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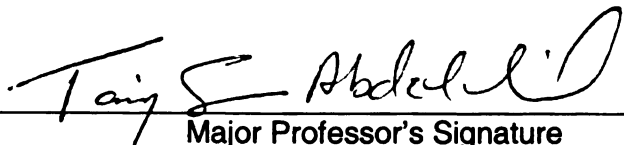
**ASSESSMENT OF UNCERTAINTY MANAGEMENT
APPROACHES IN CONSTRUCTION ORGANIZATIONS**

presented by

VENKAT JAYARAMAN

has been accepted towards fulfillment
of the requirements for the

 M.S. degree in Construction Management


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**ASSESSMENT OF UNCERTAINTY MANAGEMENT APPROACHES IN
CONSTRUCTION ORGANIZATIONS**

By

Venkataramanan Jayaraman

A THESIS

Submitted to
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ABSTRACT

Assessment of Uncertainty management approaches in construction organizations

By

Venkataramanan Jayaraman

Previous research has indicated that in about 85% of the projects, the managers underestimated the extent of uncertainty at the start of a project. Since then limited research has been conducted to study the uncertainty climate in AEC organizations. The primary goal of this research was to assess the approaches of construction organizations towards managing uncertainty. The Working Climate Survey measured two aspects of uncertainty namely – personal and work environment uncertainty and plotted a matrix based on these scores. This matrix was equally divided into four sections namely – dynamic, unsettling, status quo, and stifling. The desirable condition is when most of the respondents are in the dynamic climate. Analysis of the responses of 61 construction industry professionals from a wide spectrum of companies indicated the possibility of some correlation between demographic items and results of the study. It was also found that creating the right environment for employees is the first essential step necessary to embrace uncertainty followed by training the employees. Moreover, an improvement in the percentage of responses in dynamic climate was found when only the companies that practice any of the lean construction principles were considered separately from the entire sample. Based on the findings of the research, guidelines for embracing uncertainty in the project and production management phases were developed. The last planner system and OODA loop model when used in tandem was found to be very efficient in embracing uncertainties in the production phase of construction.

*Dedicated to my mother – **Rukmani Jayaraman***

It is her sacrifices and selfless love that has made me reach this far in life.

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TABLE OF CONTENTS

LIST OF TABLES	viii
LIST OF FIGURES	x
 Chapter 1: INTRODUCTION	 01
1.1. Motivation	02
1.2. Need Statement	05
1.3. Goals and Objectives	07
1.4. Research Scope	07
1.5. Chapter Summary	08
 Chapter 2: LITERATURE STUDY	 09
2.1. Background on Construction	10
2.2. Production Management Process	13
2.3. Lean Project Delivery System	15
2.4. Concepts and Terminologies in Lean Construction	17
2.4.1. Work Structuring	17
2.4.2. Value Stream Mapping	18
2.4.3. 5S	18
2.4.4. Target Costing	19
2.4.5. Visualization	20
2.4.6. Relational Contracting	21
2.4.7. Concurrent Engineering	21
2.4.8. Last Planner System	22

2.5. Uncertainty	26
2.5.1. What is Uncertainty	26
2.5.2. Sources of Uncertainty	27
2.5.3. Illusion of Uncertainty	29
2.5.4. Embracing Uncertainty	32
2.6. Prior Research	35
2.7. Research Tool – Uncertainty Management Matrix.....	36
2.7.1. Working Climate Survey	37
2.7.2. Factor Analysis	39
2.7.3. Development of Instrument	44
2.7.3.1. Personal Uncertainty Management	45
2.7.3.2. Organizational Uncertainty Management	46
2.8. Sample Size Calculations	47
2.9. OODA Loop	49
2.10 Chapter Summary	53
 Chapter 3: METHODOLOGY.....	55
3.1 Objective 1: Research Method	56
3.1.1. Adopting the Working Climate Survey	56
3.1.2. Personal and Organizational Uncertainty Management Measurements.	57
3.1.3. Sample Size Selection	60
3.1.4. Analysis of Data	60
3.1.4.1. Relationship between Climates and Demographic Items	62
3.1.4.2. Relationship between Climates and Outcome Variables	62
3.1.4.3. Comparison of Traditional and Lean Construction	63
3.2. Objective 2: Framework to Manage Uncertainty	63
3.3. Chapter Summary	64

Chapter 4: SURVEY RESULTS AND DATA ANALYSIS	65
4.1. Sample Size Determination	66
4.2. Data Collection	66
4.3. Data Analysis	68
4.3.1. Climates by Demographic Items	70
4.3.2. Relationship between Climates and Outcome variables	83
4.3.3. Comparison of Traditional and Lean Construction	88
4.4. Framework to Manage Uncertainty	96
4.5. Analysis Summary	109
 Chapter 5: SUMMARY AND CONCLUSION	 111
5.1. Thesis Summary	112
5.2. Conclusion	112
5.3. Contributions	115
5.4. Limitations of Research	117
5.5. Recommendations for Future Research	118
 APPENDICES	 120
Appendix A Consent Letter and Survey Questionnaire	121
Appendix B Survey responses and Analysis	130
 BIBLIOGRAPHY	 147

LIST OF FIGURES

<u>S.No.</u>	<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
1	<u>Figure 2-1</u>	Last Planner Planning Process	23
2	<u>Figure 2-2</u>	Degrees of Uncertainty	27
4	<u>Figure 2-3</u>	The cycle of Uncertainty	31
5	<u>Figure 2-4</u>	Uncertainty Management Matrix Model	36
6	<u>Figure 2-5</u>	95% Confidence Interval (C.I.) Sketch	48
7	<u>Figure 2-6</u>	OODA Loop	51
8	<u>Figure 3-1</u>	Uncertainty Management Matrix Model	59
9	<u>Figure 4-1</u>	Uncertainty Management Matrix	69
10	<u>Figure 4-2</u>	Males in various climates	70
11	<u>Figure 4-3</u>	Females in various climates	71
12	<u>Figure 4-4</u>	Residential	72
13	<u>Figure 4-5</u>	Commercial	73
14	<u>Figure 4-6</u>	Heavy/Highway	73
15	<u>Figure 4-7</u>	Industrial	73
16	<u>Figure 4-8</u>	Dynamic climate by sectors	74
17	<u>Figure 4-9</u>	<10 Years Experience	75
18	<u>Figure 4-10</u>	11-20 Years Experience	75
19	<u>Figure 4-11</u>	21-30 Years Experience	76
20	<u>Figure 4-12</u>	>30 Years Experience	76
21	<u>Figure 4-13</u>	Dynamic Climate by Work Experience	77
22	<u>Figure 4-14</u>	Revenues, <300 Million	78

LIST OF FIGURES

<u>S.No.</u>	<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
23	<u>Figure 4-15</u>	Revenues, 300 Million – 1 Billion	78
24	<u>Figure 4-16</u>	Revenues, 1 Billion	79
25	<u>Figure 4-17</u>	Dynamic Climate by Revenues	80
26	<u>Figure 4-18</u>	Age, 25-35	81
27	<u>Figure 4-19</u>	Age, 36-45	81
28	<u>Figure 4-20</u>	Age, 46-55	82
29	<u>Figure 4-21</u>	Age, >55	82
30	<u>Figure 4-22</u>	Dynamic Climate by Age	83
31	<u>Figure 4-23</u>	Outcome Variable 1	85
32	<u>Figure 4-24</u>	Outcome Variable 2	85
33	<u>Figure 4-25</u>	Outcome Variable 3	86
34	<u>Figure 4-26</u>	Outcome Variable 4	86
35	<u>Figure 4-27</u>	Outcome Variable 5	87
36	<u>Figure 4-28</u>	Outcome Variable 6	87
37	<u>Figure 4-29</u>	Lean Practices	88
38	<u>Figure 4-30</u>	Traditional Practices	89
39	<u>Figure 4-31</u>	Bubble chart for number of Lean Practices	91
40	<u>Figure 4-32</u>	PU vs. Lean Practices	92
41	<u>Figure 4-33</u>	WEU vs. Lean Practices	92
42	<u>Figure 4-34</u>	Total No. of Lean Practices Adopted by Respondents...	93
43	<u>Figure 4-35</u>	Distribution of Lean Practices	94
44	<u>Figure 4-36</u>	Model for Embracing Uncertainty in Construction	98

LIST OF TABLES

<u>S.No.</u>	<u>Figure No.</u>	<u>Title</u>	<u>Page</u>
45	<u>Figure 4-37</u>	OODA Loop	103
46	<u>Figure 4-38</u>	Project and Production Management under Lean	105

LIST OF TABLES

<u>S.No.</u>	<u>Table No.</u>	<u>Title</u>	<u>Page</u>
1	<u>Table 4-1</u>	Percentage responses in each climate	69
2	<u>Table 4-2</u>	Males/Females in each climate	71
3	<u>Table 4-3</u>	Sectors of construction in each climate	74
4	<u>Table 4-4</u>	Work Experience in each Climate	76
5	<u>Table 4-5</u>	Revenues in each climate	79
6	<u>Table 4-6</u>	Age in each climate	82
7	<u>Table 4-7</u>	Lean Practices in each climate	89
8	<u>Table 4-8</u>	Traditional Practices in each climate	90

Chapter 1
INTRODUCTION

1.1 Motivation

One of the classic hypotheses of Chaos Theory is - The Butterfly Effect. “The butterfly effect is an illustration of sensitive dependence on initial conditions. According to this theory, a random flapping of a butterfly’s wings in one location can eventually alter weather patterns on the opposite side of the world” (Hilborn, 2003).

As illustrated by the Business Week magazine, a phenomenon to this effect happened on March 17, 2000, which changed the face of the global cellular telecommunication industry. A lightning bolt sparked a fire in Albuquerque, New Mexico, destroying a Philips semiconductor plant. Across the globe in Scandinavia, both Finland-based Nokia and Sweden-based Ericsson depended on this factory for key chips in their cellular phones, and this incidental disaster threatened to cut off their supplies for production (Hopkins, 2005).

This accidental fire sparked off a corporate crisis that shifted the balance of power between two of the world's biggest electronics companies. Nokia responded fast with foresight and flexibility. Nokia immediately patched together a solution (even before the news of the unfortunate incident was released to public), by creating an executive lead team to encourage Philips to dedicate their other plants to making the RFC’s (Radio Frequency Chips) that Nokia needed. Nokia engineers also quickly redesigned the RFC’s so that the company’s other suppliers in Japan and the U.S.A. could produce them. However, Ericsson lost their potential revenues, as they did not have a plan B for such unexpected circumstances. This paved the way for Nokia to become world leaders in cellular telephone, as Ericsson was compelled to outsource its cellular handset

manufacturing business to another firm after posting a \$1.86 billion loss for that financial year (Hopkins, 2005).

The case study illustrated above, is one of the simplest forms of uncertainty faced by managers. It is also sometimes called known unknowns. These are predictable forms of uncertainties with a very low probability of occurrence, for which it is possible to have some contingency plans. A more challenging uncertainty would be when you have no clue of what is going to happen – for example, a Tsunami striking a city, which had no prior recorded history of Tsunamis before this one for centuries. Such uncertainties are also called unknown unknowns.

So how do we brace ourselves by coming up with a plan B or C, when there are so many uncertainties around us? All the above stated examples only emphasize how important it is to embrace uncertainty, rather than trying to run away from it. The farther we try to run away from accepting uncertainties, the more we are prone to failure when we encounter different situations.

If the stakes are so high in times of uncertainty, how can organizations deal with such situations? That is where the organizations approach to uncertainty comes into the picture. As Richard Feynman, a Nobel Prize-winning physicist, said once: “I feel a responsibility to proclaim, that doubt is not to be feared but that it is to be welcomed as the possibility of a new potential for human beings. If you know that you are not sure, you have a chance to improve the situation (1963)”. This is the essence to embracing uncertainty.

Any organization must encourage its employees to embrace uncertainty. Clampitt and DeKoch, (2001) aptly state that there are two important reasons for encouraging

organizations to embrace uncertainty. Firstly, to recognize that there are several things for which leaders do not have any answers, and cannot make any predictions, or they have fuzzy and incomplete notions. Secondly, it is important that managers shouldn't feel compelled to provide a definitive answer when one doesn't exist. If there are no obvious answers to problems, then it is better to embrace the uncertainty rather than patching up some solution just for the sake of doing so.

Construction organizations, face a lot of inherent uncertainties, like the political situation in a country, inflation, company's fluctuating profit margin, competitive bidding process, weather changes, supply shortage, productivity on site, safety issues, etc. Moreover, disputes arising due to a wide range of issues like contractual rights and responsibilities, market competition, etc., make a construction organization more vulnerable to never ending changes. It is therefore paramount for construction companies to be sensitive to the issue of embracing/managing uncertainty.

Project management has in the modern world, become one of the essential tools for a successful project completion. Planning is the first of the many steps involved in project management. If planning were not done meticulously, then the project control and execution would become very difficult. Of equal importance is the process of production management, which is basically the planning of day-to-day production activities and controlling them to accomplish project objectives. It is for these reasons that, the production management in a construction project is of vital importance while studying the organizations approach to uncertainty.

Moreover there are lots of different types of construction. For example the construction of a residential complex is a lot different from that of a commercial complex

or any infrastructure/heavy projects like highways, bridges and dams. Approximately of the total construction expenditure in USA, 30-35% is residential, 35-40% is non-residential, 20-25% is heavy, and 5-10% is industrial (Syal, 2005). There is a massive potential for better project performance by exploiting the opportunities hidden in uncertainties, by embracing them in various types of construction.

1.2 Need Statement

In a study conducted by Howell and Ballard (1994), 175 project managers from a broad spectrum of project sizes and types were surveyed to find the extent of uncertainty they faced. In the first study, they were asked to report on the state of uncertainty at the beginning of a typical construction project. In the second study, they were asked to report on their recent projects as opposed to their typical projects. The results were disturbing and compelling. In 85 % of the projects, the manager underestimated the extent of uncertainty. The problems they didn't know about were bigger than the problems they knew about. Were they ignorant of the prevailing uncertainties, because they were trying to avoid them? Did they not have any policies for managing uncertainties?

Traditionally, and as of yet, all industries have been following risk management philosophies to brace themselves against uncertain events. Risk is said to exist in situations where the outcome has a known probability of occurrence. The risk management literature mostly focuses on treating risk as a threat and tries to avoid it (Ward and Chapman, 2003). However, uncertainties are situations where the probability of outcome of results is unknown. The construction industry has also been traditionally following the risk management ideology to account for the "known unknowns" (foreseen

uncertainty with a low probability of occurrence) and the “unknown unknowns” (unforeseen uncertainty which was never thought of having a chance to occur).

According to Bjorn et al. (2004), construction industry has several uncertainties, which may be grouped in two categories: External or internal source of uncertainty. External sources of uncertainty may include events like the political situation in a country, uncertainty in the contract document, changes in the local infrastructure, availability of natural resources, variations in currency rates, etc. The internal sources of uncertainty could include events like uncertainty related to goals and organizational competence, change in management etc.

The extent of uncertainty on construction projects led to a comparison of manufacturing and construction (Howell and Ballard, 1994). This was the origin of a new understanding called Lean Construction (Inspired from the Toyota Production Process). Lean thinking is just a new way of managing construction. “Lean thinking takes a project-as-production-system view as opposed to the current activity or contract-centered perspective. This way lean embraces the uncertainty and complexity of construction” (Howell and Ballard, 1998). However, there has been no specific research done to substantiate these claims.

It has been proved from case studies like Nokia that, more than avoiding uncertainties, it would be beneficial to identify the uncertainties and try to benefit from them, when the right moment comes. Of the many benefits of Lean construction, it also claims to tackle uncertainty at the production phase by making the workflow more reliable. However, whether it actually helps in making the process dynamic by embracing uncertainty is a matter requiring more research.

1.3 Research Goals and Objectives

The goal of this research was to develop a framework for assessing the approaches of construction organizations towards managing uncertainty. For attaining this goal the following objectives were proposed:

1. Develop a methodology for measuring and analyzing the level at which a construction company's embrace uncertainty.
2. Develop a conceptual framework for managing uncertainty in construction industry.

1.4 Research Scope

The scope of this research was restricted to analyzing the attitude or approach of construction professionals towards managing uncertainty. This thesis does not quantify uncertainty or propose solutions to manage any particular kind of uncertainty. The main intention of all the analysis in this thesis was to show how the framework for uncertainty assessment would work. The target population for the study included all the managers and professionals in the entire AEC (Architect, Engineer, and Construction) industry. Hence the scope included all types of construction namely - residential, commercial, industrial, and infrastructure. The sampling method assumed for this research is simple random sampling and hence, the required sampling size was to be determined statistically to represent the entire population of construction professionals with a 95% confidence level. However, due to budget and time limitations, the research was limited to analyzing 61 responses, recognizing that the intent of the research is to demonstrate the approach and not establish a generalizable fact.

1.5 Chapter Summary

This chapter of the thesis illustrated the amount of uncertainty prevalent in the construction industry. It also mentioned how the author got motivation for this topic and highlighted the need for this research. It also explained the goals and objectives of this research.

Chapter 2
LITERATURE STUDY

2.1 Background on Construction

There are four main types of construction: residential, commercial, heavy/highway, and industrial. Each type of construction requires a unique team to conceptualize, plan, design, construct and maintain the project.

Building construction is the process of adding structure to real property. It includes residential construction which approximately accounts for 30-35% of total construction expenditure in USA (Syal, 2005). Commercial construction includes the construction of projects like shopping centers, office buildings, sports complexes, community centers and hotels, representing 35–40% of the total construction expenditure in USA (Syal, 2005). In a typical mid sized commercial project, there are at least 150 different parties involved like designers, general contractor, various specialty contractors, labor contractor, electrician etc. Building industry is exposed to several uncertainties, which will be discussed in detail later in this section.

Heavy/highway construction is the process of adding infrastructure to the built environment. Owners of these projects are usually government agencies, either at the federal or state level. Such projects are generally undertaken to service public interest, however sometimes these projects are also undertaken by large private corporations. The construction of such projects generally takes longer duration compared to residential units and many more parties are involved as compared to commercial construction. Hence due to nature of such projects, lots of uncertainty prevails in their execution. This sector accounts for 20-25% of the total construction expenditure in the United States (Syal, 2005).

Industrial construction, is a relatively small part of the entire construction industry, and accounts for 5-10% of total construction in the US (Syal, 2005). Owners of these projects are usually large industrial corporations such as pharmaceuticals, petroleum, chemical, power generation, manufacturing, etc. Processes in these industries require highly specialized expertise in planning, design, and construction. The uniqueness, long duration and presence of many different parties give rise to uncertainties on such projects.

As explained above, there is a lot of variation in the number of parties involved in construction projects especially with the different types of construction projects. Some of the important parties involved are general contractors, sub-contractors, architects, engineers and the owners. As the name general contractor (GC) implies, they have expertise in many areas of construction and often hire another contractor (specialty contractor) to perform specific work for them. These specialty contractors are called sub-contractors, where the word sub is used to indicate the contractual hierarchy. On most occasions, depending on the project size, there is one general contractor and several sub-contractors hired by the GC to perform various specific tasks.

Similarly, the architect is the main party involved in the design process, who hires design engineers and a number of other consulting engineers to design the project. Moreover, construction managers could also be involved in the project as a separate entity who in the contractual hierarchy reports directly to the owner. In such a case the owner holds the trade contracts. Construction managers could also be involved in the contractor form in some cases, where they directly hold the trade contracts and execute the jobs. Another project delivery method could involve a design-build firm which

assumes the responsibility of both the design and contractor. Such firms could contract specific jobs like design to an architectural firm and act like a contractor or vice-versa. However, these firms will be responsible for both the design and contractor performances. Apart from these major parties, there are a number of other parties like suppliers, bankers, insurance agencies, etc. The project delivery methods discussed in this section are the traditional ways of project delivery; it is very different from a new project delivery method emerging in the last ten years or so, which is termed as lean or integrated.

It is very difficult to plan the production process where so many parties are involved. Also there are so many external uncertainties involved such as the political situation in a country, inflation, weather changes, productivity on site, safety issues, etc. In the production phase on a number of occasions, crew has to make a call based on their instincts or hunches. For example, while deciding on the duration of a project, a rough assumption of the productivity, climatic conditions, and availability of the resources is made. The schedule prepared for the job with these assumptions is fair, but the organization should be in a position to accept any unknown changes, and ensure that the overall progress of the project is not affected. It is in such situations that some companies can out think their competitors and emerge victorious when others are perplexed at the sudden change of events.

The unforeseen uncertainties are generally identified during the production planning phases. It is during these phases when the production process is planned, that a plan B needs to be kept ready. According to De Meyer et al. (2002), such unknown-unknowns make people uncomfortable because their existing decision tools do not

address them. Unforeseen uncertainty is not always caused due to out of the blue events; however, it also rises from the unanticipated interaction of many events. A classic example for this would be companies, which pushes the technology envelope or enters a new or partially known market. However, before trying to understand the cause of uncertainties and to look at why they should be embraced in construction industry, it is essential to understand the production process first.

2.2 Production Management Process

The term production was first defined when the manufacturing industry started and it means making something. A production process can be defined in simple terms as the method or the steps involved in making/manufacturing a product. In construction, the production process includes, site preparation, construction of the complete structure, and delivering of the end product.

The production process consists of two phases, production planning and production control. Production planning is defined as the process of organizing and developing a plan for the day-to-day activities to be executed to complete the production process. This is distinctly different from project planning, which is the phase where a grand scheme is selected for the best way to execute a project.

The production planning process in construction would include co-ordination of resources, materials, and equipment on the site to ensure continuity of the work. Ensuring a smooth workflow without any wastage of resources is the main goal of production planning. According to Lean construction literature, achieving smooth workflow during daily production activities is not only influenced by site coordination but also by the

supply chain and the design process. Moreover, while planning, there are some other important factors that also need to be considered. These are, planning for risks and uncertain events.

The concept of project control is different from production control. According to Ballard (2000a), project control is a phase dedicated to causing events to conform to the plan and changing plans when events cannot be conformed. Whereas, production control conceives production as a flow of materials and information among specialist, dedicated to generating value for the customers and stakeholders. Production control is the process by which ongoing and planned production activities are monitored in a proactive manner to make sure they are done at cost and time.

Traditionally production management has flowed from project management where it was assumed that by dividing work into parts (e.g. using work breakdown structure) that workflow can be managed. However, this assumption is more appropriate for control of the project against scope, budget, and schedule commitments. This perspective according to Ballard (2000a) facilitates the management of contracts rather than management of production or workflow. Based on the definition of production as envisioned by Koskela (1992), Ballard (2000a) also conceived the production process in three different ways: 1) as a process of converting inputs to outputs, 2) as a flow of materials and information through time and space, and 3) as a process for generating value for customers. This inspired the origin of the last planner system of production as a new alternative to solve the problems arising during the production control phase.

The main drawback of following the traditional project management principles blindly was that there was no emphasis on workflow improvement or value generation to

owners. This forced some construction professionals to rethink the way construction was being done. This view of production has led to the birth of Lean construction, which replaces the transformation-dominated construction management. (Koskela and Howell, 2002).

According to Abdelhamid (2005), Lean construction in short can be defined as a project-based production management philosophy that challenges the belief that a tradeoff between time, cost, and quality is inevitable throughout the construction process. The main aim of Lean construction is to design a production system such that project workflow and value to owners is maximized. This aim definitely calls for the early involvement of contractors in the product design process and the supply chain itself. Workflow improvement is seen as a function of minimizing waste (the unproductive use of resources), the reduction of variability in performance, and the reduction of workload on machines/humans.

2.3 Lean Project Delivery System (LPDS)

Lean thinking was inspired from the Toyota Production System. Lean thinkers have been successful in developing tools and techniques, which has enabled the implementation of lean philosophy in the construction environment (Garnett et. al, 1998).

Lean project delivery system is well explained by Ballard (2000b) as the means by which a project is structured and managed as a value generating process. The domain of LPDS encompasses project-based production systems, i.e., where projects and production systems intersect. A project-based production system is a temporary infrastructure of

resources and value-generating processes strategically arranged for new product or capital facility development (Tsao, 2005).

According to the philosophy of LPDS, there are four stages, and in every stage there will be interdependent functions. The major functions in each of these phases are as follows (Ballard, 2000b):

1) Project definition:

- Needs and values determination
- Design criteria
- Conceptual design

2) Lean design:

- Conceptual design
- Process design
- Product design

3) Lean Supply:

- Product design
- Detailed engineering
- Fabrication/logistics

4) Lean assembly:

- Fabrication/logistics
- Site installation
- Testing/turnover

2.4. Concepts and Terminologies in Lean Construction

Some of the common concepts and terminologies in lean construction will be discussed in this section. Since these terminologies have been mentioned in the survey, they are briefly introduced in this section.

2.4.1. Work Structuring

The Lean Construction Institute (LCI) initially equated the term ‘Work Structuring’ with process design (Ballard, 1999). Ballard (2000b) then adjusted the term ‘Work Structuring’ to represent the most fundamental level of process design. Ballard et al. (2001) later expanded work structuring to encompass production system design. It determines what work must be done on a project, who would be best suited to execute it, when they should be doing it, and how they should be doing it.

As defined by Ballard (2000b), work structuring involves the development of operations and process design in alignment with product design, the structure of supply chains, allocation of resources, and design-for-assembly efforts. The main purpose of work structuring is to make the work flow more reliably and faster while delivering value to the customer.

Work structuring decisions are generally made at all project phases. Typically, during the project definition and lean design phases, planners develop and compare various work structures (work methods) to determine the appropriate one to use on the project. During the lean supply and lean assembly phases, project participants begin executing the selected work structure. If they find they cannot execute certain aspects of the selected work structure, they may modify it to better match their requirements.

Finally, during the facility's use phase, project participants determine if the executed work structure successfully met customer needs. Thus, work structuring is an ongoing, adaptive process. They can then add their experience to the learning loop to guide them in work-structuring efforts on future projects (Howell and Ballard 1999).

2.4.2. Value Stream Mapping

According to Howell and Ballard (1998), identifying the value stream, i.e. the way value will be realized, establishes when and how decisions should be made in the project. Mapping the value stream shows when the information necessary to meet owner requirements will be available and when it is required. A value stream map is a comprehensive model of the project that reveals issues hidden in current approaches. Value stream maps are process flow charts that identify what action releases work to the next operation. Mapping exposes the choices available to the surface and raises the possibility of maximizing performance at the project level. Normally maps are prepared at the project level and then broken down to better understand how the design of planning, logistics and operations systems work together to support customer value.

2.4.3. 5S

According to Liker (2004), the "five S program" was successfully adopted by many Japanese companies to eliminate wastes that contribute to errors, defects, and injuries in the workplace. The first step to implement the 5S is to sort through items and keep only what is needed while disposing of what is not. The items that are rarely used are red tagged. The second step is to bring in orderliness (straighten) by organizing and labeling

everything in place. This takes us to the third step where cleaning process (shine) takes place. This step acts as a form of inspection that exposes abnormal and pre-failure conditions that could affect quality. The fourth step is to develop systems and procedures to maintain and monitor the first three S's. This step essentially creates rules for maintenance and could also be called as the step to standardize. This brings us to the last step in the loop – sustaining. Here maintaining a stabilized workplace is considered as an ongoing process of continuous improvement. The 5 S's namely, sort, straighten, shine, standardize, and sustain will help the company to make the working environment clean and also acts as a visual control device by exposing the pre failure conditions.

2.4.4. Target Costing

According to Crow (2002), until recently development personnel have viewed a product's cost as a dependent variable that is the result of the decisions made about a products function, features and performance capabilities. Because a product's cost is often not assessed until later in the development cycle, it is common for product costs to be higher than desired. Target costing represents a fundamentally different approach. It is based on three premises: 1) orienting products to customer affordability or market-driven pricing; 2) treating product cost as an independent variable during the definition of a product's requirements; and 3) proactively working to achieve target cost during product and process development. Target costing builds upon a design-to-cost (DTC) approach with the focus on market-driven target prices as a basis for establishing target costs. Once the target price is established, a worksheet is used to calculate the target cost by subtracting the standard profit margin, warranty reserves, and any uncontrollable corporate

allocations. Then the target cost is cascaded down to lower level assemblies of subsystems in a manner consistent with the structure of teams or individual designer responsibilities. A well-defined process is required that integrates activities and tasks to support target costing. Then brainstorming sessions are held to analyze alternatives and support the decision making process. However, at every stage the estimated costs need to be tracked against target cost throughout development of the product and non-value added costs (indirect cost) should be controlled as far as possible.

2.4.5. Visualization

A more in-depth understanding of the construction process and construction planning can be achieved by using advanced visualization tools. According to Messner and Horman (2003), advancements in visualization tools provide the opportunity to improve engineering understanding by allowing construction professionals to experience and experiment with virtual design and construction projects in large-scale immersive virtual reality displays. For example, during the phase where the product is being designed, a 3D visualization would help in creating a shared understanding of the design. In a similar fashion; if the process design is also animated in a 4D (a 3D building design with time as the 4th dimension) then it would become easier to ensure that the process design is done in a smooth fashion without any problems. The use of such tools would be of immense help during the design phase (both product and process design). Moreover, advanced visualization technologies like 3D and 4D Computer Aided Design (CAD), can help managers and foremen visualize the impact and usefulness of the lean principles.

2.4.6. Relational Contracting

According to Lichtig (2005), relational contract is an agreement that is signed between the architect, CM/GC, and the owner and would describe how they were to relate throughout the life of the project. This agreement also addresses the underlying principles of lean project delivery so that all members of the integrated project delivery team have a clear understanding of how the project would be administered. The agreement calls for a team selected based upon responses to requests for proposal – it is a quality, value-based selection rather than based upon lowest price. According to Colledge (2005), such type of contracting has been found to improve working relationships between all project stakeholders, facilitate efficient construction and minimize conflicts. Moreover a relational contract allows the parties to utilize their detailed knowledge of their specific situation and also to adapt to new information as it becomes available.

2.4.7. Concurrent Engineering

According to Agogino (1998), concurrent engineering is a strategy which replaces the traditional product development processes with one in which tasks are done in parallel and there is an early consideration of every aspect of a product's development process. In essence, both the design of the product and the processes are done simultaneously.

This strategy focuses on the optimization and distribution of a firm's resources in the design and development process to ensure effective and efficient product development process. In order to be competitive, corporations must alter their product and process development cycle to be able to complete diverse tasks concurrently. However, to successfully implement this process, the company will require a large amount of refinement. This is because, concurrent engineering is a process that must be

reviewed and adjusted for continuous improvements of engineering and business operations. Moreover, Lean construction goes a step further to set-based concurrent engineering. This is an added feature where multiple alternatives are considered until the last responsible moment.

Companies that use concurrent engineering are able to transfer technology to their markets and customers more effectively, rapidly and predictably. Companies recognize that concurrent engineering is a key factor in improving the quality, development cycle, production cost, and delivery time of their products. It enables the early discovery of design problems, thereby enabling them to be addressed up front rather than later in the development process.

2.4.8. Production Control Tool: Last Planner System

Construction industry requires a lot of planning and control that is carried out by number of people at different stages of the project. To achieve the goals, there is someone who actually decides what specific work would be executed on the given day. This individual who makes this decision is called the Last Planner (Ballard and Howell, 1994). This is why the Lean Construction Institute calls the system of production control the Last Planner System (Ballard, 2000b).

Last planner adds a production control phase, in addition to the project control phase of the traditional project management system. According to Ballard (2000a), last planner is a mechanism for transforming what 'Should' be done into what 'Can' be done, thus forming an inventory of ready work, from which weekly work plans can be formed. Included in the assignments on weekly work plans is a commitment by the last planner

(e.g. foreman/squad boss) to what they actually ‘Will’ do. The LPS in that sense is a big shift from the Can-Do approach of traditional system to a Should-Can-Will-Did approach. The formation of assignments in the last planner process is as shown in Figure 2.3.

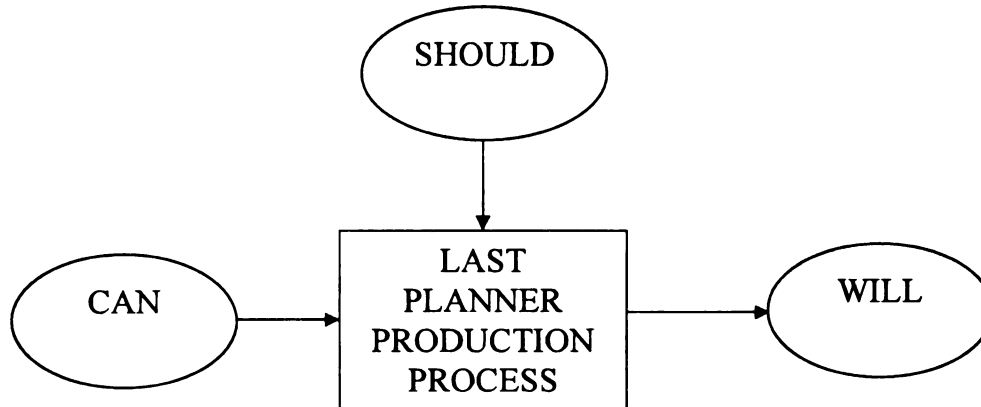


Figure 2.1: Last Planner Planning Process

(Source: Ballard, 2000a)

According to the philosophy of Last Planner System (LPS), the performance of a production system is dependent on the output quality. This introduces us to Percent Plan Complete (PPC), which represents the number of completed production activities divided by the total number of production activities committed. The PPC actually measures the extent to which the commitment of the last planner was realized.

The use of explicit work selection rules and quality criteria as explained above for assignments was termed as “shielding production from upstream uncertainty and variation” (Ballard and Howell, 1994). However, because of its short-term nature, shielding cannot avoid under loading resources when workflow is out of sequence or

insufficient in quantity. Consequently, the second element of LPS was created - 'workflow control', to make assignments ready by proactively acquiring the materials and design information needed, and by expediting and monitoring the completion of prerequisite work.

The tool for workflow control is called phase and lookahead schedules. According to Ballard and Howell (2003), a phase schedule is based on a pull technique where work is done from a target completion date backwards, which causes tasks to be defined and sequenced so that their completion releases work ahead. A rule of "pulling" is to only do work that releases work - requested by someone else ahead in the chain. Some companies call this process as reverse phase scheduling. Working backwards from a target completion date eliminates work that has customarily been done but doesn't add value.

Using the phase schedule, the lookahead process begins. The major functions of the Lookahead process are activity definition, constraints analysis, load-capacity match, and pull system from upstream (Ballard, 2000a). According to Ballard (1997), the phase schedule released at or near the beginning of the construction phase, extends from beginning to end of the project. Such schedules may serve the purposes of even specifying terms of payment. However, such total project schedules cannot be accurately detailed too far into the future because of lack of information about actual durations and deliveries. Consequently, construction projects use some form of short-term schedule to coordinate and direct the various trades and crews working on the job. These schedules are often called "lookahead schedules" because many look ahead several weeks into the future.

Elaborating on how these lookahead schedules are formed, Ballard (1997) tells that once the master schedules are prepared, they are expressed at the level of milestones, typically by phase. Then the phase schedules are produced by cross-functional teams using pull techniques near in time to scheduled start of the phase. Then the phase schedules are fed into the lookahead window, which is normally 3 to 12 weeks in duration. The lookahead window is just a measure of how far ahead of scheduled start activities in the master schedule are subjected to be zoomed in on. In fact Ballard (1997), also said that lookahead planning is the key to improving PPC, and consequently the key to reducing project cost and duration. Thus it is clearly seen that production control uses the lookahead process to manage workflow control and weekly work planning to manage production unit control. Hence, work structuring and Production Control are complementary and managed concurrently during all phases of project delivery (Ballard 2000b).

Finally summarizing the LPS it can be said that, LPS conceptualizes projects as temporary production systems. It is explicitly dedicated for reducing and managing variability. It facilitates workflow improvement and value generation. Moreover, it resists the tendency towards local sub optimization. It is also important to note that, when the environment is uncertain and variations are high, no amount of advance planning and scheduling will be of use. In such cases a production control tool like LPS is most appropriate. Failure in controlling the production process would increase the uncertainty and makes the overall project progress go haywire.

Lean construction also advocates embracing uncertainty (Howell and Ballard, 1998). However there has been no direct research done to verify if the construction

companies adopting lean thinking are embracing uncertainty more than other companies that follow traditional project management principles. The benefits of embracing uncertainty are explained in the following sections.

2.5 Uncertainty

Before we start looking into the advantages of embracing uncertainty, it would be apt to look at what uncertainty is and understand the sources of uncertainty. It is also imperative to look at the reason why people suppress uncertainty.

2.5.1. What is uncertainty?

Certainty is something that is fixed or known as a fact. Those who are certain are free of doubts and are sure of what they know. Uncertainty is the opposite of this definition. For example, the world was shocked when Einstein discovered the theory of relativity. After all these years of believing that the Newton's laws are accurate, it was proved by Einstein that the Newtonian laws are not applicable in all cases/conditions (Einstein, 1919). This just accentuates the point that – everything that we believe today as accurate and true may not necessarily be so. We should develop an attitude of accepting things that may change and are uncertain, and we should be prepared to deal with them when things go haywire.

Moreover, there are different degrees to uncertainty. It is never a yes or no choice between certainty and uncertainty. As stated by Clampitt and DeKoch, 2001, “Most people could mark a spot on the scale characterizing their level of uncertainty for any situation. It is for this reason that, a continuum may be considered the best way to

human community will not progress without continually peeling back the innumerable layers of our ignorance”. Such ignorance could include the lack of knowledge of technical issues, market, people, cost, schedule and quality (De Meyer et al., 2002).

Amongst the other sources of uncertainty, there are also times when people are aware of their ignorance. For example, ‘I don’t know Java’. Even with vast amounts of knowledge, one may be faced with another important dimension of uncertainty – randomness. The lightening bolt that struck the Philips semiconductor plant in New Mexico is a classic example of randomness. Complexity is yet another hurdle that acts like a trap to the maze of uncertainty. Because, complex situations are confusing and when a person does not understand such situations clearly he will be uncertain of what he can expect. A combination of all these factors acts as sources for uncertainty in the construction industry.

According to Bjorn et al. (2004), external sources of uncertainty in construction may include events like the political situation in a country, uncertainty in the contract document, changes in the local infrastructure, availability of natural resources, variations in currency rates, etc. The internal sources of uncertainty could include events like uncertainty related to goals and organizational competence, change in management etc.

In construction projects, most of the uncertainties are faced during the production phase. A simple example as illustrated by De Meyers et al. (2002), tells that although geological studies exist, the moisture level and exact soil type are unpredictable. That’s a problem because moist earth requires more excavation and takes longer to settle before anyone can build on it. Also, some soil types may require different slopes for stability and that can affect the amount of flat area available for houses and streets. The team

could, in theory, handle that problem as a series of foreseen uncertainties, building a contingency plan for each scenario. (“If soil is moist and type X at location Y, use Plan A. If it is dry and type Z, use Plan B.” And so on.) However, that rapidly becomes infeasible because of the interdependence of cuts and fills across locations. Sometimes, markedly unexpected events such the discovery of prehistoric Indian ruins or a rare animal or plant species can alter the operation completely too.

To handle such unforeseen events, the relationship should be characterized by trust and should not be aimed at the managers taking advantage of the subcontractors on such occasions. Without such trust, no subcontractor would cooperate until the project team had drawn up a formal contract to manage uncertain events. This example illustrates the point that the sources of uncertainty in construction cannot be removed. If at all something can be done, it is to clear the mind of any illusion of certainty.

2.5.3. Illusion of certainty

Organizations engage in a host of activities to suppress uncertainty. It is due to this reason that an illusion of certainty is created. According to Coyne et al. (1990), most of the managers they interviewed were uncertain as to what their core competency was. They therefore suggested that the companies should stop proclaiming that they have a competency and get serious about defining, testing and developing one. “If they do not they will see mirages and perish in the sand” (Coyne et. al., 1990).

Proper project planning definitely benefits construction. However, most of the companies address the potential dangers by over-planning. According to Clampitt and DeKoch (2001), it is ironical that the more attempts are made to drive out the

uncertainties, the more unpredictable the results get. They believe it happens so because, they systematically avoid information that might alter or change their plans.

One of the common ways to drive out uncertainty is to create a business model such as the Cost-benefit analysis, in the planning stage. It is definitely a useful tool, but there are limitations to its use. For example, intangible issues cannot be quantified. It is also worth noting that, Columbus did not have a business model when he sailed across the oceans, nor did NASA when they sent astronauts to the moon. It is when we try to quantify everything with numbers that we lose track of the unpredictability of the project.

The other reasons for developing an illusion of certainty in the construction industry could be due to enforcing inappropriate deadlines, improperly using experts, submitting to authoritarians or over relying on success recipes. These are issues that need to be addressed so that a false mirage of certainty is not created. It is therefore very important to understand the dangers of creating artificial certainty. A typical cycle of artificial certainty would be as shown in Figure 2.3

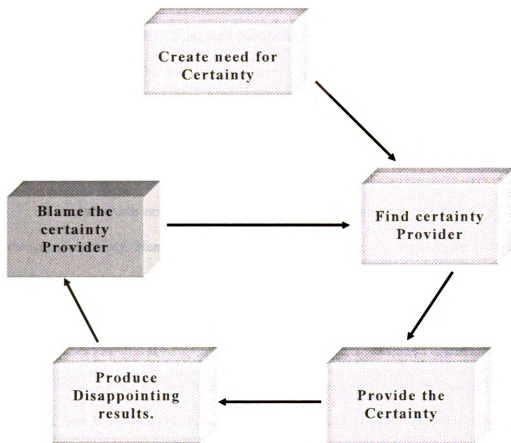


Fig: 2.3 The Cycle of Certainty (Source: Clampitt and DeKoch, 2001)

In an attempt to create such artificial certainty, organizations these days have more faith on cookie-cutter solutions than on truly understanding the nature of complex problems. “Certainty at the price of learning is a terrible price to pay. Only when you accept things that you do not know, can you learn them” (Clampitt and DeKoch, 2001). This is the essence of embracing uncertainty.

2.5.4. Embracing Uncertainty

Embracing uncertainty is not possible until the process begins by creating a foundation. Clampitt and DeKoch (2001), call this foundation as a platform, which is the central idea behind the concept. The platform represents a closely coupled bundle of notions, activities, or decisions that provide either a foundation or a springboard from which to act. Once a platform is created, there is a choice of either refining the existing platform or using it as a springboard to explore other platforms.

It is also worth noting here that refining reduces uncertainty whereas exploring increases uncertainty. Hence, there is a subtle point where, the exploration should give way for consolidation. It is difficult to realize the point where the optimal point of uncertainty lies, but whenever one encounters resistance to further exploration, it is fair enough to assume that it is now time for consolidation. (Clampitt and DeKoch, 2001)

A classic example for such a platform idea would be the Microsoft product - Windows. The Windows '98, Windows 2000 and Windows XP are different platforms. In each of these platforms there are various versions, e.g., in Windows XP, different versions are available such as Professional edition, Home edition, Tablet PC edition, Media Center edition, and Professional x64 edition. Few years down the line, when Microsoft decides to explore more, we could get another new platform (Say Windows ZZ), which will again start refining and give various versions.

An awareness to embrace uncertainty can be cultivated in an organization, by following the steps given by Clampitt and DeKoch (2001):

- a. Occasionally shake the platform, when in the quest of certainty the employees get a little too comfortable.

- b. Challenge the existing heuristics or rules of thumb, to break the spell of overconfidence in estimating their accuracy of judgment.
- c. Fuzzy up the expectations, to account for the time line and methods, which are normally unclear. In other words, blurring up the expectations.
- d. Putting an information perish date on all communications, to push people to not be dependent on a single fact and focus on longer-term trends.
- e. Asking penetrating questions, to make the employees think deeper.
- f. Monitoring the environment, which is the survival skill required in uncertain environments.

Being competent to embrace uncertainties requires a lot of practice. A classic example of this is seen in the training of the U.S. Air Force's Air Para Rescue Units, whose mission involves extracting pilots from hostile territory. These elite teams are trained in arduous conditions such as, perilous mountain ranges, violent seas, snow, heat, and water. But even this rigorous training cannot replicate all the situations that they may encounter. "This team embraces uncertainty by cultivating an awareness of the situations, processing them, and then catalyzing decisive action (Clampitt and DeKoch, 2001)". This example strongly emphasizes the importance of embracing uncertainty.

According to De Meyers et al. (2002), unforeseen uncertainty makes contingency planning more difficult because the project team cannot anticipate everything. Because it is impossible to create a complete contingency plan, the plan must evolve as the project progresses. Teams must go beyond mere crisis management and continually scan for emerging influences — either threats or opportunities. When enough new information arises, they must be willing to learn and then formulate new solutions. To deal with

unforeseen uncertainty, project managers must embrace uncertainty and move from troubleshooting to vigilant orchestrating and networking.

To track projects featuring unforeseen uncertainty, project teams must monitor not only which activities are complete, but also which branch of the decision tree (sketched during the production planning phase), has materialized. The manager shifts from master scheduler and troubleshooter to reactive consolidator of what the team has achieved so far. With unforeseen uncertainty, managers must ensure all parties know the contingencies and, from the project's outset, buy into the alternative plans and outcomes. Moreover, during the project construction, managers must constantly monitor all risks and communicate them to stakeholders (De Meyers et al., 2002).

It is clear from all the literature study done on uncertainty, that it is the general tendency of people to either avoid uncertainty or embrace it. Those who embrace it see uncertainty as a challenge and do not try to artificially drive out the ambiguities. Organizations too work with the same framework like individuals and by embracing it they encourage meaningful discussions and foster innovations and emphasize on planning the project and the production process well. Such organizations would not try to shun uncertainty by inflexible planning or overusing consultants or by using rigid control procedures. The desirable condition is obviously where both the employees and the organization embrace uncertainty. Such a climate is very dynamic, energetic and ever changing.

2.6 Prior Research

Howell and Ballard (1994) conducted a survey of 175 project managers representing a broad spectrum of project sizes and types. They plotted two charts to assess the uncertainty at the start of Construction for typical projects and the assessment of uncertainty at the start of Construction for recent projects. It was found that, in 85% of the projects, the manager underestimated the extent of uncertainty. The problems they didn't know about were bigger than the problems they knew about. Apart from this a similar study was done by Howell et al. (1993), in which the research recommended that objectives should not be prematurely fixed. Starting with the initial objectives and their premise, the objectives should be tested against means, before fixing them.

Prior approaches to measure the management of uncertainty in the construction industry have been lacking in several respects. Firstly, there have been no comparisons of the different attributes of the study (such as the production management process) with the results to determine if there are any correlations. Second, the relationship between personal and organizations approach to uncertainties have never been explored in the construction company settings. Last, but not the least, no efforts have been made to quantify the management of uncertainty in the construction industry.

Researches in other fields have provided some useful insights into how uncertainty can be quantified (Clampitt et al. 2000). For example, Clampitt and DeKoch (2001) present an Uncertainty Management Matrix (UMM) that was formed based on the relationship between personal and organizational management of uncertainty. For this purpose, a working climate survey was prepared to quantify the personal and organization uncertainty scores. Based on the responses to this working climate survey

the respondents were placed in one of the four climates – Status Quo, Unsettling, Stifling, or Dynamic. The drawbacks in previous research, necessitates the need for developing a method to quantify uncertainty management in construction setting, so that a better understanding of the areas of improvement can be achieved.

2.7 Research Tool: Uncertainty Management Matrix

The matrix used in this thesis for assessing the uncertainty management is based on the research of Clampitt et al. (2000). A brief summary of the approach in constructing this matrix is outlined in this section. The specific details of the methodology adopted will be explained in Chapter 3. The uncertainty management matrix, which will be used to compare the uncertainty management in construction firms, is shown below. The x-axis reflects the organizations approach to uncertainty and the y-axis reflects the personal approach to uncertainty. Depending on the scores relative to the organizational and personal approach to uncertainty, a corresponding part of the matrix space will be selected that identifies the overall uncertainty management.

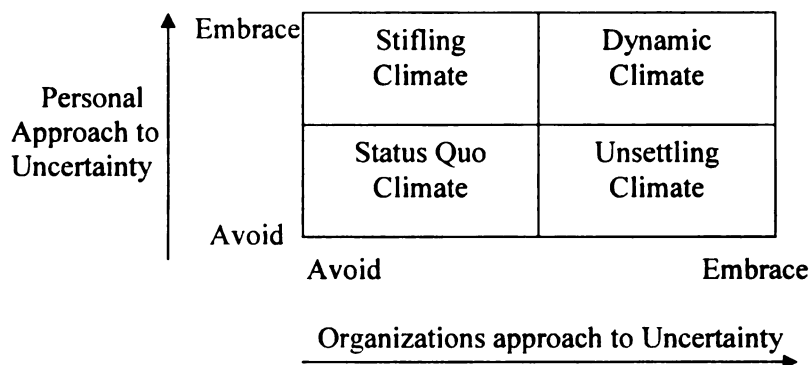


Fig 2.4: Uncertainty Management Matrix Model

(Source: Clampitt and DeKoch, 2001)

The four climates produced from combining these two dimensions are (Clampitt and DeKoch, 2001): Status quo climate (where employees want very few surprises and they rarely get them), Unsettling climate (where employees become unsettled and overwhelmed by the chaotic work environment), Stifling climate (where employees embrace uncertainty but their organization does not do so) and Dynamic climate (where both employees and organization embrace uncertainty). The matrix shown above, was constructed by Clampitt et al. (2000), on the basis of the working climate survey. Since the uncertainty management matrix has been adopted in this research, it is important to understand the history behind the creation of this instrument (both working climate survey and uncertainty management matrix).

2.7.1. Working Climate Survey

The survey instrument that is used for this research is the Working Climate Survey. This survey was designed by Clampitt and DeKoch (2001) to study how employees and organizations manage uncertainty. According to Clampitt and DeKoch (2001), the development of the work climate survey spanned several years and involved three phases. The three phases of preparation of survey and analysis are briefly explained in this section.

In phase one, theoretical rationale for the survey was developed. About 90 items (includes 45 personal and 45 organizational uncertainty survey questions) were used in the survey and the results of over 200 employees working in a wide variety of organizations were factor-analyzed (refer Appendix C) and standard statistical procedures were used to delete, reword, or replace some items. According to Clampitt et al. (2000),

the purpose of this initial survey analysis was to delineate the factor structure. The 16 items of the personal uncertainty questions and the 13 items from work environment uncertainty questions were obtained as an optimal solution in the process. This phase basically just reduced the list of items based on the factor analysis.

In phase two, survey of another cross section of 239 people was done to refine the scale. After analyzing the results of the first stage, some new items were introduced and a total of 82 items were asked in the survey. Factor analysis of this version of the instrument produced 12 items to measure how employees managed uncertainty and 11 items measured employee's perspective of how their organization managed uncertainty. In this phase, the instrument was fine tuned and revised.

According to Clampitt et al. (2000), in phase three both the personal uncertainty scale and work environment scale were considered in constructing the uncertainty management matrix. Each quadrant in the matrix represented different climates as shown above Figure 2.4. The purpose of this phase was to fine tune the instrument by testing the revised items and create a 12-item scale for both individual employees' tolerance to uncertainty and organization's desire to embrace uncertainty. Then a total of 789 responses were collected and analyzed using standard statistical procedures (Clampitt and DeKoch, 2001).

These stages are explained in more detail with respect to the personal and organizational uncertainty oriented questions in section 2.7.3. However, to understand the theory behind the development of this instrument, knowledge of factor analysis might be essential. Since factor analysis is not done in this research, a brief explanation of the

development of the instrument and factor analysis is presented in the following portions of this section.

2.7.2. Factor Analysis

According to Darlington (1997), factor analysis is a statistical procedure where a determination is to be made as to whether the observed variables could be largely explained in terms of a much smaller number of variables called factors. In other words, it is a procedure of reducing the attribute space from a large number of variables to a small number of factors. The purpose of factor analysis is to discover simple patterns in the pattern of relationships among the variables.

A simple example to understand factor analysis (Wikipedia, 2005) follows. From a group of 1000 students, if one student is to be selected for a scholarship on the basis of his/her intelligence, where intelligence is comprised of two types, mathematical and verbal intelligence. Consider that the evidence for this is to be sought from 13 courses that the students have taken. Then according to the theory, the average of the 13 courses is equal to a certain number of times the mathematical intelligence and a certain number of times the verbal intelligence. In other words, it is a linear combination of these two factors.

The above-mentioned theory could take the following mathematical form: Avg. of all Variables = 12 x (Mathematical Intelligence) + 7 x (Verbal intelligence). Hence the factor loadings/weights in this case are 12 and 7 respectively. In case some other factors are also considered for awarding the scholarship, but their factor loadings are much lesser

than 12 and 7, then they may be neglected. A factor matrix can be formed for this example by representing the factors as columns and the variables as rows.

According to Darlington (1997), principal component factor analysis (PCA) is the most common form of factor analysis, which seeks the least number of factors that can account for the common variance (correlation) of a set of variables. PCA starts with a data matrix denoted Y with I rows and J columns, where each row represents a unit described by J measurements, which are almost always expressed as Z -scores. Correlation is a statistical procedure that can indicate how strongly pairs of variables are related. It is to be noted that the factor loadings are the correlation coefficients between the variables (row) and factors (column). Since building a testable model to explain the intercorrelations among input variables is sought in this research, the principal factor analysis was selected for designing the working climate survey.

Before discussing the procedure by which the survey was designed, it is imperative to understand a few technical terms. One such term is varimax rotation, which is the most commonly adopted rotation option. According to Darlington (1997), in order to make the interpretation of the factors that are considered relevant, the first selection step is generally followed by a rotation of the factors that were retained. Orthogonal varimax rotation was selected for the process. "Varimax rotation is an orthogonal rotation of the factor axes to maximize the variance of the squared loading of a factor (column) on all variables (rows) in a factor matrix, which has the effect of differentiating the original variables by extracted factor (NCSU, 2005)". Each factor will tend to have either a large or a small loading of any particular variable. The varimax searches for a rotation (i.e., a linear combination) of the original factors such that the variance of the loadings is

maximized. This simplifies the interpretation because, after a varimax rotation, each original variable tends to be associated with a small number of factors, and each factor represents only a small number of variables.

To illustrate the procedure for a varimax rotation, Abdi (2003) illustrates a very simple example. Consider that there are 5 wines described by the average rating of a set of 7 experts on their hedonic dimension, how much the wine goes with dessert, how much the wine goes with meat; each wine is also described by its price, its sugar and alcohol content, and its acidity. It is represented in a matrix form with the five wines as the rows and the seven variables as columns. The data for the example is not provided in here, because, the example is only for the purpose of explaining the concept. A PCA of this table extracts four factors (with eigenvalues of 4.7627, 1.8101, 0.3527, and 0.0744, respectively), and a 2-factor solution (corresponding to the components with an eigenvalue larger than unity) explaining 94% of the variance is extracted and kept for rotation. Now a matrix with 2 factors as rows and 7 variables as columns was considered. When the variables were plotted on the factor axis, only one of the variables (price) appeared to be an easy solution. However, the varimax rotation procedure applied to the table of loadings gave a clockwise rotation of 15 degrees (corresponding to a cosine of .97). This gives the new set of rotated factors. In this example, the improvement in the simplicity of the interpretation was somewhat marginal, because the factorial structure of such a small data set is already very simple. The first dimension remains linked to price and the second dimension now appears more clearly as the dimension of sweetness (without the rotation it would have been difficult to select the second factor as sweetness).

After factor analysis is done, it is a common practice to attach a descriptive name to each common factor once it is extracted and identified. The assigned name is indicative of the predominant concern that each factor addresses and is useful during the subsequent predictive analysis. However, reliability tests are especially important at this juncture, where it is intended to use derivative variables for subsequent predictive analyses.

According to Darlington (1997), the most common reliability test is Cronbach's alpha reliability. The Cronbach's alpha measures how well a set of items (or variables) measures a single one-dimensional latent construct. When data have a multidimensional structure, Cronbach's alpha will usually be low. Technically speaking, Cronbach's alpha is not a statistical test - it is a coefficient of reliability (or consistency). Cronbach's alpha can be written as a function of the number of test items and the average inter-correlation among the items. Moreover if you increase the number of items, you increase Cronbach's alpha. Additionally, if the average inter-item correlation is low/high, alpha will be low/high. Therefore, when a survey has a "high" or "good" reliability this refers to how well the survey items measure a single one-dimensional latent construct (UCLA, 2005).

A simple example to explain the Cronbach's alpha reliability test is illustrated by Gliem and Gliem (2003). A single statement (item) was presented to each student and then this same statement was presented to the students 3 weeks later. The statement presented to each student was, "I am pleased with my graduate program at The Ohio State University." Students were asked to respond to the statement using a five-point Likert scale ranging from 1 (Strongly Disagree) to 5 (Strongly Agree). When the scatter plots for the two responses were compared, the reliability coefficient for the statement

was found to be 0.11. Cronbach's alpha is the average value of the reliability coefficients one would obtain for all possible combinations of items when split into two half-tests. Cronbach's alpha reliability coefficient normally ranges between 0 and 1. However, there is actually no lower limit to the coefficient. The formula for the standardized Cronbach's alpha is shown below:

$$\alpha = \frac{N \cdot \bar{r}}{(1 + (N - 1) \cdot \bar{r})}$$

Here, N is equal to the number of items and $\bar{r}$ is the average inter-item correlation among the items. The closer Cronbach's alpha coefficient is to 1.0 the greater the internal consistency of the items in the scale. However, as a rule of thumb, a proposed instrument should only be used if an "α" value of 0.70 or higher is obtained on a substantial sample.

According to Darlington (1997), a thumb rule for selecting a number of factors is that it should have eigenvalues greater than 1. Since a component analysis is supposed to summarize a set of data, to use a component that explains less than a variance of 1 is something like writing a summary of a book in which one section of the summary is longer than the book section itself. Eigenvalue is the variance in a set of variables explained by a factor, and denoted by lambda. It is defined as the sum of squared values in the column of a factor matrix (NCSU, 2005). Each component's eigenvalue is called the "amount of variance" the component explains.

An alternative method to select factors is using the scree plots. Scree plot is a graph of eigenvalues to the variable number in the decreasing order. A rule of thumb is to plot all the eigenvalues in their decreasing order. The plot looks like the side of a mountain, and "scree" refers to the debris fallen from a mountain and lying at its base.

That is exactly the shape of a scree plot. The scree test proposes to stop analysis at the point the mountain ends and the debris (error) begins. In this instance, the point coincides with the eigenvalue criterion for selecting which factors are to be considered as major.

As mentioned before, factor analysis was used to develop the working climate survey. It is not in the scope or intent of this research to go much into details of the factor analysis performed to draft the working climate survey. Further queries about the factor analysis can be found in the papers presented by Clampitt et al. (2000) and Darlington (1997). The development of the instrument is explained in detail in the next section.

2.7.3. Development of the Instrument

According to Clampitt et al. (2000), the same analysis was adopted in the first and second phases of the development of the survey, as described below in sections 2.1 and 2.2. Basically a principal component analysis with orthogonal varimax rotation was done to analyze the responses to the personal uncertainty items and the work environment uncertainty items. Factors with an eigenvalue of 1.0 or greater were selected for extraction and rotation. The scree plot was also consulted for extracting the factors. Then after the third phase of refining the survey, responses to acceptable items were summed up to create an overall scale score for both personal and organizational uncertainty. After this the uncertainty management matrix could be drawn. The development of each section of the survey (personal and organizational uncertainty management) is explained in detail below.

2.7.3.1. Personal Uncertainty Management

The first section of the survey concentrates on assessing the personal uncertainty management. In stage one, the factor analysis of the 45 personal uncertainty items produced 9 factors with an eigenvalue above 1.0. According to Clampitt et al. (2000), the optimal solution appeared to be the four major factors found after the initial factor analysis. The four major factors were perceptual uncertainty, process uncertainty, expressed uncertainty, and outcome uncertainty.

Perceptual uncertainty addresses the individual's willingness to perceive uncertainty in the environment or work situation, e.g., actively looking for signs that the situation is changing. Expressed uncertainty addresses the acceptability or comfort associated with expressed uncertainty, e.g., acting like you know, even when you don't know. Process uncertainty is concerned with the degree to which the person embraced uncertainty in the decision making process, e.g., being comfortable using intuition to make a decision. Outcome uncertainty is addressed by the tolerance one has for working on something when the outcome is not clear, e.g., when starting a project, all the relevant drawings are needed to exactly know what is to be constructed. These four factors explained a total of 55.5% of the variance.

According to Clampitt et al. (2000), the final version of the principal factor analysis forced items into a three-factor solution and the items, which were unrelated to the primary factors or showed a low item-whole correlation, were systematically eliminated. These three-factors are Perceptual, Process and Outcome uncertainty. The overall Cronbach's alpha reliability was found to be 0.7.

2.7.3.2. Organizational Uncertainty Management

The second section of the survey concentrates on assessing the organizational uncertainty management. According to Clampitt et al. (2000), the factor analysis of the 46 personal uncertainty items produced 12 factors with eigenvalue above 1.0. However, most of the items had low factors, and hence, were removed. After this initial factor analysis, the optimal solution appeared to be the four major factors as mentioned below. The factors considered in this section of the survey are perceptual, process, expressed, and outcome uncertainty.

Perceptual uncertainty addresses the organization's willingness to perceive uncertainty in the environment or work situation, e.g., whether the organization actively looks for new ideas to address problems. Expressed uncertainty addresses the acceptability or comfort associated with expressing uncertainty, e.g., is being unsure of something a sign of weakness in the organization. Process uncertainty is concerned with the degree to which the organization embraces uncertainty in the decision making process, e.g., an organization is comfortable with the employees making a decision following their instincts. Outcome uncertainty addresses by the tolerance the organization has for working on something when the outcome is not clear, e.g., an organization rewards employees who have a definite sense of direction. These four factors explained a total of 60.0% of the variance.

According to Clampitt et al. (2000), a three-factor scale was developed after the principal factor analysis using varimax rotation. The three factors were expressed uncertainty, perceptual uncertainty and outcome uncertainty. The overall Cronbach's

alpha reliability was found to be 0.78. Any further queries about the analysis done or the validation of the instrument can be found in the paper presented by Clampitt et al. (2000).

2.8 Sample Size Calculations

Confidence interval (c) gives an estimate of the amount of error involved in our data. The confidence interval is the plus-or-minus Figure usually reported in newspaper or television opinion poll results. For example, if you use a confidence interval of 5 and 48% percent of your sample picks an answer you can be "sure" that if you had asked the question of the entire relevant population between 43% (48-5) and 53% (48+5) would have picked that answer. The confidence level tells you how sure you can be. It is expressed as a percentage, e.g. 95%, and it represents how often the true percentage of the population who would pick an answer lies within the confidence interval. The larger your sample, the more sure one can be that the results are a true reflection the population. This indicates that for a given confidence level, larger the sample size, smaller the confidence interval. However, if an infinite population is considered, the confidence interval formulas are not valid.

Because the survey is a simple random sampling, the sample size (SS) for this research was calculated using the formula given below for an infinite population (Lohr, 1999).

$$SS = \frac{Z^2 * p * (1-p)}{e^2}$$

Where:

Z = Z value (e.g. 1.96 for 95% confidence level)

p = percentage possibility of picking a choice, expressed as decimal.

e = margin of error, expressed as decimal

According to Lohr (1999), generally a value of 0.5 is assumed when the sample size needs to be calculated. Also for a 95% confidence level, the Z value = 1.96. The Z value considered in the formulae for SS calculation is the value of mean represented on the x-axis in a normal distribution graph as shown below. The mildly shaded middle portion of the figure below indicates the 95% confidence interval (c or CI) for this distribution of sample means. The 95% confidence interval ranges from -1.96 to 1.96 (Lohr, 1999).

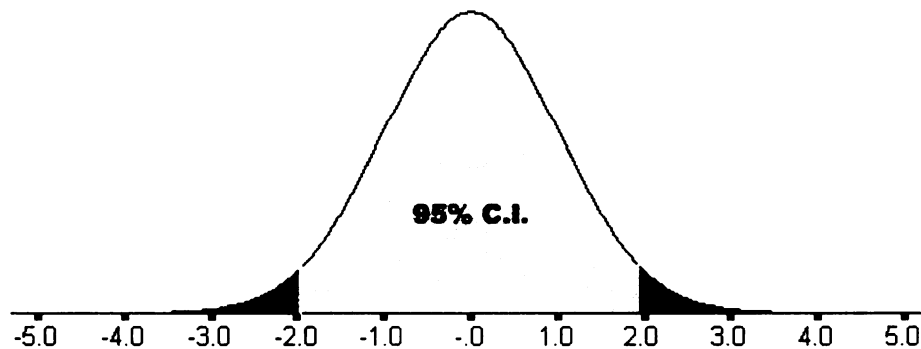


Figure 2.5: 95% Confidence Interval (C.I.) Sketch

2.9 OODA Loop

Another tool used in this thesis to develop the framework is the OODA Loop. Col John Boyd, USAF (Ret), coined the term and developed the concept of the "OODA Loop". Boyd was instrumental in explaining the concept of cycle time. Considering an example given by Hammonds (2002) of the F-16 fighter jet, a supersonic military aircraft, which really is just a modest machine. It weighs about half as much as its predecessor, the F-15. It can't fly as high as or faster than an F-15. But in battle, its design allows extreme maneuvers even at low speeds. It dumps and regains energy in an instant, and despite its light weight, it can withstand nine times the force of gravity, which enables some serious twisting and rolling. The plane is unthinkably agile and has a much lower cycle time as compared to other fighter planes. It is for this reason that F-16 planes became the most popular planes in the air force.

Although the OODA model was created for military purposes, elements of the same theory can also be applied to business strategy. A construction company could either be like an F-16 or an Aeroflot turboprop. In general success in business isn't simply a matter of being quickest to market, spending the most, or selling the highest-quality products. Success can be tasted by using any of these methods but only if you do one thing more: Outmaneuver the uncertainties. A company has to decode the environment before their competitors do, act decisively, and then capitalize on it. Agility is the essence of strategy in war and in business. A simple example to illustrate this point would be the New Mexico mobile-phone chip factory of Philips Electronics (Refer Chapter 1). According to Hammonds (2002), Nokia reacted immediately, sending employees to help Philips recover, demanding production from other Philips fabs, and seeking out

alternative suppliers. Ericsson, supplied by the same factory, lost several months' worth of production. Nokia capitalized on Ericsson's confusion by pushing in new mobile handsets, allowing Nokia to grab even more market share and this ultimately forced Ericsson to outsource production. This master strategy paved way for Nokia to become world leaders in mobile-phone industry. Construction companies need to learn to outmaneuver the uncertainties as it is an industry plagued with several types of uncertainties. This would not only help the companies outmaneuver their competitors in the bidding process, but also in completing their projects successfully.

On the face of it, Boyd's loop is a simple reckoning of how human beings make tactical decisions. But it's also an elegant framework for creating competitive advantage. Managers must be able to observe and orient themselves in such a way that they can survive and prosper by shaping the environment where ever possible and by adapting to it where they must. According to Hammonds (2002), doing so requires a complex set of relationships that involve both isolation and interaction. Knowing when each is appropriate is critical to their success. One does so through a combination of rapidity, variety, harmony, and initiative. Rapidity of action or reaction is required to maintain or regain initiative. Variety is required to make the organization unpredictable, so that there are no patterns to recognize their plans in advance. Harmony is the fit with the environment and others operating in it. Initiative is required so that managers can take charge of their own destiny and master circumstances rather than being mastered by them.

According to Richards (2004), the OODA Loop is structured in a sequential and non-sequential fashion (Also refer Figure 2.6 in page 43).

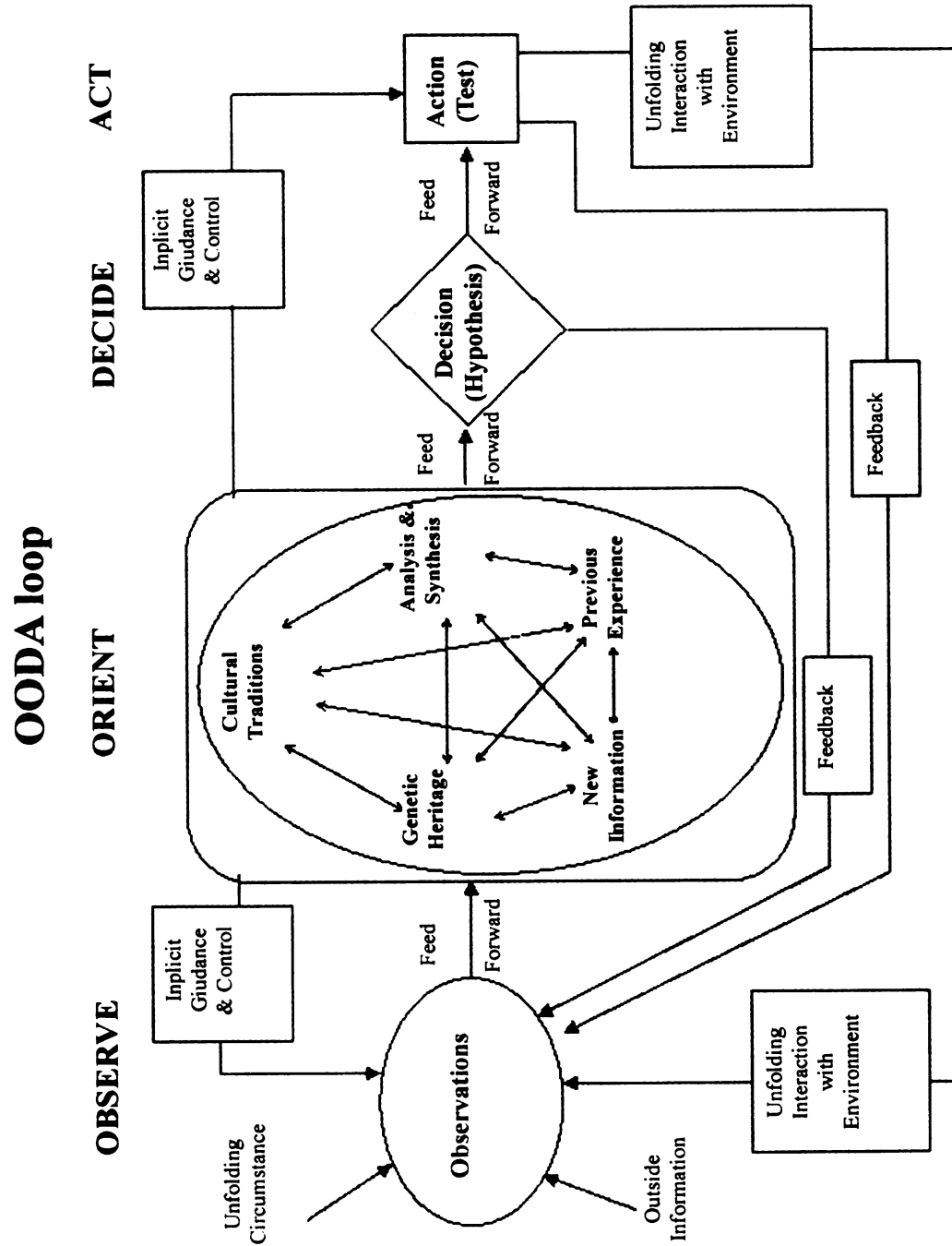


Figure: 2.6. OODA Loop

Knowledge of the strategic environment is the first priority. Hence the first step is to observe, so as to acquire sufficient knowledge for making a decision. This step requires recognition of unfolding events and feedbacks from the various other stages namely – orient, decide and act. This makes the OODA loop non-sequential at times. The second step is to orient the information. This step involves utilizing previous experience, waiting for all new information to arrive, cultural traditions of the organization, collecting information about the genetic heritage of the problem and analyzing the problem. This leads us to the hypothesis stage where a decision is made on how the problem can be approached. Depending on the decision made considering all the information received, an appropriate action would be taken. However, it is to be noted that this is a continuous monitoring process where once the action is taken; observation starts again to look for any new problems. This is an effective way to detect any unforeseen uncertainties, as it is a very vigilant process where there is constant monitoring of the environment.

Boyd extensively studied the Toyota Production System and considered it as an implementation of ideas similar to his own (Richards, 2004). According to Richards (2004), the self-organized, multifunctional teams at Toyota developed products and manufacturing processes in response to demand, turning out new models in just three years compared with Detroit's cycle of four or five. Boyd felt that systems like Toyota's worked so well, because of *schwerpunkt*, a German term meaning organizational focus. That is, employees decide and act locally, but they are guided by a keen understanding of the bigger picture. It is important to note that the Toyota production system inspired the origin of Lean Construction.

The OODA loop can be compared to the Last Planner System where what “Should” be done is compared to what “Can” be done to decide what “Will” be done eventually (refer section 2.4.8). According to Richards (2004), the OODA loop talks about creating an environment of trust to permit implicit communication amongst team members. Moreover, the well defined framework in lean construction that talks about muri (overburdening people or equipment), mura (uneven workflow), and muda (wastes) helps the lean companies to work faster and more efficiently, even though the people within it do not appear to be working any harder than their competitors in other companies do. This is the reason why lean companies have a faster OODA loop. A faster OODA loop is essential for companies to ensure the success of projects in this competitive world. This would not only improve the reputation of the company but also help it in securing new projects. A faster OODA loop would also mean that the company would be in a position to outbid its competitors in the bidding process, as this would enable the companies to allocate lesser amount to account for risks and uncertainties.

2.10 Summary of chapter

This chapter provided the relevant literature study for this thesis. Literatures regarding different types of construction, the production process, the Lean Project Delivery method and some important terminologies in lean construction were discussed. The source of uncertainty, different uncertainties that affect the construction industry, how they create an illusion of certainty, and how to embrace uncertainty were also presented in this chapter. The chapter also listed the previous research works in this area and their limitations. The latter part of the chapter also details the history of the development of the

research tool – the working climate survey and the formulas involved in finding out the sample size required for the research. The last part of the chapter discusses in detail the tool used for developing the framework of this thesis – OODA loop.

Chapter 3

METHODOLOGY

3.0. Methodology and tools for objectives:

The goal of this research was to develop a framework for assessing the approaches of construction organizations towards managing uncertainty. To attain this goal, the research tool used was uncertainty management matrix (UMM). This matrix was constructed considering the two survey scores of personal uncertainty and organizational uncertainty. The UMM measures the degree to which both the company and the employees have embraced uncertainty. Two objectives were proposed to achieve this goal. To accomplish these objectives, the methods, tools and procedure used are explained in the following sections.

3.1. Objective I

A methodology was developed for assessing the level at which the construction industry embraces uncertainty. This objective was achieved in three steps as mentioned below.

3.1.1. Adopting the Working Climate Survey

The working climate (Adopted from Clampitt et al. 2000) survey consists of two different kinds of questions. The first section concentrates on assessing the personal uncertainty management and the second section concentrates on assessing the organizational uncertainty management. The work climate survey was selected as the instrument here because it is the only tool available that caters to measurement of uncertainty levels. However, since the target population for the study is construction industry personnel, the questions in the survey were revised to make them more construction industry specific. As mentioned in section 2.3, lean project delivery method is the only project delivery

method, which talks about embracing uncertainty. Hence questions regarding the same were included in the survey to analyze later if the companies practicing lean construction manage uncertainties better. Also, some other general demographic questions were included in the survey to look at the relationship of these attributes to the final results. These include gender, age, work experience in the present company, company revenue, construction sector, project delivery methods generally used in typical projects and job position (Appendix A).

3.1.2. Personal and Organizational Uncertainty Management Measurements

As this research is based on the earlier research done by Clampitt et al. (2000), the same three-factor scale developed for the personal uncertainty (refer section 2.7.3.1), was assumed here. The three-factors are, perceptual uncertainty, process uncertainty and outcome uncertainty. Similarly for the organizational uncertainty, the three-factor scale developed as explained in section 2.7.3.2 above, gives us three factors - expressed uncertainty, perceptual uncertainty and outcome uncertainty. This research does not do a factor analysis to eliminate the factors showing a low item-whole correlation, but assumes what Clampitt et al. (2000) did as true for this case (Refer Appendix C). The scores of personal and organization uncertainty management calculated from the survey responses was used to sketch the uncertainty management matrix.

To draw this matrix the survey questions were scored first. The survey had 50 questions to be marked on a scale of seven. Of these, 22 questions asked to check the personal uncertainty management and 17 questions to check the organizational uncertainty management. The remaining eleven questions in the survey were

demographic question. However only 12 questions of the personal uncertainty management and 12 questions of organizational uncertainty management were used to determine the uncertainty scores. This is due to the factor analysis results from Clampitt and DeKoch (2001). The responses to remaining questions were only used to look for statistical analysis purpose. Like for example to find relationship between the individual attributes and the results of the study.

The formulas to calculate the personal and organization uncertainty scores were also adopted from Clampitt and DeKoch (2001). So considering that we have 12 questions on personal uncertainty and 12 questions in organizational uncertainty, the least score for both of them would be 12 and the highest will be 84 as the survey is based on a 7-point Likert scale. For the **Personal Uncertainty** score (**PU**), the sum of personal uncertainty perceptual score, personal uncertainty process score and personal uncertainty outcome score was taken. As each of these scores had specific questions associated with them, the formula given below was used to calculate each of these scores individually first and then they were added up (Clampitt and DeKoch, 2001).

$$\text{PU Perceptual Score} = (\#2) + (\#6) + (\#8) + (\#10)$$

$$\text{PU Process Score} = (\#1) + (\#5) + (\#9) + (\#14)$$

$$\text{PU Outcome Score} = 24 - (\#4) - (\#7) + (\#11) - (\#13)$$

$$\text{Therefore, Overall PU score} = \text{Perceptual score} + \text{Process score} + \text{Outcome score}$$

For the organizational uncertainty score or **Work Environment Uncertainty** score (**WEU**), the sum of organizational uncertainty perceptual score, organizational uncertainty expressed score and organizational uncertainty outcome score was recorded. As each of these scores had specific questions associated with them, the formula given

below was used to calculate each of these scores individually first and then they were added up.

$$\text{WEU Perceptual Score} = (\#23) + (\#26) + (\#28) + (\#32)$$

$$\text{WEU Expressed Score} = 32 - (\#25) - (\#30) - (\#33) - (\#35)$$

$$\text{WEU Outcome Score} = 24 + (\#27) - (\#29) - (\#31) - (\#34)$$

Therefore, Overall WEU score = Perceptual score + Expressed score + Outcome score

The matrix is basically an X-Y axis plot with organizational and personal approach to uncertainty scores indicated along the X and Y-axis respectively as shown below in Fig: 3.1. With the overall scores of PU and WEU a point was plotted on the matrix for each respondent. All such points for the people surveyed were plotted on the same matrix to understand the working climate of the construction industry. In the sense, how good the construction industry is in embracing uncertainty. Since the minimum and maximum scores of the two axes are known to be 12 and 84, by simply dividing the X and Y-axis into two halves, the 4 climates were created.

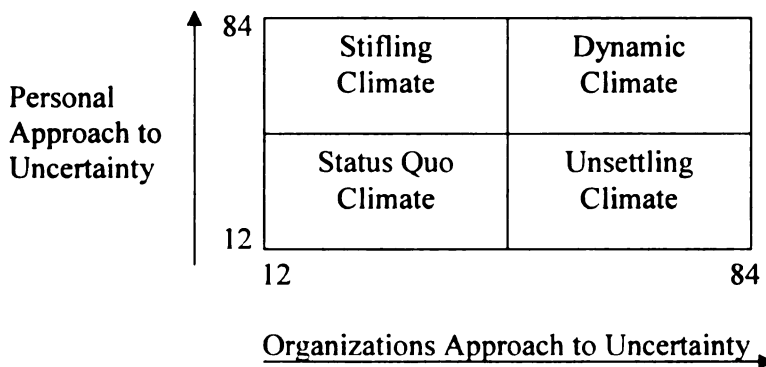


Fig: 3.1: Uncertainty Management Matrix Model

(Source: Clampitt and DeKoch, 2001)

3.1.3. Sample Size Selection

The intent of this step was to select a sample size, which would represent the total population of the managers and other employees in construction industry. This was achieved by first assuming a suitable confidence level desired for this research work. The sampling unit for this research was employees and managers of construction companies. The confidence level for this study is fixed at 95%. The same formula to calculate sample size as explained in section 2.7 was used.

3.1.4 Analysis of Data

The survey was posted online at www.hostedsurvey.com and participation of subjects was solicited through an email announcement to various construction industry list serves and personal contacts in the industry. The announcement was sent to about 800 subjects, which also included a few list servers. The email referred to the URL where the survey was hosted. Efforts were made to post the email invitations on list servers of organizations like Associated General Contractors and Construction Management Association of America. However since no positive response was received from these organizations on time, the analysis was done based only on the responses received from the personal contacts in the industry.

Once the desired number of completed responses was received, the recorded responses were downloaded from the website server in excel format. Moreover, a robust spreadsheet was developed in such a way that once the raw data was pasted on to the spreadsheet, all the analysis would be done automatically. The spreadsheet was designed to analyze 500 responses. Several preliminary test trials were conducted on this

spreadsheet developed to ensure that it provided reliable and correct analysis that was consistent with the methods established by Clampitt et al. (2000). The discussion of the procedure of all the analysis done on the data is elaborated in the following pages of this chapter.

The most important analysis of the data received from the responses was to find the percentage of respondents in each of the quadrants in the uncertainty management matrix. The comparison was done by finding the ratio of dots in each of the four blocks described in the matrix below in Figure 3.1, i.e., the status quo, stifling, unsettling and dynamic climates to the total number of dots in the complete matrix. The ratio analysis was useful to understand the overall ability of construction industry (at present), in embracing uncertainty.

Also the responses to question numbers (3,12); (24,39); and (36,38) were monitored to ensure the consistency of the respondents in answering the survey questions. For example questions 3,12 tried to evaluate the same parameter but were just worded differently. If any fluctuation of greater than 2 on the scale of 7 was recorded in either of the 3 comparisons done, the responses of that particular subject was considered inconsistent and were rejected.

Moreover, there were other secondary analyses done in the research to compare various attributes to the results of the survey to identify trends, if any. The next few sub-sections will elaborate on the nature of these analyses.

3.1.4.1. Relationship between Climates and Demographic Items

To identify trends, a comparison of some of the demographic items with respect to all the four climates was performed in this research. For example, consider that there is a comparison of the number of females in each of the four climates of the matrix (UMM). Then, if there were a very high/low percentage of females in any of the climates as compared to the others, then a trend may be established about the female population. All such analysis of the demographic items was done using bar charts.

The demographic items (refer survey questions 40-46 in Appendix A) that were considered for sketching the bar charts were, gender (male, female), job classification (management, non-management), experience (1-10, 11-20, 21-30, and >31), company revenues (<300 million, 300 million–1 billion, and >1 billion), and age (25-35, 36-45, 46-55, >56). Each of these categories was divided into groups as indicated in parenthesis above and the relationship between the results of each of these groups were analyzed.

3.1.4.2. Relationship between Climates and Outcome Variables

Outcome variables are analogous to dependent variables and they translate into results. The variables mentioned in questions 16 to 21 in the survey (refer Appendix A), are the outcome variables of this research. These questions ask if an individual is satisfied with their job, committed to their organization, identifies with the organization, satisfied with organization communication, satisfied with supervisor communication, and cynical about organization life. Depending on the responses to each of these questions, a bar chart was sketched showing the mean scores for every question in each of these four climates. Looking at all the bar charts, if any climate had a very high/low mean value for a

particular question, trends were established. For example, consider the question, if an individual is satisfied with his job or not. By looking at the averages of the response to this question alone in each of the four climates, the relationship between climate and the response to this question could be established.

3.1.4.3. Comparison between Traditional and Lean Construction

Only respondents who adopt lean practices were considered to sketch a matrix. Similarly, the companies following any of the traditional practices of construction were clubbed together to sketch another matrix. The percentages of responses that lie in each of the climates in both the matrices were then compared to look for any trends. The intent behind this comparison was to check the claims of lean construction practices in embracing uncertainty better than the traditional ways of construction.

3.2. Objective II - Framework to Manage Uncertainty in Construction

A framework was developed to manage uncertainty in construction industry based on the responses received from the survey and literature study. The open-ended question in the survey, which asked the respondents to express their views on how their organization can help them manage uncertainty, was considered while drafting the framework. The OODA loop model created by Boyd (Richards, 2004) and the framework given by Clampitt et al. (2000) were researched upon before coming up with this conceptual framework.

3.3. Summary of chapter

This chapter explained the methodology and tools that were used to meet the objectives of this research. The chapter explained how the data was collected and also listed all the attributes that were considered for the analysis. It also mentioned all the tools used for performing the analysis. Moreover, the chapter also outlined the major elements of the framework/guidelines proposed in this thesis for managing uncertainty in construction.

Chapter 4

SURVEY RESULTS AND DATA ANALYSIS

4. Survey Results and Data Analysis

This chapter presents the survey data and its analysis based on the steps discussed in chapter 3. This research focuses on managers and other employees in construction firms as explained in chapter 1.

4.1. Sample Size Selection

Using the formula mentioned in section 2.8 the sample size was determined. The Z value was taken as 1.96 and p-value as 0.5 (Lohr, 1999). The margin of error was initially fixed at 5%, as per industry standards. However, for a confidence interval of $\pm 5\%$, the sample size required was 384. Due to time and budget restrictions, it was decided to collect only about 50 responses for this study. In this case, the margin of error was calculated using the same formula used above. For about 50 responses the margin of error was calculated to be 13.86%. Hence, it was decided to keep the survey online until at least 50 completed responses are collected. Moreover, this research aims to demonstrate how to assess uncertainty and not to make generalized statements about the industry. As mentioned in chapter 3, email invitations were sent to about 800 subjects, which included some list servers too.

4.2. Data Collection

A total of 103 responses were received in the reasonable time frame that was set for the survey to be online. Of these, 40 responses were neglected as they were either incomplete or were not from current practitioners. After monitoring the responses to question numbers (3, 12), (24, 39) and (36, 38), 2 responses were neglected, as they were

inconsistent. This check was done to ensure the removal of any casual responses where the respondents were probably answering without even reading the question properly. Eventually only 61 useful responses were recorded. The analysis was done on the basis of these 61 responses.

The respondents were from a broad range of companies; small to large corporations (refer Appendix B, Table B.3). Moreover there was a good mixture of non-management, lower management, middle management and top management respondents. Hence the data collected can be considered as a reasonably good representation of the AEC industry. The method used to select the sample was simple random sampling. A simple random sample is defined to consist of individuals from a population chosen in a way that every individual has an equal chance of being selected. Even though a genuine effort was made to have a random sample with participants from various construction organizations of different sizes, there was bias in the selection of the prospective respondents as it was not completely blindfolded.

According to Lohr (1999), a random sample is one that is selected blindfolded. However, that is not possible for this research because there are no sampling frames available. A sampling frame is defined as the listing of the accessible population from which the sample is selected. In future research, if any sampling frame is drawn up with the list of all the people who work in construction industry, then this study could be repeated without any selection bias. Hence due to time and budget restrictions, the simple random sampling method was adopted for this research despite the selection bias. Moreover, the selection of a random sample requires that the sample be selected from a population with replacement. This means that even after selection of an individual, the

same individual must be considered again while selecting the next prospective respondent. Since the total population of this research is quite huge, the selection of a sample (individual) without replacement would hardly make any difference to the probability of selection of the remaining individuals. Hence a simple random sample without replacement was adopted for gathering responses from the subjects.

4.3. Data Analysis and Discussion of results

The data collected from the server of the website hosting the survey was imported to MS Excel for data analysis (refer Tables B.1, B.2, and B.3 in Appendix B). The methodology established in section 3.1.2 was used to calculate the personal uncertainty scores (PU) and the work environment uncertainty scores (WEU). The calculations for the total scores of PU and WEU are given in Appendix B – Table B.8. Using these scores the responses were placed in appropriate climates as established in section 3.1.2. In the Table B.9 in the Appendix B, quadrant numbers 1, 2, 3, and 4 represents the dynamic, unsettling, status quo, and stifling climates respectively.

The uncertainty management matrix created using these scores is presented in Figure 4.1. By calculating the total count of dots in each of the climates, the percentage of responses in each of the climates was calculated. The average of PU scores was 58.36 with a standard deviation of 7.90. The average of WEU scores was 53.39 with a standard deviation of 8.89.

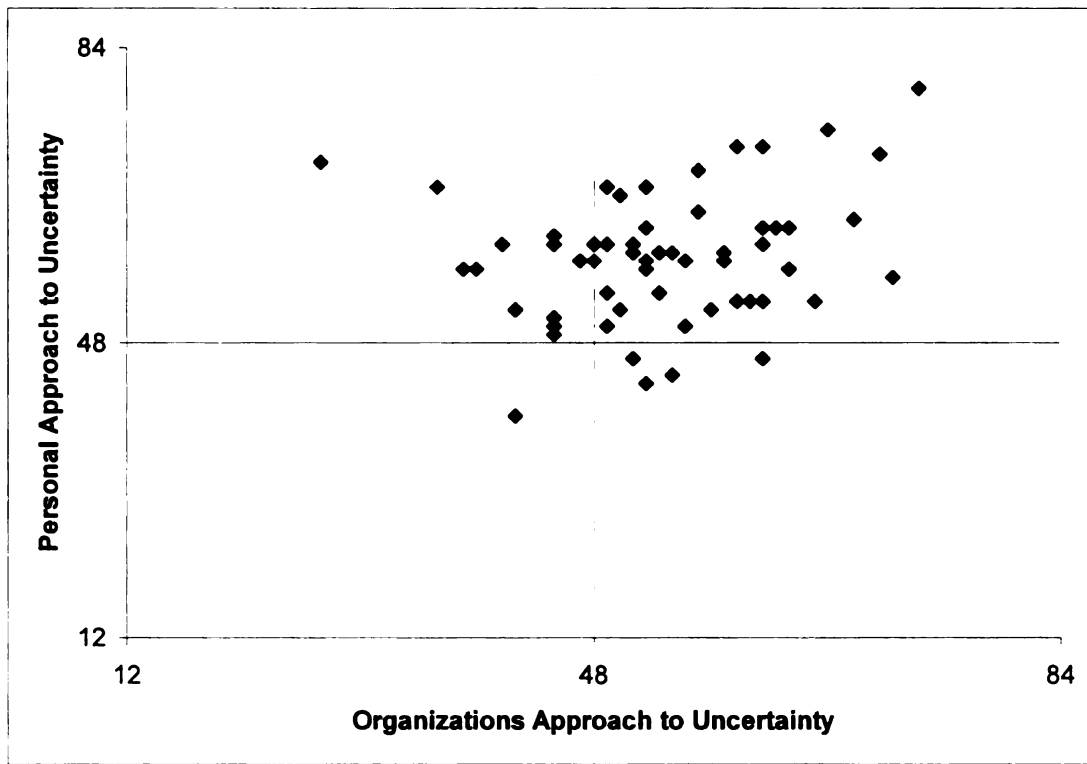


Figure: 4.1 – Uncertainty Management Matrix

Table: 4.1 – Percentage responses in each climate

Number	Climate	Total Count	Percentage
1	Dynamic	42	68.85
2	Unsettling	4	6.56
3	Status Quo	1	1.64
4	Stifling	14	22.95

On an average about 68.9% of the responses were in the dynamic climate. Moreover in the Table 4.1, it is interesting to note that only a total of 8.2% of the responses were in the unsettling and status quo climates combined. This indicates that only 8.2% of the respondents believed that their personal willingness to embrace

uncertainty was lower. It is also observed from Table 4.1 that a total of 24.6% of the respondents in stifling and status quo climates believed that their company was not as much ready to embrace uncertainty. From the analysis it is clearly seen that, 91.8% of the respondents believed that their personal ability to embrace uncertainty was high. This is the sum of responses in the dynamic and stifling climates.

4.3.1. Climates by demographic items

The various demographic items compared with the different climates are gender, work experience, company revenues, sector of construction, and age. The analysis of each of these items is presented in the following pages. It is to be noted that the whole point of the analysis was to show how the framework of uncertainty assessment would work. It is also to be noted that the study was affected by non-equal sample size and lack of enough samples in some of the sub-categories. The study of responses based on gender gave the following results as indicated in Figures 4.2, 4.3 and Table 4.2.

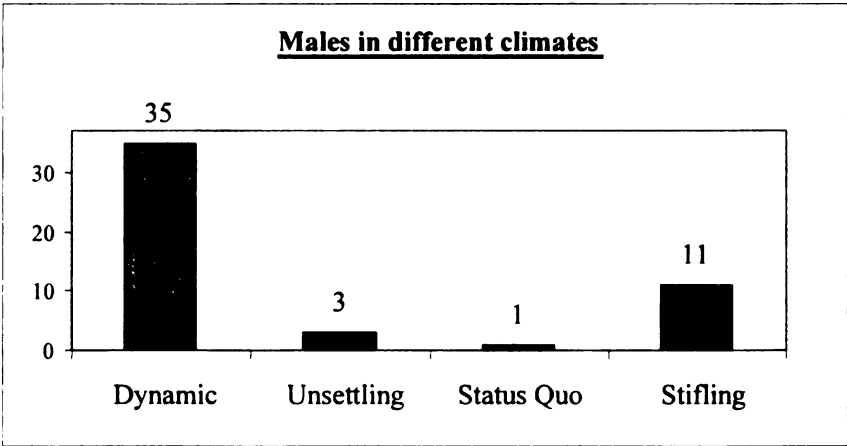


Figure: 4.2 Males in various climates

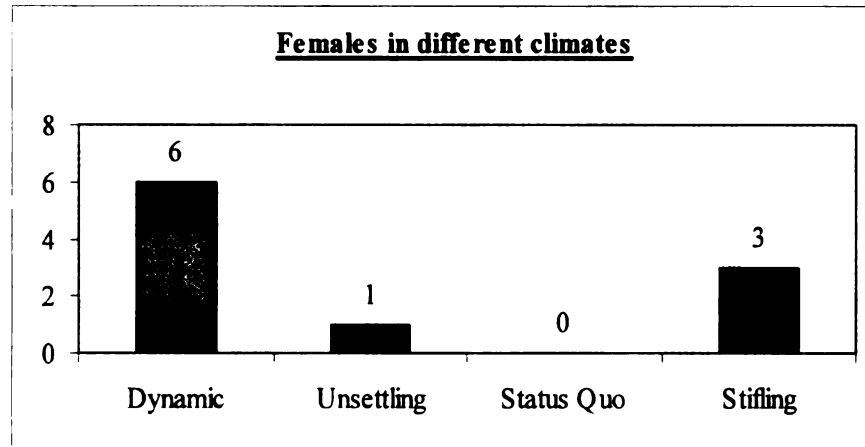


Figure: 4.3 Females in various climates

Table: 4.2 Males/Females in each climate

Climate	Males	Females
Dynamic	35	6
Unsettling	3	1
Status Quo	1	0
Stifling	11	3

The results indicate that about 70% of the male respondents and 60% of the female respondents are in the dynamic climate. Moreover, it was found that a greater percentage (30%) of females were in stifling climate as compared to 22% of the males. This also showed that approximately the same percentage of males and females are found when both the stifling and dynamic environments are combined. This indicates that there is no correlation between gender and personal uncertainty. However, it is clear that females have lower percentage of representation in dynamic climate as compared to males.

Even though similar percentage of males and females are ready to embrace uncertainty, why is a 10% variation seen in the dynamic climate? To understand this, interviews need to be conducted with the respondents of the study, which is out of the scope of this research. Further research needs to be done to investigate the percentage of responses of males and females in different climates within the same company. This could indicate whether the respective companies are comfortable with females embracing uncertainty. As of now it does appear that gender is correlated to climates; however only further research as mentioned above could shed more light on this.

Looking at the various sectors of construction like residential, commercial, heavy/highway, and industrial gave the following results as shown in Figures 4.4, 4.5, 4.6 and 4.7. Table 4.3 shows the number of responses in each of the climates for individual sectors of construction. Figure 4.8 gives a pictorial representation of the percentage of responses in each of the sectors for just the dynamic climate.

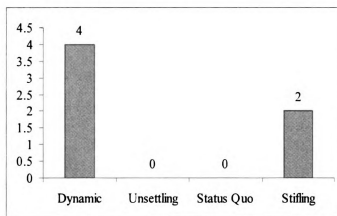


Figure: 4.4 Residential

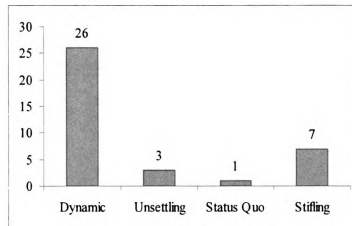


Figure: 4.5 Commercial

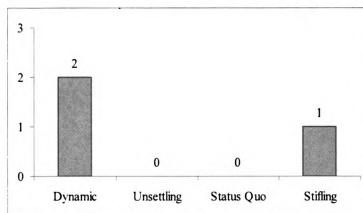


Figure: 4.6 Heavy/ Highway

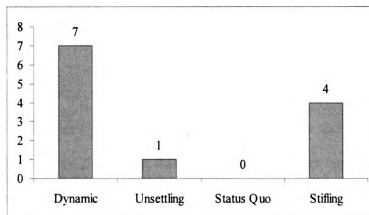


Figure: 4.7 Industrial

Table: 4.3 Sectors of construction in each climate

Climate	Residential	Commercial	Heavy	Industrial
Dynamic	4	26	2	7
Unsettling	0	3	0	1
Status Quo	0	1	0	0
Stifling	2	7	1	4

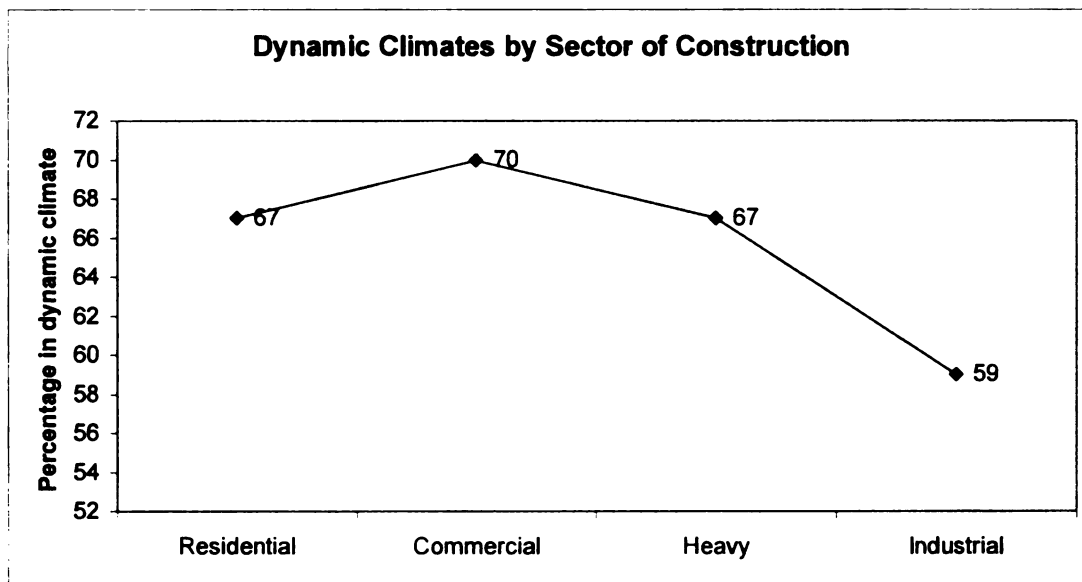


Figure: 4.8 Dynamic climates by sectors

Figure 4.8 illustrates that the average percentage of responses in the dynamic climate is almost similar for all respondents (refer Table 4.3), except for the industrial climate. It is also observed from Table 4.3 that out of the 12 responses received from the industrial sector, 4 were in the stifling climate. This indicates that even though a high percentage of the employees were ready to embrace uncertainty, the companies were not

so willing to embrace uncertainty. Due to the greater variation seen in the industrial sector, it can be concluded that sector of construction could to some extent be correlated to the climates.

The results of work experience in a company with respect to the different climates are shown below in Figures 4.9 - 4.13 and Table 4.4.

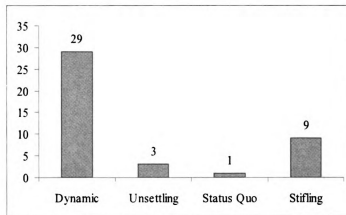


Figure: 4.9 <10 Years Experience

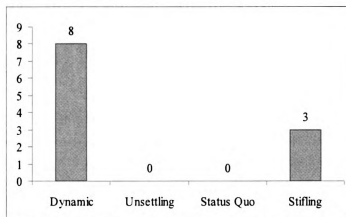


Figure: 4.10 11-20 Years Experience

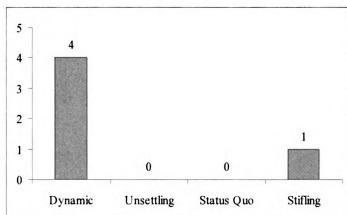


Figure: 4.11 21-30 Years Experience

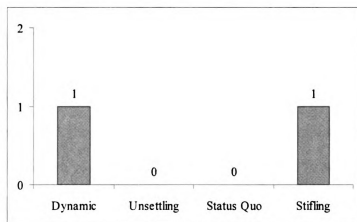


Figure: 4.12 >30 Years Experience

Table: 4.4 Work Experience in each climate

Climate	<10 Years	10- 20 Years	20- 30 Years	> 30 Years
Dynamic	29	8	4	1
Unsettling	3	0	0	0
Status Quo	1	0	0	0
Stifling	9	3	1	1

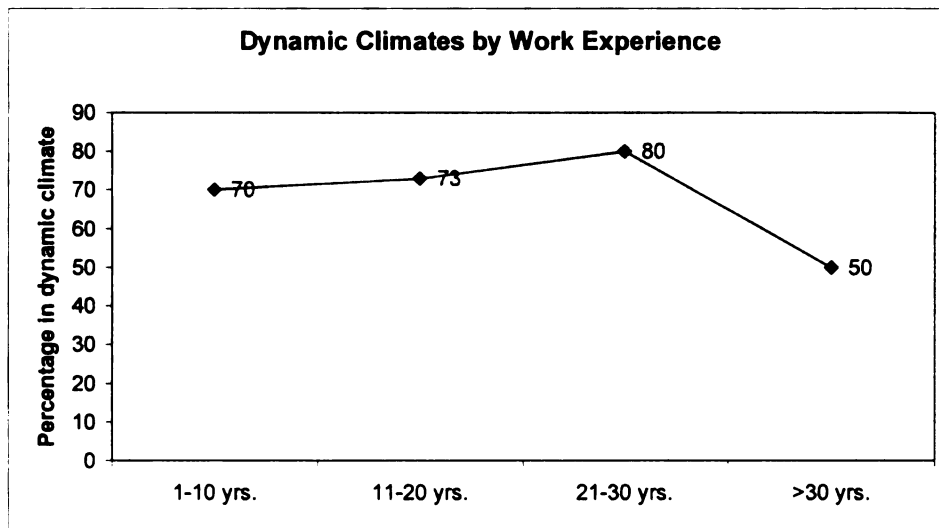


Figure: 4.13 Dynamic Climates by Work Experience

Figure 4.13 shows that there is a gradual increase in the percentage of responses in dynamic climate with the increase in work experience of respondents in a company. For individuals with 1-10 year's experience, the percentage (70%) was a little lower than for individuals with 11-20 years experience (73%). Similarly the percentage for 21-30 years increases to 80%. However for individuals with >30 years experience (50%), the percentage was much lower. This trend shows that as the work experience of an individual increases in a company, the percentage of his/her response falling in the dynamic climate increases. However, once the individual works more than 30 years for a company, then the probability of his/her response falling in dynamic climate becomes significantly lesser. This could be due to the small number of responses (refer Table 4.4) received in that category. On observing the PU and WEU (refer Table B.8 in Appendix B) scores of these respondents it was found that, the companies were not so willing to embrace uncertainty when these employees were willing to do so.

It is reasonable to assume that it is a case where either the company's policies have changed or there was a change in the top management or the specific company was never willing to embrace uncertainty since the last 30 years.

The analysis of company revenue with climates revealed the following results as shown below in the Figures 4.14 - 4.17, and Table 4.5.

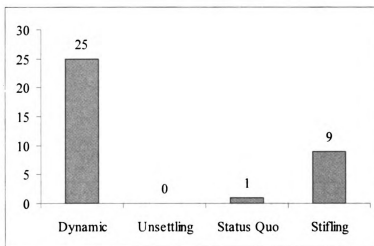


Figure: 4.14 Revenues, <300 Million

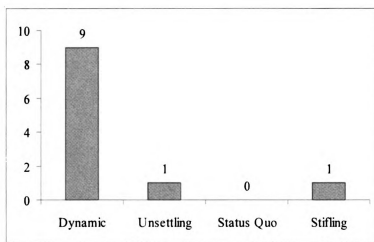


Figure: 4.15 Revenues, 300 Million – 1 Billion

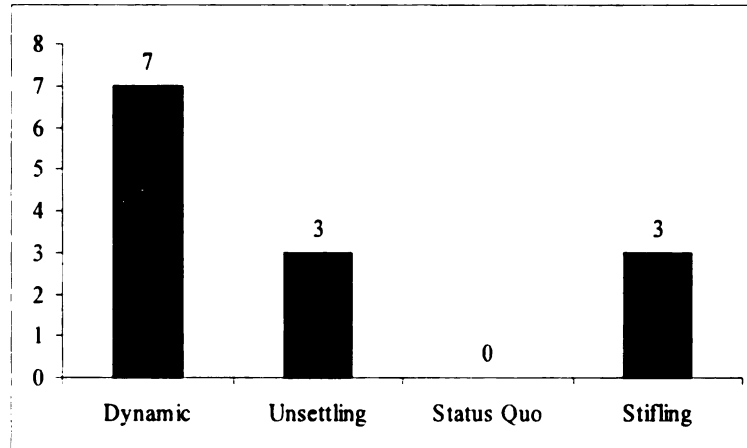


Figure: 4.16 Revenues, 1 Billion

Table: 4.5 Revenues in each climate

Climate	< 300 Million	300 Mill - 1Billion	> 1 Billion
Dynamic	25	9	7
Unsettling	0	1	3
Status Quo	1	0	0
Stifling	9	1	3

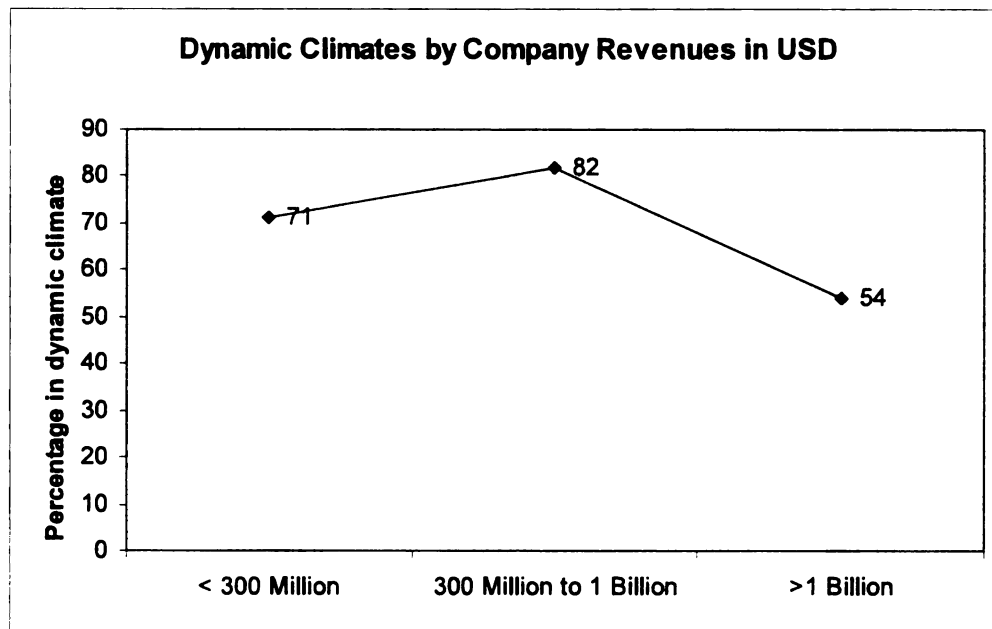


Figure: 4.17 Dynamic Climates by Revenues

It is seen from Figure 4.17 that a significantly lower percentage of responses in dynamic climate were recorded for companies with revenues greater than 1 billion (54%) compared to the average (69%) shown in Table 4.2. It is also worth noting that these large corporations had 46% responses in stifling and unsettling climates combined. This means that in 23% of the cases, the respondents were not willing to embrace uncertainty when the organization was ready to embrace uncertainty and vice-versa.

Moreover, a significant percentage of responses in companies with revenues upto 300 million were recorded in stifling climate (26%). This indicates that despite these individuals were willing to embrace uncertainty the organization was not so willing to embrace uncertainty. Companies with revenues between 300 million and 1 billion showed the highest percentage of responses in the dynamic climate as shown in Figure 4.17. Hence, the large variation in the percentage of responses registered for the dynamic

climate of companies in different revenue groups reveals that there could be a correlation between the company revenues and climates.

The age analysis of respondents with climates revealed the following results shown below in Figures 4.18 - 4.21 and Table 4.6.

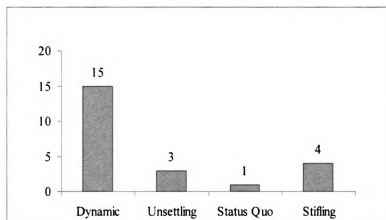


Figure: 4.18 Age, 25-35

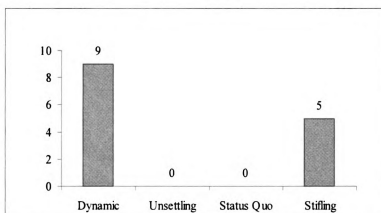


Figure: 4.19 Age, 36-45

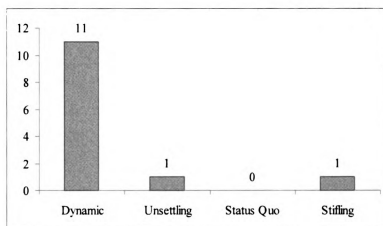


Figure: 4.20 Age, 46-55

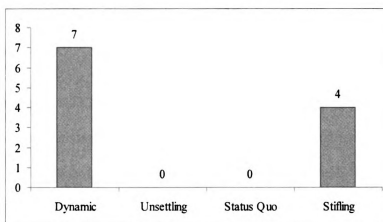


Figure: 4.21 Age, >55

Table: 4.6 Age in each climate

Climate	Age, 25-35	Age, 36-45	Age, 46-55	Age, >55
Dynamic	15	9	11	7
Unsettling	3	0	1	0
Status Quo	1	0	0	0
Stifling	4	5	1	4

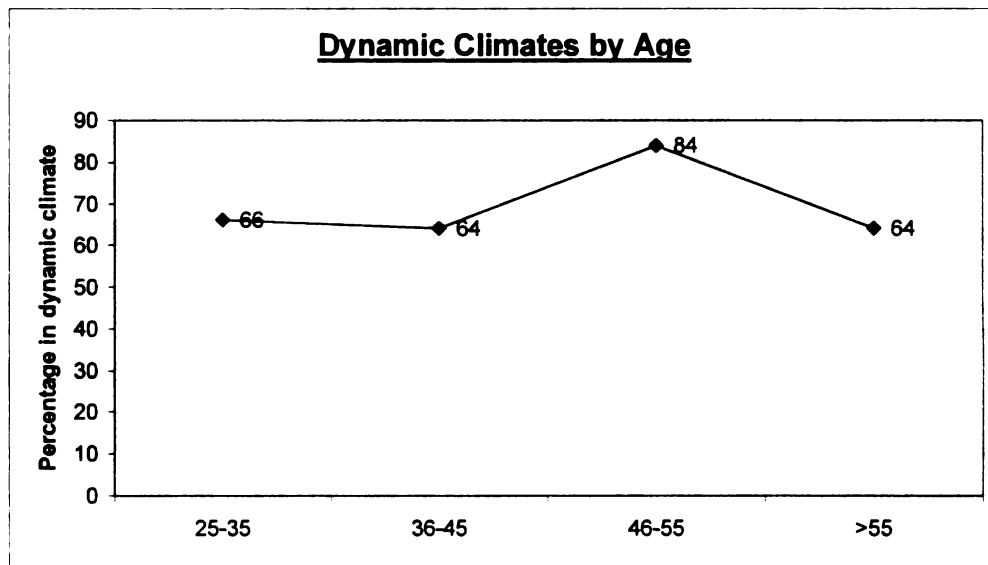


Figure: 4.22. Dynamic Climate by Age

As seen from Figure 4.22 above, except the people of age group 46-55 years, there was no other significant change found in the percentage of respondents in the dynamic climate. It is observed that normally people in the age group 46-55 have a much higher probability of falling in the dynamic climate (84%) as compared to the others. Hence, there could be some correlation of climate with the age groups.

4.3.2. Relationship between Climates and Outcome variables

The average scores of various outcome variables were sketched for different climates. The results of this analysis are as shown in Figures 4.23- 4.28 in the following pages.

As seen from these figures, high averages to the respective questions in the dynamic and unsettling climates indicates that irrespective of whether an individual is ready to embrace uncertainty or not, a higher satisfaction for job, commitment to organization, satisfaction with communication in organization, satisfaction with

communication from supervisor, identification with organizations values is achieved by the respondents if their company is ready to embrace uncertainty. However, it has also been observed in all these cases that unsettling climate had the highest average scores followed by dynamic climate. From Figure 4.27 it is seen that in unsettling climate, the respondents felt least cynical about the organization, followed by dynamic climate. This clearly indicates that even if the organization is more ready to embrace uncertainty, it fosters more job satisfaction and commitment to organization. This may not be what the companies desire as it is beneficial for the organization only when the employees also gel in with the company culture. The ideal condition is when both the employees and organization are ready to embrace uncertainty.

Thus the analysis of the climates with outcome variables indicated that the respondents expect the company to be willing to embrace uncertainty for them to get job satisfaction and be committed to the organization. Hence if such organizations that embrace uncertainty, train its employees also to do the same, then the ideal condition (dynamic climate) could be attained. Hence it is apparent that the first step for an organization to be in dynamic climate is to create a dynamic environment for the employees and then start training the employees to embrace uncertainty.

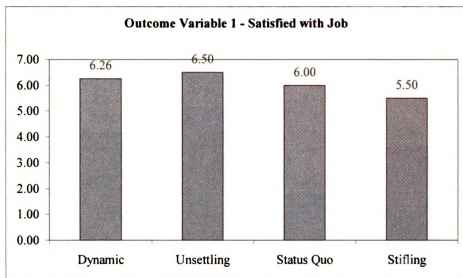


Figure: 4.23. Outcome Variable 1

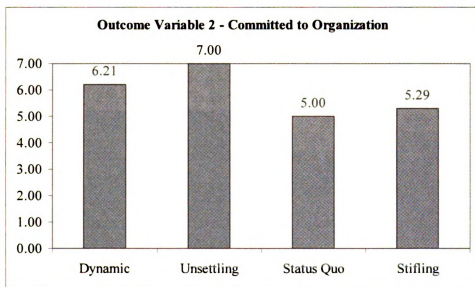


Figure: 4.24. Outcome Variable 2

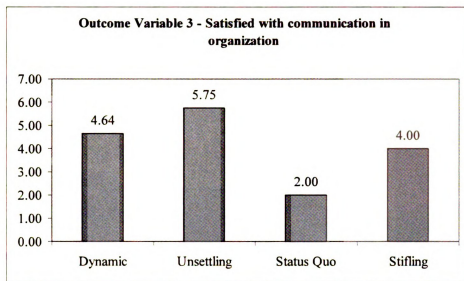


Figure: 4.25. Outcome Variable 3

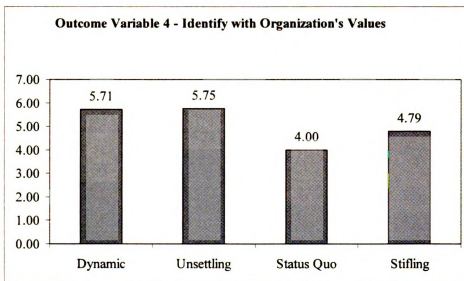


Figure: 4.26. Outcome Variable 4

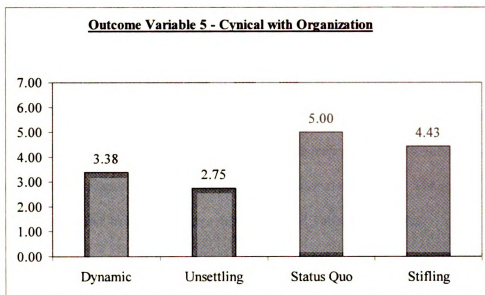


Figure: 4.27. Outcome Variable 5

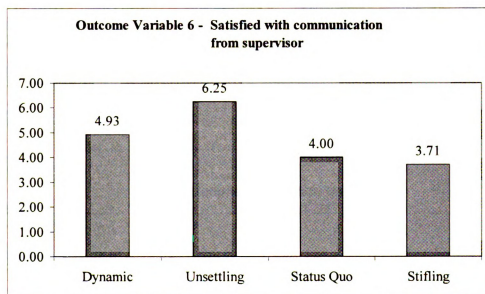


Figure: 4.28. Outcome Variable 6

4.3.3. Comparison of Traditional and Lean Construction

The respondents who mentioned that they follow any of the lean practices were extracted and a matrix was drawn with their scores of PU and WEU. Similarly all the responses that did not follow any of the lean practices were extracted to sketch another matrix. A total of 25 responses received had claimed to practice lean principles to varying degrees. The remaining 36 responses were considered as traditional companies. The results of this analysis are as shown below in Figures 4.29, 4.30, and Tables 4.7 and 4.8.

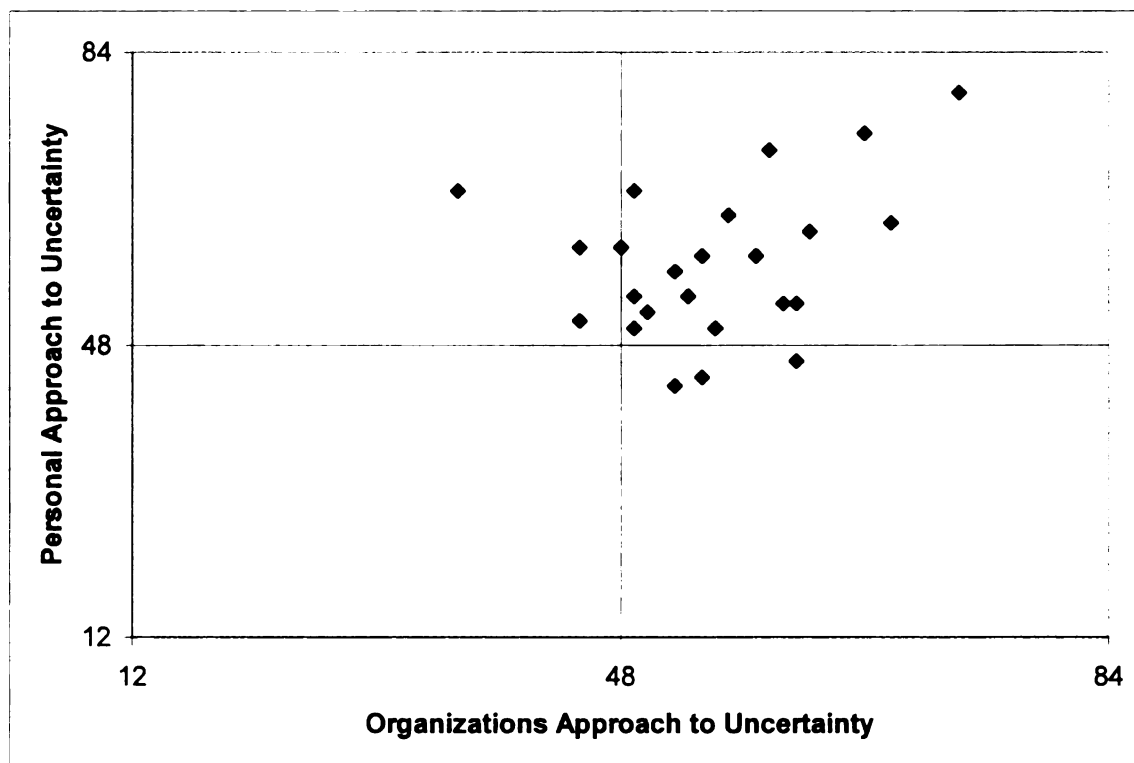


Figure: 4.29 Lean Practices

Table: 4.7 Lean Practices in each climate

Number	Climate	Total Count	Percentage
1	Dynamic	18	72
2	Unsettling	3	12
3	Status Quo	0	0
4	Stifling	4	16

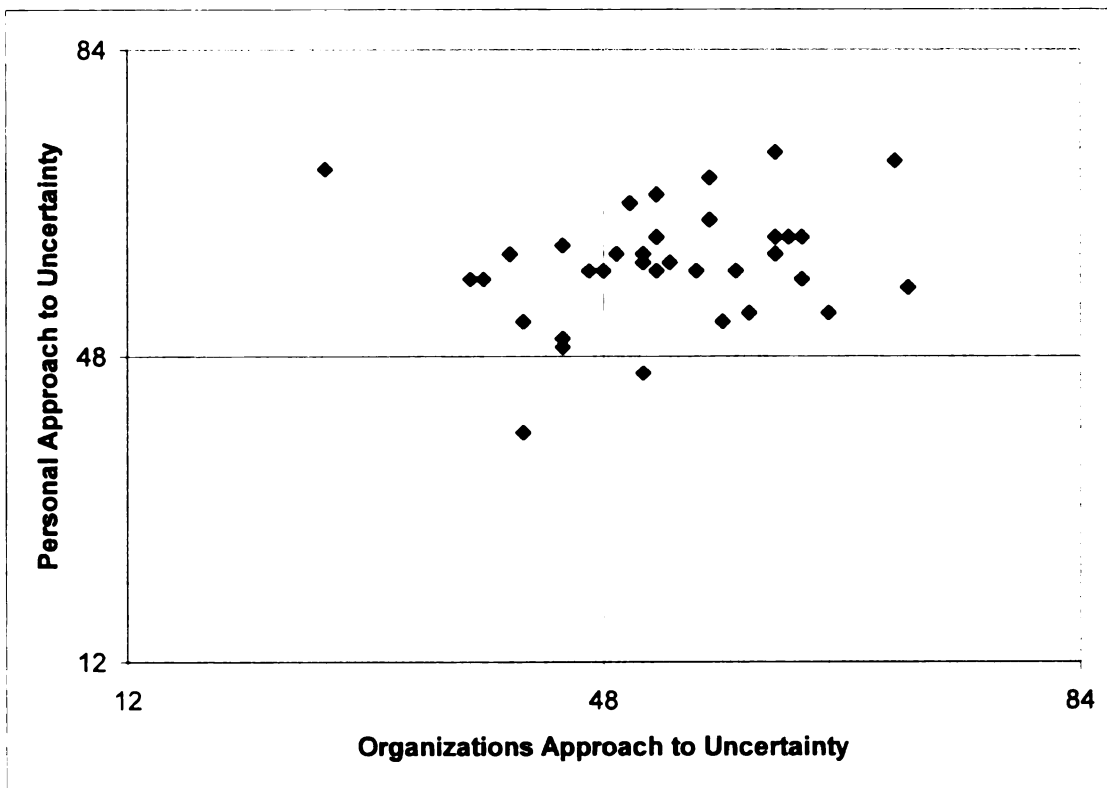


Figure: 4.30 Traditional Practices

Table: 4.8 Traditional Practices in each climate

Number	Climate	Total Count	Percentage
1	Dynamic	24	66.67
2	Unsettling	1	2.78
3	Status Quo	1	2.78
4	Stifling	10	27.78

A 5% improvement in the percentage of responses in dynamic climate was observed due to implementing lean principles (refer Tables 4.7 and 4.8). However, a 12% reduction was seen in the stifling climate of companies that adopt lean construction principles as compared to traditional practices. There was also a 9% increase seen in the unsettling climate of companies that adopt lean principles. Hence by observing the percentage of responses in dynamic and unsettling climates it can be concluded that about 84% of the respondents from companies that practice lean agree that their organizations embrace uncertainty, whether or not they personally are willing to embrace uncertainty. Whereas only 69.5% of the respondents from traditional practices believe that their organization is willing to embrace uncertainty.

To check if the number of lean practices adopted by companies' impact their position in the matrix, an intensity bubble chart was sketched. The bubble chart as shown below in Figure 4.31 was sketched using the data provided in Tables B.4, B.5, and B.6 (refer Appendix B). The size of bubbles were determined based on the number of lean practices and the X-Y axis represents the PU and WEU scores of lean companies. The

results of this chart were inconclusive as it did not indicate whether the number of lean practices adopted increase the personal or work environment scores. This is because both the smaller bubbles (which represent lesser number of lean practices) and larger bubbles (which represent greater number of lean practices) were found in the dynamic climate and elsewhere in the matrix without indicating any sort of patterns.

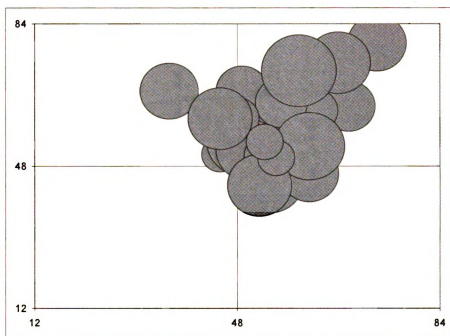


Figure: 4.31 Bubble Chart for number of lean practices

Since the above adopted method of study failed, scatter plots were generated to analyze if there were any characteristic relationship between the algebraic sum of the number of lean practices adopted by each of the lean respondents and their respective PU/WEU scores. Using Table B.6 (refer Appendix B) the following scatter plots shown below in Figures 4.32 and 4.33 were drawn. Ideally some of the practices like Last Planner System should carry more weighting factor than other practices like 5S or

Visualization. However, as the scope of this research did not include assessment of weighting factor to be given for different lean practices and hence equal weights were assumed for all the practices.

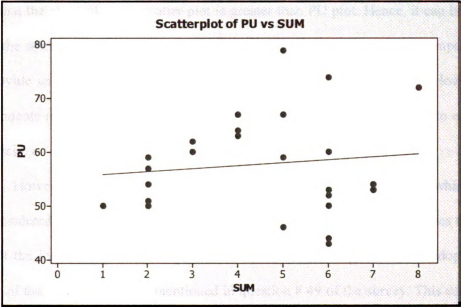


Figure: 4.32 Scatter Plot for PU Scores

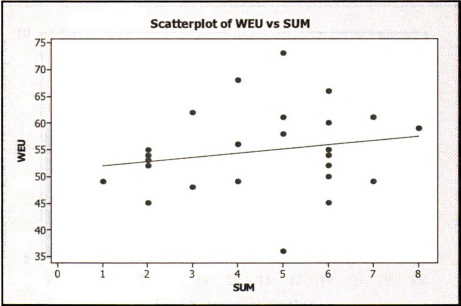


Figure: 4.33 Scatter Plots for WEU Scores

From the figures above it is observed that as companies start using more lean principles, the PU and WEU scores increase linearly. Increase in both PU and WEU scores would result in the responses moving towards the dynamic climate. It is clearly seen that the slope of WEU scatter plot is greater than PU plot. Hence, it can be inferred from the scatter plots above that as more lean practices are adopted, the companies tend to provide an environment to move towards a dynamic working climate. However, the respondents require more training to match up with the company's efforts to embracing uncertainty.

However, there were some obvious drawbacks in this comparison which should be considered by future researchers. On observing the responses of companies that adopt any of the lean practices it was found that 15 of the 25 responses were adopting 5 or lesser of the 10 lean practices mentioned in question # 49 of the survey. This can be seen from the histogram shown below in Figure 4.34.

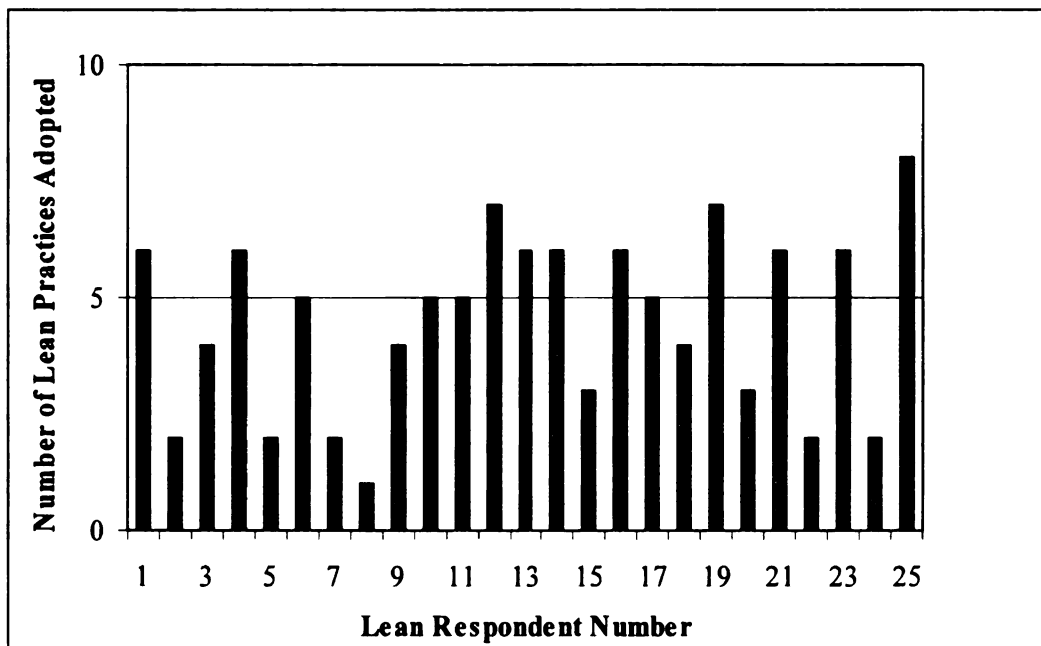


Figure: 4.34 Total Number of Lean Practices adopted by Respondents

Another histogram was sketched as shown below in Figure 4.35 to understand which lean practices were more popular or otherwise in the industry. The codes used for the lean practices shown below are presented in Table B.5 in Appendix B. The Figure 4.35 indicates that the most practiced lean principle is off-shore fabrication. This is followed by Last Planner Process, Target Costing, Work Structuring, and Concurrent Engineering in the order of popularity from highest to lowest. It was also seen that the least popular practice was Daily Huddles. However, from these figures it is not clear to what intensity these practices are being adopted. As mentioned before in chapter 2 of this thesis, the implementation of lean principles is usually a slow process and takes several years for a company to become completely lean.

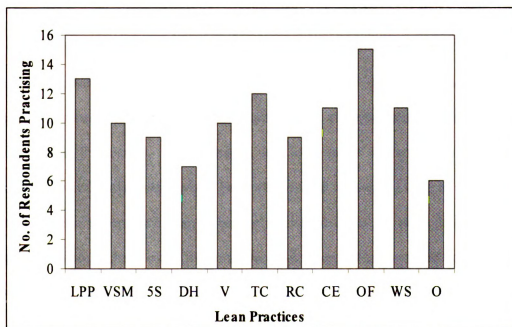


Figure: 4.35 Distributions of Lean Practices

From the data received in this research (refer Table B.4 in Appendix B) it is also not known how long these companies had been practicing lean. By monitoring the number of lean practices which companies adopt and also the time duration and intensity with which these practices have been adopted a scale should be developed that would indicate how much percentage the company is lean. Then these responses can be analyzed using statistical tools like bubble charts, scatter plots, and regression analysis. Moreover, a greater sample size may be necessary to perform a linear regression to understand the exact relationship between the PU and WEU scores and number of lean practices. As these elements were out of the scope of this research it could be considered for future research.

Thus it can be said that the comparison of companies that practice atleast some of the lean construction principles to the traditional companies showed that adopting lean construction principles does help in embracing uncertainty. It is seen from Figures 4.32 and 4.33 that the companies that practice lean provide an environment for the employees to embrace uncertainty. Due to a higher percentage of respondents in the unsettling climate (refer Table 4.7), the results of lean companies showed only a marginal improvement in the dynamic climate. However, if these employees were to be trained to start embracing uncertainty, then a bigger difference could be seen. It is clear that adopting lean principles provide the employees with the right environment for embracing uncertainty. What is required beyond practicing lean is rigorous training so that employees are better prepared to deal with fuzzy and uncertain environments.

4.4. Framework to manage uncertainty in construction

The framework suggested in this section to manage uncertainty is based on the literature review of the model designed by Clampitt and DeKoch (2001) and the responses received to the open-ended question in the survey. Those who embrace uncertainty see it as a challenge and do not try to artificially drive out the ambiguities. If organizations too work with the same framework like employees it will encourage meaningful discussions and foster innovations.

Twenty one responses were received for the open ended question #50 in the survey (refer Table B.7 in Appendix B). Of these 13 comments were received from people who claimed that their company practices lean principles. The most common comment received from all these 21 responses was that training needs to be given to the employees to encourage them embrace uncertainty. Another commonly found comment that was reflected in the responses was the need for a positive working environment where people get more latitude to make decisions. This implies that the respondents wanted the organization to embrace uncertainty and provide the employees the opportunity to do so. Better planning and need for adopting various lean principles were some of the other comments that were prominently found in these responses. These views were considered in the development of the framework.

The probabilistic uncertainties or foreseen uncertainties are the ones that have a low probability of occurrence. These are generally managed by having some contingency planning ready beforehand. However, if contingency planning becomes very complicated then these uncertainties would also have to be considered like unforeseen uncertainties, which is the main focus for developing this framework. This framework is developed to

embrace the unforeseen uncertainties for which no contingency planning can be made as these are totally unexpected. Effective handling of these uncertainties would determine how successful the project would be.

This section outlines a framework for both the organization and employee's to embrace uncertainty. From the analysis in section 4.3.2 it is clear that the respondents had highest job satisfaction, commitment to organization and were least cynical of the organization when the companies provided an environment for embracing uncertainty. Moreover, from the analysis in section 4.3.3 it is clear that adopting lean principles create an environment for the company to embrace uncertainty; however the employees require more training so that the working climate becomes more dynamic. It is suggested that in the project planning phase, the initial goals and objectives must be flexible and tested against the means before fixing the objectives eventually at the last responsible moment. This could be done using lean principles, by matching "Should" with "Can" before deciding what "Will" be done, as practiced in the Last Planner System.

From chapter 2 (refer section 2.9) we know that OODA loop (Observe, Orient, Decide and Act) is a simple reckoning of how human beings make tactical decisions. Even though the OODA model was initially created for military purposes, elements of the same theory can also be applied to business strategy. The OODA loop is an elegant framework for creating competitive advantage. Hence, it is also suggested that the OODA loop should be followed by managers to continually observe, orient, decide and act in order to achieve and maintain freedom of action and maximize the chances for survival and prosperity. This continuous monitoring would help managers act decisively at uncertain times during the production phase. The organization should also provide ample

training to the employees so that they become deft at handling different kinds of situations that could prop up during construction. Such training would help the employees involved in the production phase which is very critical as it requires constant monitoring and skillful adaptation to the changing situations. The above mentioned methods have been elaborately discussed in the following parts of this section and these could be used by construction companies to cultivate the habit of embracing uncertainty. The framework is depicted pictorially in Figure 4.34 below.

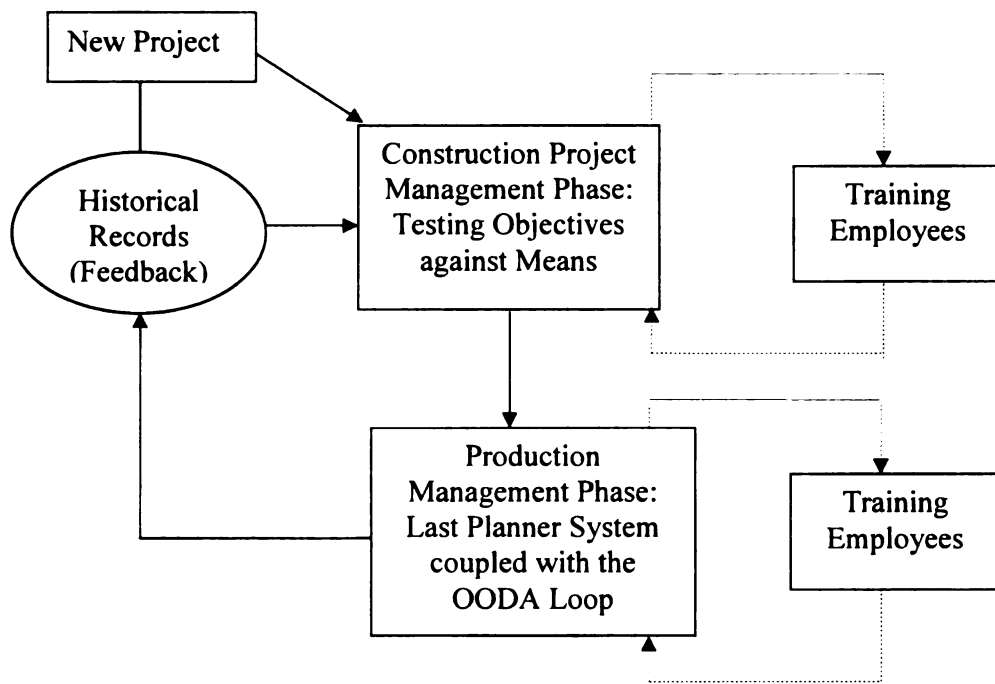


Figure: 4.36 Model for Embracing Uncertainty in Construction Projects

STEP 1: Organization creating an environment for embracing uncertainty in the project-planning phase.

As explained in chapter 2, embracing uncertainty is not possible until the process begins by creating a platform. In construction projects this platform is created in the project-planning phase. This platform would represent notions, activities, or decisions that provide either a foundation or a springboard from which to act. “Project planning is a rational determination of how to initiate, sustain, and terminate a project” (Cleland, 1990). According to Howell et al. (1993), two basic questions that construction industry faces whenever there is an uncertain event are: “What is to be built” and “How it is to be built”. In other words, uncertainty remains both in the project objectives and in the means of achieving those objectives. It is necessary to resolve these issues as a project moves from an idea to a reality.

According to Syal et al. (1992), construction project planning begins with defining the project objectives. Then a detailed description of the project and its scope are outlined. This is followed by preparation of the construction schedule, cost estimate and deciding on the project team. All these stages of planning are done before the execution phase starts. This logic is a traditional project management philosophy, which is not ideal for the construction industry. Though it is good that some level of strategic planning is done upfront, keeping the goals and objectives rigid would not solve the problems encountered during uncertain times. If any unforeseen uncertain event occurs in a project, then all the planning done before is not going to help achieve the project objectives, because during the initial planning stages these events were not accounted for and no contingency planning was done for them. Hence, the first essential step is to realize that

flexibility of changing the project goals and objectives is necessary to deal with such circumstances.

According to Howell et al. (1993), project objectives are an expression of constraints that the organization imposes on planners. The constraints of the finance, operations, human resource and marketing departments etc. determine the project objectives. They are unlike corporate objectives and represent a balance of constraints negotiated between divisions; together they achieve the results desired by the corporation. Each of the constraints rests on some premise; explicit identification and testing of these premises will provide the basis for controlling the objective setting. For example while the initially determined completion date may change as a result of internal problems, costly and wasteful decisions may be made if managers of the project lose sight of the premises upon which the schedule exists.

The project objectives evolve early in the life of a project, at some point stability may be required if wasteful decisions are to be avoided. The exploration phase as mentioned in section 2.5.4 goes on until the bases of the objectives laid down are being tested. Initial objectives do not account for all the constraints, which will surface during the project because uncertainty exists both in the higher corporate goals and in the unexamined means of accomplishing the project itself. However, identifying stable premises is a pre-requisite to identifying stable objectives, which is difficult due to the high level of uncertainty that surrounds the project.

It is at this time that examination of the means will help. The project objectives evolve as new constraints evolve. Testing the objectives against means would also help in identifying and minimizing the potential damage that could be caused due to impact of

unforeseen changes late in a project. The foreseen uncertain events can be determined using simulation techniques, where the probability of various outcomes of foreseen uncertainties can be evaluated. However, for tackling unforeseen uncertainties the decision makers need to wait until enough new information arises to formulate new solutions.

Now there is a choice of either refining the existing platform or using it as a springboard to explore other platforms. Once the critical stage is reached where no further exploration is possible, it must give way to consolidation. Consolidation in the case of construction would mean the phase where the project goals and objectives are fixed. However, it is important to note that this critical stage should be encountered only at the last responsible moment. Until then the exploration phase should be active. Moreover, the experiences are recorded as feedback for future reference as shown in Figure 4.34. These feedbacks could be useful at a later stage in the same project or for new projects later on.

The emphasis of this step has been on keeping the initial goals and objectives flexible and testing them against the means before fixing the objectives eventually at the last responsible moment. The lean construction literature talks about testing the objectives against means and taking decisive action only at the last responsible moment. Matching objectives to means can be applied to the principle of matching “Should” with “Can” at the outset, as practiced in the Last Planner System (refer section 2.4.8). Hence this step of the framework can be implemented by following the above-mentioned principles of lean construction.

STEP 2: Monitoring the environment in the production phase, which is the survival skill required in uncertain environments.

To deal with unforeseen uncertainty, project managers must embrace uncertainty and move from troubleshooting to reactive consolidation of what the team has achieved so far. One such tool that could be of great use in monitoring the environment and to act decisively during uncertain times is the OODA loop (Observation, Orientation, Decision, and Action). The OODA loop is shown in Figure 4.37 below.

As explained before in section 2.9 of this thesis, the first step in OODA loop is to observe, so as to acquire sufficient knowledge for making a decision. This step requires recognition of unfolding events and feedbacks from the various other stages namely – orient, decide and act. This makes the OODA loop non-sequential at times. The second step is to orient the information. This step involves utilizing previous experience, waiting for all new information to arrive, cultural traditions of the organization, collecting information about the genetic heritage of the problem and analyzing the problem. This leads us to the hypothesis stage where a decision is made on how the problem can be approached. Depending on the decision made considering all the information received, an appropriate action can be taken.

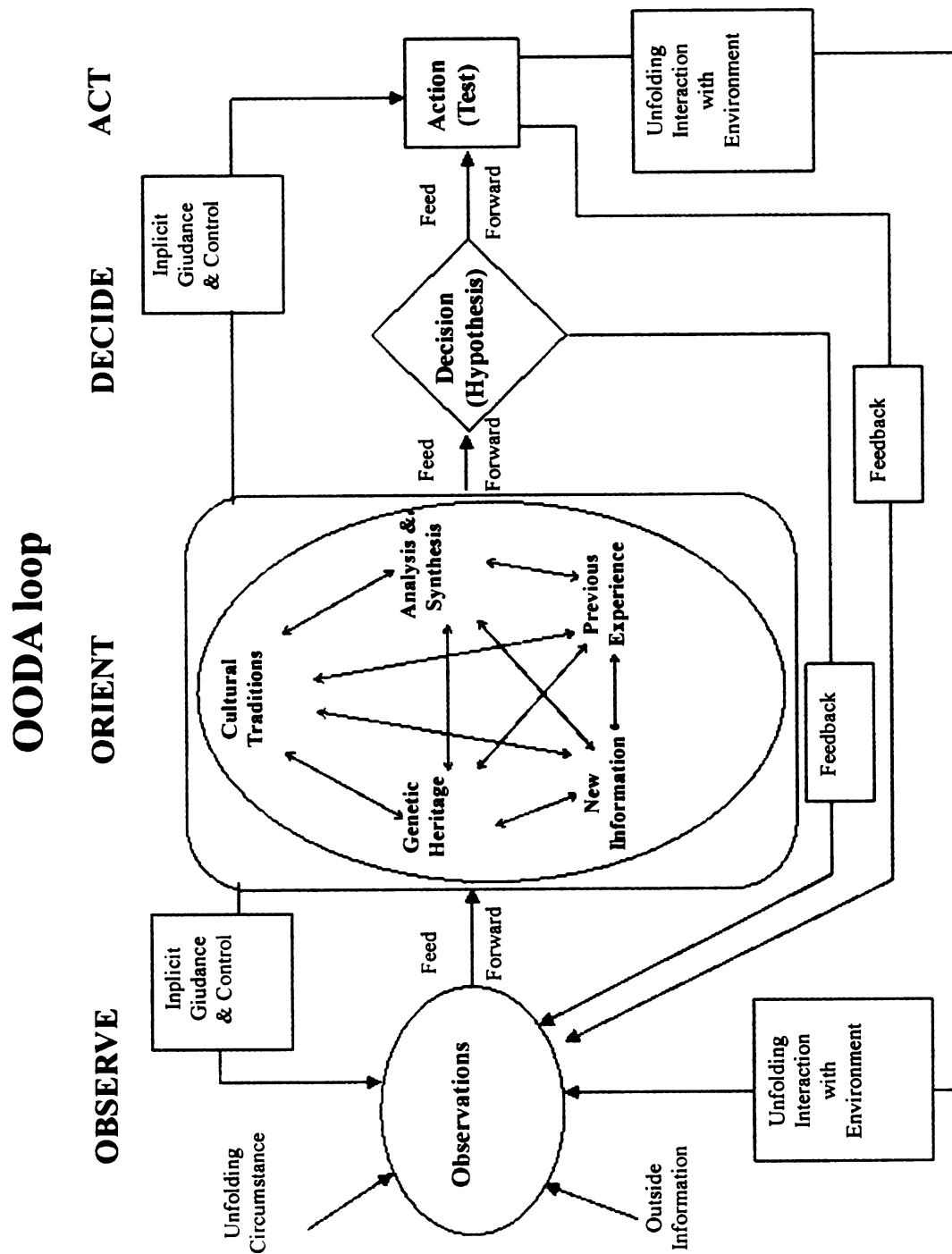


Figure: 4.37. OODA Loop

Monitoring the production phase is very critical because it is this phase that suffers the first effect of any problem occurring due to the occurrence of an unforeseen uncertain event. The lean construction principles have been suggested in this thesis to be helpful in embracing uncertainty (refer section 4.3.3). Hence, along with implementing lean principles the OODA loop is appropriate for monitoring the production phase for uncertainties. Because the OODA loop contains the same essence of lean construction and it also tells in a nutshell how to observe, orient, decide and act which is the most essential concept for managing uncertainties. This drives us to the next bigger question – where the OODA loop needs to be implemented and which lean construction principle would assist the implementation of the OODA loop? To understand this concept it is essential to understand the production process well. The Figure 4.38 shown below illustrates the difference between project and production management and also indicates how the OODA loop can be implemented in the production process.

The difference between the project and production control process in terms of the “Should-Can-Will-Did” system of Last planner can be seen from the formulas shown below: “DID” / “Should” = Project Control; and “DID” / “WILL” = Production Control. As indicated by the formulas above, the project control is the process by which the “Should” is compared to the “Did” to get an overall idea of how the project is moving forward. The project control process looks at the higher picture of whether the objectives that were set during the project planning phase were met or not. The production process however cannot follow the same yardstick for comparison with the objectives.

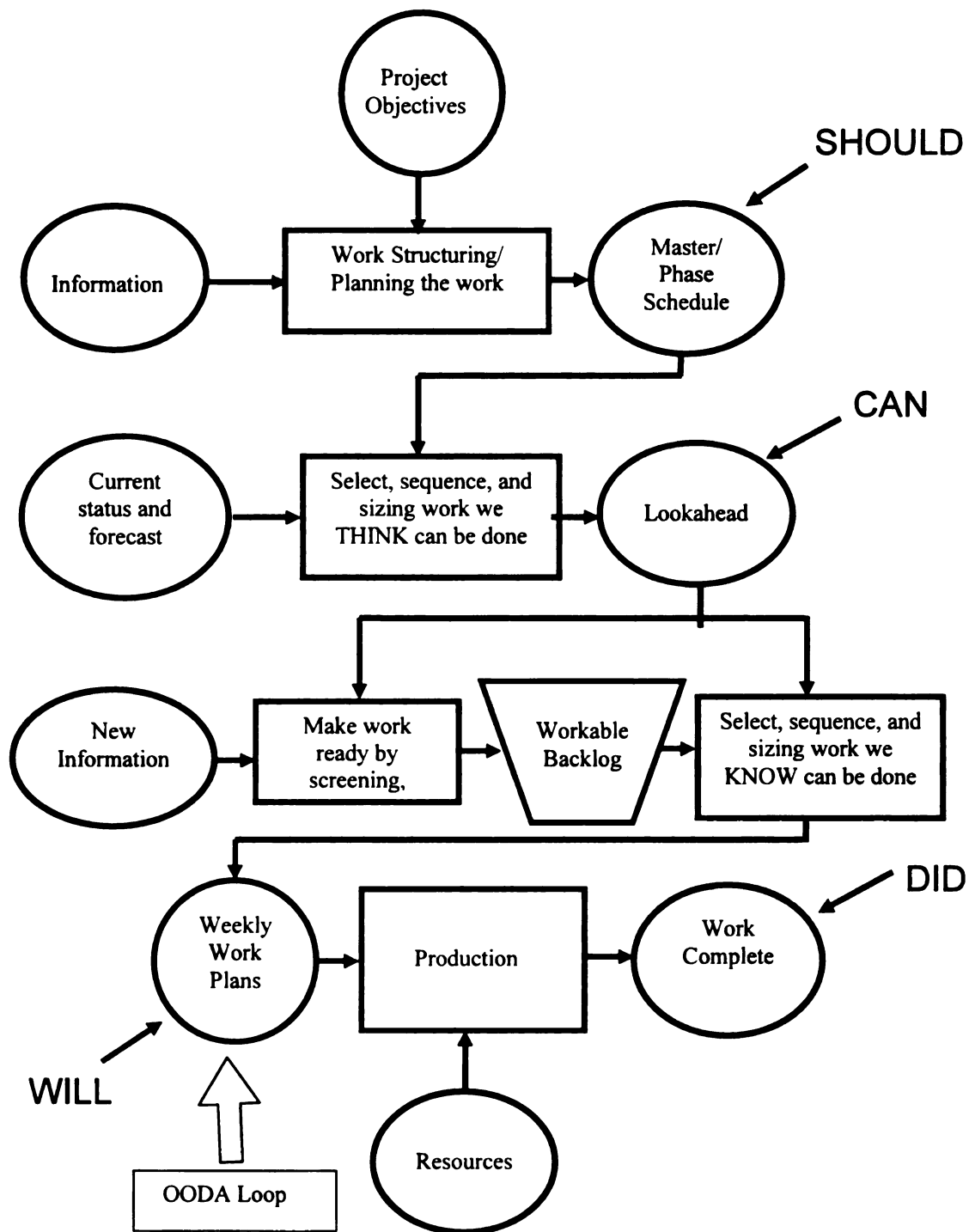


Figure: 4.38. Project and Production Management under Lean Construction
(Source: Modified from Abdelhamid, 2005)

The Figure 4.38 shows how the last planner system of production control works and where exactly the OODA loop is beneficial. As explained in chapter 2, the last planner process involves two inputs – “Should” and “Can” to decide the output – “Will”. According to lean construction principles, after looking at the new information that is available, forecast for the next few weeks, and the current status of work a decision is made on what “Can” be done. This is the first phase of last planner system where a lookahead schedule is prepared. Then based on the realities faced by the project team on field, weekly work planning is done to decide how it “Will” be done, which is the second phase of the last planner system. The decisions made at the weekly work planning are the actual commitments made by the project team. It is in this stage that the OODA loop needs to be implemented.

Weekly work planning is one of the aspects of last planner system where based on the PPC (Percentage Parts Complete) measurements made at the end of a week, the next weeks work planning is done. The PPC is measured by the formula “DID” / “WILL”. The OODA loop would go hand-in-hand with the weekly work planning and assists in planning for the next weeks activities. Only the activities that are free from foreseen uncertainties will be carried forward to the next weeks work plan. All other activities should be monitored in the OODA loop fashion to ensure that the next weeks work is done smoothly after removing all obstacles. Moreover when faced with unforeseen uncertainties, by working in the OODA loop fashion the project team can act decisively by removing all obstacles. The main advantage of the OODA loop will be realized in handling the unforeseen uncertainties as it is a systematic procedure of action. By documenting the procedure adopted at every instance where uncertainties are dealt with

in the OODA loop way, a very resourceful database can be created. Moreover the OODA loop is a better measurement tool to check the cycle time to overcome uncertainties.

A faster OODA loop is essential for companies to ensure the success of projects in this competitive world. This requires practice and hence rigorous training should be given to the employees to get comfortable working in the OODA loop fashion. This would not only improve the efficiency and help the construction companies (contractors) to be successful in their projects, but will also increase their reputation and help in securing new projects. According to Richards (2004), the OODA loop talks about creating an environment of trust to permit implicit communication amongst the team members. The owners would feel more comfortable as they would be inclined to believe that the contractors are more committed to working with efficiency. This would not only help the construction companies to finish their current projects on-time and on-budget, but will also help in securing new projects with the owner based on the success of their previous projects.

The feedback from every experience of using the OODA loop either at times when uncertain events affect the project or during the training process of employees is recorded as historical records for future references. As shown in Figure 4.35 these feedbacks could be used for the same project at a later stage or for new projects later on. These past records help the organization and employees to improve on their OODA loop cycle time to be more competitive and efficient.

STEP 3: Training employees by occasionally shaking the platform when in the quest of certainty the employees get a little too comfortable.

As mentioned in step 2, rigorous training needs to be given to the employees. Hence, occasionally shaking the platform in which employees are very comfortable, will serve as a drill for both the organization and the employees to embrace uncertainty. This means that even on occasions when there are no problems due to uncertainties and the employees get too comfortable with processes, they should be exposed to uncertainties by artificially simulating such situations. This is necessary because it has been observed from the section 4.3.2 of this thesis that the highest averages are seen for outcome variables in the unsettling climate, where the company is ready to embrace uncertainty but the individuals were not so ready. Since this is not the ideal condition, the employees need to be trained to embrace uncertainty at whatever phase they are involved in. For example the executives and project managers should be trained to embrace uncertainty at the project management level. The field engineers, schedulers, estimators and superintendents should however be trained to embrace uncertainty at the production level.

This would also help the employees to start working in the OODA loop fashion. Being competent to embrace uncertainties requires a lot of practice. Hence a rigorous training must be undertaken, which would help them handle different kinds of situations that could prop up during construction. Since unforeseen uncertainties are totally unexpected, even this rigorous training cannot replicate all the situations that they may encounter. However, this is the only way to train the employees to handle uncertainties. The team should be ready to embrace uncertainty by cultivating an awareness of the

situation, processing it, and then catalyze a decisive action. The following practices are suggested for training the employees.

1. Asking penetrating questions, to make the employees think deeper. One way to do that is by using the famous “5- Why” approach of Toyota to ask why the problem happened 5 times in series till the root cause of the problem is encountered (Liker, 2004).
2. Challenge the existing heuristics or rules of thumb, to break the spell of overconfidence in estimating their accuracy of judgment.
3. Fuzzy up the expectations, to account for the time line and methods, which are normally unclear. In other words, blurring up the expectations.
4. Putting an information perish date on all communications. This should be done to push people to not be dependent on a single fact and focus on longer-term trends.

4.5. Analysis Summary

This chapter presented the data collected for the research and the analysis using the uncertainty management matrix to assess the uncertainty management approaches in the construction industry. The raw data received from the survey can be viewed in the appendix B at the end of this thesis. Most of the subjects who participated in the survey showed a higher personal uncertainty score while the organizational uncertainty score recorded varied with respondents. It was observed that 68.9% of the responses were in the dynamic climate. The secondary analysis revealed that there could be a correlation between climates and some of the demographic items. However, establishing any such relationship might require a statistically determined sample that would represent the

entire population considered in the study. The scores of outcome variables in different climates revealed that organizations that embrace uncertainty foster more job satisfaction and commitment of employees to the organization. It was observed that to be in the dynamic climate, the organization must first provide an environment for the employees to embrace uncertainty and then train them. The comparison of lean construction companies to traditional companies revealed that the lean principles help more in embracing uncertainty as compared to the traditional practices.

Chapter 5

SUMMARY AND CONCLUSIONS

Chapter 5

SUMMARY AND CONCLUSIONS

5.1. Thesis Summary

The goal of this research was to develop a framework for assessing the approaches of construction organizations towards managing uncertainty. Chapter 1 gave an introduction to the research area. It also explained the need for this research and the goals and objectives were outlined. Chapter 2 detailed the concept of embracing uncertainty and its benefits. The difference between project management and production management, and the importance of embracing uncertainties in both these phases were also explained. Moreover, a literature study on the various lean principles was also presented in this section to familiarize the readers to the terms used in the survey questionnaire. Chapter 3 outlined the methodology that was adopted to achieve each of the objectives and thereby the goal of this research. It also explained the methodology for the different kinds of secondary analysis that were done in this research to observe if any trends could be established with their results. Chapter 4 presented the analysis done with the data collected from the online survey of construction professionals.

5.2. Conclusions

On an average, about 68.9% of the responses were in the dynamic climate. Even though this figure indicates that about two-thirds of the respondents were in the dynamic climate, there is still a possibility for improvement. The remaining one thirds of the respondents could also be pulled into the dynamic working climate to achieve the ideal condition. In the analysis of the uncertainty management matrix for all the responses received it was clearly seen that 91.8% of the responses believed that their personal ability to embrace uncertainty was high. It is possible that this figure is high because of individuals

overestimating their personal ability to embrace uncertainty in contrast to what they felt about their organizations.

In the secondary analysis done in this study it was seen that there could be a correlation between climates and some of the demographic items. However, establishing any such relationship might require a statistically determined sample that would represent the entire population considered in the study. There is no correlation established between gender and personal uncertainty. However, females had a lower percentage (10%) of representation in dynamic climate as compared to males. The matter needs to be investigated further by conducting a study specifically to verify if the organizations are comfortable with females embracing uncertainty.

Moreover, due to the greater variation seen in the industrial sector, it is possible that sector of construction to some extent could be correlated to the climates. Similarly work experience and company revenues show some pattern in different climates due to the variations seen in their analysis. It was also observed that the age group 46-55 has a much higher percentage of responses in dynamic climate than other age groups. It is clear that there could be some trends established by considering the factors mentioned above. However, since correlation analysis was not in the scope of this research, future studies could do that provided a statistically valid sample size is used for the study.

The scores of outcome variables in different climates revealed that even if only the organizations embrace uncertainty, it fosters more job satisfaction and commitment of employees to the organization. It was also noted that respondents in unsettling climate had highest average scores in the following categories:

- Satisfaction for job
- Commitment for the organization
- Satisfaction with communication in organization
- Satisfaction with communication from supervisor
- Identification with organizations values

The dynamic climate respondents were found to have the next highest average scores in all the above mentioned categories. Moreover the respondents in unsettling climate were least cynical with organization followed by respondents in dynamic climate. This may not be what the companies' desire as it is beneficial for the organization only when the employees also gel in with the company culture. Hence it is apparent that the first step for an organization to be in dynamic climate is to create a dynamic environment for the employees and then start training the employees to embrace uncertainty. This would create a win-win situation where both the employees and organization have a matching work style.

Only a marginal 5% improvement in the results of dynamic climate was observed on sketching the matrix with only companies that adopted any of the lean principles. However, on observing the responses it was found that a significant number of the lean respondents were practicing only few of the lean principles and the time duration over which these principles are being used is unknown. However with the available data it was observed that as the number of lean practices a company adopted increased the probability of respondents to be in the dynamic climate increased. Since implementing lean principles in a company is a gradual process and takes time, more research needs to

be done to rate companies based on their intensity of adopting lean principles. Only then a true picture of the comparison can be found.

The framework developed in this research emphasizes that the organization should be ready to embrace uncertainty in both the project management phase and the production-management phase. In the project planning phase, it is suggested that the initial goals and objectives must be kept flexible and tested against the means before fixing the objectives eventually at the last responsible moment. This could be done using lean principles, by matching “Should” with “Can” before deciding what “Will” be done, as practiced in the Last Planner System. It is also suggested that the OODA Loop should be followed by managers to continually observe, orient, decide and act in order to achieve and maintain freedom of action and maximize the chances for survival and prosperity. This continuous monitoring would help managers act decisively at uncertain times during the production phase. The organization should also provide ample training to the employees so that they are prepared to act when uncertain events occur. Few methods of training the employees were also suggested in the thesis.

5.3. Contributions

This research developed a methodology for assessing the approaches of construction organizations towards managing uncertainty. The survey adopted from Clampitt and Williams (2003) was modified and made more specific for construction settings. This modified survey could be used to ascertain the working climate environment of any construction organization.

Moreover, this research has enhanced the existing literature on project delivery methods and has demonstrated that management of uncertainty is an important consideration for the owners in selection of suitable project delivery methods for their unique project needs. For example in infrastructure projects where there are several uncertainties surrounding the project, selection of the right project delivery method is the key. Another important contribution of this research is demonstration of lean construction principles in being helpful in embracing uncertainties better than the traditional methods of construction.

Another key contribution of the thesis is in establishing through the survey results that the first step for a company to embrace uncertainty is to provide an ideal environment for the employees to embrace uncertainty. Then by training the employees, they could also be made comfortable to embrace uncertainty. Moreover the training suggested in the thesis for employees would be very useful for the companies to train their employees.

The thesis also developed guidelines/ conceptual framework to better understand how to embrace uncertainties. These guidelines have for the first time applied the OODA loop model to the construction setting. OODA loop is suggested to be a useful tool that can be used in tandem with last planner system to observe, orient, decide and act appropriately to counter uncertainties in the production phase of construction. The framework developed in this thesis would be suitable for managing uncertainties in both the project and production management phases of construction.

5.4. Limitations of research

Similar to any research, there are limitations and assumptions made in this research. It is always difficult to trust self-reported measures. It is possible that employees and managers over-estimate their abilities or their organizations ability to embrace uncertainty. The response to survey is likely to be heavily dependent on the supervisor's behavior towards the respondent and the communications from the top management. Moreover, since a number of companies are being considered for the survey, it is not possible to manually collect the survey sheets from the individuals due to economic and time constraints. Hence an online survey was conducted due to this reason.

The major limitation of an online survey is the non-response factor. There would be employees or managers who do not know how to navigate in the internet or just consider the survey as not so important. The companies selected in the sample vary from very large corporations to small sized companies, which tried to bring a true representation of the Architectural, Engineering, and Construction (AEC) industry as a whole. However, the selection process was biased, as there were no sampling frames available to get a genuine random sample. Hence the selection process was not totally blindfolded as required statistically for a random sample selection.

Moreover since a statistically acceptable sample size was not used for the analysis, it is important to note that any correlations indicated by the study would have to be statistically validated by using a greater sample size which would give a margin of error not more than 5%. Analysis of several demographic items in various climates revealed that personal interviews would be required to investigate further so as to establish some correlation between the results of the study and the demographic items.

However, this research contained several critical questions that required total anonymity of the respondents. Hence, the research was committed to not identifying any of the respondents with their answers to the survey. Therefore conducting any personal interviews with the respondents was ruled out. Hence, due to a small sample size and the inability to conduct personal interviews with respondents, the research was limited from bringing out any specific correlations between results of the study and demographic items.

5.5. Recommendations for future research

There could be a series of studies that could be undertaken to understand how uncertainty can be managed more effectively in the AEC industry, such as by practicing Lean Construction. In future, researchers could consider the following recommendations:

1. From this research it has been found that companies that adopt lean construction practices have better uncertainty embracing approach. However, the companies that claim to adopt lean construction should be observed to understand the intensity with which these companies adopt lean principles and for how long they have been adopting lean principles. There could be a percentage wise rating given to all such companies depending on how much lean each company is.
2. The data collected for this research indicate that communication practices and protocols play an important role in cultivating uncertainty-embracing organizational practices. Future researchers might investigate what specific supervisor behaviors build uncertainty-embracing climates.

3. A bigger sample size would bring statistical validity to the results. The normal industry standards for such researches may require a 95% confidence level with a $\pm 5\%$ confidence interval for the results. Hence future studies may also consider collecting a statistically determined sample size. Moreover, the demographic items could be checked for statistical correlation with the different climates. This would help establish trends.
4. The survey tool could be modified to include a section that would analyze the psychology of the respondent while responding to the survey. Since it is observed in this research that the respondents could have overestimated their personal ability to embrace uncertainty, the psychology section could throw more light on this. Moreover, the results of the psychology section could also be considered to adjust the PU and WEU scores used to plot the uncertainty management matrix.
5. Future researchers could also investigate the approaches of managers who adopt lean principles at a personal level in their projects, even though their company does not adopt lean principles in their processes. A study could be done to understand how much this would help the managers in embracing uncertainty at a personal level.

APPENDICES

Appendix A
CONSENT LETTER AND SURVEY QUESTIONNAIRE

**ASSESSMENT OF UNCERTAINTY MANAGEMENT APPROACHES IN
CONSTRUCTION ORGANIZATIONS - CONSENT FORM**

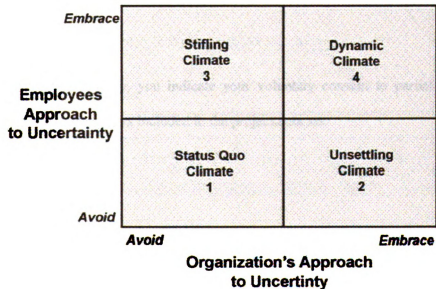
Principal Investigator: Tariq S. Abdelhamid, PhD

Research Assistant: Venkat Jayaraman, B.E.

THE SURVEY IS FOR CURRENT PRACTITIONERS ONLY

The Construction Management program at Michigan State University is conducting a research project to assess the Architectural, Engineering, and Construction (AEC) organizations' approach to managing uncertainty.

By completing an on-line questionnaire, and based on your project experiences, you will allow us to identify where AEC organizations generally falls in the matrix below (source: Phillip Clampitt and Lee Williams, 2003). This study is the first in a series that will be undertaken to understand how uncertainty can be managed more effectively in the AEC industry, such as by practicing Lean Construction.



There are 50 questions, and we estimate it will take less than 10 minutes to complete. Your completion of this survey is completely voluntary. You are free to not answer any question or to stop participating at any time. Your identity as a respondent is anonymous and cannot be matched to your responses. We also don't track or record the IP address from which you are responding. There are no risks or individual benefits associated with taking this survey. The responses collected will be kept confidential by the researcher to the maximum extent allowable by law.

If you have any questions about this project, you can do so by contacting Dr. Tariq Abdelhamid (tariq@msu.edu), Construction Management Program, Michigan State University at (517) 432-6188. Also, if you have questions or concerns regarding your rights as a study participant, or are dissatisfied at any time with any aspect of this study, you may contact – anonymously, if you wish – Dr. Peter Vasilenko, Ph.D., Director of Human Research Protections, by phone: (517) 355-2180, by fax: (517) 432-4503, e-mail: irb@msu.edu, or by regular mail: 202 Olds Hall, Michigan State University, East Lansing, MI 48824-1047

By completing this survey, you indicate your voluntary consent to participate in this study and have your answers included in the project data set.

CONSTRUCTION WORKING CLIMATE SURVEY

(Source: Phillip Clampitt and Lee Williams, 2003, adopted with permission)

Objective: The intent of this survey is to assess construction organizations' approach to managing uncertainty.

Please note:

- Your responses are strictly confidential.
- This is not a test.
- There is no right or wrong answers.

Instructions: Below you will find a series of statements about your approach to various situations. Some items may sound similar, but they address slightly different issues. Please respond to all items. Indicate your degree of agreement with each statement by placing the appropriate number in the box next to each item.

Please use the following scale:

1	2	3	4	5	6	7
Strongly Disagree	Moderately Disagree	Slightly Disagree	No Feeling	Slightly Agree	Moderately Agree	Strongly Agree

Section I - Personal Uncertainty Items: These questions concern your preferred individual style of working.

- | | |
|--|----------------------|
| 1. I'm comfortable making a decision on my gut instincts. | <input type="text"/> |
| 2. I actively look for signs that the situation is changing. | <input type="text"/> |
| 3. I need precise plans before starting a job. | <input type="text"/> |
| 4. When I start a project, I need to know exactly where I'll end up. | <input type="text"/> |
| 5. I'm comfortable using my intuition to make a decision. | <input type="text"/> |
| 6. I'm always on the lookout for new ideas to address problems. | <input type="text"/> |
| 7. I need to know the specific outcome before starting a task. | <input type="text"/> |
| 8. I'm quick to notice when circumstances change. | <input type="text"/> |
| 9. I'm willing to make a decision based on a hunch. | <input type="text"/> |
| 10. I easily spot changing trends. | <input type="text"/> |
| 11. I don't need a detailed plan when working on a project. | <input type="text"/> |
| 12. I'm skilled at making decisions when information is limited. | <input type="text"/> |
| 13. I need a definite sense of direction for a project. | <input type="text"/> |
| 14. I'm comfortable deciding on the spur-of-the-moment. | <input type="text"/> |
| 15. I'm comfortable with uncertainty. | <input type="text"/> |
| 16. I'm satisfied with my job. | <input type="text"/> |
| 17. I'm committed to my organization. | <input type="text"/> |
| 18. I'm satisfied with the communication in my organization. | <input type="text"/> |
| 19. I identify with my organization's values. | <input type="text"/> |

20. The longer I work in this organization, the more cynical I become.

21. I'm satisfied with the communication from my supervisor.

22. I'm a highly productive member of my organization.

Section II - The following questions concern your work environment. Please use the same scale.

23. I'm comfortable making a decision on my gut instincts.

24. My organization flexibly responds to different situations.

25. In my organization, being unsure about something is a sign
of weakness.

26. My organization easily spots changing trends.

27. My organization doesn't need a detailed plan when working on
a project.

28. Even after my organization makes a decision, it will reevaluate
the decision when the situation changes.

29. My organization needs to know the specific outcome before
starting a project.

30. My organization doesn't encourage employees to discuss their
doubts about a project.

31. When my organization starts a project, it needs to know exactly
where the project will end up.

32. My organization actively looks for signs that the situation is
changing.

33. My organization doesn't want employees to admit that they are
unsure about something.
34. My organization wants precise plans before starting a job or project.
35. My organization discourages employees from talking about their
misgivings.
36. Many employees in my organization are cynical.
37. My organization is concerned about employee satisfaction.
38. Many employees in my organization feel overwhelmed by the
degree of change.
39. My organization is comfortable with uncertainty.

Section C: The following questions are only asked for classification purposes.

40. What is your gender? ☐ Male ☐ Female
- In what year were you born?
41. How long have you worked at your current job? (years)
42. How would you classify your current job position?
- | | |
|---|---|
| ☐ Field Engineer | ☐ Superintendent |
| ☐ Project Manager | ☐ Scheduler |
| ☐ Senior Scheduler | ☐ Estimator |
| ☐ Senior Estimator | ☐ Construction Manager |
| ☐ Engineer | ☐ Architect |
| ☐ Foreman | ☐ Tradesman |

- ☐ Procurement Manager
 ☐ Sub-contractor: specify
- ☐ Owner
 ☐ Purchasing Manager
- ☐ Senior Management
 ☐ Other

43. Which construction industry sector does your company work in?

- ☐ Residential
 ☐ Commercial
- ☐ Heavy/Highway
 ☐ Industrial

44. In your company's typical projects, what type of project delivery method is generally adopted?

- ☐ Design-Bid-Build
 ☐ CM-agency
- ☐ CM-risk
 ☐ CM-both
- ☐ Lean Construction
 ☐ Program Management
- ☐ Design Build
 ☐ Other

45. Is your organization based in the USA?

- ☐ Yes ☐ No

What is your organization's name? (optional)

If in USA, what is your organization's zip code?

If outside USA, which country?

46. How would you classify your company on the basis of revenue? (US\$)

- Greater than 1 billion ☐ 301 Mill to 1 billion ☐ Less than 300 Million ☐

48. Does your company use lean construction practices? ☐ Yes ☐ No

49. If yes, which of the following lean practices does your company adopt?

- | | |
|---|---|
| ☐ Last Planner System | ☐ Value-stream Mapping |
| ☐ 5S | ☐ Daily Huddles |
| ☐ Visualization | ☐ Target Costing |
| ☐ Relational Contracting | ☐ Concurrent Engineering |
| ☐ Off-site Fabrication | ☐ Work Structuring |
| ☐ Other <input type="text"/> | |

50. In what ways can your organization help you manage uncertainty on construction projects more effectively? Please Comment.

Appendix B
SURVEY RESPONSES AND THEIR ANALYSIS

Table: B.1. Section 1 - PU Responses

Quest.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Resp.																						
1	3	5	5	3	5	6	2	7	5	5	3	3	5	5	5	6	5	2	2	5	2	5
2	4	7	7	7	5	6	6	6	3	5	1	5	7	3	5	6	7	7	7	2	5	7
3	6	6	5	5	5	6	5	6	6	5	5	3	5	5	5	4	4	2	2	5	3	6
4	5	7	6	6	5	6	6	7	5	7	5	7	5	4	2	4	4	4	6	4	6	7
5	5	4	3	2	5	6	2	4	4	4	3	5	3	5	3	6	6	3	5	5	2	6
6	6	5	5	4	4	6	3	6	4	5	3	6	4	5	5	7	7	6	6	1	6	6
7	6	6	6	6	6	7	6	6	6	5	5	5	6	5	5	6	6	5	5	5	2	7
8	6	5	3	1	5	6	1	6	3	5	6	6	2	5	6	7	7	7	7	1	6	6
9	6	6	5	5	5	7	5	6	5	4	5	5	3	5	6	2	2	1	2	5	1	5
10	6	7	7	7	6	7	6	7	6	7	5	7	6	4	6	4	5	5	5	7	5	7
11	4	3	6	3	4	6	3	7	5	5	5	6	7	6	5	7	6	6	7	5	4	5
12	7	5	2	2	7	6	2	5	7	5	6	7	2	6	7	7	6	3	3	3	2	5
13	6	6	2	2	6	5	1	7	6	5	6	5	5	3	6	6	6	3	6	3	5	7
14	4	7	7	7	5	7	4	7	4	7	2	6	7	4	1	7	7	5	7	1		7
15	7	3	2	5	7	5	2	2	4	3	3	5	5	5	5	7	7	3	6	1	3	7
16	6	4	5	5	5	5	5	5	4	4	4	4	5	4	3	3	5	3	3	3	3	3
17	6	6	1	2	3	6	3	6	3	5	5	5	5	5	5	6	7	5	7	3	5	7
18	6	4	3	2	6	5	3	5	4	5	3	7	3	5	4	7	5	3	2	4	5	7
19	6	7	5	5	6	7	6	7	5	6	5	6	6	6	6	6	7	7	7	1	7	6
20	6	7	3	2	6	7	3	6	6	5	7	5	5	7	7	7	7	6	7	2	6	5
21	6	6	6	7	6	7	4	5	5	6	5	5	5	3	2	7	7	2	4	5	2	7
22	6	6	7	6	3	6	5	6	6	6	2	3	6	2	2	7	7	3	7	4	6	7
23	2	5	5	5	3	6	4	6	1	6	3	2	6	5	2	6	7	5	3	5	7	6
24	6	6	2	2	6	7	2	5	6	5	2	6	6	6	6	6	6	6	6	3	7	6
25	5	6	4	3	5	7	3	5	5	4	3	6	5	7	6	7	6	6	5	5	7	6
26	7	7	7	5		6	2		6	6	2	4	4	6	4	7	7	7	5	2	7	6
27	6	7	1	1	7	7	1	6	6	6	6	6	1	7	6	7	7	6	7	1	4	7
28	6	5	1	1	6	6	2	5	5	7	5	7	6	7	7	1	1	1	2	7	1	7
29	6	7	4	7	6	7	6		5	6	6	6	6	6	6	6	5	3	6	5	3	6
30	5	7	6	6	6	7	5	6	2	5	2	5	6	5	5	7	7	5	5	5		7

Table: B.1.... Section 1 - PU Responses (Cont.)

Quest.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
Resp.																						
31	3	6	5	5	6	7	5	5	5	3	5	3	5	3	3	6	6	3	6	3	6	6
32	3	4	5	6	3	5	6	4	3	4	3	4	6	4	2	6	5	2	4	5	4	5
33	7	7	1	1	7	7	1	7	5	6	6	7	5	5	5	7	7	5	5	1	7	7
34	7	5	3	5	7	7	3	5	6	6	6	6	5	7	6	7	6	3	6	5	6	7
35	6	5	3	3	7	7	3	5	7	5	5	5	3	7	5	7	7	1	5	7	1	7
36	5	6	4	3	5	7	2	6	4	4	5	5	4	5	4	7	7	5	7	1	7	7
37	3	5	5	3	5	6	2	5	3	4	2	3	5	3	4	7	7	6	6	2	6	7
38	7	7	6	6	7	6	6	7	5	6	6	7	7	6	6	6	7	6	7	5	6	6
39	2	7	6	5	5	7	6	5	2	5	2	2	5	3	5	7	7	6	6	2	6	5
40	6	7	5	5	6	6	4	7	6	6	6	6	7	6	6	7	6	6	6	2	6	6
41	3	6	4	1	6	6	1	3	3	5	2	3	6	7	7	7	3	2	2	6	2	7
42	5	6	3	3	5	6	3	5	2	5	4	5	5	2	5	6	7	5	7	1	3	6
43	2	6	6	2	2	7	2	6	2	6	6	6	5	6	2	7	5	5	5	6	1	6
44	5	6	7	7	5	7	7	7	5	6	2	6	6	6	4	7	7	6	6	2	6	6
45	5	7	5	6	6	7	4	7	4	7	4	7	6	5	7	7	5	6	6	3	6	6
46	5	6	2	2	5	7	2	6	2	5	6	6	3	3	5	6	6	3	6	5	5	6
47	2	5	6	3	6	7	5	6	5	6	5	7	6	6	3	6	7	6	7	2	7	6
48	1	7	2	3	1	7	3	6	1	6	7	7	6	1	6	7	6	5	7	3	7	7
49	3	7	3	3	5	7	1	6	3	6	2	5	2	5	6	6	7	7	7	6	7	7
50	6	6	7	7	4	7	7	6	1	6	1	3	7	3	2	7	7	5	7	2	7	7
51	3	6	6	5	5	5	5	5	5	5	3	5	6	5	5	6	6	3	6	5	3	6
52	6	7	2	7	7	7	6	6	6	5	6	7	3	6	6	7	7	5	7	2	6	7
53	7	6	5	3	5	7	5	6	5	6	3	6	6	5	6	5	6	5	5	7	7	7
54	6	6	1	1	6	6	2	7	6	6	5	6	5	6	6	3	3	2	4	5	3	6
55	6	6	3	3	6	6	2	5	3	5	5	5	5	4	5	5	5	5	5	5	6	6
56	6	6	6	6	6	7	6	6	5	6	5	6	4	5	6	6	6	6	6	5	6	6
57	5	7	5	5	7	6	5	5	3	6	5	3	7	3	3	7	7	6	7	1	6	6
58	6	6	4	7	7	7	2	3	6	3	6	6	3	5	7	6	6	5	5	5	5	4
59	6	6	1	2	6	7	2	6	5	6	6	7	3	7	6	6	7	6	7	2	6	7
60	6	7	2	6	6	6	6	6	7	6	2	6	5	6	5	6	7	5	5	2	7	6
61	6	5	6	6	6	7	6	6	2	6	2	5	6	6	2	6	7	5	7	4	5	7

Table: B.2. Section 2 - WEU Responses

Quest.	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Resp.																	
1	5	5	2	5	5	5	2	4	3	5	5	3	7	6	2	5	3
2	5	6	1	6	2	7	7	1	7	7	2	7	4	2	7	4	3
3	5	3	3	3	5	5	5	3	5	3	4	3	3	5	3	4	5
4	6	4	4	5	5	4	6	2	6	6	2	6	4	4	7	4	2
5	4	5	3	5	4	5	2	2	2	6	3	2	3	5	5	3	3
6	5	3	2	4	2	5	5	2	5	5	3	5	3	1	6	4	5
7	6	5	5	5	5	5	5	5	5	5	5	5	5	6	5	5	5
8	6	6	3	5	3	3	5	3	5	6	3	6	5	3	6	6	3
9	5	2	5	3	5	4	5	3	3	3	3	3	5	5	3	3	3
10	6	5	4	3	2	5	5	6	5	4	5	5	5	6	3	5	2
11	5	7	3	6	4	7	2	1	2	6	2	2	1	1	7	4	5
12	7	6	3	5	3	6	3	2	3	6	3	5	3	3	6	2	5
13	5	2	4	5	3	3	5	5	5	5	2	3	3	3	3	3	3
14	4	7	1	7	1	7	4	1	7	7	1	7	1	4	6	2	1
15	6	2	6	2	3	6	5	2	5	2	2	5	5	5	6	3	3
16	5	3	6	3	3	3	3	1	5	5	5	5	5	5	5	5	5
17	3	5	3	5	5	5	3	2	5	6	3	3	3	3	5	3	5
18	6	7	5	2	6	7	5	4	3	5	4	3	4	2	5	5	3
19	5	6	5	6	3	7	6	1	1	7	1	5	2	4	7	6	7
20	6	5	2	6	3	6	3	1	3	6	1	2	1	5	6	7	5
21	5	2	6	2	3	3	6	2	6	3	4	6	4	5	4	6	3
22	4	2	6	5	2	4	3	2	6	5	5	2	3	5	3	4	2
23	2	6	1	6	2	6	7	5	6	6	3	2	3	7	1	7	4
24	6	5	2	6	2	6	2	2	2	6	2	2	2	2	6	2	6
25	6	5	4	4	4	5	5	3	5	5	4	5	3	6	6	5	5
26	7	7	4	4	3	7	3	7	6	7	1	2	2	2	7	4	2
27	6	5	1	6	6	6	1	7	1	6	1	1	1	2	7	5	6
28	7	5	7	3	6	3	6	5	6	3	6	6	6	6	3	3	3
29	6	3	3	5	5	5	6	3	7	5	5	6	3	3	3	5	5
30	3	2	6	5	2	6	6	3	6	6	6	6	3	5	6	6	5

Table: B.2... Section 2 - WEU Responses (Cont.)

Quest.	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39
Resp.																	
31	5	5	3	5	2	5	5	3	5	5	3	6	3	5	4	2	5
32	3	3	4	4	3	5	5	5	5	3	4	5	4	5	3	5	2
33	7	7	1	6	4	7	4	1	7	7	1	6	1	1	7	7	5
34	7	5	5	5	5	6	5	5	5	6	4	6	3	3	5	5	3
35	7	2	1	1	5	5	3	3	3	5	5	3	5	5	3	5	3
36	5	5	2	5	3	5	4	1	3	5	1	5	1	3	7	4	3
37	3	6	2	5	1	5	3	3	2	6	2	6	3	4	5	5	6
38	6	7	1	6	5	7	6	3	6	7	1	6	2	2	6	6	5
39	2	6	1	5	4	4	3	1	3	5	2	3	2	2	7	3	5
40	6	6	3	5	5	6	6	2	5	6	4	5	3	5	5	5	5
41	5	6	5	3	3	5	5	5	6	2	6	6	2	7	6	4	2
42	5	5	2	4	5	5	3	2	4	5	2	4	2	2	6	6	3
43	2	2	2	5	2	6	3	2	2	6	2	6	2	7	6	5	5
44	6	7	2	6	6	6	6	1	4	6	2	3	3	2	6	3	4
45	5	6	4	6	2	6	6	3	6	7	4	6	5	6	5	7	6
46	5	3	3	4	3	5	3	3	5	5	3	5	4	5	5	4	3
47	3	6	2	3	2	2	6	2	3	5	2	5	3	2	5	5	3
48	1	5	5	2	2	7	5	3	6	6	2	6	2	5	6	5	5
49	3	7	5	5	3	3	1	1	3	6	1	3	1	2	7	3	3
50	5	6	4	5	1	7	7	2	7	7	1	7	1	4	5	4	5
51	4	5	3	5	5	6	6	2	5	5	3	5	2	5	2	5	5
52	6	7	1	3	2	5	2	1	6	2	1	6	1	5	7	6	3
53	5	3	4	3	3	5	5	3	3	3	3	5	3	6	5	6	3
54	2	3	6	3	2	3	6	6	6	3	6	6	6	6	2	6	2
55	5	5	5	5	6	6	5	3	3	5	2	2	2	3	4	4	5
56	6	5	5	6	4	5	6	6	6	6	5	6	4	4	5	5	5
57	5	5	3	4	3	5	4	3	5	6	3	5	3	2	7	2	3
58	6	5	6	4	3	5	4	6	2	4	7	3	5	5	5	6	6
59	6	7	3	5	1	6	6	1	6	7	2	2	2	3	5	1	6
60	6	5	1	5	3	5	6	3	6	5	1	6	4	5	7	2	3
61	6	7	6	6	5	6	5	1	6	7	1	7	3	4	7	7	2

Table: B.3. Section 3 – Demographic Section Responses

Quest.	40	41	42	43	44	46	47	48
Resp.								
1	M	1980	2	Engg.	Ind.	Y	301M	N
2	M	1978	1	P.M.	Comm.	Y	1B	Y
3	F	1966	7	18	Comm.	Y	1B	N
4	M	1982	1	Field Engg.	Comm.	Y	1B	N
5	M	1973	6	Arch.	Comm.	N	301M	N
6	M	1977	3	Scheduler	Ind.	Y	1B	Y
7	F	1949	7	18	Ind.	Y		
8	M	1954	11	S.Mgmt	Comm.	Y	301M1B	Y
9	M	1977	3	C.M.	Comm.	Y	301M	N
10	M	1946	3	S.Mgmt	Ind.	Y	301M	N
11	M	1952	1	Owner	Res.	N	301M	N
12	F	1960	10	P.M.	Comm.	Y	301M	N
13	M	1971	6	Field Engg.	Comm.	Y	301M1B	N
14	M	1971	4	18	Ind.	N	301M	Y
15	M	1977	1	18	Comm.	N	301M	Y
16	M	1970	3	Estimator	Heavy	Y	301M	N
17	F	1956	10	C.M.	Comm.	Y	301M	Y
18	M	1977	4	P.M.	Res.	N	301M	Y
19		1981	2	Arch.	Comm.	N	301M	N
20	M	1953	20	S.Mgmt	Comm.	N	301M1B	N
21	M	1970	6	Owner	Comm.	Y	301M	N
22	M	1962	8	S.Mgmt	Res.	N	301M1B	Y
23	F	1978	2	Field Engg.	Comm.	Y	1B	N
24	M	1946	30	18		N	301M	Y
25	M	1961	16	Owner	Comm.	Y	301M	N
26	F	1978	3	Arch.	Comm.	Y	301M	N
27	M	1937	6	Owner	Comm.	N	301M	Y
28	M	1961	30	P.M.	Comm.	Y	301M	Y
29	M	1958	5	S.Mgmt	Comm.	N	301M1B	Y
30	M	1945	15	Owner	Res.	Y	301M	N

Table: B.3.... Section 3 – Demographic Section Responses (Cont.)

Quest.	40	41	42	43	44	46	47	48
Resp.								
31	M	1947	1	18		N	301M	Y
32	M	1976	6	Engg.	Comm.	N	301M	N
33	M	1957	6	C.M.	Comm.	Y	301M	Y
34	M	1960	6	S.Mgmt	Ind.	N	301M1B	N
35	M	1970	6	C.M.	Res.	N	301M	N
36	M	1980	1	Estimator	Ind.	Y	1B	Y
37	M	1977	8	Estimator	Ind.	Y	301M1B	Y
38	M	1961	23	S.Mgmt	Comm.	Y	1B	N
39	M	1976	4	Field Engg.	Comm.	Y	301M1B	Y
40	M	1938	11	P.M.	Comm.	Y	301M1B	Y
41	M	1965	5	18	Comm.	Y	301M	N
42	M	1945	12	S.Mgmt	Comm.	Y	301M	Y
43	M	1945	3	18	Comm.	Y	301M	N
44	M	1979	2	Field Engg.	Comm.	Y	301M	N
45	M	1975	5	S.Mgmt	Comm.	Y	1B	Y
46	M	1949		Engg.	Ind.	Y	301M1B	N
47	M	1978	3	C.M.	Res.	N	301M	N
48	M	1938	20	S.Mgmt	Ind.	Y	301M1B	N
49	F	1970	2	P.M.	Heavy	Y		
50	M	1959	9	18	Ind.	Y	1B	Y
51	M	1952	25	S.Mgmt	Comm.	N	301M	Y
52	M	1957	10	Owner	Comm.	Y	301M	N
53	F	1962	10	P.M.		Y	301M	N
54	M	1952	17	P.M.	Comm.	Y	1B	N
55	M	1968	3	P.M.	Heavy	N	301M	N
56	F	1974	6	P.M.	Ind.	Y	301M	Y
57	M	1957	23	S.Mgmt	Comm.	Y	301M	Y
58	F	1962	10	18	Comm.	Y	1B	N
59	M	1968	7	P.M.	Comm.	Y	1B	Y
60	M	1975	8	C.M.	Comm.	Y	1B	
61	M	1976	8	S.Mgmt	Comm.	Y	301M	N

Table: B.4. Q.49 – Lean Practices Section Responses

Pract.												
R.No.	LPP	VSM	5S	DH	V	TC	RC	CE	OF	WS	O	SUM
2	1	0	0	1	0	1	0	1	1	1	0	6
6	0	0	0	0	0	1	0	1	0	0	0	2
8	0	0	1	0	0	0	0	1	1	1	0	4
14	1	1	1	0	0	0	0	1	0	1	1	6
15	0	0	1	0	1	0	0	0	0	0	0	2
17	1	1	0	0	0	0	1	0	1	1	0	5
18	1	0	0	0	0	0	0	0	0	0	1	2
22	1	0	0	0	0	0	0	0	0	0	0	1
24	1	0	0	0	0	1	1	1	0	0	0	4
27	1	0	0	0	0	1	1	0	1	0	1	5
28	1	1	0	0	1	1	0	0	1	0	0	5
29	1	1	0	0	1	1	1	0	1	1	0	7
31	1	1	1	1	1	0	0	0	0	0	1	6
33	0	0	0	0	1	1	1	1	1	1	0	6
36	0	0	0	0	0	0	1	0	1	1	0	3
37	0	1	1	1	1	0	1	0	0	0	1	6
39	0	0	0	1	0	1	1	0	1	1	0	5
40	0	0	0	0	1	1	0	1	0	1	0	4
42	1	1	1	0	0	1	1	1	1	0	0	7
45	0	0	0	0	0	1	0	0	1	1	0	3
50	1	1	1	1	1	0	0	0	1	0	0	6
51	0	0	1	0	0	0	0	1	0	0	0	2
56	0	1	0	0	1	1	0	1	1	1	0	6
57	0	0	0	1	0	0	0	0	1	0	0	2
59	1	1	1	1	1	0	0	1	1	0	1	8

Table: B.5. Codes for Lean Practices

LPP	Last Planner System
VSM	Value-stream Mapping
5S	5 S
DH	Daily Huddles
V	Visualization
TC	Target Costing
RC	Relational Contracting
CE	Concurrent Engineering
OF	Off-site Fabrication
WS	Work Structuring
O	Other
Pract.	Practices
R.No.	Respondent Number

Table: B.6. Number of Lean Practices and Scores

Respondent Number	Sum of Lean Practices	PU	WEU
2	6	44	54
6	2	57	52
8	4	67	49
14	6	53	60
15	2	51	45
17	5	59	58
18	2	59	54
22	1	50	49
24	4	63	68
27	5	79	73
28	5	67	36
29	7	54	49
31	6	52	50
33	6	74	66
36	3	62	62
37	6	50	55
39	5	46	61
40	4	64	56
42	7	53	61
45	3	60	48
50	6	43	52
51	2	50	55
56	6	60	45
57	2	54	53
59	8	72	59

Table: B.7. Responses to question #50

S. No.	Open - Ended Question #50 Responses
1	Better Planning.
2	The construction industry is a changing environment. Sometimes changes happen and they have to be dealt with at the time they change. I am personally please with the way the firm i work for manages change and uncertainty. Ask me in another year or two.
3	Look at all levels of employment on the project. From the broom pusher to the president all have excellent suggestions. Everyone observes from a different point of view. all should employees on the project should attend meetings.
4	We (lower level people) need more interaction from the experienced people. There is a lot of knowledge that does not get implemented because the 'smart' people are not around the problems.
5	Innovative workflow management and control practices coupled with multi-disciplinary practice within a fully integrated, information-driven design delivery program (integrated with procurement and construction). This gives absolute control of all 'control.
6	Development of better purchase contracts that incorporate lean principles.
7	Reorganizing the process of managing projects, the current system has accrued many faults and shortcomings that impede the concentration on the process to achieve the product.
8	Education/Training
9	Using PPC Techniques
10	Be more amenable to a lean and agile philosophy

Table: B.7.... Responses to question #50 (Cont.)

S. No.	Open - Ended Question #50 Responses
11	Utilize brutal honesty so problems can be taken care of. Utilize systems and processes to control communication and act timely on decisions through feedback from meetings and information flow.
12	By getting the design and site conditions/working conditions and salary conditions nailed down before the contract begins. This will remove uncertainty amongst the workers and increase harmony and collaboration.
13	Communication
14	By providing more information as it becomes available.
15	Implement commissioning.
16	Work with architects and owners who can make up their minds on what they want to build.
17	I am a long standing believer in lean construction working in an organization that will not change as long as current practices remain profitable.
18	Detailed Logistical Planning Prolog Project Management database. Robust employee training (30-hour annual requirement) ISO Procedures - audited Documented Lean Best Practices - Audited Lessons Learned Input/review/analysis - Audited Job Site Quality Plans
19	More latitude to make decisions.
20	More training and by creating a positive working environment
21	Continued effort at implementing the tools mentioned above, as well as others.

Table: B.8. PU and WEU Scores of Respondents

Res.No.	PU Scores				WEU Scores			
	Perceptual	Process	Outcome	Total	Perceptual	Expressed	Outcome	Total
1	23	18	17	58	20	14	21	55
2	24	15	5	44	25	24	5	54
3	23	22	14	59	16	19	16	51
4	27	19	12	58	21	20	11	52
5	18	19	20	57	20	21	22	63
6	22	19	16	57	19	22	11	52
7	24	23	11	58	21	12	14	47
8	22	19	26	67	20	18	11	49
9	23	21	16	60	15	16	18	49
10	28	22	10	60	18	12	11	41
11	21	19	16	56	24	25	22	71
12	21	27	24	72	24	21	16	61
13	23	21	22	66	18	18	14	50
14	28	17	8	53	25	28	7	60
15	13	23	15	51	16	17	12	45
16	18	19	13	50	16	15	14	45
17	23	17	19	59	19	21	18	58
18	19	21	19	59	20	15	19	54
19	27	23	12	62	25	23	15	63
20	25	25	21	71	24	27	19	70
21	24	20	13	57	13	16	9	38
22	24	17	9	50	18	16	15	49
23	23	11	12	46	20	20	11	51
24	23	24	16	63	24	24	20	68
25	22	22	16	60	20	18	13	51
26	19	19	15	53	25	18	16	59
27	26	26	27	79	24	22	27	73
28	23	24	20	67	16	8	12	36
29	20	23	11	54	21	18	10	49
30	25	18	9	52	20	14	8	42

Table: B.8.... PU and WEU Scores of Respondents (Cont.)

Res.No.	PU Scores				WEU Scores			
	Perceptual	Process	Outcome	Total	Perceptual	Expressed	Outcome	Total
31	21	17	14	52	20	20	10	50
32	17	13	9	39	15	15	12	42
33	27	24	23	74	27	28	11	66
34	23	27	17	67	24	15	13	52
35	22	27	20	69	18	18	20	56
36	23	19	20	62	20	27	15	62
37	20	14	16	50	19	22	14	55
38	26	25	11	62	26	25	11	62
39	24	12	10	46	16	26	19	61
40	26	24	14	64	23	20	13	56
41	20	19	18	57	15	14	10	39
42	22	14	17	53	19	24	18	61
43	25	12	21	58	19	24	15	58
44	26	21	6	53	24	24	17	65
45	28	20	12	60	24	16	8	48
46	24	15	23	62	19	19	14	52
47	24	19	15	58	13	23	12	48
48	26	4	19	49	16	20	9	45
49	26	16	20	62	17	24	20	61
50	25	14	4	43	24	24	4	52
51	21	18	11	50	20	22	13	55
52	25	25	14	64	16	28	12	56
53	25	22	13	60	16	19	14	49
54	25	24	21	70	11	8	8	27
55	22	19	19	60	21	20	20	61
56	25	22	13	60	23	12	10	45
57	24	18	12	54	20	20	13	53
58	19	24	18	61	19	8	18	45
59	25	24	23	72	24	24	11	59
60	25	25	9	59	21	23	9	53
61	24	20	8	52	25	21	11	57

Table: B.9 – Scores and Location in the Matrix

Respondent ID	PU Score	WEU Score	Quadrant in the Matrix
1	58	55	1
2	44	54	2
3	59	51	1
4	58	52	1
5	57	63	1
6	57	52	1
7	58	47	4
8	67	49	1
9	60	49	1
10	60	41	4
11	56	71	1
12	72	61	1
13	66	50	1
14	53	60	1
15	51	45	4
16	50	45	4
17	59	58	1
18	59	54	1
19	62	63	1
20	71	70	1
21	57	38	4
22	50	49	1
23	46	51	2
24	63	68	1
25	60	51	1
26	53	59	1
27	79	73	1
28	67	36	4

Table: B.9... Scores and Location in the Matrix (Cont.)

Respondent ID	PU Score	WEU Score	Quadrant in the Matrix
29	54	49	1
30	52	42	4
31	52	50	1
32	39	42	3
33	74	66	1
34	67	52	1
35	69	56	1
36	62	62	1
37	50	55	1
38	62	62	1
39	46	61	2
40	64	56	1
41	57	39	4
42	53	61	1
43	58	58	1
44	53	65	1
45	60	48	4
46	62	52	1
47	58	48	4
48	49	45	4
49	62	61	1
50	43	52	2
51	50	55	1
52	64	56	1
53	60	49	1
54	70	27	4
55	60	61	1
56	60	45	4
57	54	53	1
58	61	45	4
59	72	59	1
60	59	53	1
61	52	57	1

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