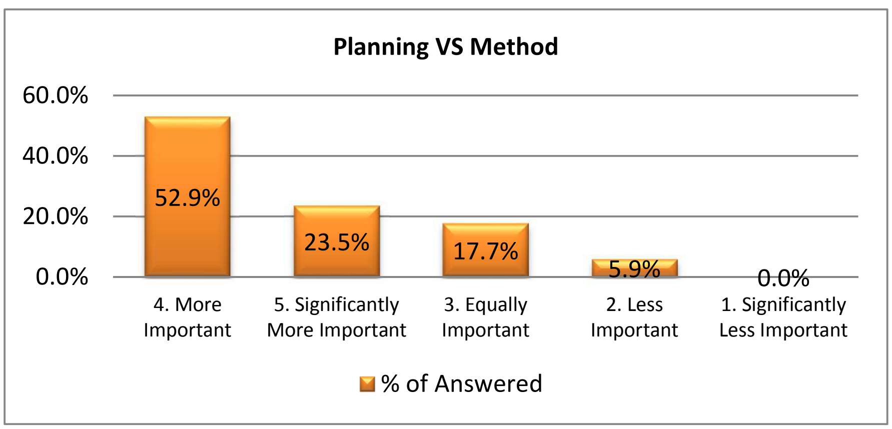


Comparison 2.12

Planning
Vs.
Method

Total responses	17	Out of	18	Response rate	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.88%
3. Equally Important	3	16.67%	17.65%
4. More Important	9	50.00%	52.94%
5. Significantly More Important	4	22.22%	23.53%
	17		1

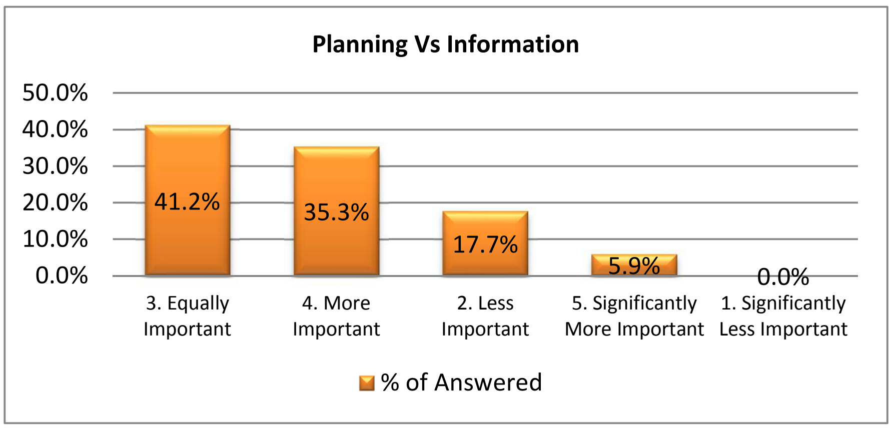


Comparison 2.13

Planning
Vs.
Information

Total responses	17	Out of	18	Response rate	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	3	16.67%	17.65%
3. Equally Important	7	38.89%	41.18%
4. More Important	6	33.33%	35.29%
5. Significantly More Important	1	5.56%	5.88%
	17		1

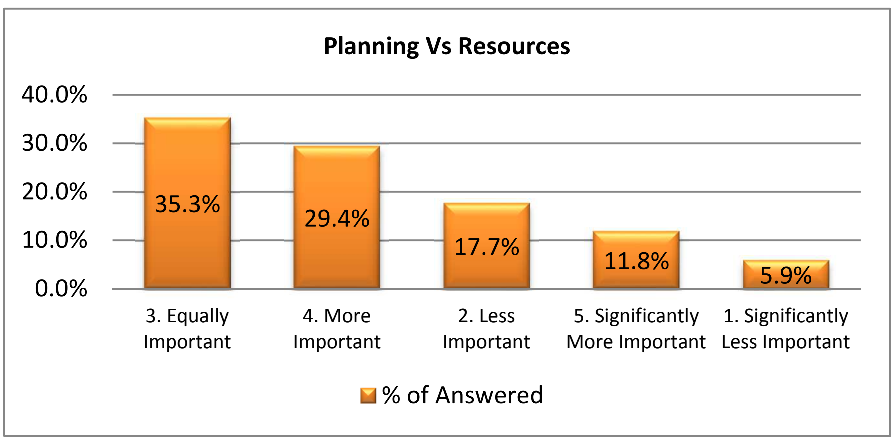


Comparison 2.14

Planning
Vs.
Resources

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	3	16.67%	17.65%
3. Equally Important	6	33.33%	35.29%
4. More Important	5	27.78%	29.41%
5. Significantly More Important	2	11.11%	11.76%
	17		1

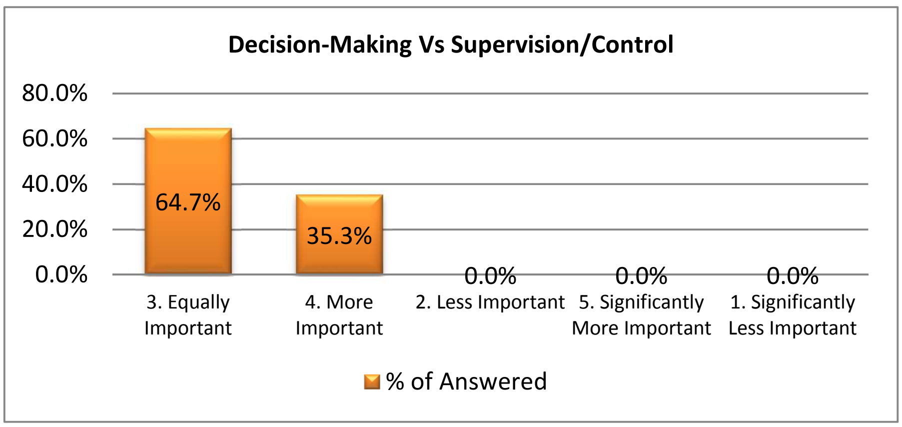


Comparison 2.15

Planning
Vs.
Supervision/Control

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	0	0.00%	0.00%
3. Equally Important	11	61.11%	64.71%
4. More Important	6	33.33%	35.29%
5. Significantly More Important	0	0.00%	0.00%
	17		1

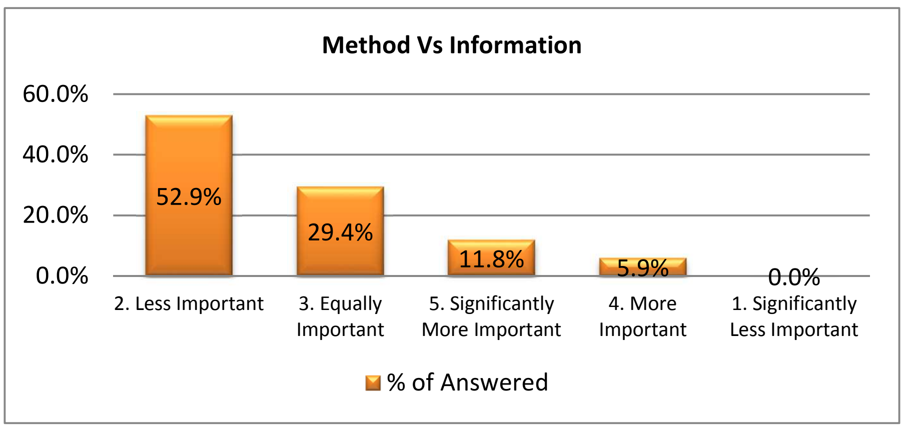


Comparison 2.16

Method
Vs.
Information

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	9	50.00%	52.94%
3. Equally Important	5	27.78%	29.41%
4. More Important	1	5.56%	5.88%
5. Significantly More Important	2	11.11%	11.76%
	17		1

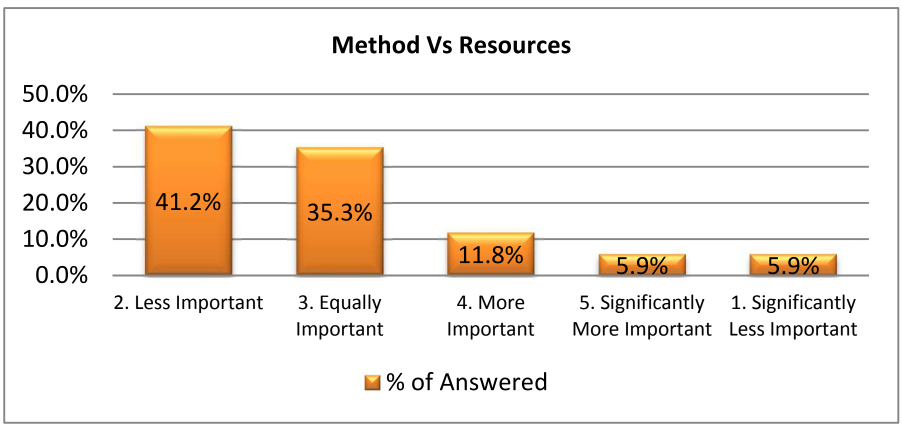


Comparison 2.17

Method
Vs.
Resources

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	7	38.89%	41.18%
3. Equally Important	6	33.33%	35.29%
4. More Important	2	11.11%	11.76%
5. Significantly More Important	1	5.56%	5.88%
	17		1

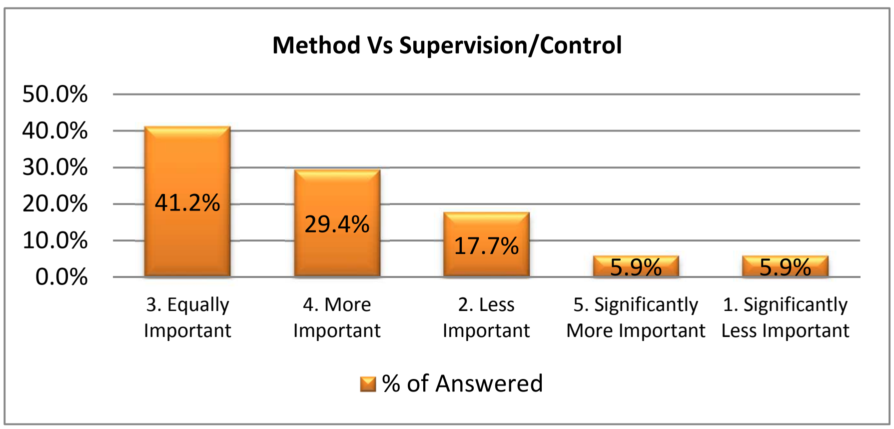


Comparison 2.18

Method
Vs.
Supervision/Control

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	3	16.67%	17.65%
3. Equally Important	7	38.89%	41.18%
4. More Important	5	27.78%	29.41%
5. Significantly More Important	1	5.56%	5.88%
	17		1

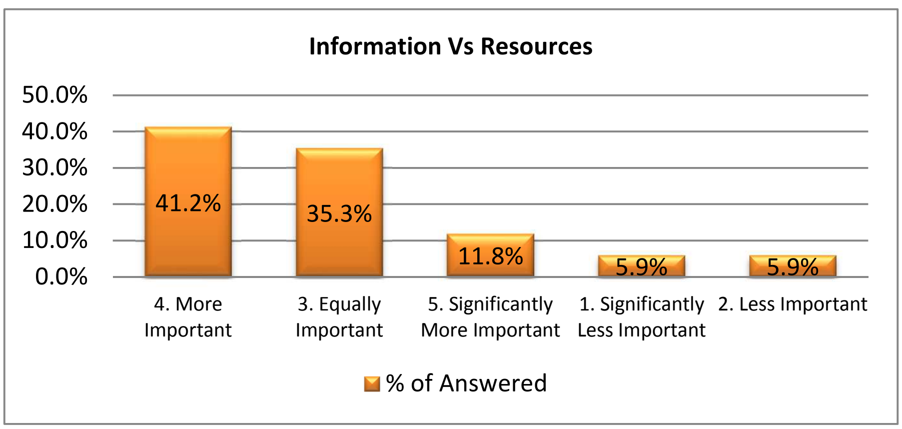


Comparison 2.19

Information
Vs.
Resources

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	1	5.56%	5.88%
3. Equally Important	6	33.33%	35.29%
4. More Important	7	38.89%	41.18%
5. Significantly More Important	2	11.11%	11.76%
	17		1

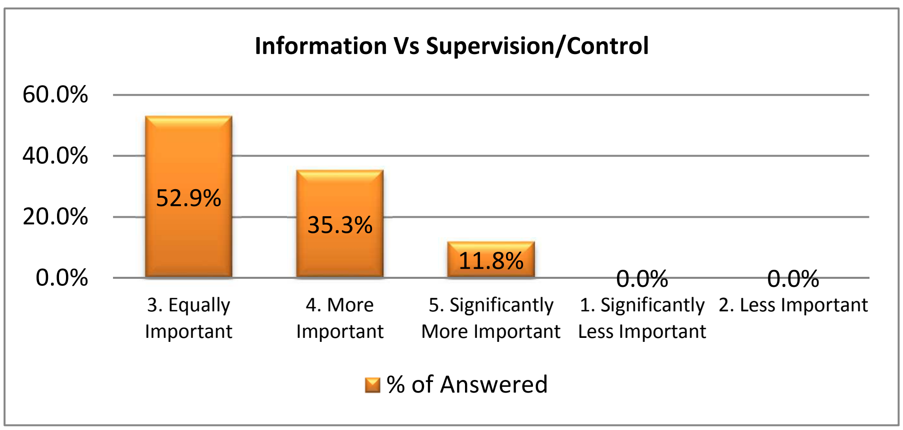


Comparison 2.20

Information
Vs.
Supervision/Control

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	0	0.00%	0.00%
3. Equally Important	9	50.00%	52.94%
4. More Important	6	33.33%	35.29%
5. Significantly More Important	2	11.11%	11.76%
	17		1

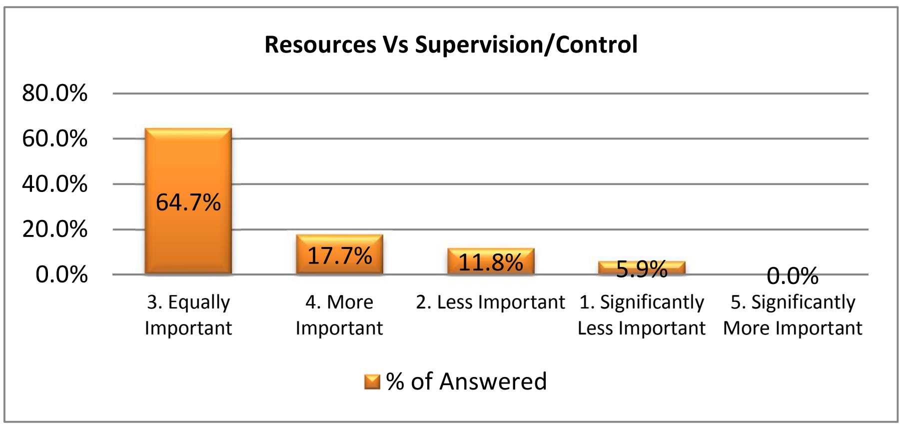


Comparison 2.21

Resources
Vs.
Supervision/Control

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	2	11.11%	11.76%
3. Equally Important	11	61.11%	64.71%
4. More Important	3	16.67%	17.65%
5. Significantly More Important	0	0.00%	0.00%
	17		1



LEVEL 3

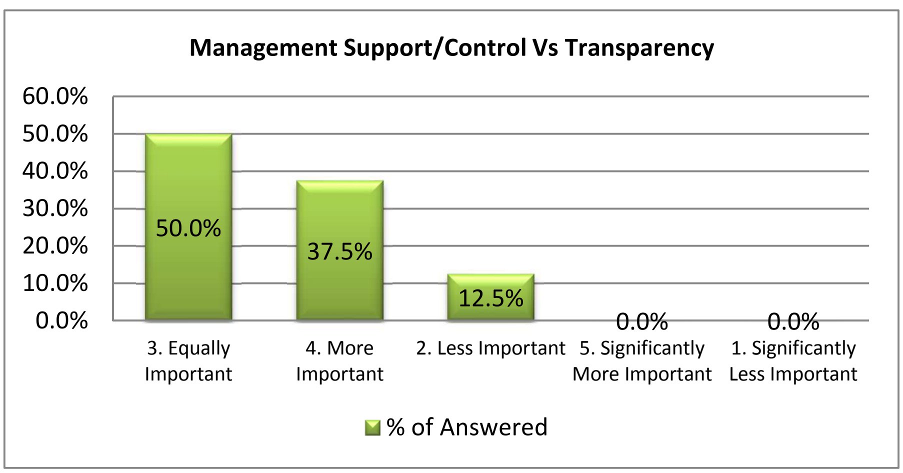
Comparison 3.1

Supervision/Control

Management Support/Control
Vs.
Transparency

Total responses 16 **Out of** 18 **Response rate** 88.89%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	2	11.11%	12.50%
3. Equally Important	8	44.44%	50.00%
4. More Important	6	33.33%	37.50%
5. Significantly More Important	0	0.00%	0.00%
	16		1



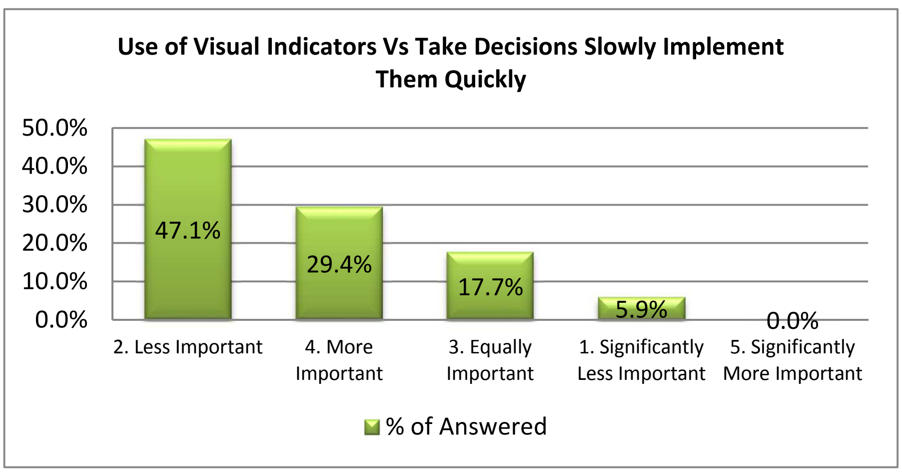
Comparison 3.2

Supervision/Control

Use of Visual Indicators
Vs.
Take Decisions Slowly Implement them Quickly

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	8	44.44%	47.06%
3. Equally Important	3	16.67%	17.65%
4. More Important	5	27.78%	29.41%
5. Significantly More Important	0	0.00%	0.00%
	17		1



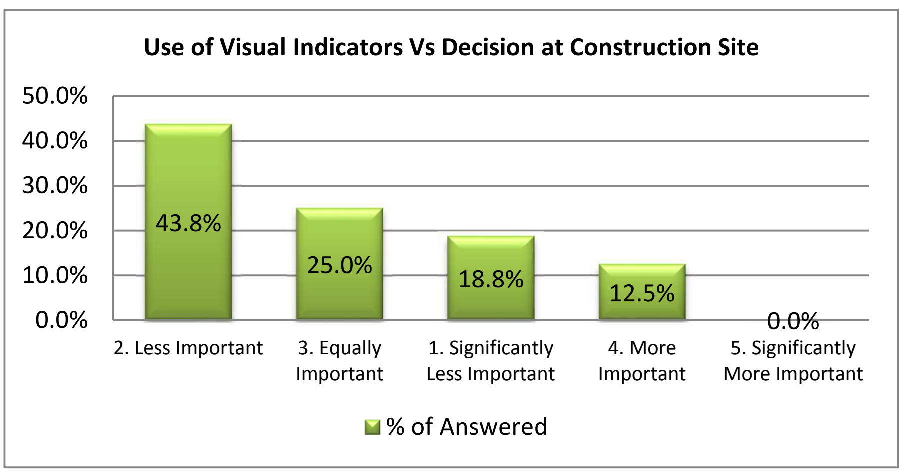
Comparison 3.3

Decision-Making

Use of Visual Indicators
Vs.
Decision at Construction Site

Total responses 16 **Out of** 18 **Response rate** 88.89%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	3	16.67%	18.75%
2. Less Important	7	38.89%	43.75%
3. Equally Important	4	22.22%	25.00%
4. More Important	2	11.11%	12.50%
5. Significantly More Important	0	0.00%	0.00%
	16		1



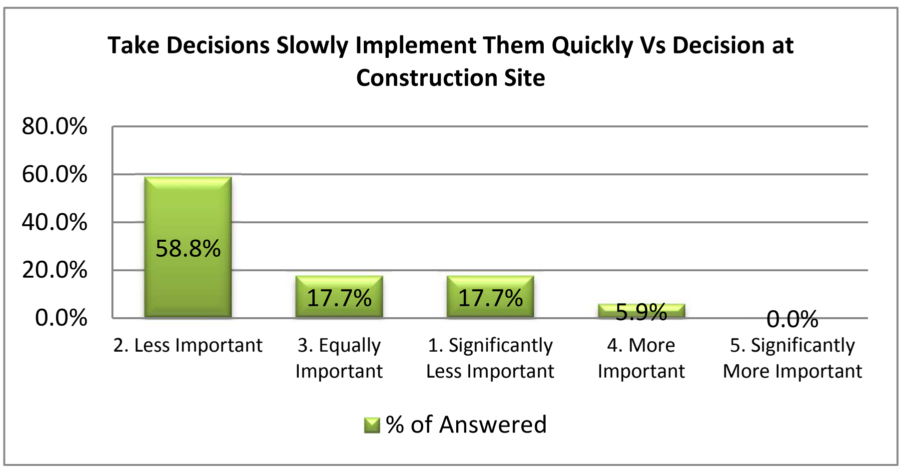
Comparison 3.4

Decision-Making

Take Decisions Slowly Implement them Quickly
Vs.
Decision at Construction Site

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	3	16.67%	17.65%
2. Less Important	10	55.56%	58.82%
3. Equally Important	3	16.67%	17.65%
4. More Important	1	5.56%	5.88%
5. Significantly More Important	0	0.00%	0.00%
	17		1



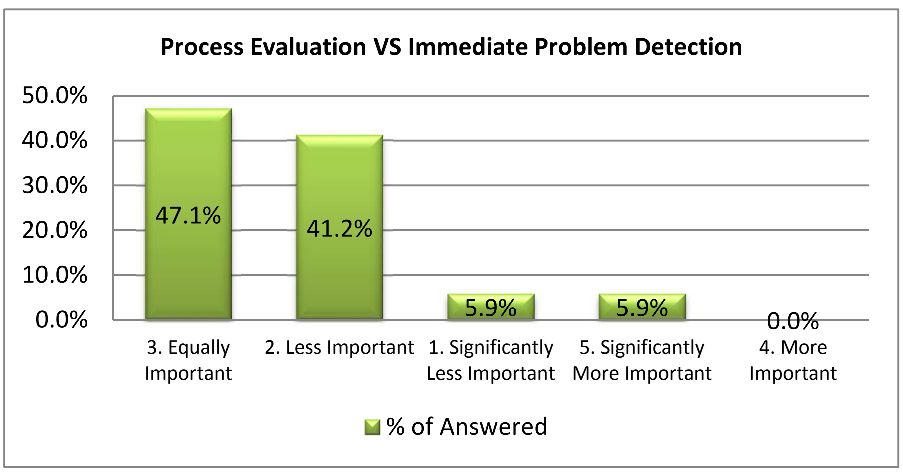
Comparison 3.5

Quality

Process Evaluation
Vs.
Immediate Problem Detection

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	1	5.56%	5.88%
2. Less Important	7	38.89%	41.18%
3. Equally Important	8	44.44%	47.06%
4. More Important	0	0.00%	0.00%
5. Significantly More Important	1	5.56%	5.88%
	17		1



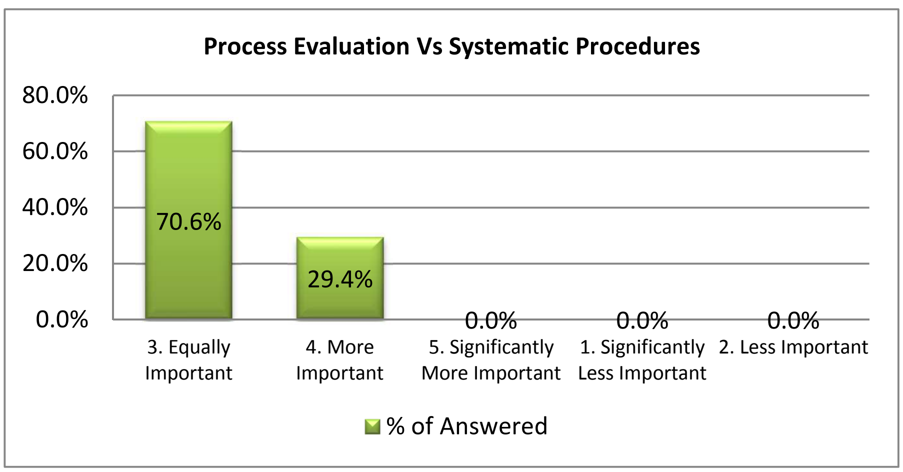
Comparison 3.6

Quality

Process Evaluation
Vs.
Systematic Procedures

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	0	0.00%	0.00%
3. Equally Important	12	66.67%	70.59%
4. More Important	5	27.78%	29.41%
5. Significantly More Important	0	0.00%	0.00%
	17		1



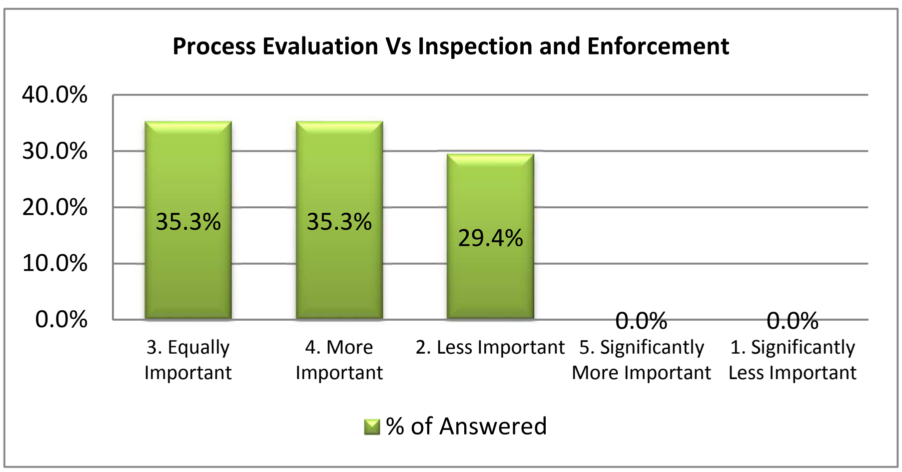
Comparison 3.7

Quality

Process Evaluation
Vs.
Inspection and Enforcement

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	5	27.78%	29.41%
3. Equally Important	6	33.33%	35.29%
4. More Important	6	33.33%	35.29%
5. Significantly More Important	0	0.00%	0.00%
	17		1



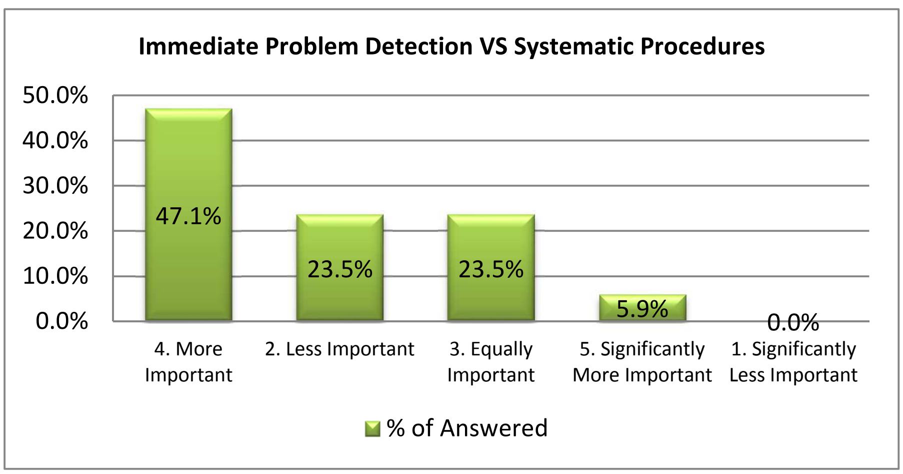
Comparison 3.8

Quality

Immediate Problem Detection
Vs.
Systematic Procedures

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	4	22.22%	23.53%
3. Equally Important	4	22.22%	23.53%
4. More Important	8	44.44%	47.06%
5. Significantly More Important	1	5.56%	5.88%
	17		1



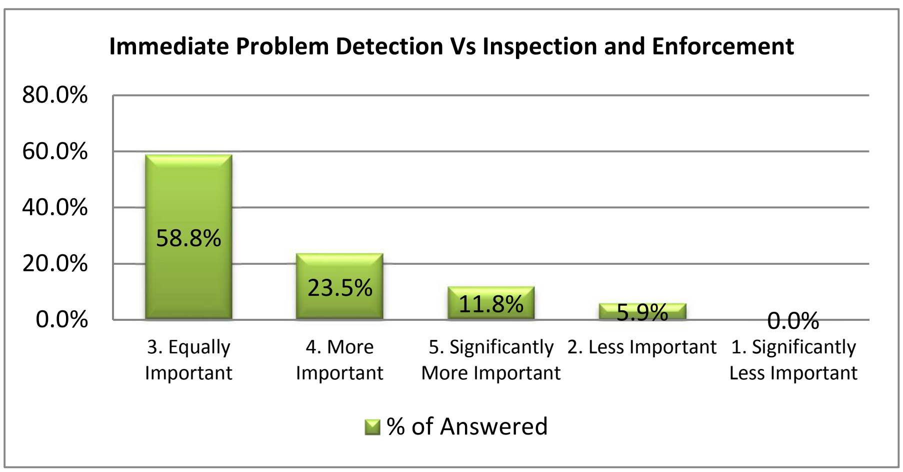
Comparison 3.9

Quality

Immediate Problem Detection
Vs.
Inspection and Enforcement

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.88%
3. Equally Important	10	55.56%	58.82%
4. More Important	4	22.22%	23.53%
5. Significantly More Important	2	11.11%	11.76%
	17		1



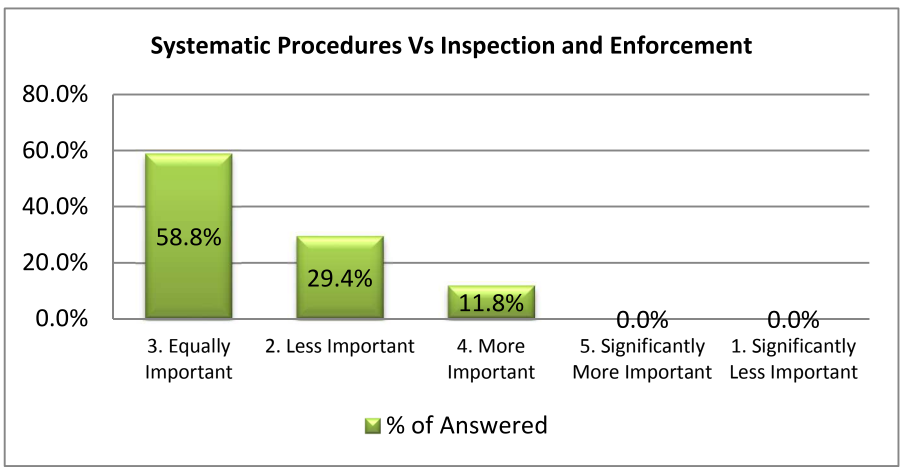
Comparison 3.10

Quality

Systematic Procedures
Vs.
Inspection and Enforcement

Total responses	17	**Out of**	18	**Response rate**	94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	5	27.78%	29.41%
3. Equally Important	10	55.56%	58.82%
4. More Important	2	11.11%	11.76%
5. Significantly More Important	0	0.00%	0.00%
	17		1



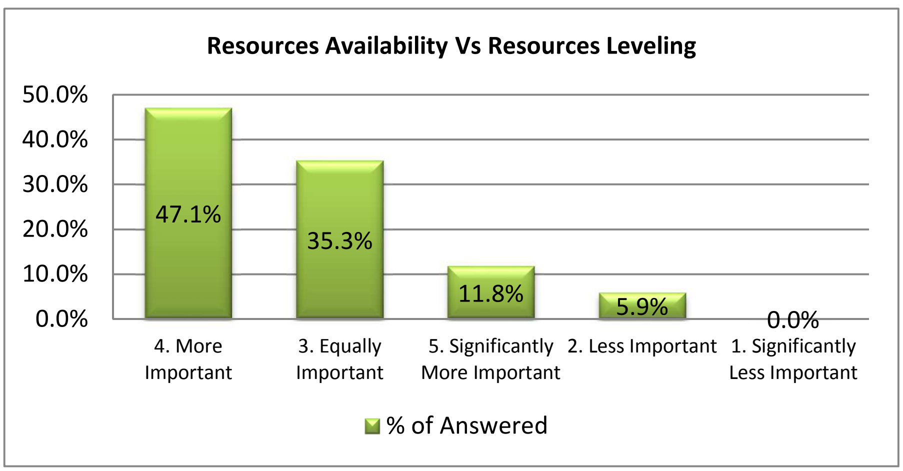
Comparison 3.11

Resources

Resources Availability
Vs.
Resources Leveling

Total responses 17 **Out of** 18 **Response rate** 94.44%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.88%
3. Equally Important	6	33.33%	35.29%
4. More Important	8	44.44%	47.06%
5. Significantly More Important	2	11.11%	11.76%
	17		1



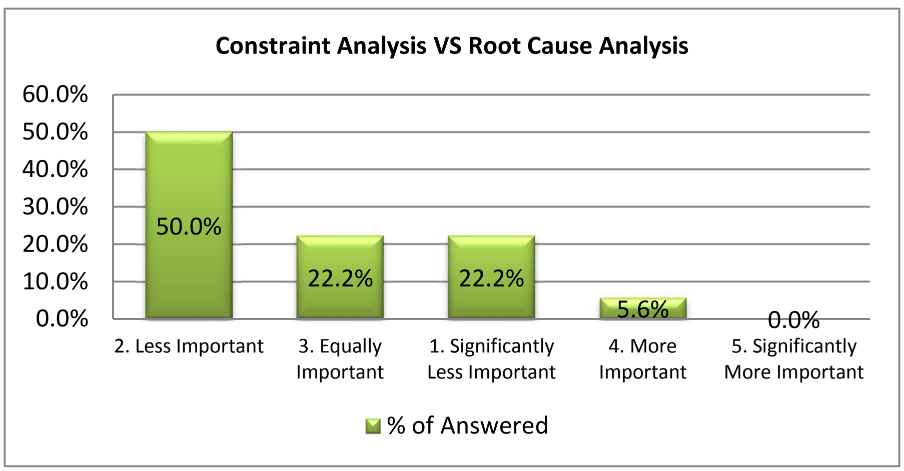
Comparison 3.12

Planning

Constraint Analysis
Vs.
Root Cause Analysis

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	4	22.22%	22.22%
2. Less Important	9	50.00%	50.00%
3. Equally Important	4	22.22%	22.22%
4. More Important	1	5.56%	5.56%
5. Significantly More Important		0.00%	0.00%
	18		1



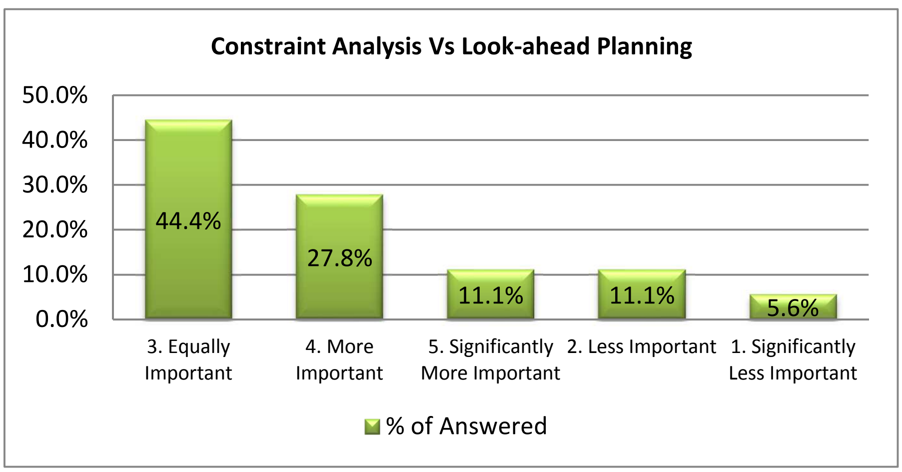
Comparison 3.13

Planning

Constraint Analysis
Vs.
Look-ahead Planning

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	1	5.56%	5.56%
2. Less Important	2	11.11%	11.11%
3. Equally Important	8	44.44%	44.44%
4. More Important	5	27.78%	27.78%
5. Significantly More Important	2	11.11%	11.11%
	18		1



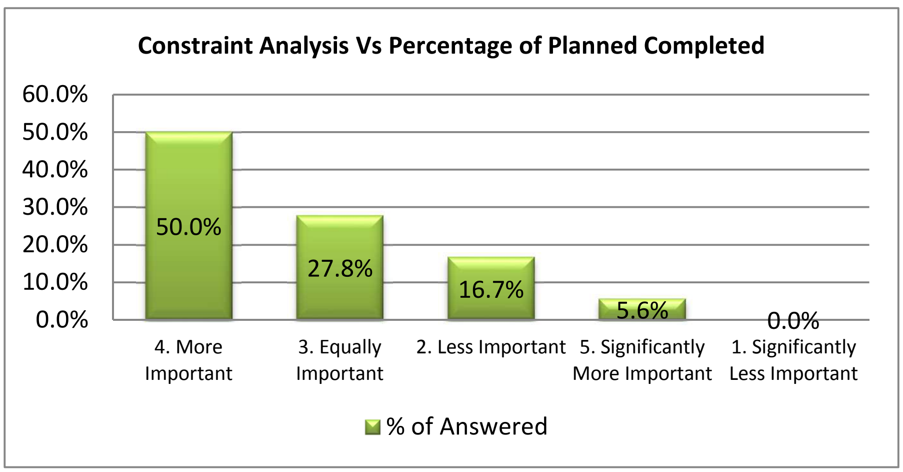
Comparison 3.14

Planning

Constraint Analysis
Vs.
Percentage of Planned Completed

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	3	16.67%	16.67%
3. Equally Important	5	27.78%	27.78%
4. More Important	9	50.00%	50.00%
5. Significantly More Important	1	5.56%	5.56%
	18		1



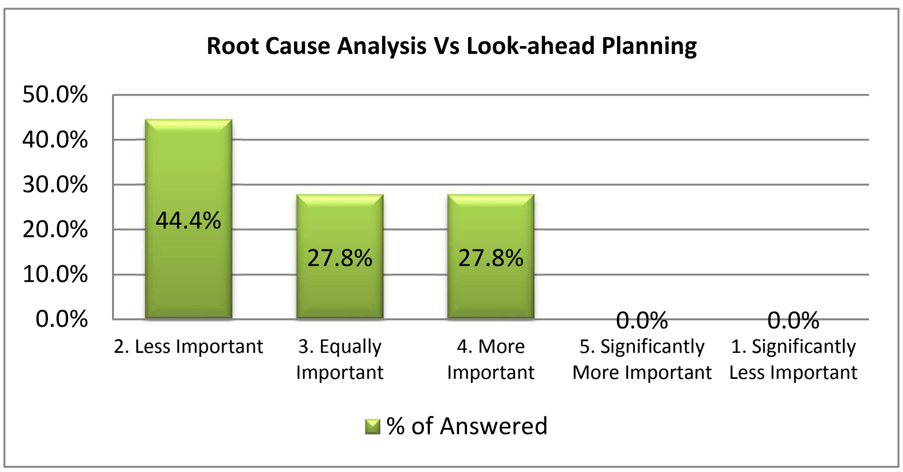
Comparison 3.15

Planning

Root Cause Analysis
Vs.
Look-ahead Planning

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	8	44.44%	44.44%
3. Equally Important	5	27.78%	27.78%
4. More Important	5	27.78%	27.78%
5. Significantly More Important	0	0.00%	0.00%
	18		1



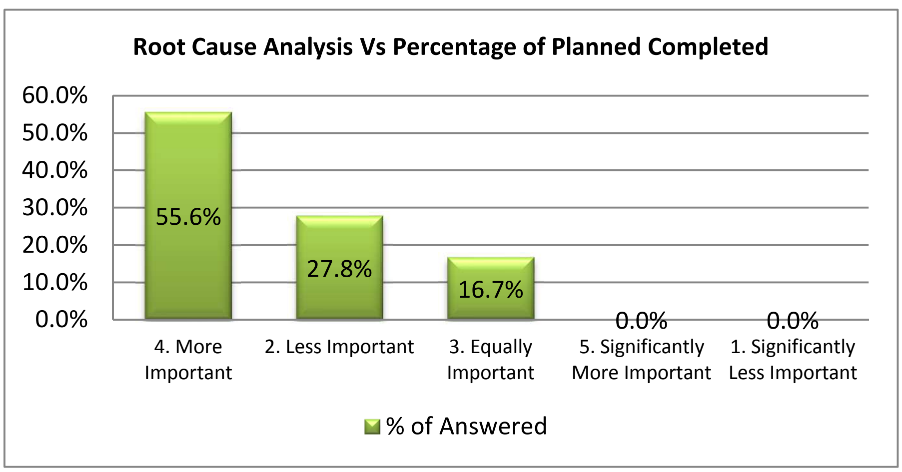
Comparison 3.16

Planning

Root Cause Analysis
Vs.
Percentage of Planned Completed

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	5	27.78%	27.78%
3. Equally Important	3	16.67%	16.67%
4. More Important	10	55.56%	55.56%
5. Significantly More Important	0	0.00%	0.00%
	18		1



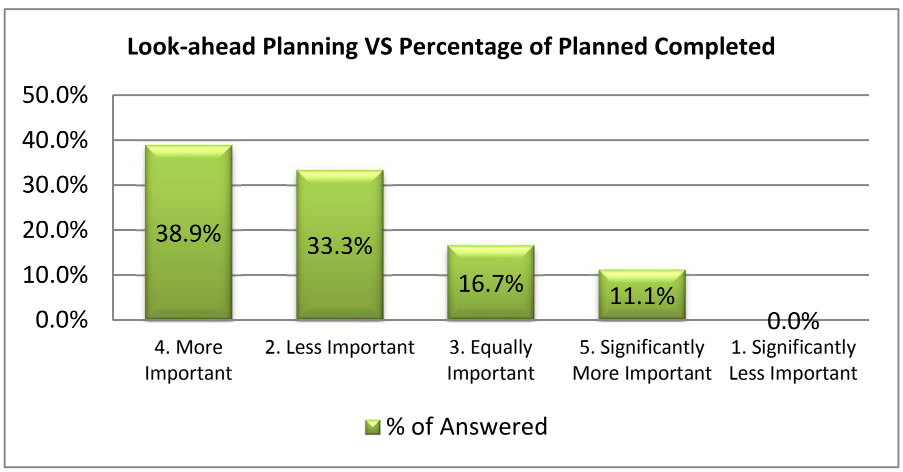
Comparison 3.17

Planning

Look-ahead Planning
Vs.
Percentage of Planned Completed

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	6	33.33%	33.33%
3. Equally Important	3	16.67%	16.67%
4. More Important	7	38.89%	38.89%
5. Significantly More Important	2	11.11%	11.11%
	18		1



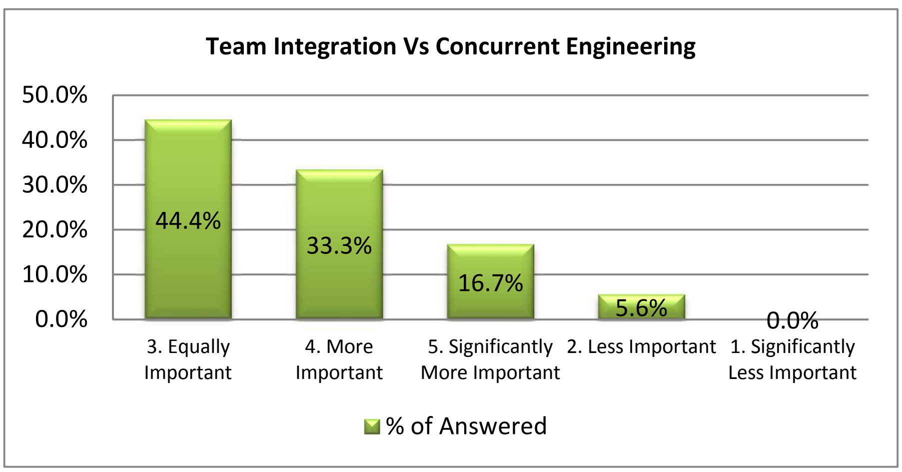
Comparison 3.18

Method

Team Integration
Vs.
Concurrent Engineering

Total responses 18 **Out of** 18 **Response rate** 100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.56%
3. Equally Important	8	44.44%	44.44%
4. More Important	6	33.33%	33.33%
5. Significantly More Important	3	16.67%	16.67%
	18		1



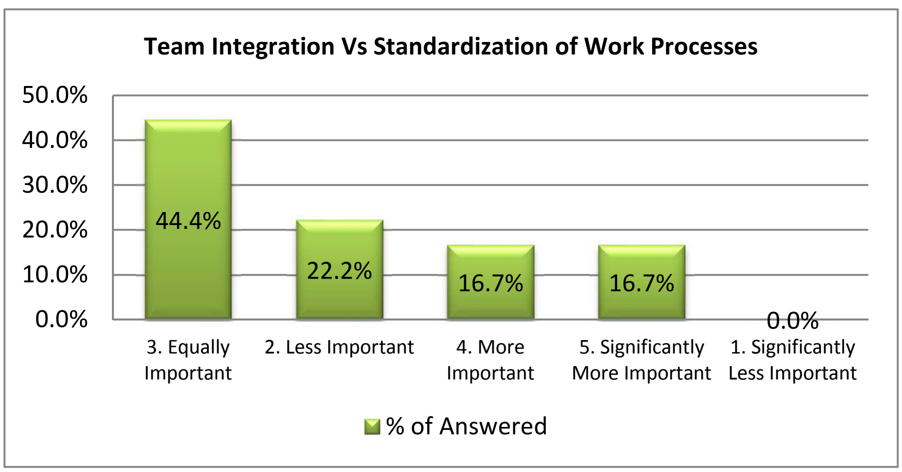
Comparison 3.19

Method

Team Integration
Vs.
Standardization of Work Processes

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	4	22.22%	22.22%
3. Equally Important	8	44.44%	44.44%
4. More Important	3	16.67%	16.67%
5. Significantly More Important	3	16.67%	16.67%
	18		1



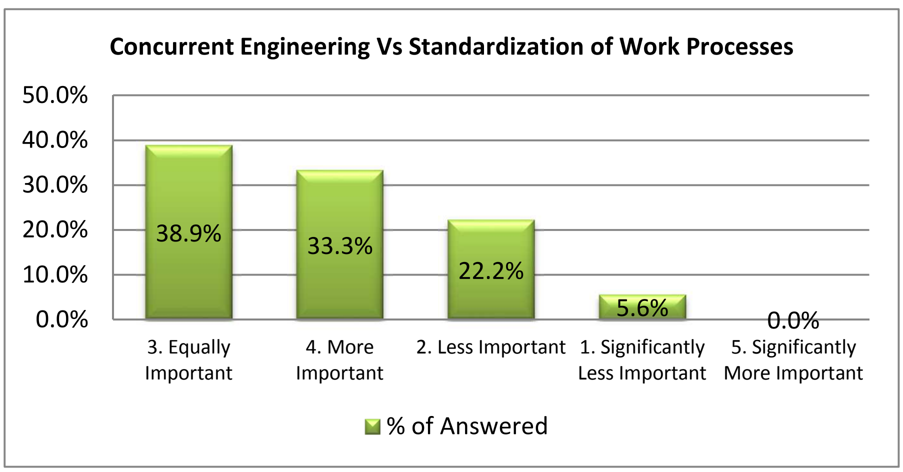
Comparison 3.20

Method

Concurrent Engineering
Vs.
Standardization of Work Processes

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	1	5.56%	5.56%
2. Less Important	4	22.22%	22.22%
3. Equally Important	7	38.89%	38.89%
4. More Important	6	33.33%	33.33%
5. Significantly More Important	0	0.00%	0.00%
	18		1



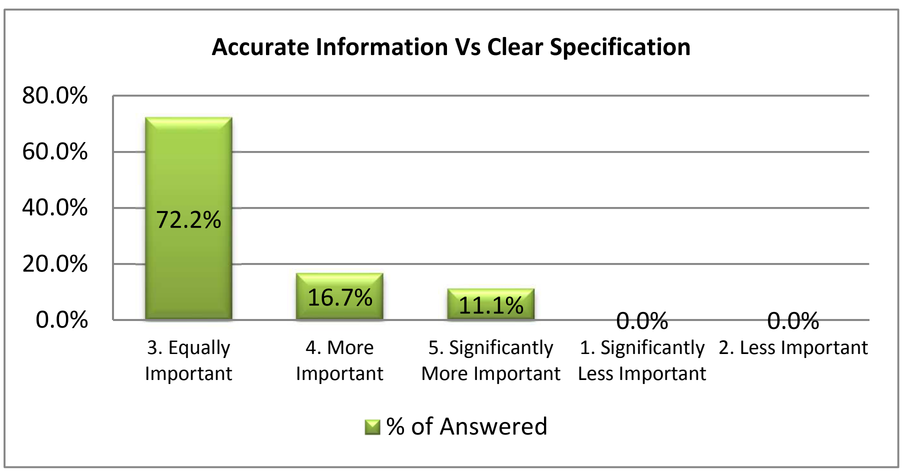
Comparison 3.21

Information

Accurate Information
Vs.
Clear Specification

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	0	0.00%	0.00%
3. Equally Important	13	72.22%	72.22%
4. More Important	3	16.67%	16.67%
5. Significantly More Important	2	11.11%	11.11%
	18		1



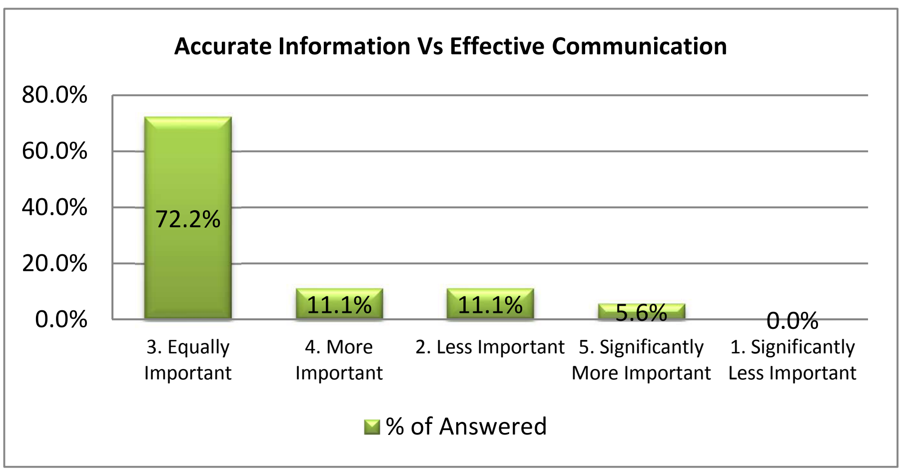
Comparison 3.22

Information

Accurate Information
Vs.
Effective Communication

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	2	11.11%	11.11%
3. Equally Important	13	72.22%	72.22%
4. More Important	2	11.11%	11.11%
5. Significantly More Important	1	5.56%	5.56%
	18		1



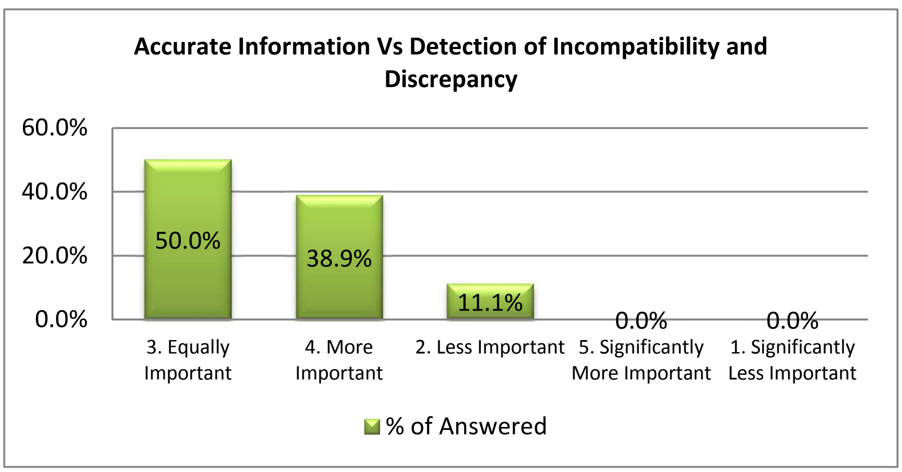
Comparison 3.23

Information

Accurate Information
Vs.
Detection of Incompatibility and Discrepancy

Total responses	18	**Out of**	18	**Response rate**	100.00%

Level of Preference	**Quantity**	**% of Total**	**% of Answered**
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	2	11.11%	11.11%
3. Equally Important	9	50.00%	50.00%
4. More Important	7	38.89%	38.89%
5. Significantly More Important	0	0.00%	0.00%
	18		1



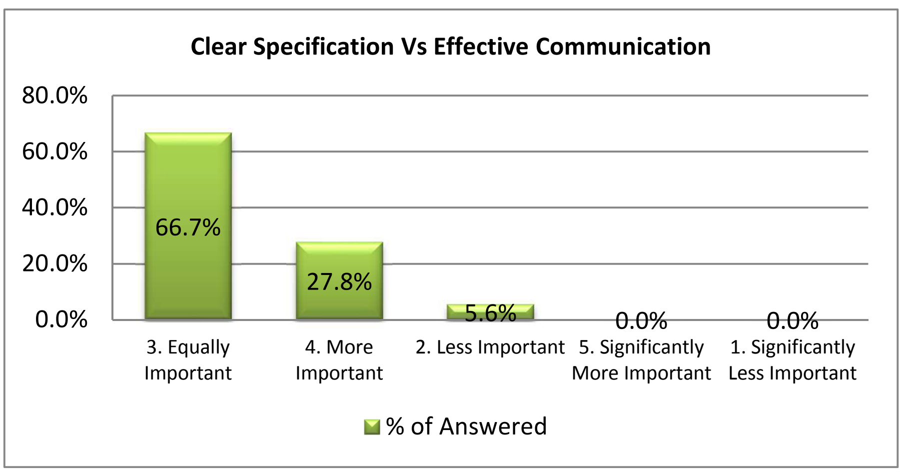
Comparison 3.24

Information

Clear Specification
Vs.
Effective Communication

Total responses 18 **Out of** 18 **Response rate** 100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.56%
3. Equally Important	12	66.67%	66.67%
4. More Important	5	27.78%	27.78%
5. Significantly More Important	0	0.00%	0.00%
	18		1



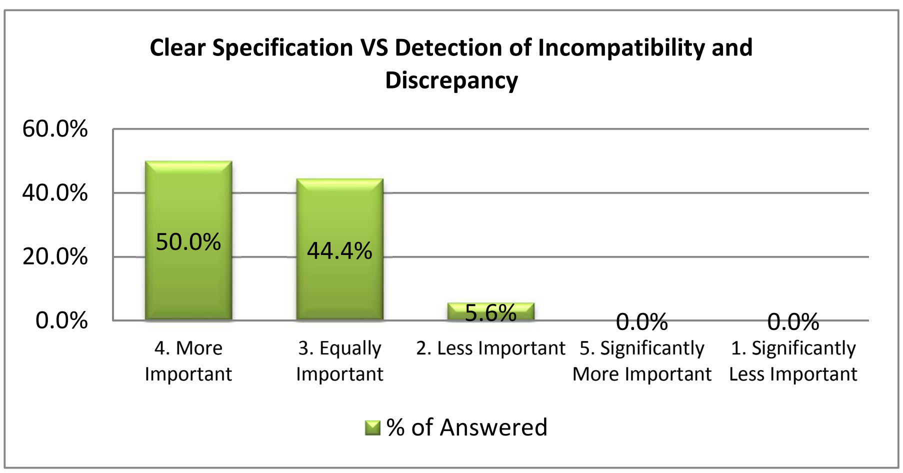
Comparison 3.25

Information

Clear Specification
Vs.
Detection of Incompatibility and Discrepancy

Total responses 18 **Out of** 18 **Response rate** 100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.56%
3. Equally Important	8	44.44%	44.44%
4. More Important	9	50.00%	50.00%
5. Significantly More Important	0	0.00%	0.00%
	18		1



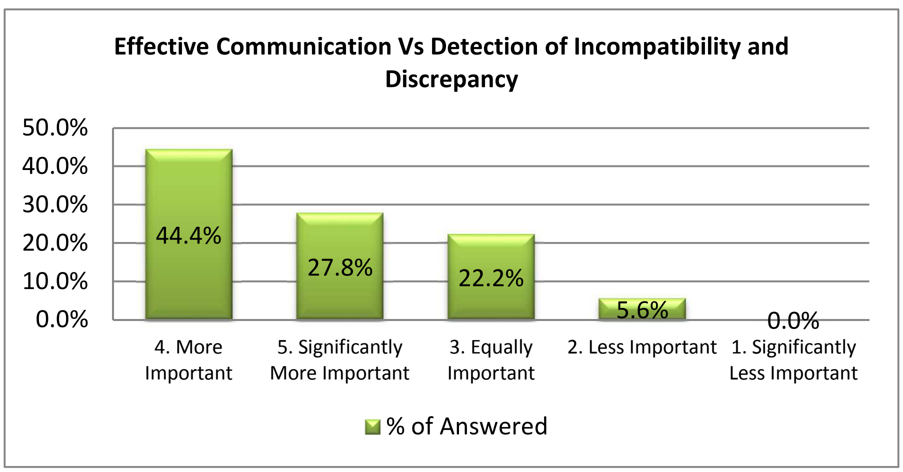
Comparison 3.26

Information

Effective Communication
Vs.
Detection of Incompatibility and Discrepancy

Total responses 18 **Out of** 18 **Response rate** 100.00%

Level of Preference	Quantity	% of Total	% of Answered
1. Significantly Less Important	0	0.00%	0.00%
2. Less Important	1	5.56%	5.56%
3. Equally Important	4	22.22%	22.22%
4. More Important	8	44.44%	44.44%
5. Significantly More Important	5	27.78%	27.78%
	18		1



Appendix C

DATA VALIDATION

LEVEL 1

Parameter	Management Activities	Conversion	Flows			
Management Activities	1	3	1			
Conversion	0.333	1	0.333			
Flows	1	3	1			
Total	**2.333**	**7.000**	**2.333**			
Parameter	Management Activities	Conversion	Flows	**Total**	**Average**	**Consistency**
Management Activities	0.429	0.429	0.429	1.286	42.9%	3.0000
Conversion	0.143	0.143	0.143	0.429	14.3%	3.0000
Flows	0.429	0.429	0.429	1.286	42.9%	3.0000
Total	1.000	1.000	1.000	Total	100%	9.0000
					λ_{max}	3.000
					CI	0.000
					RI =	0.580
					CR= CI/RI	0.000

LEVEL 2

Parameter	Decision Making	Quality	Planning	Method	Information	Resources	Supervision /Control
Decision Making	1	1	0.667	1	1	1	1
Quality	1	1	1	3	1	1	1
Planning	1.499	1	1	3	1	1	1
Method	1	0.333	0.333	1	0.333	0.333	1
Information	1	1	1	3.003	1	3	1
Resources	1	1	1	3.003	0.333	1	1
Supervision /Control	1	1	1	1	1	1	1
Total	**7.499**	**6.333**	**6.000**	**15.006**	**5.666**	**8.333**	**7.000**

Parameter	Decision Making	Quality	Planning	Method	Information	Resources	Supervision /Control	**Total**	**Average**	**Consistency.**
Decision Making	0.133	0.158	0.111	0.067	0.176	0.120	0.143	0.908	0.130	7.279
Quality	0.133	0.158	0.167	0.200	0.176	0.120	0.143	1.097	0.157	7.382
Planning	0.200	0.158	0.167	0.200	0.176	0.120	0.143	1.164	0.166	7.350
Method	0.133	0.053	0.056	0.067	0.059	0.040	0.143	0.550	0.079	7.180
Information	0.133	0.158	0.167	0.200	0.176	0.360	0.143	1.337	0.191	7.523
Resources	0.133	0.158	0.167	0.200	0.059	0.120	0.143	0.980	0.140	7.359
Supervision /Control	0.133	0.158	0.167	0.067	0.176	0.120	0.143	0.964	0.138	7.262
Total	1.000	1.000	1.000	1.000	1.000	1.000	1.000	Total	100%	51.335
									λ_{max}	7.334
									CI	0.0556
									RI	1.320
									CR= CI/RI	**0.043**

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LEVEL 3

DECISION-MAKING

Parameter	Use Visual Indicators	Decision at Construction Site	Take Decision Slowly, Implement them Quickly
Use Visual Indicators	1	0.5	0.5
Decision at Construction Site	2	1	2
Take Decision Slowly, Implement them Quickly	2	0.5	1
Total	**5.000**	**2.000**	**3.500**

Parameter	Use Visual Indicators	Decision at Construction Site	Take Decision Slowly, Implement them Quickly	**Total**	**Average**	**Consistency**
Use Visual Indicators	0.200	0.250	0.143	0.593	20%	3.030
Decision at Construction Site	0.400	0.500	0.571	1.471	49%	3.078
Take Decision Slowly, Implement them Quickly	0.400	0.250	0.286	0.936	31%	3.053
Total	1.000	1.000	1.000	Total	100%	9.161
					λ_{max}	3.054
					CI	0.027
					RI =	0.580
					CR= CI/RI	**0.046**

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LEVEL 3

QUALITY

Parameter	Process Evaluation	Immediate Problem Detection	Systematic Procedures	Inspection & Enforcement			
Process Evaluation	1	1	1	2			
Immediate Problem Detection	1	1	3	1			
Systematic Procedures	1	0.333	1	1			
Inspection & Enforcement	0.5	1	1	1			
Total	**3.500**	**3.333**	**6.000**	**5.000**			
Parameter	Process Evaluation	Immediate Problem Detection	Systematic Procedures	Inspection & Enforcement	**Total**	**Average**	**Consistency**
Process Evaluation	0.286	0.300	0.167	0.400	1.152	28.8%	4.174
Immediate Problem Detection	0.286	0.300	0.500	0.200	1.286	32.1%	4.281
Systematic Procedures	0.286	0.100	0.167	0.200	0.752	18.8%	4.177
Inspection & Enforcement	0.143	0.300	0.167	0.200	0.810	20.2%	4.229
Total	1.000	1.000	1.000	1.000	Total	100%	16.862
						λ_{max}	4.215
						CI	0.072
						RI =	0.900
						CR= CI/RI	**0.080**

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LEVEL 3

PLANNING

Parameter	Constraint Analysis	Root Cause Analysis	Look-ahead Planning	% of Planned Completed
Constraint Analysis	1	0.5	1	2
Root Cause Analysis	2	1	0.5	2
Look-ahead Planning	1	2	1	2
% of Planned Completed	0.5	0.5	0.5	1
Total	**4.5**	**4**	**3**	**7**

Parameter	Constraint Analysis	Root Cause Analysis	Look-ahead Planning	% of Planned Completed	**Total**	**Average**	**Consistency**
Constraint Analysis	0.222	0.125	0.333	0.286	0.966	24.2%	4.111
Root Cause Analysis	0.444	0.250	0.167	0.286	1.147	28.7%	4.221
Look-ahead Planning	0.222	0.500	0.333	0.286	1.341	33.5%	4.244
% of Planned Completed	0.111	0.125	0.167	0.143	0.546	13.6%	4.165
Total	1.000	1.000	1.000	1.000	Total	100%	16.742
						λ_{max}	4.185
						CI	0.062
						RI	0.900
						CR= CI/RI	**0.069**

LEVEL 3

INFORMATION

Parameter	Accurate Information	Clear Specification	Effective Communication	Detection of Incompatibility & Discrepancy			
Accurate Information	1	1	1	1			
Clear Specification	1	1	1	3			
Effective Communication	1	1	1	3			
Detection of Incompatibility & Discrepancy	1	0.333	0.333	1			
Total	**4.000**	**3.333**	**3.333**	**8.000**			
Parameter	Accurate Information	Clear Specification	Effective Communication	Detection of Incompatibility & Discrepancy	**Total**	**Average**	**Consistency**
Accurate Information	0.250	0.300	0.300	0.125	0.975	24.4%	4.103
Clear Specification	0.250	0.300	0.300	0.375	1.225	30.6%	4.204
Effective Communication	0.250	0.300	0.300	0.375	1.225	30.6%	4.204
Detection of Incompatibility & Discrepancy	0.250	0.100	0.100	0.125	0.575	14.4%	4.116
Total	1.000	1.000	1.000	1.000	Total	100%	16.627
						λ_{max}	4.157
						CI	0.052
						RI	0.900
						CR= CI/RI	**0.058**

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LEVEL 3

METHOD

Parameter	Team Integration	Concurrent Engineering	Standardization of Work Process
Team Integration	1	1	1
Concurrent Engineering	1	1	1
Standardization of Work Process	1	1	1
Total	**3**	**3**	**3**

Parameter	Team Integration	Concurrent Engineering	Standardization of Work Process	**Total**	**Average**	**Consistency**
Team Integration	0.333	0.333	0.333	1.000	33.3%	3.000
Concurrent Engineering	0.333	0.333	0.333	1.000	33.3%	3.000
Standardization of Work Process	0.333	0.333	0.333	1.000	33.3%	3.000
Total	1.000	1.000	1.000	Total	100%	9.000
					λ_{max}	3.000
					CI	0.000
					RI =	0.580
					CR= CI/RI	**0.000**

LEVEL 3

SUPERVISION/CONTROL

Parameter	Management Support	Transparency			
Management Support	1	1			
Transparency	1	1			
Total	**2**	**2**			
Parameter	Management Support	Transparency	**Total**	**Average**	**Consistency**
Management Support	0.500	0.500	1.000	50%	2.0000
Transparency	0.500	0.500	1.000	50%	2.0000
Total	1.000	1.000	Total	100%	4.0000
				λ_{max}	2.000
				CI	0.000
				RI =	0.000
				CR= CI/RI	0.000

LEVEL 3

RESOURCES

Parameter	Resources Availability	Resources Leveling			
Resources Availability	1	3			
Resources Leveling	0.333	1			
Total	**1.333**	**4.000**			
	Resources Availability	Resources Leveling	**Total**	**Average**	**Consistency**
Resources Availability	0.750	0.750	1.500	75.0%	2.000
Resources Leveling	0.250	0.250	0.500	25.0%	2.000
Total	1.000	1.000	Total	100%	4.000
				λ_{max}	2.000
				CI	0.000
				RI =	0.000
				CR = CI/RI	Not Applicable

References

Ahmed, S., and Forbes, L. (2011). *Modern Construction: Lean Project Delivery and Integrated Practices*. CRC Press, New York, NY.

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Biographical Information

Yasir Abdelrazig earned his Bachelor's of Science Engineering Degree in Construction Engineering Technology from University of North Texas (UNT) in 2013. While pursuing his undergraduate studies, he started a Fast-Track graduate program in Construction Management at UNT. Abdelrazig maintained a strong academic standing and decided to pursue his Master's in the area of Construction Engineering and Management at the University of Texas at Arlington (UTA) in 2013.

Abdelrazig has been the recipient of numerous honors and awards from prestigious organizations, including TEXO Education and Research Foundation Scholarship and The Association of General Contractors (AGC) Education and Research Foundation Scholarship. Furthermore, he serves as an Exceptional Engineers Tutor at UNT Learning Center.

While earning his Master's Degree, Abdelrazig participated in the Institute of Industrial Engineers (IIE) - Construction Division International Student Paper Competition, and his paper was selected as second place in the competition. Abdelrazig serves as Student Liaison of the Construction Division at the Institute of Industrial Engineers. In addition, he awarded the Lean Greenbelt Certification.

Abdelrazig represented UTA at the American Society of Civil Engineers (ASCE) Student Competition in the ASCE'S Pipelines Conference, August 3-6, 2014 in Portland, Oregon.