A STATISTICAL APPROACH TO LEAN CONSTRUCTION IMPLEMENTATIONS OF CONSTRUCTION COMPANIES IN TURKEY

A THESIS SUBMITTED TO
THE GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
OF
MIDDLE EAST TECHNICAL UNIVERSITY

BY

BÜLENT ALGAN TEZEL

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR
THE DEGREE OF MASTER OF SCIENCE
IN
CIVIL ENGINEERING

AUGUST 2007

Approval of the thesis:

A STATISTICAL APPROACH TO LEAN CONSTRUCTION IMPLEMENTATIONS OF CONSTRUCTION COMPANIES IN TURKEY

submitted by **BÜLENT ALGAN TEZEL** in partial fulfillment of the requirements for the degree of **Master of Science in Civil Engineering Department, Middle East Technical University** by,

Prof. Dr. Canan Özgen
Dean, Graduate School of **Natural and Applied Sciences** _____________________

Prof. Dr. Güney Özcebe
Head of Department, **Civil Engineering** _____________________

Asst. Prof. Dr. Yasemin Nielsen
Supervisor, **Civil Engineering Dept., METU** _____________________

Examining Committee Members:

Assoc. Prof. Dr. İrem Dikmen Toker
Civil Engineering Dept., METU _____________________

Asst. Prof. Dr. Yasemin Nielsen
Civil Engineering Dept., METU _____________________

Asst. Prof. Dr. Rıfat Sönmez
Civil Engineering Dept., METU _____________________

Asst. Prof. Dr. Ali Murat Tanyer
Department of Architecture, METU _____________________

Mesut Özden
Manager, Nurol Construction and Trading Co. Inc. _____________________

Date : _____________________

I hereby declare that all information in this document has been obtained and presented in accordance with academic rules and ethical conduct. I also declare that, as required by these rules and conduct, I have fully cited and referenced all material and results that are not original to this work.

Name, Last name : Bülent Algan Tezel

Signature :

ABSTRACT

A STATISTICAL APPROACH TO LEAN CONSTRUCTION IMPLEMENTATIONS OF CONSTRUCTION COMPANIES IN TURKEY

Tezel, Bülent Algan

M.S., Department of Civil Engineering

Supervisor: Asst. Prof. Dr. Yasemin Nielsen

August 2007, 194 pages

One of the major change efforts for the construction industry is lean construction. This thesis analyzes the practices of the construction companies in Turkey from the lean construction perspective. Prior to the analysis in question, requisite information about change in the construction industry, lean thinking and lean construction will be presented.

A questionnaire, based on a lean construction model, is used to survey the practices and gather the data for the analysis. Various statistical analysis methods are performed on the gathered data to make inferences. According to these analyses, the lean construction characteristics of the construction companies will be discussed and the recommendations for improving the lean conformance of the construction companies will be presented.

Keywords: Turkish construction industry, lean construction, lean conformance, change, lean thinking.

ÖZ

TÜRKİYE'DEKİ İNŞAAT ŞİRKETLERİNİN YALIN İNŞAAT UYGULAMALARINA İSTATİSTİKSEL BİR YAKLAŞIM

Tezel, Bülent Algan

Yüksek Lisans, İnşaat Mühendisliği Bölümü

Tez Yöneticisi: Yard. Doç. Dr. Yasemin Nielsen

Ağustos 2007, 194 sayfa

İnşaat sektöründeki en önemli değişim çabalarından biri yalın inşaattır. Bu tez, Türkiye'de faaliyet gösteren inşaat şirketlerinin uygulamalarını yalın inşaat açısından incelemektedir. Söz konusu incelemeden önce, inşaat sektöründe değişim, yalın düşünce ve yalın inşaatla ilgili gerekli bilgiler sunulacaktır.

Uygulamaları ölçmek ve analiz için verileri toplamak amacıyla yalın inşaat modeline dayalı bir anketten faydalanılmaktadır. Çıkarımlar yapabilmek maksadıyla, toplanan veriler üzerinde çeşitli istatistiksel analiz yöntemleri uygulanmaktadır. Bu analizler doğrultusunda, inşaat şirketlerinin yalın inşaat nitelikleri tartışılacak ve yalın inşaata uygunluklarını arttırabilmeleri amacıyla tavsiyelerde bulunulacaktır.

Anahtar Kelimeler: Türk inşaat sektörü, yalın inşaat, yalın uygunluk, değişim, yalın düşünce.

To My Beloved Father and Late Mother

ACKNOWLEDGEMENTS

I would like to express my deep gratitude to Asst. Prof. Dr. Yasemin Nielsen for her supervision, guidance, patience, effort and moral support throughout my research.

I acknowledge the participated firms, Mr. Ender Tombuş, Ms. Neyire Özmen, Mr. Orhan Taşanlar and Ms. Gökçe Basan for their contributions to this research.

I am thankful to Assoc. Prof. Dr. Murat Gündüz for his valuable advices.

I am also grateful to all my friends for their encouragement and to my family for their endless support throughout my life.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVATIONS

A. P. I. C. S.	American Production and Inventory Control Society.
A. S. C. E.	American Society of Civil Engineers.
B. P. R.	Business Process Reengineering.
B.Sc.	Bachelor of Science
B. S. I.	British Standards Institution.
C. E. O.	Chief Executive Officer.
C. I. M.	Computer Integrated Manufacturing.
C. P. M.	Critical Path Method.
D. E. T. R.	Department of Environment, Transport and the Regions.
F. I. F. O	First In - First Out.
F. M. S.	Flexible Manufacturing Systems.
G. T.	Group Technology.
H. M. S. O.	Her Majesty's Stationary Office.
I. G. C. L.	International Group for Lean Construction.
I. M. V. P.	International Motor Vehicle Program.
I. S. O.	International Standards Organization.
İ. T. Ü.	Istanbul Technical University.
J. I. P. M.	Japan Institute of Plant Maintenance.
J. I. T.	Just in Time.
L. C. I.	Lean Construction Institute.
L. C. J.	Lean Construction Journal.
L. P. D. S.	Lean Project Delivery System.
M. I. T.	Massachusetts Institute of Technology.
M. R. P.	Material Resource Planning.
M. R. P. II	Material Resource Planning II.

M.Sc.	Master of Science
N. A. F. T. A.	North American Free Trade Agreement
O. E. E.	Overall Equipment Effectiveness.
O. P. T.	Optimized Production Technology.
P. C. W. E.	Plan Conditions of Work Environment
P. P. C.	Percent Plan Complete.
Q. A.	Quality Assurance.
Q. C. C.	Quality Control Circles.
Q. M.	Quality Measurement.
S. M. E. D.	Single Minute Exchange of Dies
S. P. C.	Statistical Process Control.
S. Q. C.	Statistical Quality Control.
T. F. V.	Transformation – Flow - Value
T. M. M. O. B.	Union of Chambers of Turkish Engineers and Architects.
T. P. M.	Total Productive Maintenance.
T. P. S.	Toyota Production System.
T. Q. C.	Total Quality Control.
T. Q. M.	Total Quality Management.
T. S. E.	Turkish Standards Institution.
T. Ü. B. İ. T. A. K.	The Scientific and Technological Research Council of Turkey.
T. V. E. L.	Toyota Verification of Assembly Line.
U. K.	United Kingdom.
U. S.	United States.
W. B. S.	Work Breakdown Structure.
W. I. P.	Work – in – Progress.
W. T. O.	World Trade Organization.

CHAPTER 1

INTRODUCTION

In the last two centuries, the manufacturing industry has experienced some substantial technical and managerial changes. Once being the symbol of industrialization and development, the construction industry has been increasingly criticized for remaining “backward” and being static parallel to the changes in the manufacturing industry. Coupled with various environmental dynamics, these criticisms have been turning into searches for a suitable improvement framework for the construction industry.

Indeed, the construction industry seems to contain seriously wasteful practices and struggles to satisfy the parties involved. It is also such an important and fundamental industry that its shortcomings create huge detrimental effects. The people, who strive for a better construction context, set their eyes on the manufacturing industry. One of the revolutionary practices, rooted from the car manufacturing industry, is lean production. After the Second World War, lean production contributed a lot to the competitiveness of the Japanese car manufacturers against their Western counterparts and spread quickly to the rest of the world. Today, many manufacturing firms have been and are trying to deploy the lean manufacturing methodologies/tools at their firms. There are many books, papers, technical reports about lean production. It is an important topic in production engineering and management.

Being “lean” basically means endeavoring to minimize waste and maintaining continuous flow in a production plant. Although lean implies certain methodologies and tools, lean production is more than just a collection of techniques. It contains many cultural elements in its lean production framework.

Starting from the early 1990s, lean production has seriously taken the attention of numerous researchers in the construction industry. These people, referring to lean production, created the term “lean construction”. Lean construction shares the basic motives of lean production. The challenge here is to overcome the differences between the manufacturing industry and the construction industry. The lean movement in the construction industry led the formation of an institute, a group and a refereed journal dedicated completely to lean construction. Especially via the universities located in the American continent and Northern Europe, lean construction is developing and lean practices are diffusing into the construction industry. Lean construction suggests a wider perspective that systematically adds both flow and value management to conventional transformation management of projects. It also tries to adapt the practical methodologies/tools of lean production to the construction industry.

In Turkey, the studies of lean construction are comparatively few. With this thesis, the author hopes to contribute to the study of lean construction.

1.1 Aim of the Study

This thesis specially aims,

- to provide information about change dynamics, lean production and lean construction.
- to determine the existing lean characteristics of the construction companies in Turkey.
- to discuss the applicability of lean construction among the construction companies in Turkey.
- to help the contractors understand their internal practices better from a lean construction perspective.
- to give recommendations for improving the lean conformance values of the construction companies in Turkey.
- to discuss future research opportunities for lean construction in Turkey

1.2 Research Overall Methodology

Research overall methodology can be summarized as follows:

- Conducting a detailed literature review on change dynamics in the construction industry, lean production and lean construction to create a conceptual base for further analysis.
- Conducting a lean conformance survey, based on a lean construction framework, on the construction companies in Turkey. The survey aims at measuring the companies' lean characteristics via a questionnaire.
- Displaying and analyzing the gathered data in various forms.
- Making necessary inferences according to the analysis of the data set.

1.3 Contents of the Study

This study consists of six chapters:

1. Chapter 1 – Introduction: This chapter contains the general outlines, purposes and research methodology of this study.
2. Chapter 2 – Change in Construction Industry: In this chapter, the general dynamics of change, change in the manufacturing industry and change efforts in the construction industry are presented.
3. Chapter 3 – Lean Thinking and Lean Production: In this chapter, the essential principles and methodologies of lean thinking and lean production are presented.
4. Chapter 4 – Lean Construction: This chapter contains the explanation of lean construction in terms of its principles and methodologies.
5. Chapter 5 – Measuring Lean Conformance: In this chapter, a methodology for measuring lean conformance for construction companies is presented. The overview of the research methodology and structure of the questionnaire are explained. The results after the statistical analyses are given in numbers. Those results are discussed at the end of the chapter.
6. Chapter 6 – Conclusion and Recommendations: In this chapter, an overall summary of the study is presented. General recommendations for future research and the construction companies in Turkey are given. The study and chapter are concluded with a conclusion part.

CHAPTER 2

CHANGE IN CONSTRUCTION INDUSTRY

In the second chapter, the term “change” is examined from the perspective of the construction industry covering the reasons, main dynamics and the proposed means of change, surrounding the local and the global construction environment. Parallel to these, the change in the manufacturing industry is discussed also. The second chapter is concluded with the introduction of “lean construction” as a way of proposed change for the construction industry. In the third chapter, the main theoretical and the practical dimensions of lean thinking are discussed; which is rooted within the car manufacturing industry and constituted mainly by industrial, mechanical and manufacturing engineers. In the fourth chapter, lean construction, which has been developing from the main lean thinking motives by scholars and practitioners within the construction industry, is summarized according to its main concepts, principles and methodologies. This chapter is concluded with the importance of measuring lean conformance for construction firms before any further or in - dept execution of the lean construction related studies and practices. The second, third and fourth chapters constitute the theoretical background for a research study presented in the fifth chapter.

2.1 Change – In a Wide Sense

Change is inevitable. Heraclitus of Ephesus, realizing this fact 2500 years ago, stated that : “*Change alone is unchanging.”*. Being sociotechnical systems, organizations respond to change by analyzing the political, economic, social, technological, legislative, ecological factors and modifying their organizational structures, organizational strategies, management styles, working practices, employment patterns and innovative solutions (Buchanan and Huczynski, 2004). Kocel (2003), on the other hand, underlines the increase in the rate of change in today's world and lists some of the major phenomena that have been considerably affecting organizational structures and operations as; globalization, excellence in management, human rights, information age, knowledge based organization, international competition, system thinking, knowledge society, lean management and organizations, total quality perspective and advancements in computer and telecommunication systems.

In today's rapidly changing environment and under the pressure of global competition, organizations discuss whether their inter-organizational responses are proactively faster than the external change, how to sustain sound organizational transformations and how to change an organization into a learning one, rather than the necessity of change. Bruch, Maier and Gerber (2005) stated that organizations, in essence, were forced to change due to environmental inconsistency and uncertainty.

Although the reasons, impacts and the management of change along with the buzzwords, mentioned as the catalyzers of the change, have been widely discussed in the literature, Esin (2004) summarized the key success factors, in a new era shaped by the concepts referred above. These key factors are cost, quality, flexibility and agility. Esin, located these parameters on the sides of a triangle called "success" and claimed that in order to be successful in today's business environment, one should strive for increasing the area of the triangle by reducing costs and improving quality, agility and flexibility. The triangle is shown in Figure 2.1:

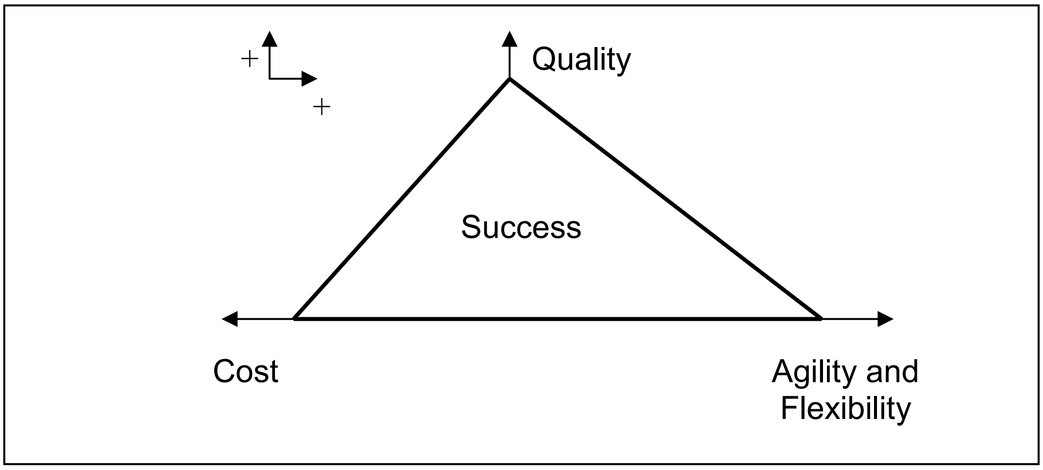


Figure 2.1– The Success Triangle
(Source: Esin, 2004)

By taking a closer look at the triangle, it can be deduced that its three sides represent the main customer demand variables. Van der Aalst and Van Hee (2002) names this kind of a perception as an organizational paradigm shift from a supply-driven economy to a demand-driven economy in which it is the customers who are scarce. The customer driven markets push organizations to create value for their customers in order to survive.

Esin (2004) defined agility as; the responsiveness in satisfying customers' needs and expectations. Flexibility is the ability in adapting oneself to change. Definitions of quality are abundant in the literature, the author of this thesis chooses to utilize Cornick's (1991) definition through a three-level scale such as the first scale, conformance to requirements, the second scale, fitness for purpose and the third scale, level of excellence.

2.2 The Importance of Construction

Construction activities, on the other hand, have maintained their fundamental role in shaping civilizations all around the globe. Wherever people are, there is construction. Construction has been affected by the society it takes place and also has affected enormously many aspects of the society itself. Trademarks or symbols of any former or present human group are some kind of constructed identities. The pyramids of ancient Egypt, the Great Wall of the Qin Dynasty, the Eiffel Tower of France, Hagia Sophia in İstanbul or the Channel Tunnel across the English Channel are some of the inspiring samples that were brought existence through immense physical and intellectual resource consumption.

Along with its social impacts, construction industry has an indispensable place in the world’s economy. Tapscott, Ticol and Lowy (2000) and El-Higzi (2002) stated that the global construction industry had reached to a size of around 3.2 trillion U.S. dollars by 1998. Tulacz (2005) claimed that the industry’s volume neared 4 trillion U.S. dollars in 2004. Additionally, the construction industry serves as a gigantic customer for various other industries. Being predominantly craft based, it provides many employment opportunities as well. Shortly, the construction industry is of great importance for the vast majority of national economies.

During the 19^{th} century, the construction sector was associated with the highest technology – its achievements, ranging from the Crystal Palace and to the transcontinental railway, were symbolic of the new age of industrialization. However, by the 1920s, awareness of a new age in manufacturing was penetrating and the relative lack of change in construction processes were becoming apparent (Winch, 2003).

2.3 Manufacturing and Its Transformation

Arguably, it is manufacturing that has been exposed to some utterly substantial transformations starting from the industrial revolution. Chryssolouris (1992) defines manufacturing as: “The process of transforming materials and information into goods for the satisfaction of human needs”. Lanigan (1992) proposes another definition: “The application of technology to wealth creation by providing cost-effective solutions to human needs and problems.”.

2.3.1 The First Stage of Industrialization

Saylan (1999) states that the first stage of the industrial revolution was initiated by the utilization of James Watt’s efficiently working steam powered engine, mainly in the textile industry and the railway transportation, during the late 18th century. After the considerable inclusion of machines into the manufacturing processes, the present social, technological and economical state changed drastically at that time. Up to that era, the works of individuals were quite close to each other, autonomous, seasonal and the specializations were not that distinct. It is the industrial revolution that required the formation of “factory” as a production unit and enabled the mass production through the high percentage of machine utilization. Factories, unlike the traditional way of doing work, required a disciplined workforce. Discrete worker groups were collected in a factory in which people were paid by the piece. These workgroups were self organized. The factory manager acted as a coordinator who set goals and provided materials needed. This system was quite like the construction industry's in that sense. Product and price standardization could have been observed to a certain degree. In this context, the division of labor become more pronounced. The specialization concept was born. Surely this phenomenon triggered the arising of new job types and increased production rate. Productivity and harmonization of man with machine problems crystallized noticeably at this stage.

The United Kingdom (U. K.), being the birthplace of such an enormous transformation in manufacturing, reached its apogee and was regarded as the most industrialized nation in the 1850s (Winch, 2003). The British dominance, later on, was challenged by the American companies that had managed to manufacture products relatively cheaper and faster.

2.3.2 The American Impact

Coupled with both a booming economy and shortage in skilled labor, the American companies took the British way of manufacturing to a different level where, in essence, interchangeable parts were used in order to be more efficient in assembly processes and lower the costs of maintenance and repair. This kind of an approach generated competitive advantage that helped the United States (U. S.) take the place of the United Kingdom as the world's industrial leader.

2.3.2.1 Taylorism

Not only were new methods of manufacturing introduced but also the seeds of the classical management theory were sown in this period. An American mechanical engineer, Frederick Winslow Taylor worked on productivity and harmonization problems intensively. He devised time and motion studies inspecting brick layering, shoveling and the transportation of pig iron. He was regarded as one of the pioneers of the scientific management. Taylor proclaimed there was always "one best way" to fix a problem. He was one of the intellectual leaders of the Efficiency Movement and his ideas, broadly conceived, were highly influential in the Progressive Era. Believing in a scientific approach in management, he claimed that the most efficient results could have been reached by the cooperation between a trained and qualified management and a cooperative and innovative workforce. Taylor's approach is often referred to as Taylor's Principles or as Taylorism. Taylor (1967) developed five main principles:

1. Each part of a task should be scientifically studied to determine the one best way.
2. The most suitable person for any job should be selected.
3. Training and teaching of the worker are necessary.
4. Provide financial incentives for following the methods.
5. Divide work and responsibility so that managers are responsible for planning the work methods and workers are responsible for executing the work accordingly.

While scientific management principles improved productivity and had a substantial impact on industry, they also increased the monotony of work. The core job dimensions of skill variety, task identity, task significance, autonomy, and feedback all were missing from the picture of scientific management. Despite the complaints that Taylorism is dehumanizing, it changed the way that work was done, and forms of it continue to be used today.

2.3.2.2 Fordism

Following Taylor’s principles, Henry Ford developed another influential model of manufacturing called Fordism. It can be perceived as the meeting of mass production with mass consumption. Ford applied the assembly line in mass production for the first time which led to a relative increase in standardization and efficiency. Just like Taylor, he considered workers some sort of machines that had to do a small portion of tasks in the way he/she was told. Huge stocks and economy of scale are the essentials of this approach. Ford’s belief in paying workers high enough to buy whatever they produce triggered consumption and formed the rapid development of western countries after the Second World War.

2.3.2.3 The First Seeds of Quality Consciousness

The production philosophy of the time was :”Produce as much as you can”. Taylorism strongly believed that workers were not capable of controlling what they produced. Thus, some people were assigned specifically to check already produced goods. In other words, quality was based on inspecting finished products. As the inspection activity was performed after the production, it had no preventive aspect. Non-conformed, produced goods were either reprocessed or sorted to scrap. In time, these inspectors were collected into an organizational division forming a hierarchical structure. Testing laboratories were also included into the system.

After the Second World War, due to enormous amount of increase in demand and problems in fulfilling quality standards, timely delivery of goods could not have been maintained successfully. Some statistical techniques like sampling and control schemes were incorporated into quality inspection and testing. With the introduction of statistics, controlling the whole production outputs was replaced with taking a small portion from the produced batch and making decisions by that selected portion.

In the 1960s, the quality function evolved from finding defects into preventing them prior to their occurrence. It was understood that finding defects in products after production had led to a huge scrap and reprocessing, in other words, inefficiency and eventually waste. This period of change in the quality paradigm is called Quality Assurance Movement.

2.3.3 The Rise of Japan

From the 1950s onward, Japan, combining the revolutionary thoughts of management and production scholars like William E. Deming, Armand V. Feigenbaum, Joseph Juran, Philip B. Crosby, Kaoru Ishikawa, Genichi Taguchi, Taiichi Ohno and Shigeo Shingo with its own cultural features, succeeded in reaching higher productivity increases compared to the West. These scholars formed a quality conciseness primarily in Japan and the rest of the world. They were praised later as the founders of the concepts like Total Quality Management, Just-in-Time Production, Lean Manufacturing and so on. Efficiently working, quality sensitive Japanese organizations managed to flexibly manufacture diverse-high quality goods cheaper and faster than their western counterparts. The striking competitive advantage of these firms is repeatedly narrated over the famous cases of Canon/Xerox, Fuji/Kodak and Mazda/Ford. For instance, Canon could sell quality photocopiers in the United States cheaper than Xerox's manufacturing costs. This bitter fact led to a major process restructuring at Xerox.

2.3.3.1 The Peculiarities of the Japanese Style

Ouchi (1981) exhibited peculiarities of the so called Japanese management style popularized during the Asian economic boom of the 1980's. It is stated that after the Second World War the efficiency in Japan increased by 400% compared to the United States (Simsek, 2002). Life long employment which enables the integration of personal life with job itself is a main target among the Japanese employers and employees. Salary and responsibility depend on seniority whereas in the western communities they considerably depend on capability. In Japan, discriminating symbols that separate superior form his/her subordinates like discrete working areas, distinct uniforms etc. are rarely seen. People, not only mentally but also physically, work together. Unspecialized occupational development is a part of the Japanese management model. This term refers to a sort of job rotation in which all employees are worked in different segments of an organizations for a while prior to their principal departments. Collective decision making and responsibility are essential. Before making a major decision, opinions from every group, which will possibly be affected by the decision, are taken. These opinions may be economically irrational or against organizational politics. Every opinion is taken into consideration. Groups are granted authority and responsibility. A veiled control mechanism is developed within groups. Each member of a group should control other members. This is mainly because of the group responsibility point of view. Japanese feudal roots help managers form a holistic organizational atmosphere in which employees are proud to be a part of. Contrary to that, the western culture is mainly based on a self-centered individualism.

2.3.3.2 Total Quality Management

An American, Walter A. Shewhart of Bell Laboratories, developed a system of measuring variance in production systems known as Statistical Process Control (S. P. C.). Statistical Process Control is one of the major tools that Total Quality Management uses to monitor consistency, as well as to diagnose problems in work processes. His student William E. Deming manifested the fundamentals of Total Quality Management but he took more attention in economically collapsed Japan just after the Second World War (Deming, 1986). The Japanese broadened the basic idea taken from the Americans to a level in which everyone in the organization takes part of (Kovanci, 2001). Promoted by the Japanese impact in the business world, Total Quality Management has been discussed, investigated and applied by many scholars and business people. Imai (1994) credited Total Quality Management with facilitating the Japanese economical domination in the post-war years. Juran (1993) mentioned the vital role of Total Quality Management in restoring the competitive power of the U.S firms. Total Quality Management is an integrated management philosophy and a set of practices that are mainly based on meeting customers' requirements, continuous improvement, reducing rework, long-range thinking, process redesign, effective employee involvement and teamwork, benchmarking, constant measurement of results, collective problem solving and close relations with suppliers (Ross, 1999). Total Quality Management is a set of performance improvement efforts that covers everyone till workers, in every organization at every level (Imai, 1994). The motive for Total Quality Management is sustainable company competitiveness while satisfying external and internal customers. Strong customer focus, continual improvements, top management involvement, improvement in the quality of everything, cultural change, empowerment of employees are all Total Quality Management obligations. Management by fact but not by myth, no process without data collection, no data without analysis, no analysis without a decision can be considered as some of the basic principles of Total Quality Management. Quality circles, benchmarking, brainstorming, pareto analysis, cause and effect (Ishikawa) diagrams, check sheets, control charts, customer data tables, histograms are of the most frequently utilized tools and techniques.

2.3.4 Other Developments in Manufacturing

In addition to the significant impacts mentioned above, rapidly developing information and telecommunication technologies have been improving manufacturing processes as well. Crowley (1998) summarizes the principal innovations that have changed manufacturing for the last 40 years:

Quality Systems:

- Statistical Quality Control (S. Q. C.)
- Total Quality Control (T. Q. C.)
- Total Quality Management (T. Q. M.)

Planning and Scheduling Systems:

- Materials Resource Planning (M. R. P.).
- Manufacturing Resource Planning (M. R. P. II).
- Optimized Production Technology (O. P. T.).
- Just-in-Time (J. I .T.).

Manufacturing Systems:

- Group Technology (G. T.).
- Cellular Manufacturing.
- Flexible Manufacturing Systems (F. M. S.).
- Computer Integrated Manufacturing (C. I. M.).

2.4 The Need for Change in Construction

Construction, without a doubt, has also been affected by these improvements in terms of the development of advanced engineering materials, the utilization of mechanical power, the application of information and telecommunication technologies and the quality and the productivity conciseness to a degree (Crowley, 1998). The effects on construction are basically over the technological utilization, application and the adaptation of the primarily manufacturing related phenomena. However, the adaptation and the penetration of the organizational and the managerial foundations that lead to some real quality improvements, cost reduction and flexibility are questionable.

2.4.1 The Specific Nature of Construction

Manufacturing is consisted of various industries. The construction industry is most closely analogous to the discrete assembly industries. Stinchcombe (1959) compared the construction industry to the automotive industry and stressed the roots of the differences between the Weber's bureaucratic administration and the craft administration. The same kind of a research and comparison were carried on by Woodward (1980) under the context of the contingency approach. Although this type of analogies and comparisons are beneficial for a better understanding, it should also be noted that the construction industry has its own, unique characteristics and resident problems. These attributes and problematic nature prevent the direct application of a manufacturing oriented phenomenon. Sun and Aouad (2000) exposed the conditions of the construction industry:

- Fragmented supply chain.
- Lack of industry standards for information exchange.
- Poor cross-disciplinary communication.
- Lack of process transparency.
- Poor knowledge management at industry, enterprise and project levels.

Schleifer (2002) supported the strong presence of the problematic conditions mentioned by Sun and Aouad (2000). He also added the lack of leadership factor after his study among the sector's professionals. The industry has also its very own nature:

- Different parties come together for every single project. Long term relations with workers and other parties are rare.
- Construction projects are extremely varied in size and type. Contrary to manufacturing, no extensive standardization in either processes or finished products
- Each project is unique, static, big in size and constructed on site. Erection and installation are the main processes (Salem et al., 2006).
- Site conditions highly determine the quality of a process (Salem et al., 2006).
- In construction, clients are the main determinants of the aspects of a finished product. Change orders are common (Salem et al., 2006).

- In manufacturing, producer-supplier relations are clearer, more manageable and open to repetition. In construction, however, these relations are more dynamic and complex (Salem et al., 2006).
- In construction, compared to manufacturing, more uncertainties should be met with lesser control in parameters (Salem et al., 2006).
- In construction, generally, contractors prefer to rent or lease their machineries (Salem et al., 2006).
- Construction firms vary in size but the majority of firms are small-medium sized.
- Construction is labor intensive. This fact increases the risk of human error, lowers productivity and automation.
- A hectic business environment.
- In construction, quality perception is generally limited to product conformance (Arditi and Gunaydin, 1997). Rework and Quality Assurance are widespread (Salem et al., 2006).
- Subcontracting is a common practice in construction. Due to the interrelations between processes, subcontractor performance can highly affect a finished product in construction (Salem et al., 2006).
- Supply is generally based on client. Rather than in-time supplying in manufacturing, in-case supplying according to schedule is observed.
- The difficulty of obtaining statistical data, which is a must for the quality revolution, is a widespread problem.

The National Audit Office (2001) of the United Kingdom underlined the poor safety record and inability of recruiting gifted people, no culture of learning from the past, no organizational career structure, the poor level of investment into research and development that had restricted the innovation capability and the limited usage of technology as the additional problematic aspects of the construction industry.

2.4.2 The Early Standardization Efforts

In the first half of the 20^{th} century, architects such as Le Corbusier, Walter Gropius, Bemis and Buckminster Fuller believed soundly in the idea of mechanization and industrialization of construction. Houses were especially thought to be produced in factories (Gann, 1996). The main motive of this attempt was to benefit from economies of scale, tighter managerial control over the construction processes and technical possibilities to develop and deploy capital equipment. Three main principles are shaped industrialized construction: standardization, pre-fabrication and systems building (Crowley, 1998). Standardization is a must to pre-fabricate construction components in factories. The coordination of this two efforts leads to systems building. Even the Toyota Company, relying on its successful automotive production past and experience, endeavored to build houses all over Japan in the late 1970s. In spite of these efforts, very little or none productivity improvement, cost reduction and increase in the compilation of projects were attained by the system buildings approach and extensive standardization brought some social controversies as well (Gann, 1996).

2.4.3 Competitiveness, Value and Change

Perhaps, it would be more explaining to look at all of these change efforts or terms through the window of competitiveness. There are many competitiveness definitions, which are based on market, firm and national competitiveness, in the literature. Concisely, according to

Garelli (2006): “competitiveness analyses how nations and enterprises manage the totality of their competencies to achieve prosperity or profit.”. Within capitalist economic systems, the drive of enterprises is to maintain and improve their own competitiveness. Today, enterprises compete not only nationally but also internationally as well. Markets are open for most. Tariffs on goods are less than 4% among the members of the World Trade Organization (W. T. O.). The O. E. C. D., since its creation, has fostered the development of the free movement of capital, goods and services. Free trade areas such as N. A. F. T. A. and regional integration identities such as the European Union support the competitive atmosphere. Technological developments and globalization factors also create some threads and opportunities for enterprises to be successful in the competition at the national and the international level. Nations’ and enterprises’ obligation to compete turns the factors affecting the competitiveness level into an important issue to study on.

2.4.3.1 Changing Global Actors

Another reality is the expected change at the global actors in the near future. China, by the year 2020, will have been the largest construction economy. India, likewise, will have a huge impact. Most of the developed countries, especially in Europe, will try to put more emphasize on public private partnership and build-operate-transfer projects with the aim of renewing their infrastructures (Flanagan and Jewell, 2005). Creating and expanding competitiveness are issues that draw the attention of scholars in this context. Porter (1990), stressing the importance of competitive economical advantage over the classical comparative economical advantage, tried to identify the main factors affecting a country’s global competitiveness. He summed his findings in a model generally named as the Porter’s diamond. One of his main points is that a country attains a competitive advantage if its firms are competitive. He further indicates that firms become competitive through innovation. Innovation can include technical improvements to the product or to the production process. Thus, innovation is directly related to creating value for customers.

2.4.3.2 Value and Innovation for Construction

Value, in this sense, represents anything that customers are ready to pay for. Value management, thus, is a concept born in the manufacturing industry in the 1940s, which targets to achieve value for money through quality products at a reduced cost (McGeorge and Palmer, 1997). Dubois and Gadde (2002) stated that the construction industry could be conceived as a 'loosely coupled system' and proposed that certain changes in the couplings would stimulate innovation. Although not every change attempt can be considered as innovative or progressive, the concept of change contains innovation as its subset.

2.4.4 An Economic Perspective to Change

From a construction economics' point of view, an urge for change or change initiatives can be explained through a basic economic term named opportunity cost. It can be simply defined as the cost of an alternative that must be forgone in order to pursue a certain action. Put another way, the benefits you could have received by taking an alternative action. Since our resources are limited, economic decisions lead to the conclusion that there is always a trade-off between the deployment of any resource for one or more alternative deployments. Hypothetically, if we can deploy all of our resources to the construction industry, there will be no production in other industries and the yield from the construction industry will reach its maximum in amount. As we lessen the amount of the resources spared for the construction industry and begin to transfer them to another industry, then we expect a rise in the amount of production in that chosen industry and a drop in the amount of production in the construction industry. Therefore, between a certain period of time and at a known productivity level in an economy, there is an indirect, curvilinear relationship between two economic sectors in terms of unit produced.

Myers (2004) indicates that the attempt for change in the construction industry aims at increasing the total amount of unit produced from the same amount of resources by increasing the productivity level. That means an increase in the area under the production curve without increasing resources. The effect of trade-offs made on an industry will be lesser in that case.

Flyvbjerg, Skamris and Buhl (2003), after the evaluation of 258 major public transport infrastructure projects, constructed across the U.S., Europe, Japan and many developing countries between 1927 and 1998, indicated that on average costs had overrun by approximately 30% and client revenues had failed to meet their targets by around 40%. This study can be referred to give an idea about the economical loss in the construction industry. These losses reduce the amount of units produced compared to the resources spared and push the real opportunity cost of other industries upwards over the construction industry, affecting every aspect of an economy.

2.4.5 The Global Change Efforts in Construction

Koskela, Howell and Ballard (2003) state that many countries already realized that there is a need for change in construction and initiated various initiatives and programs for achieving that desired change (Table 2.1). On the other hand, they indicate the fact that only few of these attempts have recorded consequent and significant success. At the same time, they underline that there surely are firms that have advanced in overcoming the generic problems of the construction industry successfully.

Table 2.1- Change Initiatives in Various Countries

Country	*Programme or initiative*
Australia	Building Regulation Reform, Building for Growth
Denmark	ProjektHus
Finland	Vision 2010
Hong Kong	Quality Reform Initiatives
The Netherlands	BouwBeter
Singapore	Construction 21
United Kingdom	Rethinking Construction
U.S.A.	FIATECH

(Source: Koskela, Howell and Ballard, 2003)

2.4.6 The Special Need for Change in Turkish Construction Industry

As far as Turkey is concerned, there is another additional vital need for change apart from the reasons mentioned above. Turkey is located on one of the most seismically active regions on the planet. Earthquakes frequent the country, leaving devastating outcomes. Between 1902 and 2004, 116 major earthquakes hit Turkey, with 97123 dead, 40812 injured severely and billions of dollars of monetary loss (Deprem Bilgi

Bankası, “Türkiye Deprem Kronolojisi”), These figures are only the approximated and reported ones of course. In many cases, especially at the time of a major earthquake, like the Kocaeli earthquake in 1999, it is almost impossible to precisely record the injured and the dead. Another major earthquake is expected in the future around the city of Istanbul which is the most populous area of the country.

2.4.6.1 The Lack of Conformance

The recent bitter earthquake experiences have shown that there is a lack of conformance to the requirements (Istanbul Technical University, 1999; T. M. M. O. B. Chamber of City and Regional Planners, 1999; Ministry of Public Works and Settlement, 2000a; Ministry of Public Works and Settlement, 2000b). The lack of conformance here refers to both the inadequate technical practice of construction activities and the violation of the related constructive codes at the design and the construction phases. Technically, earthquake engineering and the related codes aim at designing and constructing structures that don’t kill or severely injure people, even though they experience extreme damages and deformations during a strong earthquake (Celep and Kumbasar, 2004). In the regions, where the effects of an earthquake are weaker or lesser, it is expected that structures do not exceed their elastic deformation limits. Thus, by the Cornick’s (1991) three-level quality definition, the public and the private structures that violate these principles can be labeled clearly as low-quality. In fact, it can be said that the real danger lies in 4 to 8 storey buildings which consist of the majority of the building stock in the country (National Earthquake Council, 2002). These buildings are prone to being low-quality, in a sense that they stand at an average complexity in terms of engineering. Low rise buildings were observed as having very minor deficiencies after the major earthquakes.

High-rise buildings, on the other hand, enjoy special technical attention and care due to their importance and complexity.

2.4.6.2 The Features of Turkish Construction Industry

The conditions of the structures in the earthquake struck regions rose discontent about the rest of the structure stock in the country. Positively, serious concerns about the current structures led to wide discussions over the context of the construction industry in Turkey. The inherent problems of the industry had already been mentioned right before these earthquake catalyzed discussions took place (Dikbas, 1995; Sorguc, 1996; Sorguc, 1997; Toklu, 1996). Along with lack of occupational education and penetration of developing technologies, excessive bureaucratic procedures, insufficient technological know-how, inadequate control mechanism, the state procurement process's lowest bid politics were also mentioned to have significant effects on quality. Under the politics in question, contractors sacrifice as much as they can in order to be awarded. These sacrifices often include quality and safety. On the other hand, Turkish contractors take the attention of the rest of the world with their successes in global markets. Oz (2001) states that along with cheap labor, cultural and geographic proximity to the highly active markets, Turkish contractors also experience a high level of competition among each other and show solid entrepreneurship in global markets. This competitive, dynamic and adaptive nature of the sector is a chance to succeed in a considerable change.

2.4.6.3 Change Dynamics

The Turkish state felt the necessity of taking some precautions, implementing some sanctions and revising the context of the construction sector in the country. The efforts include adoption of new taxes to finance the revisions and the preparations, revisions on the construction codes and the regulations, implementation of an obligatory private control system, promotion of the earthquake related researches at the universities and so on. These efforts are all in accordance with the 8^{th} Five-Year Development Plan, covering the years 2001–2005. Koraltan and Dikbas (2002) stated that the core of the plan was to improve processes holistically through technology implementation, continuous education and simplification of bureaucratic procedures. Koraltan and Dikbas (2002) also mentioned a widespread recognition in the need for change in the construction industry in Turkey, in terms of processes and quality.

The need for change is observed to have reached at a level that is desirable among various parties such as designers, contractors, customers and the state itself. The basic intra-extra industrial dynamics and the local-global promoters of that need for change have been attempted to state above. The highly debatable question in this case whether or not the desired change can be reached via revision of some codes, acts and mostly on-paper development plans.

The situation resembles of the Quality Assurance (Q. A.) movement in the construction industry in the early 1980s to a degree. McCabe et al. (1998) described this period as being quite straightforward, rigid and bureaucratic in which people were expected to obey some procedures in manuals and document their compliance systematically in order to get accreditation from the British Standards Institution (B. S. I.). Regular control mechanisms were implemented by institutes to keep the system in control. Accreditations were used to be awarded in tenders or to create a competitive advantage over competitors. The system promoted the process based thinking and the documentation of these processes. On the other hand, it put strict rules that might be unnecessary, even detrimental in some cases, took too much time of staff for documentation. On the accreditation body visit days, people were "on best behavior", rather than throughout the work itself (McCabe et al., 1998).

2.4.6.4 Control Mechanism

After the raising recognition and the demand for change in Turkey, some buzzwords like "with I. S. O. 9001", "T. S. E. guaranteed", "earthquake resistant", "with technical safety report", "tunnel formwork", "raft/pillar foundation on strengthened soil", "shear walled" have been frequently heard. Even some popular scientists are put in act on commercials. The state entailed private control bodies in 2001, knowing that the revised codes and the regulations are nothing without application. However, T. M. M. O. B. Chamber of Civil Engineers (2006) stated that this system had had either none or very minor effect since these bodies' works were not controlled regularly by anyone. Another real earthquake test should be waited to see their level of service. They are licensed by the state arranged commissions rather than independent occupational identities. In practice, mostly, these private control bodies control only the compliance of the materials being used on the site but nothing more. At the end of the day, the sole aim can easily turn into making profit. The control system has not been extended to all cities in the country yet. The system is primarily operated during the construction phase. It is far from being holistic and coordinating. These bodies are also financially dependent on the contractors and/or identities that they are supposed to control. This fact can drive their level of service off from their purpose of being. Although there are private control firms that are trying to do their best with the consciousness about the vitality of their job, the system itself looks like as if it were implemented to ease the reactions from the public. Put another way, it is still far from being satisfactory. Many in the sector believes that the system is an on-paper political maneuver rather than an effective precaution. The state is thought to consider and promote the post-earthquake activities, such as search and rescue operations, more than designing a new construction context.

2.4.6.5 Need for Cultural Change

The analogy between the Q. A. movement in the U. K. during the early 1980s and the latest situation after the major earthquakes in Turkey can be established through their resembling natures. Perhaps one of the most primary point is that they both lack in a comprehensive cultural change. The cultural change here stands for gaining a different understanding about the overall construction process. The main motivation in both cases is to make people do what is thought to be right or correct for ensuring that some certificates, regulations and codes are used. Ironically, these certificates and regulations are utilized as tools for marketing or seen as bureaucratic obstacles against doing business that should be overcome in one way or another. This understanding can be put into the first level of quality. Implementing the philosophy of doing things better in a continuous and holistic manner seems hard to be reached in these systems. Secondly, their rigidity and mostly on-paper being do not seem to be convenient in an ever changing environment of business today. The inertia in their nature can hinder the institutionalization of a learning organization. Due to these two critical reasons, the Q. A. movement left its place to the Total Quality (T. Q.) Movement, which was believed to be more beneficial to the construction companies (Burati, Mathews and Kalidendi, 1991; Kline and Coleman, 1992). Although the T. Q. Movement's effectiveness, its implementation, the differences between what is real and what is promised in the construction industry have been extensively discussed ever since, the author thinks that the conscious desire of changing or "modernizing" construction in terms of technical and managerial processes can be considered as an instructive example for Turkey.

2.4.7 The Long-Term Change Efforts in the U. K.

The U.K is one of the most experienced or leading countries in terms of conscious change in construction. Mostly with economical concerns, the state - promoted industrial analysis and investigation are old practices in the U.K. The Simon Report in 1944, the Emmerson Report in 1962 and the Banwell Report in 1964 are only some of the earliest examples of these practices in the country. There have been formed significant joint industry-government initiatives organized mainly by the Department of Environment, Transport and the Regions (D. E. T. R.) and the Her Majesty's Treasury. These initiatives have triggered discussions among both the industrial and the academic parties since the early 1990s. The essence of these initiatives is briefly to photograph the conditions of construction and advise about the change needs necessary to modify the whole construction process in order to make it more capable of satisfying the new business environment. The ideas were collected later in reports, the most notable of which are; the Latham Report "Constructing the Team" in 1994, the Levene Report "Construction Procurement by Government" in 1995 and the Egan Report "Rethinking Construction" in 1998. Although all of the reports are of the U.K origin, they claim that the parallels support the universality of the reports and the differences are due to various project organizations.

2.4.7.1 The Latham Report

Cooke and Williams (2004) mentions that the Latham Report in 1994 recommended about 30 different issues some of which are; better contract management, legislative simplification of dispute resolutions, team approach, implementation of 10-year building defects insurance, lateral-vertical integration, revised tendering and selection methods and so on. After the Latham Report, the U.K. government committed itself to become the best client described in the report.

2.4.7.2 The Levene Report

The Levene Report in 1995, succeeding the Latham Report, examined the government’s position and the practices towards being the best client and included some advises for the government through the perspective of procurement. Some of the advises are; better communication between parties, increased training about mostly risk management and procurement. The report also identified the culture of the government as too lowest-price oriented, rigid and defensive, almost close to criticism.
The primary portion of responsibilities were put on the government.

2.4.7.3 The Egan Report

Cooke and Williams (2004) stated that The Egan Report in 1998 was mainly concerned with improving quality, profits and productivity while decreasing accidents and the necessary steps towards the implementation of these goals. Underachievement of the industry as a whole, high level of defects, low-profits, lack of customer feed-back, high level of waste, lack of investment in research and development, high level of customer dissatisfaction were all underlined. These main defects were proposed to be overcome by a quality and customer driven approach, committed leadership under an integrated vision. Quality Assurance (Q. A.), Quality Management (Q. M.), Total Quality Management (T. Q. M.), Business Process Reengineering (B. P. R.), Lean and Agile Construction, Partnering, Supply Chain Management, Value Management, Benchmarking, System Thinking were all advised for the construction industry. The report also underlined that although the finished products of construction were all different from each other, the processes needed to realize these products were repeated from one project to another. This fact enables the sector to learn from improvements. The problems and the main solution suggestions by these three reports were summarized in the National Audit Office's 103 page report in 2001. Figure 2.2 depicts this summary. A close look at the summary reveals that it is more or less parallel and coherent to the Turkey's 8th Five-Year Development Plan.

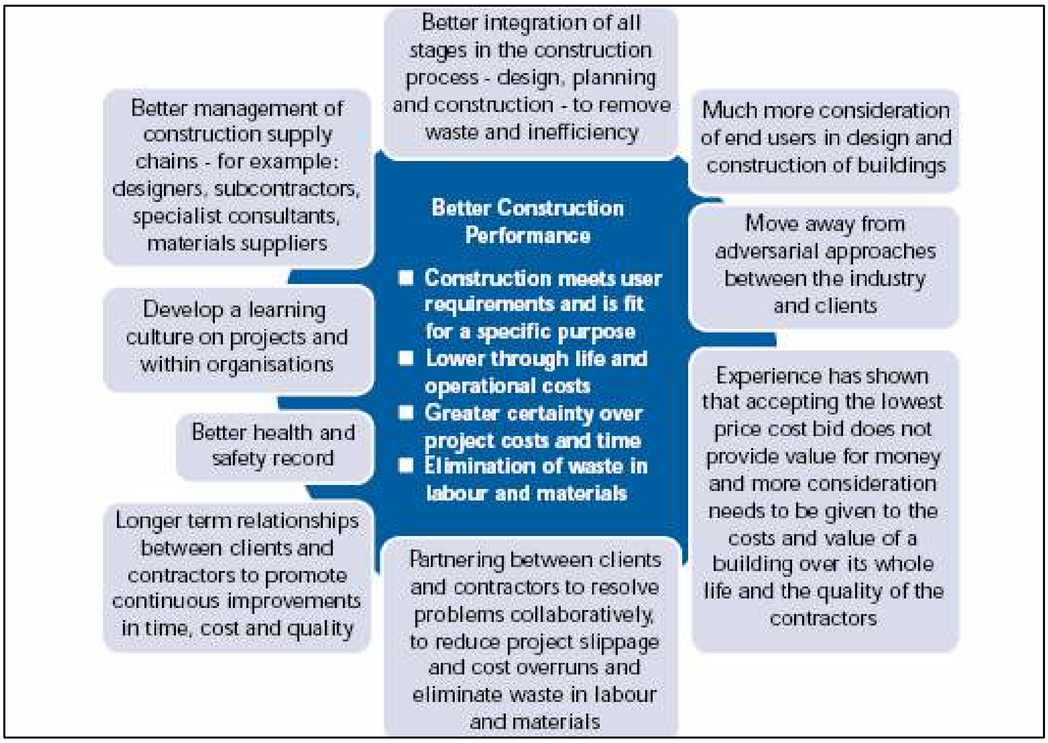


Figure 2.2- Better Construction Performance-What Is Needed? (Source: The National Audit Office, 2001)

Lean thinking and consequently lean construction are mentioned and suggested as one of those tools that aim at the improvement of the construction industry. It is no secret that construction management has learned and adopted proven tools and techniques from other industries. Especially after Koskela's (1992) pioneering report, many researches have been conducted to form a "lean construction" concept and to adapt the lean production system's tools to construction. Before elaborating the term "lean construction", it is appropriate to shed some light on the roots and the main elements of lean thinking and lean production.

CHAPTER 3

LEAN THINKING AND LEAN PRODUCTION

Lean Thinking is a concept that is based on the Toyota Production System (T. P. S.). It was ultimately developed in a manufacturing environment, more specifically in the automotive industry. The main pioneers and promoters of lean thinking is Toyota's chief engineer Taichii Ohno and the C. E. O. Eiji Toyoda. They were dedicated to eliminate both hidden and obvious waste. The system drew huge attention after Toyota's striking competitive advantage over its American and local rivals especially during the 1973 oil crisis. The term "lean production", first used in the book "The Machine that Changed the World", was coined by a member of the International Motor Vehicle Program (I. M. V. P.) team (Womack, Jones and Roos, 1991). The team was led by James P. Womack and Daniel T. Jones at the Massachusetts Institute of Technology (M. I. T.). It was a collective synonym for the Toyota Production System.

The I. M. V. P. team completed a five-year international research study, concluding in the book that introduced the term "lean" to the rest of the world. The study compared the mass production system, created by Henry Ford, extended exponentially at General Motors, and practiced by virtually every major industry in the world up to that time (except Toyota), to the production system developed by Ohno and Toyoda. It is again the I. M. V. P. team that called Toyota's production system as "lean production", referring to reducing inventories, being flexible and decreasing waste. Therefore, in essence, lean production is the Toyota Production System. Just like any manufacturing system, the lean production system is implemented to produce the highest quality products, in the shortest lead time possible, with the least amount of resource investment at the lowest possible cost. Hobbs (2003) states that although lean production offers some new concepts, it is basically a consolidation of proven techniques into powerful methodologies. The basic concepts of lean production are (Ohno, 1998):

- Pull-driven production.
- Minimizing waste by eliminating non-value adding activities.
- Doing things right at the first time by identifying and resolving defects instantly at its source.
- Continuous improvement (Kaizen).
- Building long-term relations with suppliers.
- Being able to produce various goods of various quantities.
- Team work.

3.1 The Toyota Production System Model

Lean production continues to evolve but the basic outline is clear. Design a production system that will deliver a custom product instantly on order but maintain no intermediate inventories. This is a manufacturing philosophy which is based on two pillars: Just-in-Time (J. I. T.) Production and Autonomation (Jikado). These pillars are developed in a suitable cultural framework (Ohno, 1998). It is neither all about solely some set of technical tools nor abstract piles of principles. Figure 3.1 shows the T. P. S. Model. Womack and Jones (1996) summarized lean thinking in five principles:

1. Precisely specify value by specific product. Value is defined by the customer and produced by the producer. Value is what customers are ready to pay for.
2. Identify the value stream for each product. Determine value adding, non-value adding necessary and non value adding unnecessary activities. Eliminate activities that are both unnecessary and non value adding in the short term. Necessary non value adding activities can be decreased to a degree in the long term.
3. Make value flow without interruptions in production cells.
4. Let the customers pull value from the manufacturer. Work is not performed unless the part is required downstream.
5. Pursue perfection.

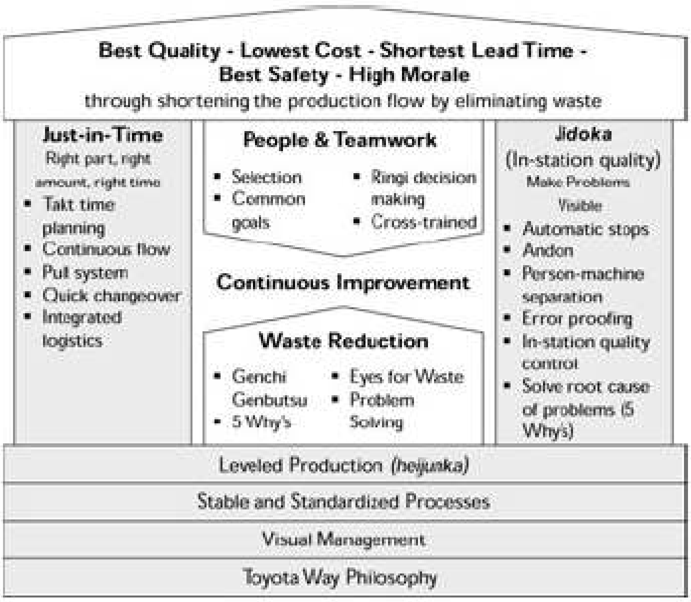


Figure 3.1- Toyota Production System (T.P.S)

(Source: Liker, 2004)

Liker (2004) summarized the lean production philosophy that shapes the culture of the production atmosphere in 14 principles:

1. Basing management decisions on a long-term philosophy, even at the expense of short-term financial goals.
2. Creating continuous process flow to bring problems to the surface.
3. Using “pull” systems to avoid overproduction.
4. Leveling the workload.
5. Building a culture of stopping to fix problems and to get quality right at the first time.
6. Standardized tasks are the foundation for continuous improvement and employee empowerment.
7. Using visual control.
8. Using only reliable, thoroughly tested technology that serves the people and the processes.
9. Growing leaders who thoroughly understand the work, living the philosophy and teaching it to the others.
10. Developing people and teams who follow the company’s philosophy.
11. Respecting the extended network of partners and suppliers by challenging them and helping them to improve.
12. Going and seeing for yourself to fully understand the situation.
13. Making decisions slowly by consensus, thoroughly considering all options and implementing decisions rapidly.
14. Becoming a learning organization through continuous improvement.

3.1.1 Just – in –Time Production

Cimorelli and Chandler (1996) cited the Just-in-Time (J. I. T.) definition from the American Production and Inventory Control Society (A. P. I. C. S.) dictionary (A. P. I. C. S. Dictionary, 1992):

> A philosophy of manufacturing based on planned elimination of all waste and continuous improvement of productivity. It encompasses the successful execution of all manufacturing activities required to produce a final product. The primary element of zero inventories (synonym for J. I. T.) are to have only the required inventory when needed; to improve quality of zero defects; to reduce lead times by reducing setup times, queue lengths, and lot sizes; to incrementally revise the operations themselves; and to accomplish these things at minimum cost. In the broad sense it applies to all forms of manufacturing job shop and process as well as repetitive.

3.1.1.1 Push – Driven Production

Engineer Ohno shifted attention to the entire production system from the narrow focus of craft production on worker productivity and mass production on machine. Ohno and Toyoda followed the work of Henry Ford and continued the development of flow based production management. But unlike Ford, who had an almost unlimited demand for a standard product, Ohno and Toyoda wanted to build cars to customer order. Ford's mass production is superior to the preceding craft production because of the extensive utilization of interchangeable parts (Willamette University, 2005). Interchangeable parts enabled production lines. Moving assembly lines were first observed in the early 1910s. Productivity was increased by a fine division of labor. Unskilled workers performed simple, repetitive jobs. Assembly workers were to be supported by narrowly skilled indirect workers such as maintenance workers, quality inspectors, rework specialists. Manufacturer imposed or planning imposed mass production philosophy, coined by Frederick Winslow Taylor and later expanded by Henry Ford, was later called as “push-driven production”.

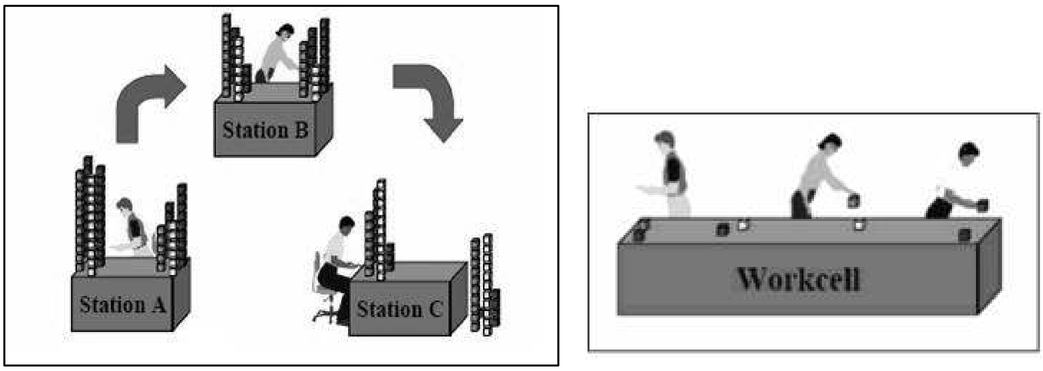
3.1.1.2 Pull – Driven Production

After the Second World War, Japanese industry did not have the scale to adopt mass production methods from the West. In the early years, Toyota produced fewer cars in total than the output of a single American assembly plant. In order to compete, they needed an alternative approach. Starting from the efforts to reduce machine set up time and influenced by T. Q. M, Ohno and Toyoda developed a simple set of objectives for the design of the production system: produce a car to the requirements of a specific customer, deliver it instantly and maintain no inventories or intermediate stores. This way of production was later called as “pull-driven production”. While the Ford’s way of thinking was pushing the product to customers, Ohno and Toyoda let customers pull products in an environment of fierce competition. Ghiani, Laporte and Musmanno (2004) mention that a choice between push-driven and pull-driven productions depends on product features, manufacturing characteristics and demand volume and variability. If the time interval between the initiation and the completion of a production process (lead time) is short, products are costly and demand is highly variable, a pull-driven production can be more suitable. For push-driven production, Material Resource Planning (M. R. P.) is generally utilized.

There are actually three types of pull-driven production. These are supermarket (replenishment) pull system, sequential pull system and mixed pull system (Society of Manufacturing Engineers, 2005). In a supermarket pull system, the company intentionally maintains inventories of each type of finished product at a certain level and when the inventory of a certain finished product falls below that certain level, a refill order is issued to produce more of the product. In a sequential pull system, production orders are issued only when demanded by an outside customer. All products are made on a made-to-order basis. In a mixed pull system, certain elements of replenishment and sequential pull systems are used in conjunction with each other.

3.1.1.3 Inventories and Work – in - Progress

Inventories are accumulation of goods that are waiting to be processed, transported or sold. Inventories are generally maintained to keep the service at a certain level, to face the unexpected fluctuations in economy, to cope with the randomness in demand, to make seasonal items available to all year and so on. Holding an inventory has a cost though. Ghiani, Laporte and Musmanno (2004) states that this cost mainly includes the opportunity cost, the warehouse maintenance costs, shortage costs- the cost of losing a customer if his/her demands are not met, obsolescence costs-if the items in the inventory lose their value over time. Partially finished products, waiting to be processed in a process, are called work-in-progress (W. I. P.) in the lean terminology. Having large W. I. P. in queue between each workstation is understandable in the name of utilizing manpower resource as much as possible. This is what was done by mass production actually. On the other hand, large W. I. P. batches occupy space in the working environment, make it difficult to determine defects and their real sources, need frequent transportation, hinder shift between products, cost money and are prone to damages (Ohno, 1998). Lean production utilizes continuous flow through cellular manufacturing units to overcome these side-effects. Typical formations of these two layouts are shown in Figure 3.2:



(A) **(B)**

Figure 3.2- Workstation Production (A) versus Continuous Flow (B) (Source: Liker and Lamb, 2000)

3.1.1.4 Continuous Flow and Cell Manufacturing Units

Continuous flow is the linking of manual and machine operations into a perfectly smooth flow in which works-in-progresses are continuously undergoing some form of processing and never become static or waiting to be processed. Continuous flow decreases the waiting time for works-in-progress, equipment or workers. In continuous flow, the ideal is one-piece flow or small batches which can be processed with virtually no waiting time between production stages. One-piece flow stands for identifying same set of materials that will go through identical processes and reserving a production line to that set (Liker and Lamb, 2000). Each product is processed in the same way, one-piece at a time by a similar machine group. The point is to identify and sort semi-finished products or raw materials by their production groups. Continuous flow may require redesign of the production layout away from groups of similar workstations located near each other and towards highly integrated production lines in which semi-finished products can move as quickly and easily as possible from one production stage to the next.

On a classical mass production line, similar works are grouped, creating traditional workstations. Organizational control is believed to be performed more effectively in that manner. Workstations are geographically located in different parts of a manufacturing plant. This grouping of work or machines generally neglects the equal distribution of capacity. This unequal distribution of capacity can create imbalances between manufacturing processes. Imbalances are often observed in piles of excess inventory. In lean production, imbalances are tried to be overcome by cellular production units and physically connected continuous flow lines.

Teamwork is achieved by forming of work cells. A cell is comprised of same set of materials that will go through identical processes and a set of machine group that is necessary to process these sets. A cell is a grouping of dissimilar work stations or operations into a flow line to produce a specific product or product family. Machines are made mobile and grouped in cells according to the product. Cells can be formed to produce a complete assembly or a portion of an assembly. Continuous flow refers to producing one product at a time within the cell. Each worker is responsible for each process within a cell. Thus workers are trained multi-functionally with basic understanding of the lean production philosophy. Cells are generally U shaped in order to minimize the movement of workers and materials. Integration and lesser interrupted flow are maintained through cells. Figure 3.3 and Figure 3.4

consecutively depicts a cell manufacturing unit and a manufacturing layout made of cellular units:

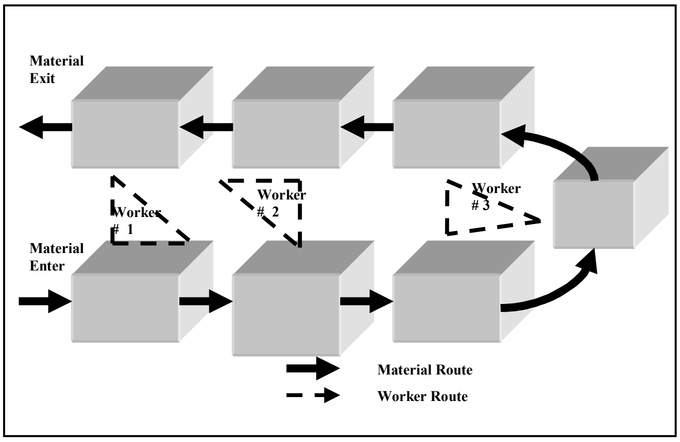


Figure 3.3– A Typical Cell Manufacturing Unit

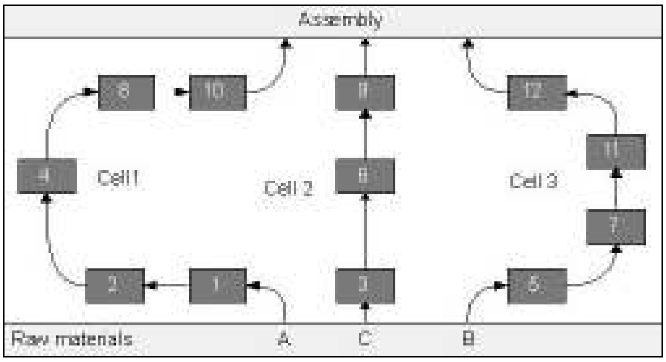


Figure 3.4– A Cell Manufacturing Layout
(Source: Russell and Taylor III, 2000)

3.1.1.5 The Kanban System

Production is pulled upstream as opposed to traditional batch-based production in which production is pushed from upstream to downstream, based on a production schedule. This means that no materials will be processed until there is a signal from downstream. The signaling system is called “kanban” which is Japanese for “sign-card”. The items in a workstation are transformed to another downstream station with a sign-card attached. There are actually two types of kanban cards: withdrawal kanban card and production-ordering kanban card (University of Cambridge, 2007). A withdrawal kanban card signals about the kind and the quantity of the material which a succeeding operator should withdraw from his/her preceding counterpart. A production-ordering kanban card signals about the kind and the property of the product which a preceding unit must produce. Each production cell possesses these two cards. Periodically, a worker from the succeeding production cell takes the accumulated withdrawal kanban cards and empty pallets to the place where the finished products of his/her preceding cell are stored. Each full pallet in the storage area of his/her preceding cell has an attached production-order kanban card. The worker removes the production-order kanban cards and places them on the schedule board of the preceding cell. Afterwards, the worker attaches withdrawal kanban cards to the full pallets and takes them back to his/her own cell. Before beginning to process the goods in the full pallets, the withdrawal kanban cards are detached and accumulated in a separate place. Figure 3.5 pictures a basic kanban system:

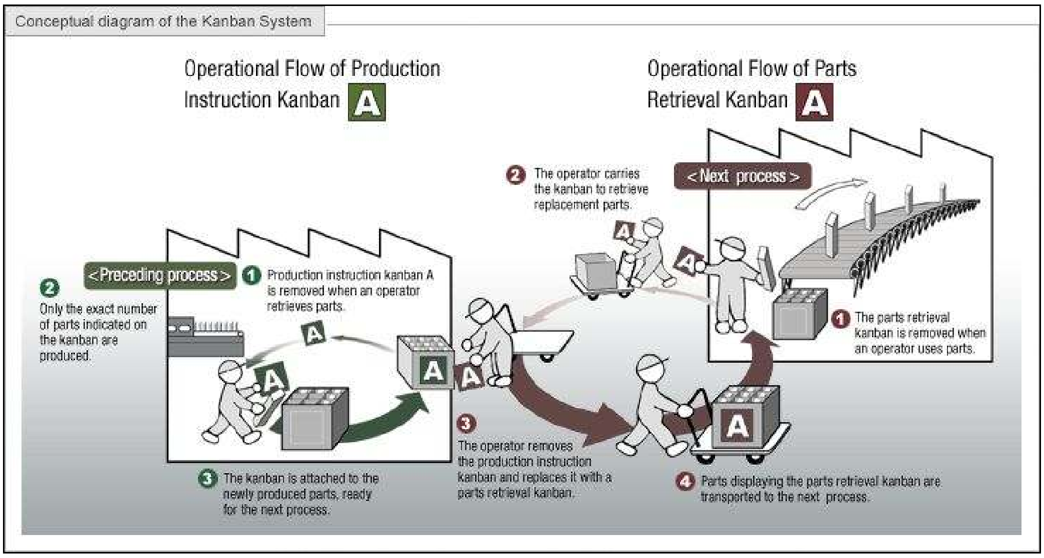


Figure 3.5– A Basic Kanban System

(Source: Toyota Motor Company, 2007a)

Gross and McInnis (2003) states that within a kanban system, operators use signals to determine when to stop, how much to run and what to do if a problem arises. Operators schedule production and determine the schedule status immediately through kanban visual signals. When an order is received from the customer and communicated to the factory floor, the production order is initially placed with the most downstream workstation. Each production stage or workstation is seen as a customer of the production stage or workstation immediately upstream of it. The rate of production at each production stage or workstation is equal to the rate of demand or consumption from its downstream customer. In a single card kanban system, the operator of a downstream operation requires a production card and the necessary material to be authorized to begin processing. He/she simply removes the card and sends it back to the upstream process signaling production to refill the material used by his/her station prior to processing the job. Ideally a customer cell should plan its own production schedule and inform its upstream supplier timely in order to get what it needs timely. Defective goods are not allowed to be sent downstream, visual inspection and W. I. P. control can be performed more effectively compared to mass production. The primary aim of this approach is to control the size of an inventory. Ohno, designing the kanban system, was inspired by American retail store chains in which customers choose and buy products instantly and each product is replaced on shelves by the amount of its pull. Krieg (2005) mentiones that the kanban signaling system is the very basic communication tool of J. I. T. production and have contributed a lot to its executers. Continuous flow, weekly and monthly production schedules are essential for an effective kanban system. A basic kanban system's rules are as follows (Halevi, 2001):

1. The earlier process produces items in the quantity and sequence indicated by the kanban.
2. The later process picks up the number of items indicated by the kanban at the earlier process.
3. No items are produced or transported without a kanban.
4. Always attach a kanban to the goods.
5. Defective products are not sent to the subsequent process. The result can be 100% defect-free goods. This method identifies the process generating defects.
6. Reducing the number of kanban cards increases their sensitivity. This reveals the existing problems and maintains inventory control.

Hobbs (2003) stated that the kanban signaling system could be expanded effectively to cover suppliers, warehouses and manufacturing lines via information technologies.

3.1.1.6 Balance and Takt Time

Balance is an important part of lean manufacturing. Even though individual manufacturing processes may require different work times, production lines are divided among equal amounts of work. Achieving balance among various processes with different working times is realized by changing the number of resources to the process. Thus, capacity balance can be achieved. Along with physically connected cellular production groups, balancing work is performed via a term called takt. Takt is basically a time/volume ratio defining the frequency with which a single piece is produced. Takt is calculated as follows (Hobbs, 2003):

$$\text{Takt} = \frac{\text{Work Minutes per Shift} \times \text{\# of Shifts per Day}}{\text{Throughput Volume per Day}} \quad \textbf{(1)}$$

Where work minutes per shift is the amount of time available for a manufacturing operator to perform work in each shift. # of shifts per day represents the number of shifts per day, per process. Throughput volume per day is the total of demand volume, including the impacts of any rework and scrap. Therefore, Liker and Lamb (2000) stated that: “Takt time is the time in which a unit must be produced in order to match the rate of customer demand.”. Each process has its own takt time rate. Takt time represents the allowable maximum time to produce a product in order to meet the customer demand. Continuous flow is maintained by relocating resources, generally manpower, to each process according to its takt rate value. Takt time is a control tool over continuous flow.

3.1.1.7 Integration of Supply Chain

Creating long term relations based on mutual support with suppliers is an important element of lean manufacturing. Having quality supplies just in time is a crucial aspect for having high quality finished products with minimum inventories. It is expected from suppliers to deliver materials that do not need to pass through an additional quality control before being processed in the main plant. Manufacturers should cooperate with, support and direct their suppliers in accordance with their production philosophy. Lean production generally dictates buying raw or semi-processed materials from suppliers frequently but in relatively lesser quantity. Therefore, it is important to establish long term relations with preferably one supplier which has geographic proximity to the main manufacturing plant. Deming (1986) stated the importance of establishing long term relations based on loyalty and trust with a single supplier among his renowned 14 principles as well. In fact, many of the lean production principles have similarities with the Deming's 14 principles.

3.1.2 Jidoka (In – Station – Quality)

Jidoka, translated as autonomation, can be explained as: "automation with human touch" (Toyota Motor Company, 2007b). Autonomation refers to transferring some human judgment skills to machines. Jidoka practically means stopping a process when something goes wrong. Machines are arranged to stop automatically if a problem arises. That makes it possible for a single operator to control many devices in terms of visual inspection. Monden (1998) stated that it was about adding autonomous capability to machines. When a part is defective, when required number of goods is processed or when there is a jam in the mechanism some intentionally integrated switches or devices terminate the process. If an all-people process is in progress, workers are allowed to stop the manufacturing line in case of a mistake or a defect. Every worker has the authority and the responsibility of stopping a production line in the lean manufacturing philosophy. Therefore, educating workers is of great importance. Workers are systematically trained about the lean production techniques, machine repair and maintenance and basic statistical terms. They are encouraged towards team work and reaching a consensus. Defects are investigated with great care. Tools like quality circles, five whys and pareto analysis are extensively employed to find the real source and the true remedy of a defect or a mistake.

3.1.2.1 Andon

Defects are avoided constantly and problems are tried to be solved at their sources. Andon is another lean production term that stands for an alert system comprised of light bulbs on a board. Moralioglu (1999) states that staff understands the situation on the production line by looking at andon bulbs. If everything is alright, the green-bulb is on. If there is something wrong and the worker wants help to settle something down, the yellow bulb is on. If the line is stopped, the red bulb is on. The main responsibility for quality inspection is done by workers, not by separate quality inspectors who inspect samples. Upstream workstations are responsible for the defects of what they released to downstream. Quality inspectors rather inspect the source of defects in order to prevent reoccurrence. When defects are spotted, production is shut down until the source of the defect can be solved. This helps ensure a culture of zero tolerance for defects and also prevents defective items from flowing downstream and causing bigger problems.

3.1.2.2 Poka – Yoke (Error – Proofing)

Poka-yoke (error-proofing) tools, mainly pioneered by Shigeo Shingo, are extensively employed. Shingo (1986) described that these tools aimed at reducing defects by limiting the behaviors of a worker on executing any operation towards the correct way of performing the operation. A 3.5" floppy disk with the top-right corner shaped in a certain way that the disk cannot be inserted upside-down is an example of poka-yoke.

3.1.2.3 5 Why's

Five why's is a five step inquiry method that aims to find the real root of a problem. It is about asking the question why to the answer of the previous why question till identifying the real root of a problem. The five why's practice is quite similar to the fishbone method used in many quality management systems. Identifying the problem statement and replying to the why questions correctly are important.

3.1.3 Standardized Work

Standardized work means that production processes and guidelines are very clearly defined and communicated in detail in order to eliminate variation and incorrect assumptions in the way that work is performed. The goal is that production operations should be performed the same way every time. Standardized work includes standard work sequence which is the order in which a worker must perform tasks, including motions and processes. This is clearly specified to ensure that all workers perform the tasks in the most similar ways possible so as to minimize variation and eventually defects. Standardized work also comprises of standard takt time and standard W. I. P. Standard takt time is sought to keep the flow in a continuous manner as explained above. Standard W. I. P. is, on the other hand, the necessary amount of material that is required to keep a cell or process moving at the desired rate. This is used to calculate the volume and frequency of orders to upstream suppliers. Instead of long textual tools, visual tools are prepared to take the attention of workers towards these standardizations. Processes are designed as simple and as lean as possible in order to keep them easier to understand and easier to manage. Keeping flexibility in a standardized work environment is achieved by empowerment. Standard works are monitored and updated in a constant manner.

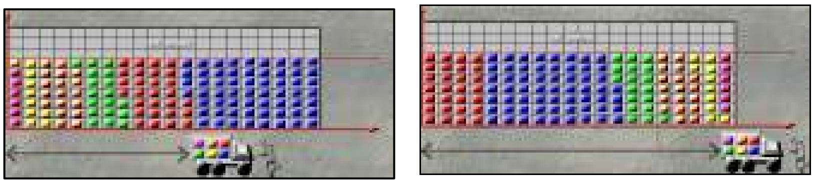
3.1.4 Visual Management

Visual Management systems enable factory workers to be well informed about production procedures, status and other important information for them to do their jobs as effectively as possible. Large visual displays are generally much more effective means of communication to workers on the factory floor than written reports and guidelines and therefore, are used as much as possible. The targeted and the real production level are made visible to everyone so is the current situation of a production line. Charts, metrics, cards, tables, procedure - process documents, visual indicators are extensively used. Visual management also helps to create a transparent working environment.

3.1.5 Heijunka (Leveled Production)

Heijunka is a Japanese term that refers to a leveled production schedule and workload (EMS Consulting Group, 2004). This stands for a balanced production of goods in terms of type and quantity. On a manufacturing plant's production line, various products of various sizes can be produced by applying changeovers between each product type. Regular, strict and "pushed" production schedules can often cause waste and an imbalanced production regime because of highly unknown and unpredictable customer demands. The classical mass production approach utilizes huge production batches and patterns as economies of scale to minimize changeover times. Along with time expending changeovers, this type of unleveled production generally leads to a higher level of inventories and imbalanced utilization of resources. Lean production employs mixed-leveled production schedule. With the help of other lean production techniques, lesser changeover times and continuous flow can be maintained as well. Balanced utilization of resources, flexible production regime and lesser inventory levels can be reached in that way. Daily scheduling by actual customer demands, in terms of type and quantity of products, is performed. Data for scheduling are derived from the analysis of the monthly manufacturing volume and the in-month scheduling reviews for fitting of daily production routes (Toyota Motor Company, 2007c). These analyses and monitoring are continuous.

Heijunka is another reflection of lean production's continuity priority. In the name of visual management, heijunka boxes are used for scheduling. A heijunka box is a wall schedule that is divided into a grid of boxes. Each box represents an equal amount of time in a predefined time span. Some colored kanban cards, by the type of products planned to be produced, are attached on each box to represent the time span reserved for that specific product and the upcoming manufacturing route (HC Online, 2006). Workers, starting a production route, remove the corresponding kanban card from the heijunka box. Figure 3.6 shows a leveled and an unleveled production schedules through heijunka boxes:



(A) (B)

Figure 3.6- Leveled Production Schedule (A) versus Unleveled Production Schedule (B)

(Source: HC Online, 2006)

Notice that with an unleveled scheduling, a customer who demands every product type from the manufacturer should wait till the end of the time span. On the other hand, with a leveled production, various and random demands are met faster.

3.1.6 Waste in Lean Production

Toyoda's and Ohno's entire focus was on the elimination of waste. The level of waste is accepted as one of the primary performance criteria for a production flow. Inventories standing idle, time beyond instant and an unsatisfied customer are all wastes. Ohno used the Japanese word "muda" referring to waste. Muda is defined as any activity that absorbs resources but creates no value. Muda, according to Ohno (1998), typically includes:

- Defects in products.
- Overproduction of goods.
- Excess inventories.
- Unnecessary processing.
- Unnecessary movement of people.
- Unnecessary transport of goods.
- Waiting time.

Womack and Jones (1996) later identified an additional source of waste:

- Design of goods and services that fails to meet the customers' needs.

Howell (1999) stated that lean production focuses on adding value to raw materials as they proceed through various processing steps until being a finished product. Value-adding activities are those that transform materials into something customers want. Lean production differs from mass production in this sense. Mass production primarily concentrates on improving value adding activities by dealing with them one by one. However, value-adding activities are only a small portion of the total lead time of a process. The major portion is comprised of non-value adding activities like waiting, transportation etc. Lean production percepts value flow in a holistic way rather than individual processes and tries to eliminate or minimize these bigger-portion, non-value adding activities. Moreover, waste is not degraded to only activities, anything that interrupts a value adding flow is a waste.

3.1.6.1 Value Stream Mapping

Value stream mapping is a set of methods to visually display the flow of materials and information through the production process. The objective of value stream mapping is to identify value-added activities and non value-added activities. Value stream maps should reflect what actually happens rather than what is supposed to happen so that opportunities for improvement can be identified. Value Stream Mapping is often used in process cycle-time improvement projects since it demonstrates exactly how a process operates with detailed timing of step-by-step activities. It is also used for process analysis and improvement by identifying and eliminating time spent on non value-adding activities.

3.1.6.2 Genchi Genbutsu

Genchi Genbutsu is a word pair in Japanese which can be translated as “go-and-see” or “go and see yourself”. It is all about not taking everything for granted or not relying on outside reports. The flow of the lean production should be monitored and analyzed firsthand by experienced people as much as possible. Numbers and facts should be blended by observing the situation and correctly analyzing some reliable data. This requires being involved in the flow itself at a detailed level, seeing the whole picture with interconnections and sensing what to come in the future.

3.1.6.3 The Five S’s (5S)

The Five S’s (5S) are some rules for workplace organization and in-house keeping which aim to organize each worker’s work area for maximum efficiency and to reduce waste associated with the workplace organization. The Five S’s are in every internal customer’s responsibility to create a working environment of which people are proud. It is believed that people who are proud of their workplace can produce high quality products easier. The Five S's are the following (U.S. Environmental Protection Agency, 2006a):

1. Seiri (Sort) – Sort frequently needed things and lesser needed things so that frequently needed things are available nearby and as easy to find as possible. Relocate or get rid of unnecessary things.
2. Seiton (Set in order) – Arrange essential things as accessible as possible to reduce the waste related to a worker's motion in locating or acquiring a needed thing.
3. Seiso (Shine) – Keep work areas and machines clean in order to reduce the waste related to uncleanness and increase workers' satisfaction.
4. Seiketsu (Standardize) – Standardize and diffuse the first 3 S's throughout the working place by means of clear procedures.
5. Shitsuke (Sustain) – Try to integrate the 5 S's in the organization's culture by means of training, promotions and control.

3.1.7 Continuous Improvement

Continuous improvement is of the very basic core elements of the lean production system. In fact, there are two types of continuous improvement; gradual improvement and periodic big leaps. The form of continuous improvement in the lean production philosophy has been gradual, yet frequent continuous improvement (Kaizen) from the beginning (Ohno, 1998). It is about being unsatisfactory with the current situation, correcting defects on their actual places, implementation of the agreed ideas immediately, aiming for high, appreciating and rewarding effort, finding opportunities in difficulties, searching for the real reasons, holistic thinking, taking ideas from different people, experimentation of ideas and believing in infinity of development. In the early 1990s, Hammer and Champy introduced the idea of business process reengineering (B. P. R.). Reengineering involves scrapping existing processes and starting from zero. Gradual increments create an “S” curve on a performance/effort chart and eventually slow down. That is to say; a new, radical approach for technology and/or processes is needed. Periodically, big leaps are taken as the new processes and technologies replace the old ones. This requires major innovation. It is claimed that this is where Process Reengineering should be utilized. Initially the new processes and technology are untried and work relatively poorly. Kaizen resumes to continuously improving it with small steps.

Continuous improvement is in the focus of every process, training mechanism, equipment and principle of a lean production system. This is to say; continuous improvement is in each and every T. P. M., T. Q. M. and lean production tool. Additionally, creating a fulfilling and safer work environment with satisfied workers is also in the scope of Kaizen. In order to perform an effective continuous improvement within a system, both quantitative (statistical) and qualitative tools are highly employed. Continuous improvement takes place within the Deming’s famous P. D. C. A. (Plan- Do- Check- Act) improvement circle. Processes are constantly measured. A challenging improvement target is determined and compared to the current situation. Improvement suggestions are applied and processes are re-measured. The working or bettering suggestions are standardized. The cycle turns back to the measurement stage.

3.2 Total Productive Maintenance

As industries become more dependent on the reliability of their machineries and processes for adding value to their products or services within acceptable costs, a company-wide systematic management approach have been evolved exclusively to maintain and improve these industry imperatives. This approach is called Total Productive Maintenance (T. P. M.). Seiichi Nakajima, of the Japan Institute of Plant Maintenance (J. I. P. M.), is credited with pioneering the development of the approach through the stages of preventive (time-based) maintenance, productive (predictive/condition-based) maintenance and then into Total Productive Maintenance.

This is a holistic system that aims at maximizing machine/tool productivity, zero accidents, zero breakdowns and zero defects. It should include every party in a production process. T. P. M. is highly integrated in the lean production philosophy as well. It is no surprise though, since a just-in-time delivery; an on-time production rate and the continuous flow of production line are sustained through machines, tools and mechanisms. McCarthy and Rich (2004) cited from Rich (2002) the relations between T. Q. M., T. P. M. and the lean production, which is shown in Figure 3.7:

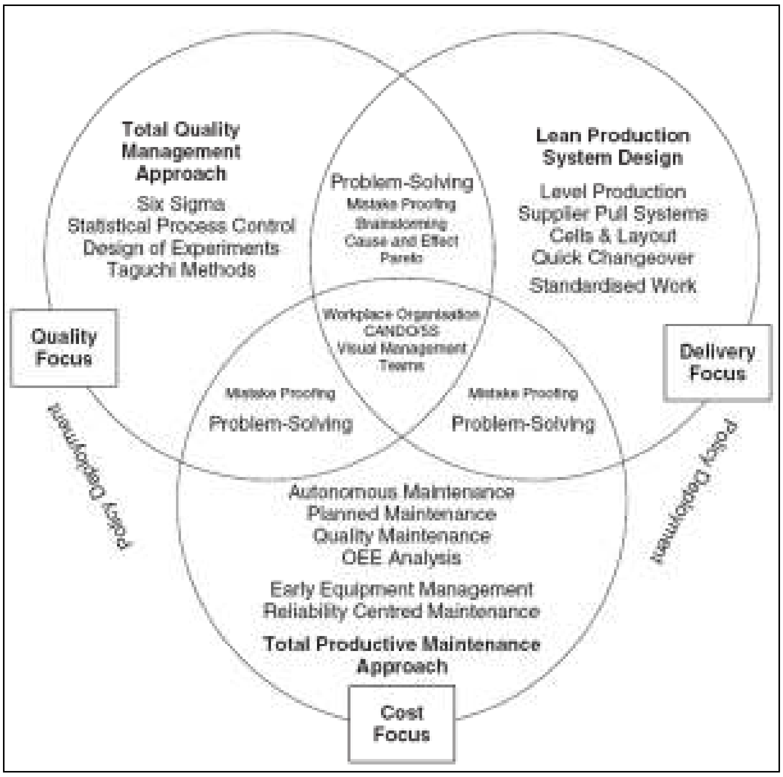


Figure 3.7- Relations between T.Q.M, T.P.M and The Lean Production System
(Source: Rich, 2002)

The measure of machine/tool effectiveness is calculated over the term Overall Equipment Effectiveness (O. E. E.). O. E. E. is directly proportional to the availability of a piece of equipment or process, its performance rate when running and the quality rate it produces (Willmott and McCarthy, 2001). The main factors affecting O.E.E and the real focuses of T.P.M are as follows (Willmott and McCarthy, 2001):

1. Breakdowns.
2. Set-ups and changeovers.
3. Running at reduced speeds.
4. Minor stops and idling.
5. Quality defects, scrap, yield, rework.

6. Start-up losses.

Availability is ensured and improved through the improvement of the first two factors. The machine or tool performance rate is proportional to the next two factors. The last two factors are concentrated to ensure the quality of a product. The main reasons of these factors are poor machine/tool condition, human defects and lack of understanding of the optimum machine/tool conditions. By calculating O. E. E., one can predict the machine/tool or mechanism that needs the most attention. Efficient equipment system is maintained by this way.

T. P. M. focuses on preventing breakdowns (preventive maintenance), "mistake-proofing" equipment (poka-yoke) to eliminate product defects, or to make maintenance easier (corrective maintenance), designing and installing equipment that needs little or no maintenance (maintenance prevention), and quickly repairing equipment after breakdowns occur (breakdown maintenance) (U.S. Environmental Protection Agency, 2006b).

The periodic maintenance work, which includes inspection, cleaning, lubricating, tightening and calibration performed by the operators, is called autonomous maintenance. T. P. M. assigns responsibility to operators, not a conventional maintenance team, to proactively identify, monitor and correct the causes of problems leading to some undesirable machine/tool related wastes. The implementation steps include; cleaning of working area, removal of concession around machineries/tools, creating checklists, training operators about the general working principles of machines/tools, implementing autonomous maintenance by training operators about the relationships between quality and machinery/tools, implementation of the housekeeping tools like the 5S, broadening and improving practices throughout the organization.

3.3 Hoshin Policy Deployment

Hoshin Policy Deployment (Hoshin Kanri) is a management style that generally constitutes the linkage between strategic plans and continuous improvement within a lean organization (Society of Manufacturing Engineers, 2006). It takes its roots from the American management style of Management by Objectives and the P.D.C.A circle. Kondo (1998) states that hoshin policy deployment is used to unite the company-wide efforts in terms of improvements. Top managers predict some challenging annual goals according to the organization's long term strategic vision. They focus on critical processes. Top managers discuss and seek a semi-informal consensus among his/her stakeholders or anyone who is in a significant position and will be affected. Once goals are predicted, each and every division's, subsidiary's, section's manager predicts his/her own goal, methodologies to reach these goals and metrics. A goal, its methodology and its metrics are grouped in the name "hoshin". An upper manager's hoshin is a basis for his/her subordinate to form his/her own hoshin. Subordinates discuss, review, and revise their hoshins with their superiors in terms of their applicability, their department's capacities, strengths and weaknesses. Each succeeding department evaluates itself in terms of its contribution to the annual goal. An ownership to the vision of an organization is tried to be created by this way. This kind of a policy deployment requires an empowerment culture in an organization.

3.4 Possible Benefits and Shortcomings of Lean Production

Lean production is strictly based on some principles, sensitive to deviations from plans. It can cause some problems in case of an uncalculated or unexpected situations like sudden material shortages or hazardous events. The 1996 Kobe earthquake in Japan was blamed for affecting lean production systems particularly. Pheng and Tan (1998) summarized possible benefits and shortcomings of the lean production system in Table 3.1:

Table 3.1- Possible Benefits and Shortcoming of the Lean Production System

Benefits	Shortcomings
Reduction in inventory level.	Being inflexible.
Reduction in storage space.	Being not responsive.
Reduction in factory overheads.	Possible disruption of workflow.
Reduction in production costs.	Possible increment of production costs.
Reduction in ratification costs.	Possible sabotaging from suppliers.
Improvement in quality.	Possible reduction in quality standard.
Improvement in productivity.	

(Source: Pheng and Tan, 1998)

3.5 Critical Discussions about Lean Production

Green and May (2003) criticize generalizing tones of the Egan report and others about improving construction processes. They state that there is an ideological filtering system in favor of some management practices. The benefits of some concepts are taken for granted without concrete systematic research. They mention that a considerable volume of literature which questions the applicability of the lean principles outside the Japanese culture and its recessive human resource management effects are not mentioned or taken into the account.

Green and May (2005) stated that there was an ambiguity about the perception and the definition of being leanness among industrial parties. They further underlined that managers and consulting firms had a mutual, beneficial relationship in terms of promoting and propagating some management fashions. Jackson (2001) states managers' eagerness in accepting management practices or “fashions” as panaceas. He furthers that this kind of an inclination is a physiological need. The contingency approach, which underlines the fact that there is no one best way to manage and each organization should tailor its own management activities to the particular circumstances, is observed to be overlooked to an extent by some lean thinking promoters.

Moralioglu (1999) states that Toyota divides its employees into four categories and only %30 of these employees has the privileges of life-long employment and intensive socio-economical support from the company. The rest of the employees have lesser rights or benefits and many of them are treated as seasonal workers. Green (1999) reported that the Japanese human resource management was based on life-long employment, promotion based on length of service and in-company union structure. Green (1999) furthered that the existing literature had paid minor attention to the subjects like Japanese companies' abolishment of life-long employment with investments in overseas and the globalization effect, the effect of physical proximity of suppliers to manufacturers in lean production and the effect of the Japanese protected home market to the success and the rooting of the lean production system.

Spar (2003) contributed to this argument by adding that the relatively low value of the Japanese yen against the U.S dollar especially before the early 1980s had contributed a lot to Toyota at the international competition. Starting from 1983, the Japanese yen has gained considerable value against the U.S. dollar and that reflected in important managerial changes in Toyota; such as increase in investment overseas, downsizing, reduction in the production volume and so on. The Japanese name the detrimental rise of the Japanese yen against the U.S dollar as "endeka".

Green (2002) states that complaints about overwork, stressful working environment, frequent overtimes, inflexibility, unlimited performance demands, unionization restrictions, and work intensifications are common in the lean manufacturing plants in Japan and overseas. Theories, promises and realities may not overlap in some cases.

3.6 A Summary of Lean Production

Picchi (2001) presented an extensive summary of lean production in terms of objectives, principles, core elements and practices. The summary is presented in Table 3.2:

Table 3.2– Lean Core Elements and Examples (Source: Picchi, 2001)

Objectives	***Principles***	***Core elements***		***Examples of related techniques***
Permanently improve company's competitive-ness by: - eliminating waste - consistently attending client's requirements in variety, quality, quantity, time, price	Value	Enhanced product / service package value	Solution that enhances value for the client	Identification of what is value for the client, services aggregation, business re-structuring
			Product variety	Modular design, interchangeability, fast set-up, planned variety compatible with production system
		Time based competition	Production lead time (order to delivery)	Small batches, product family factory lay-out, J.I.T
			Product development lead time	Black box system, heavyweight manager, set based design, concurrent engineering
	Value Stream	High value adding in the extended enterprise	Value stream redesign eliminating waste	Mapping, combining activities, eliminating non-adding value activities, supporting and promoting suppliers lean implementation
			Suppliers involvement in production and product development systems	Partnership, supplier training, black box system, J.I.T supply
	Flow	Dense, regular, accurate and reliable flow	Dense flow , with high adding value time, clear pathways and communication	Mapping, work cell, one piece flow, multifunctional worker, autonomation, product lay-out, design for manufacturing
			Regular flow - paced by client / next process demand	Takt time, kanban, one piece flow
			Accurate and reliable flow	TQC, statistical process control, poka-yoke, jidoka, Total Productive Maintenance (T.P.M)
		Standard work	Work standardization	Work instructions, work content, cycle time and standard inventory definition
			Transparency	Visual management, 5S
			Low level decision	Delegation, training
	Pull	Flexible resources	Information flexibility	Flexible information systems
			Equipment flexibility	Fast set-up, low cost automation, redundant equipment
			Workers flexibility	Multi-skill training, work cell

Table 3.2– Lean Core Elements and Examples (Cont'd) (Source: Picchi, 2001)

Objectives	*Principles*	*Core elements*		*Examples of related techniques*
Permanently improve company's competitive-ness by: - eliminating waste - consistently attending client's requirements in variety, quality, quantity, time, price	Pull	J.I.T. production and delivery	Pull versus push system	Kanban, takt time
			No overproduction, W.I.P (Work In Process) reduction	Kanban, standard inventory, F.I.F.O: first-in-first-out, small batches, one piece flow
			Demand smoothing : harmonizing market variations and production flexibility	Anticipation (Master plan), Peaks negotiation (Dealers system)
			Reflecting product variation in short periods of production	Heijunka, fast set-up, small batches
	Perfection	Learning	Fast problem detection	No buffer, no stock, kanban, small batches, one piece flow, first-in-first-out (F.I.F.O), visual management, 5S, decision in operator level
			Fast problem solving in lower level and solution retention	Empowerment, teamwork, Quality Control Circles (Q.C.C), 5 Whys, quality tools, kaizen
			Evolutionary learning	Kaikaku (dramatic changes), benchmarking
		Common Focus	Leadership and strategy	Strategic planning, Policy deployment, Hoshin management, managers in workplace
			Structure	Teamwork, hierarchy levels reduction, cross functional structure
			Client and production focus diffusion	Training, day by day coaching, leadership example
			Human respect	Laying off as the last resort, Job system, work meaning enrichment, participation, empowerment, recognition, agronomy, safety
			Total employee involvement	Suggestion system, Q.C.C., kaizen, job system, training system
			Total system diffusion	Techniques standardization, simplicity in communication, system and techniques application in all processes and in whole company

CHAPTER 4

LEAN CONSTRUCTION

The lean production philosophy, that had contributed to the manufacturing industry, took the attention of the people in the construction industry as well. Especially, since the early 1990s , a “lean construction” concept has been tried to be created and promoted by means of institutes, governmental reports, construction management scholars, some occupational organizations and so on. The most notable of the organizations that have been working solely for the development of the lean thinking in the construction industry are the Lean Construction Institute (L. C. I.) of the U. S. and the International Group for Lean Construction (I. G. L. C.). Louri Koskela was the first to introduce the lean movement in manufacturing to the construction industry. He hosted the first conference of the I. G. C. L. in Espoo, Finland in 1993. A group of researchers at the conference adopted the name “lean construction”.

The L. C. I, founded in 1997, has been publishing an international refereed journal devoted to lean construction practice and research since 2004. The journal is called the Lean Construction Journal (L. C. J.). The journal includes papers, reports and book reviews from industry practitioners and academia. The I. G. L. C. has been organizing yearly academic conferences, hosted by local universities from all over the world, since 1993. The 15th conference will be held in-between the 17th and the 22nd of July, 2007 in East Lansing, Michigan, U. S.

4.1 The Theoretical Background

The lean construction efforts are aimed at contributing to the construction industry via the lean motives and methodologies. This is not to say the direct copying of the applications from the manufacturing industry though. It would not be feasible due to the differences between the industries. Ballard and Howell (2003) explained the theoretical background of lean construction as follows: “We understand projects to be temporary production systems linked to multiple, enduring production systems from which the project is supplied materials, information and resources.”

Koskela (2000), underlining the fundamental goals of a production system as maximizing value, minimizing waste and delivering the product, explained the framework in which a production system is applied to construction. This pyramidal structure is made of, from bottom to top, methodologies/tools, concepts and principles. The pyramid is shown in Figure 4.1:

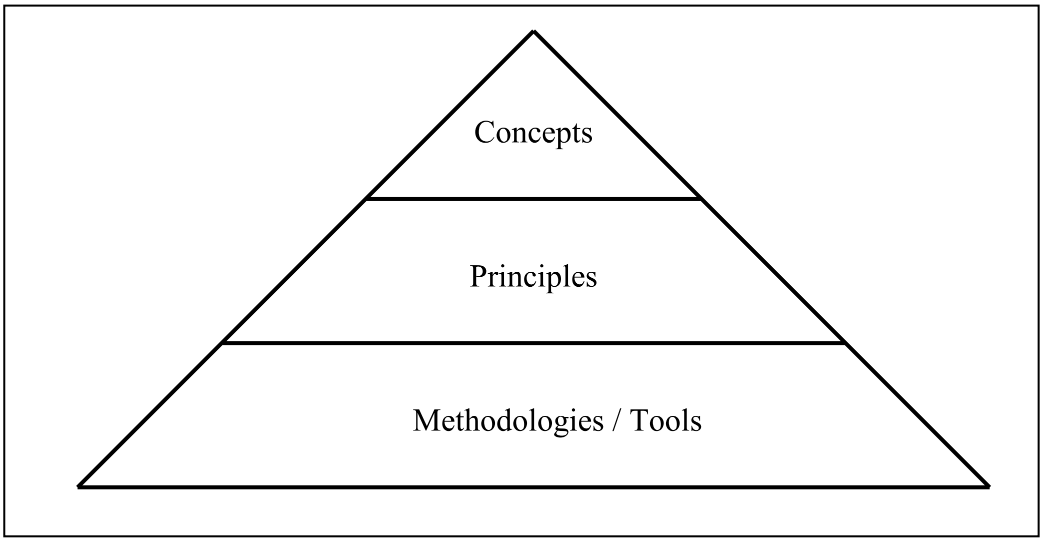


Figure 4.1- Application Framework of a Production System to Construction
(Source: Koskela, 2000)

On the other hand, perception of both manufacturing and construction as production systems, including processing stations and transfer of partially completed work by means of machinery and crews, enables some analogies. The goal is taking the basic lean motives such as elimination of waste, cycle time reduction, variability reduction, pull – driven production control, continuous flow and continuous improvement as pivotal points and developing methodologies and applications in the context of construction. Therefore, the lean contribution medium in construction is divided into roughly eleven chapters;

1. Theory.
2. Product development and design management.
3. Commercial and cost management.
4. Production system design.
5. Prefabrication, assembly and open building.
6. Supply chain management.
7. Information technology support for lean construction.

8. Production planning and control
9. Safety, quality and environment
10. People, culture and change
11. Implementation and performance measurement.

4.1.1 The Definition of Lean Construction

The Lean Construction Institute (2004) defines the term lean construction as:

> Lean Construction is a production management-based approach to project delivery -- a new way to design and build capital facilities. Lean production management has caused a revolution in manufacturing design, supply and assembly. Applied to construction, Lean changes the way work is done throughout the delivery process. Lean Construction extends from the objectives of a lean production system - maximize value and minimize waste - to specific techniques and applies them in a new project delivery process.

Abdelhamid defines lean construction as follows (Abdelhamid, "Lean Construction"):

> A holistic facility design and delivery philosophy with an overarching aim of maximizing value to all stakeholders through systematic, synergistic, and continuous improvements in the contractual arrangements, the product design, the construction process design and methods selection, the supply chain, and the workflow reliability of site operations.

Lean construction can be defined over a new production management based project delivery system that challenges the trade-off between time, cost and quality. Up to now, there are two important application channels of lean construction that have been utilized by companies around the world. One of them is a new project delivery system developed by the L. C. I. to design and build capital facilities. This delivery system is called the Lean Project Delivery System (L. P. D. S.). Howard and Ballard's Last Planner Production Control System is the other important application of the lean construction concepts and methodologies. Today, the researchers who are interested in lean construction have increasingly brought its concepts, principles and methodologies to the construction management departments of the universities and the construction industry of the U.K, the U.S., Finland, Denmark, Singapore, Korea, Australia, Brazil, Chile, Peru, Ecuador and Venezuela.

According to Howell (1999), managing construction under lean is different from the current practice because it;

- has a clear set of objectives for the delivery process.
- is aimed at maximizing performance for the customer at the project level.
- designs concurrently product and process.
- applies production control throughout the life of the project.

As the primary goal of the lean production system is to enable continuous flow of value creating activities with eliminating non value adding identities (waste), it would be appropriate to explain the main concept of lean construction from the perspective of construction waste.

4.1.2 T. F. V. Concept in Lean Construction

Waste is an inherent element of construction activities. It is hard to comprehensively quantify the level of waste though. In the construction literature, waste is observed to be investigated from the two main aspects; time waste and material waste. Time waste is researched in terms of worker productivity. Material waste is analyzed mainly due to the increasing awareness of construction and demolition debris related environmental effects. Emerging production philosophies, such as lean production, identify waste in a wider scope.

Koskela (1992) defined construction waste in his seminal report as: “any inefficiency that results in the use of equipment, material, labor or capital in large quantities than those considered as necessary in the production of a building”. He further stated that existing construction theory was predominantly based on conversion activities. Work is divided into smaller stages which are seen as conversion activities, independent of one another, that turn their input into some specific outputs. Improvement is believed to be realized by solely improving these conversion activities. This kind of perception of construction partially disables an understanding of interconnections and “flow” among activities as a whole. Koskela (1992) suggested both a conversion and a flow approach to construction.

Value adding and non-value adding activities coexist in a complex cycling flow of material, work, information, crew, space and external conditions such as; weather etc. Value adding activities are those that change material or information into something that the customer desires. In fact, there are three critical value adding stages in a production system. These are; design stage which includes engineering of a conception to a detailed level, information management which includes detailed scheduling, order taking, delivery and so on and transformation stage which includes the physical transformation of raw materials into something that customers desire (Koskela, 1992). Activities that add value to a product are conversion activities from the conventional view of construction management. Yet, waste is mainly rooted from the flow in which conversion activities take place. An example of waste in this sense is the high level of material and equipment inventories in the construction activities. This kind of a perception of construction constitutes one of the basic lean construction principles.

Ballard and Koskela (1998) mentioned that concurrent engineering, contrary to the solely conversion oriented conventional design practice, stresses conversion (sometimes referred as transformation), flow and value generation view in terms of construction design. They also clearly stated the main differences between these approaches through construction design.

Koskela (2000) later modified and expended this comparison in some ways and mentioned the differences between conversion (transformation) – flow and value management approaches in terms of physical realization of designed projects. The comparison is shown in Table 4.1:

Table 4.1– Comparison of T. F. V View in Design Realization

	Transformation view	*Flow view*	*Value generation view*
Conceptualization of production	As a transformation of inputs into outputs	As a flow of material, composed of transformation, inspection, moving and waiting	As a process where value for the customer is created through fulfillment of his requirements
Main principle	Getting production realized efficiently	Elimination of waste (non-value-adding activities)	Elimination of value loss (achieved value in relation to best possible value)
Associated principles	Decompose the production task Minimize the costs of all decomposed tasks	Compress lead time Reduce variability Simplify Increase transparency Increase flexibility	Ensure that all requirements get captured Ensure the flowdown of customer requirements Take requirements for all deliverables into account Ensure the capability of the production system Measure value
Methods and practices (examples)	Work breakdown structure, MRP, Organizational Responsibility Chart	Continuous flow, pull production control, continuous improvement	Methods for requirement capture, Quality Function Deployment
Practical contribution	Taking care of what has to be done	Taking care that what is unnecessary is done as little as possible	Taking care that customer requirements are met in the best possible manner
Suggested name for practical application of the view	Task management	Flow management	Value management

(Source: Koskela, 2000)

Lean construction initiative proposes a combined perception and application of conversion, flow and value managements (sometimes referred as T. F. V. theory) instead of a solely conversion oriented management. The ultimate goal is to create value for customers.

One important question about these views is how they will apply simultaneously in order to execute a construction project. Bertelsen and Koskela (2002) summarized the combined application approach as follows:

- Integration: In each managerial situation, all three views must be acknowledged.

- Balance: In case of contradictory principles, a balance should be sought.
- Synergy: The synergy between the three views should be utilized.
- Contingency: All views have not necessarily the same weight in each situation. Depending on conditions, the critical view for success should be predicted.

4.1.2.1 The Production Roots of T. F. V View

Abdelhamid (2004) states that conversion (transformation) – flow – value based views of Koskela and others are a reflection of craft – mass – lean production systems respectively. This combines reflection is shown in Figure 4.2:

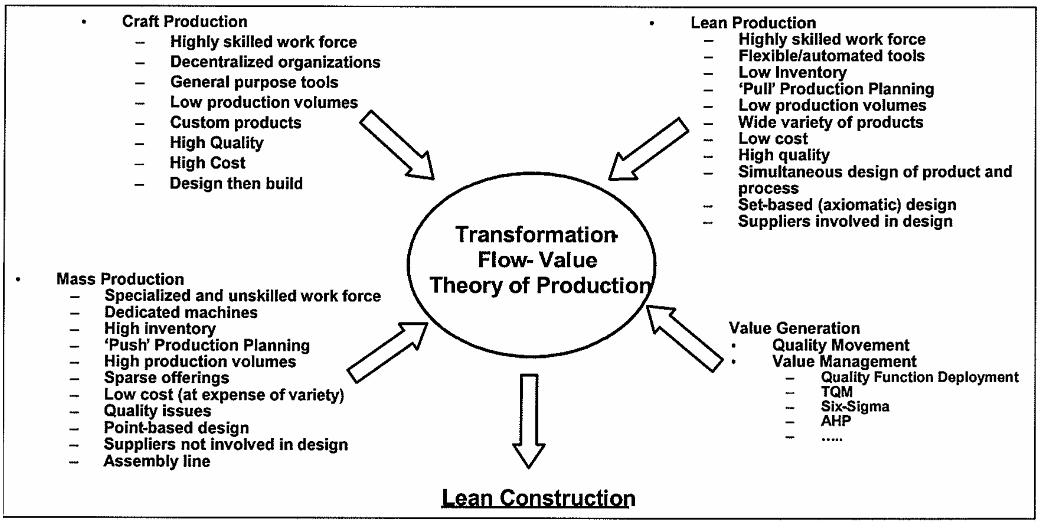


Figure 4.2- Production Roots of T. F. V View
(Source: Abdelhamid, 2004)

Bertelsen (2003) suggests that construction should be modeled in accordance with dynamic chaos - complex systems theory as it possesses chaotic - complex systems' attributes; autonomous agents, undefined values, fuzziness, nonlinearity and mutuality. Chaos theory claims that it is impossible to precisely predict attributes of a complex system at a certain time; rather general patterns and behaviors can be predicted. Bertelsen (2003), within this context, claims that construction should be understood in three complementary ways, namely, as a project-based production process, as an industry that provides autonomous agents, and as a social system.

Abdelhamid (2004) proposed a possible lean construction frame for future, incorporating conversion (transformation) – flow – value perception and chaotic – complex system view of construction. This possible future is shown in Figure 4.3:

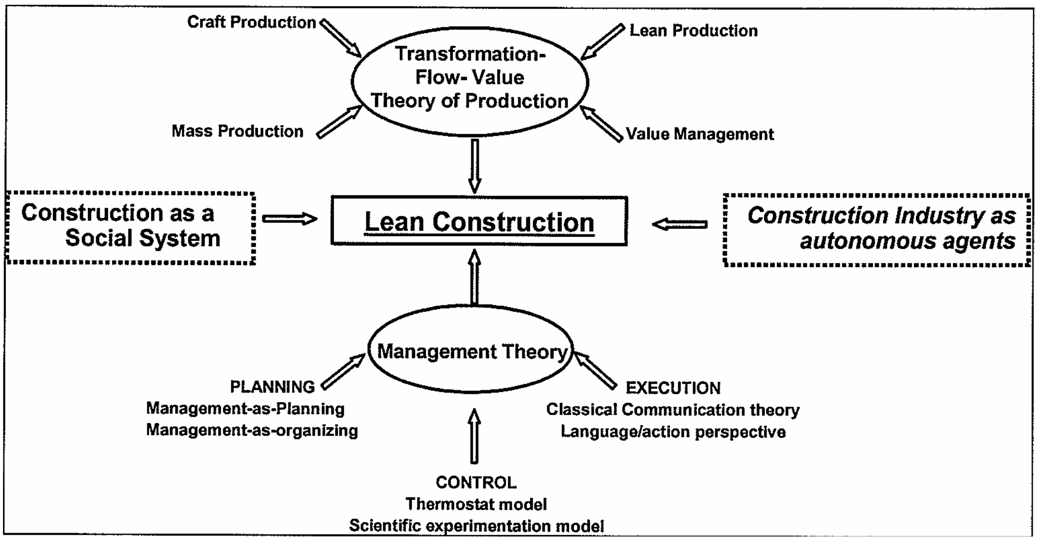


Figure 4.3- Possible Future of Lean Construction (Source: Abdelhamid, 2004)

4.1.2.2 The Main Principles of T. F. V Concept

Remembering the pyramidal production system application framework in Figure 4.1, the combined conversion (transformation), flow and value generation based view of construction is thought to constitute the concept portion of the pyramid. Based on Koskela' s (2000) work, the principles of conversion (transportation), flow and value management are summarized in Table 4.2:

Table 4.2- The Main Principles of T. F. V. Concept (Source: Koskela, 2000)

	Concept		
	Conversion(Transformation)	Flow	Value
Principles	***Decomposition:*** The transformation process can be decomposed into sub processes which are also transformation processes. ***Cost minimization:*** The cost of total process can be minimized by minimizing the cost of each sub process. ***Buffering:*** It is advantageous to insulate the production process from external environment through physical and organizational buffering. ***Value:*** The value of the output of a process is associated with the cost of inputs to that process.	***Reduce the share of non-value adding activities:*** Try to eliminate the reasons of waste that were defined by Shingo, Womack and Jones. ***Reduce the lead time:*** Basically, eliminating non-value activities will cause a reduction in the lead times. ***Reduce variability:*** Variability increases the lead time. ***Simplify:*** Reduce the number of components in a product or the number of steps and linkages in a material and/or information flow. ***Flexibility:*** Increase mix flexibility, volume flexibility, new product flexibility and delivery time flexibility. ***Transparency:*** Increase transparency by making the main flow of operations from start to finish visible and comprehensible to all employees.	***Requirements capture:*** Ensure that all customer requirements, both explicit and latent, have been captured. ***Requirement flow-down:*** Ensure that relevant customer requirements are available in all phases of production, and that they are not lost when progressively transformed into design solutions, production plans and products. ***Comprehensive requirements:*** Ensure that customer requirements have a bearing on all deliverables for all roles of customer. ***Capability:*** Ensure the capability of production system to produce products as required. **Measurement of value:** Ensure by measurements that value is generated for customers.

4.1.2.3 Non – Value Adding Activities

Formoso, Isatto and Hirota (1999) defined non-value adding activities as: “any losses produced by activities that generate direct or indirect costs but do not add any value to the product from the point of view of the client”. This is the general definition of waste via activities actually. Formoso Isatto and Hirota (1999) further classified waste into two groups; avoidable and unavoidable waste. In unavoidable waste, the necessary investment to reduce waste is higher than the benefit from reducing that waste. In avoidable waste, the benefits from reducing waste are significantly higher than the cost of reducing that waste. Non-value adding activities are also divided into two; necessary non-value adding activities and unnecessary non-value adding activities. Examining projects on-site can be an example of necessary non-value adding activities. Waiting for materials on site to start a conversion activity is an example of unnecessary non-value adding activities. The basic motive of eliminating non value activities is reducing lead or cycle time in construction. Koskela (2000) defined lead time as “the time required for a particular piece of material to traverse the flow”. This traverse often includes processing time, inspection time, waiting time and move time. Figure 4.4 depicts the positive effect of continuously reducing non-value activities (waste) on cycle time in a flow:

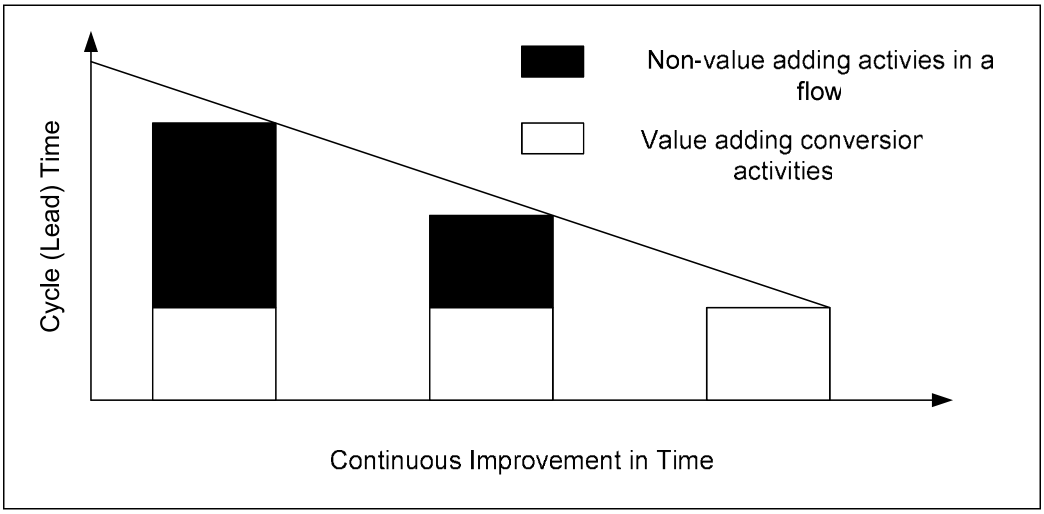


Fig 4.4- Effect of Waste Reduction on Cycle Time
(Source: Koskela, 1992)

Ohno (1998) stated that the short term focus must be on the unnecessary non-value adding activities as they consist of many improvement opportunities. Necessary non-value adding activities can be lessened in time with great care, continuous efforts and with the help of new managerial and technological tools as well. The waste classifications made by Ohno (1998) and Womack and Jones (1998) that were mentioned in Section 2.2.1.6 are of the primary waste references for lean construction researches.

4.1.2.4 The Effect of Variability

The recognition of the importance of flow enables to understand the critical effect of variability. The mathematical meaning of variability is the standard deviation of the rate of progress of an activity. The standard deviation of the number of steel members erected per day in a construction site is an example of variability in construction. Koskela (2000) categorized variability into two; process time variability and flow variability. Process time variability refers to conversion variability or variability of direct processing time at a workstation. Flow variability, on the other hand, refers to the variability of the arrival of jobs to a workstation.

According to Koskela (1992), variability in workflow in a production system increases activity cycle times and reduces output by increasing waste in processes. Tommelein, Riley and Howell (1999) clearly demonstrated over a simple dice game that the amount of workflow variability in a single-line construction production system (activates are connected with finish – to –start relationship) in which production rates were determined by dices, had led ineffective usage of production capacity, considerable amount of buffer between activities and all in all an inconsistent production system. Howell (1999) explained the effect of variability with a freeway analogy. On a freeway, as gaps between cars decrease, the impact of variability in the speed of each and every car over the traffic load of the freeway increases. Under the conditions of dependence and variability, high speed at any moment does not guarantee minimum travel time. Thus lean construction advices reduction of variability rather than an excessive emphasize on speed.

Thomas et al. (2002), after investigating 14 concrete formwork project data, state that variability in labor productivity has more impact on project success than workflow variability in most cases. They additionally stressed the importance of material, equipment, labor and information availability on flow reliability. Abdelhamid and Everett (2002) listed some of the causes of variability in construction as: late delivery of materials and equipment, design errors, change orders, equipment breakdowns, tool malfunctions, improper crew utilization, labor strikes, environmental effects, poorly designed production systems and accidents.

4.1.2.5 Six Sigma

Recently, some methodologies emerged in the manufacturing environment has been implemented in construction in order to reduce these variability problems. One of the major methodologies is Six Sigma. It was initiated and developed in the early 1980s by Bill Smith in Motorola. It aims at creating value for customers by reducing variability in products and services by means of statistical tools based on a sound cultural shift towards perfection. Since then, it has been utilized by many organizations, especially in the manufacturing environment. In the construction industry, Bechtel Company announces that it has been utilizing Six Sigma in various projects (Bechtel Company, “Six Sigma: The Way We Work”).

Pheng and Hui (2004), displaying an application example of Six Sigma in construction, described Six Sigma as follows:

> Six Sigma is a statistical measure used to measure the performance of processes or products against customer requirements. This is known as the ‘‘technical’’ definition of Six Sigma; and Six Sigma is a ‘‘cultural and belief’’ system and a ‘‘management philosophy’’ that guide the organization in repositioning itself towards world-class business performance by increasing customer satisfaction considerably and enhancing bottom lines based on factual decision making.

The system employs the renowned D. M. A. I. C. (Define, Measure, Analyze, Improve, Control) cycle. It involves combined utilization of various statistical and quality engineering tools like Design of Experiments or Pareto Analysis in order to define customer needs, measure the existing situation of processes, products or/and services, analyze root problems, improve problematic points by necessary modifications and control and monitor modified processes. Organizations invest in educating their employees for Six Sigma. These educated employees run Six Sigma projects in organizations and are called, in order of their level of knowledge and experiences, as green belts or black belts. Black belts are full time Six Sigma project executers that get extensive training. Green Belts, on the other hand, have supportive roles and do not need education about Six Sigma as extensive as black belts.

Statistically speaking, Six Sigma aims at reducing the standard deviation (σ- sigma) of a specifically predefined attribute of an output of a process, which fits on a normal distribution curve, to squeeze the standard deviation around the ideal value for that specific attribute in between the lower and the upper specification limits. The ultimate goal is fitting $\pm 6\sigma$ in between the constant lower and upper specification limits in time. In other words, it tries to sharpen the tip of the normal curve based on output's predefined attribute. The more σ is squeezed, the lesser the amount of outputs that lie outside the upper and the lower limits. Thus, outputs lie predominantly in between the accepted limits. Detailed information can be found in Pheng and Hui (2004), Abdelhamid (2003) and Pande, Nueman and Cavanagh (2004).

George (2002) claimed that the mutual usage of the lean philosophy with Six Sigma is supplementary. According to the author, the lean philosophy will help processes speed up. Six Sigma, on the other hand, will bring processes under statistical control which will contribute to the improvement of process quality. Academic studies about Six Sigma is abundant, especially in the business administration, mechanical and industrial engineering disciplines. The civil engineering and construction management literature, on the other hand, seems lacking in that aspect.

4.1.2.6 Simplification

Simplification refers to elimination of components in a production system. The importance of simplification is rather clear. Complexity can make systems more unreliable. Simpler systems reduce cycle times, increase worker productivity. A complex system costs more than the sum of its each and every component's cost (Koskela, 2000). As processes between an input and output increases, the unavoidable variability in each process in between, reflects exponentially to the output. Reducing non-value adding activities will directly contribute to simplification of a production system.

4.1.2.7 Flexibility

Flexibility is divided under four categories; mix flexibility, new product flexibility, volume flexibility and delivery time flexibility (Koskela, 2000). Mix flexibility refers to the adaptation capability of a production system to interchange among different products. New product flexibility refers to the speed of introducing a new product by customer desires. Volume flexibility refers to the adaptation capability of a production system to produce different amount of products. Delivery time flexibility refers to the adaptation capability of a production system to deliver products at different times.

4.1.2.8 Transparency

Transparency will help parties involved to better understand the conditions of the production system, the current situation, the desired goals and expectations. It also helps to simplify especially the information flow in a production system and supports to make people feel responsible and take initiatives accordingly.

Ballard (1999) suggested several production techniques that will help to decrease the amount of non value adding activities and stabilize the production processes:

- Stop the line whenever defects are recognized.
- Procure materials by a pull-type production system.
- Reduce lead time by increasing flexibility against variation.
- Design pre-planning to prevent delay and to provide a buffer.
- Apply production system process transparency to decentralize decision making.

Thomas and Horman (2006) states that lean construction correctly promotes improving flow to improve performance and in order to improve the flow in construction; equipment availability and worker utilization must be improved. Their suggested workforce management model includes some lean production concepts like multi-skilled, flexible-sized work teams.

4.1.3 Literature Review on Construction Waste

Formoso Isatto and Hirota (1999) divided stages of construction in which the construction waste occurs into two:

1. Processes preceding construction operation such as; design, planning, material manufacturing and so on.
2. Operational construction stage.

Bossink and Brouwers (1996) classified stages of construction that generates waste into six groups:

1. Design.
2. Procurement.
3. Materials handling
4. Operational
5. Residual (Debris)
6. Other (Theft etc.)

Garas, Anis and Gammal (2001) identified the material and the time related wastes in construction as follows:

Material waste due to:

1. Over-ordering
2. Overproduction
3. Wrong handling
4. Wrong storage
5. Manufacturing defects
6. Theft or vandalism

Time waste due to:

1. Idle (waiting periods)
2. Stoppages
3. Clarifications
4. Variation in information
5. Re-work
6. Ineffective work (errors)
7. Interaction between various specialties

8. Delays in plan activities
9. Abnormal wear of equipment

Koskela (1993), within this context, stated that from 6 to 10% of the total cost of constructions in the U.S and Sweden had been waste. Another striking work is about working times of workers. Horman and Kenley (2005), through the meta analysis of 26 works on workers' productivity in building projects, stated that an average of %49.6 with a standard deviation of %11.9 of the total working time of construction operating times had been waste. Zhao and Chua (2003), performing a neural network analysis on various 8 projects from a flow point of view, stated the most man-hour consuming wastes in order of importance:

1. Waiting due to crews interference
2. Waiting due to inspection
3. Equipment used by other crew
4. Waiting due to equipment's installation
5. Waiting for instruction
6. Rework due to design change
7. Stock problem
8. Material vendor delay

Material waste has both economical and environmental effects. Generally material waste is investigated material by material as each and every material has its own utilization path and ultimately own waste character. Bossink and Brouwers (1996) stated that %9 of total purchased materials by weight in the Dutch construction industry had become waste. Formoso et al. (2002), after investigating two researches in the late 1990s in Brazil about material waste in building projects, conclude that:

- Most of the wasteful practices can be reduced by changing managerial practices in terms of design, procurement and production stages, without investing much.
- Contractors are not aware of the high level of waste in their activities. Thus, they are unable to take these relatively easy precautions.
- Mostly, performance measures are solely financial. Contractors lack in taking organized records of their procurements, inventories, material usage and so on. This fact enables a lack of transparency in operations, making a healthy determination of the operational costs harder.
- Most of the material waste is caused by the lack of managerial attention on flow activities. Managers are predominantly conversion activity oriented.
- Material waste increases the number of non-value adding activities and promotes other wastes in worker and equipment utilization time.
- Pre - assembled, pre - cut or modular construction materials are proposed to be utilized in order to lower the material waste.
- Managerial problems, preceding the production stage like; coordinating design, planning construction layout, detailing of projects, lack of procurement planning are of the most important roots of the material waste in combination with insufficiently trained workforce.
- Deviations in dimensions of components such as; slab thickness have important impacts on the material waste.

4.1.3.1 Construction Waste in Turkey

Polat and Ballard (2004), performing a time and material oriented waste survey on 116 contractors in Turkey, stated the main causes of waste among Turkish contractors. These causes are, in order of importance, as follows:

Material waste due to:

1. Ordering of materials that do not meet the project requirements defined on design documents.
2. Imperfect planning of construction.
3. Workers' mistakes.

Time waste due to:

1. Delay in material supply.
2. Waiting replacement of materials that do not meet the project requirements defined on design documents.
3. Irregular cash flow.

Polat and Ballard (2004) also proposed some lean construction techniques to reduce these wastes in the Turkish construction industry.

Off-site production of construction components is widely advised in order to reduce waste. According to Gibb and Isack (2003), off-site production of components improves productivity and quality, reduces workforce need and simplifies construction processes. In Turkey, reinforced concrete structural systems are predominantly preferred. Contractors also widely prefer on-site production of reinforced concrete components rather than pre-cast concrete components or modular elements.

Polat and Ballard (2006), underlining the positive impacts of pre-cut and pre-bent reinforcement bars over the waste reduction in reinforced concrete construction, stated the driving and the restraining forces behind off-site prefabrication of reinforced concrete bars in the Turkish construction industry. These forces are shown in Figure 4.5 :

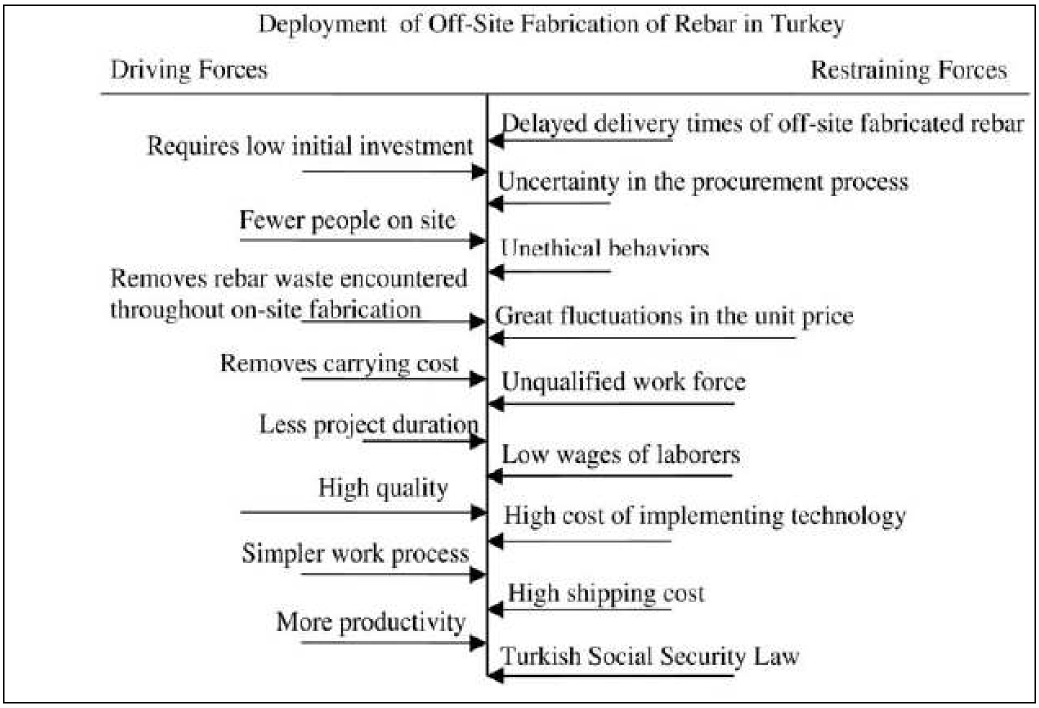


Figure 4.5- Driving and Restraining Forces Behind Off – Site Fabrication of Rebar in Turkey
(Source: Polat and Ballard, 2006)

The author of this thesis thinks that these driving and restraining forces behind off – site fabrication of rebar in Turkey can be taken as the basis for the understating of the conditions of pre – fabricated, pre – assembled construction members' utilization in Turkey.

4.1.4 The Hierarchy of Targets in Lean Construction

As lean construction claims to be a new perspective for construction, it is expected to propose some new, at least for the construction world, methodologies/tools to realize its concepts and principles. Without these realizations, the term would be stuck in an abstract world. Since the basic concept of lean construction is the addition of flow and value management efforts to the conventional conversion(transformation) management, a new approach to planning, execution and control of projects is required.

Lean construction approaches to construction projects as temporary production systems. Thus it is necessary to define the primary goals of these temporary production systems. Ballard et al. (2001) defined hierarchically the business objectives of project-based producers for the whole construction process. These objectives are shown in Figure 4.6:

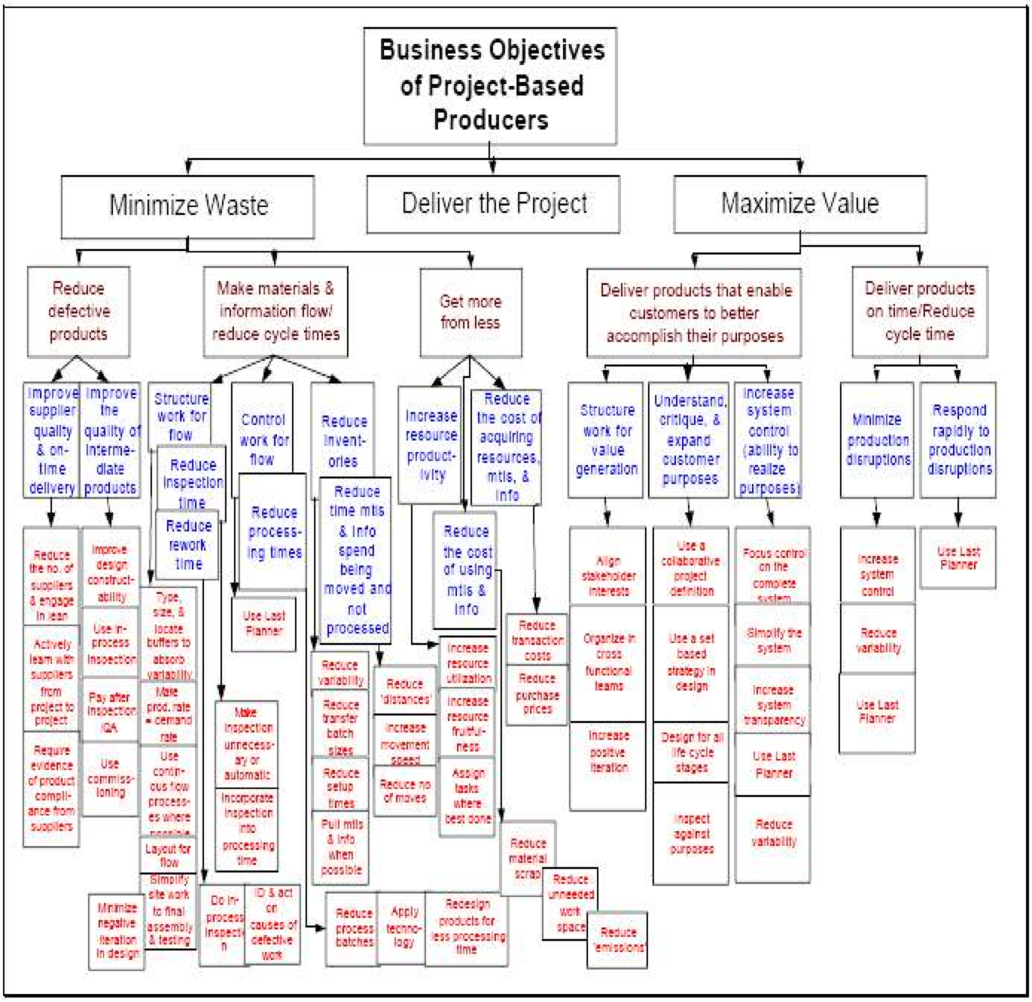


Figure 4.6- The Hierarchy of Targets in Lean Construction

(Source: Ballard et al., 2001)

Ballard et al. (2001) mentioned that the weight of importance of these objectives should have been determined depending on conditions. The integration, balance, synergy and contingency principles are valid in these determinations as well. The authors also added that the primary metrics that define the success of a production system should have been based on the second level criteria: reduce defective products, make materials and information flow, get more from less, deliver products that enable customers to better accomplish their purposes and deliver products on time.

4.2 The Lean Project Delivery System

Under these ultimate goals, main principles and concepts, lean construction offers a different application medium for delivering projects. The L. C. I calls this project delivering framework as the Lean Project Delivery System (L. P. D. S.). For the time being, the L. P. D. S. consists of 13 modules, 9 of which are interconnected within 4 phases. These phases are called; project definition, lean design, lean supply, lean assembly and use. There are also 2 other modules that extend from the beginning till the end; production control and work structuring. The framework is claimed to be especially effective in complex, quick and uncertain projects. Although L. P. D. S. was not created solely for construction projects, frequently being complex, uncertain and under time pressure, construction projects seem to suit well in this delivery system. The delivery system is shown in Figure 4.7:

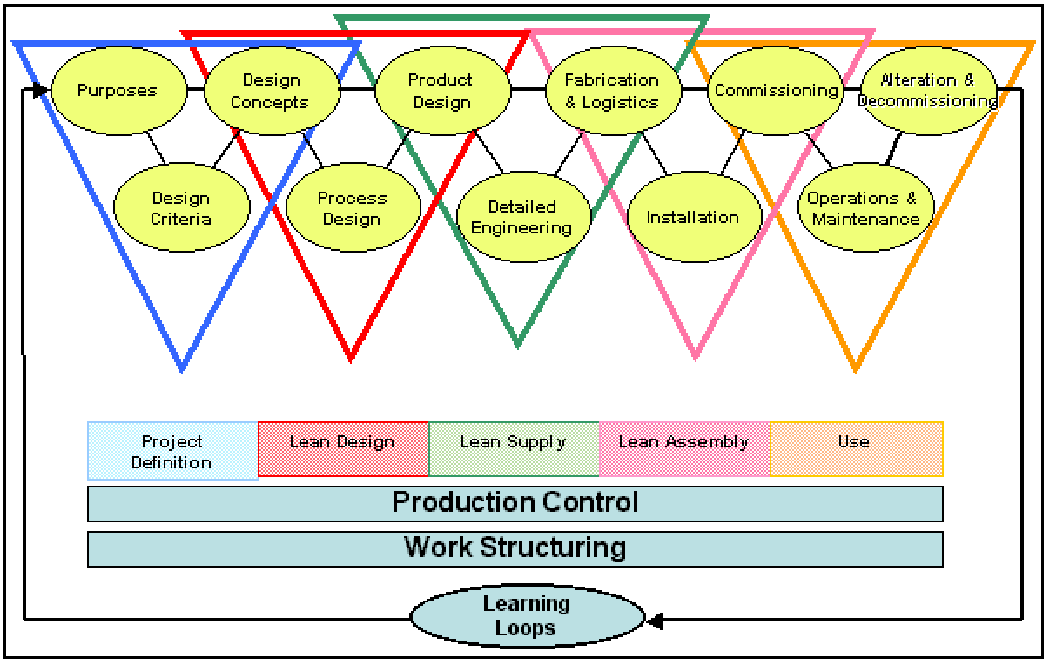


Figure 4.7- The L. P. D. S. Model (Source: Ballard, 2000a)

Ballard (2000a) indicated the important features of the L. P. D. S. :

- The project is structured and managed as a value generating process.
- Downstream stakeholders are involved in forward planning and design through cross functional teams.
- Project control has the job of execution as opposed to reliance on reactive variance detection.
- Optimization efforts are focused on making work flow reliable as opposed to improving productivity.
- Pull techniques are used to govern the flow of materials and information through networks of cooperating specialists.
- Capacity and inventory buffers are used to absorb variability.
- Feedback loops (learning) are incorporated at every level, dedicated to rapid system adjustment.

The project definition phase consists of purposes, design criteria and design concept. The lean design phase consists of design concepts, process design and product design. The lean supply phase consists of product design, detailed engineering and fabrication and logistics. The lean assembly phase consists of fabrication and logistics, installation and commissioning. The use phase consists commissioning, operations and maintenance and alteration and decommissioning. The detailed explanations of these phases can be found in Ballard (2000a).

4.2.1 Work Structuring

Ballard (2000a) defined work structuring as “the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts.". Work structuring aims at reliable and quick work flow by means of integrated process and product design. Along with continuous flow, it also underlines an increased pre assembly utilization where it is possible. According to Ballard (1999) work structuring answers to these questions:

1. In what quantity will work be assigned to worker groups?
2. How will these work quantities be sequenced trough worker groups?
3. In what quantity will work be released from one worker group to another?
4. Where will decoupling buffers be needed between worker groups? Decoupling buffers are utilized where there is an expected variability in quality, material supply and production quantity.
5. What will the size of these decoupling buffers be? The size of these decoupling buffers are determined by means of production capacity and material inventory.
6. When will different amounts of work be done?

Tsao et al. (2004) state that work structuring is a dynamic process that focuses on the whole system design at the initial phases of projects and at the later phases, coordinates execution of projects as designed, within interacting work pieces. Tsao et al. (2004) claim over a door frame case study that the current discrete contracting approach and work breakdown structuring mentality to construction hampers system view and causes lost opportunities.

Ballard (1999) identified three types of flows in a construction process: engineering, procurement and construction. Work structuring determines these flows that eventually produce the end-product. Ballard (1999) proposed process/supply chain mapping, team scheduling and locating and sizing buffers techniques while structuring work. Figure 4.8 shows these interacting flows.

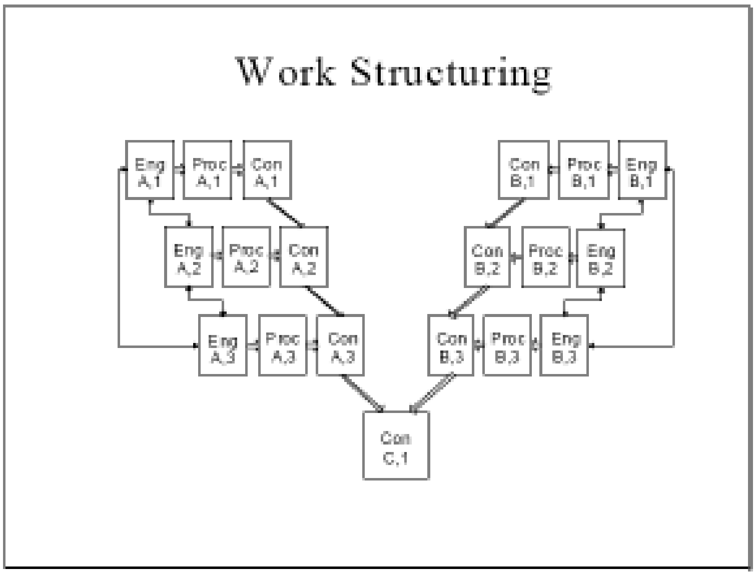


Figure 4.8- Work Structuring Model
(Source: Ballard, 1999)

The final product of work structuring is phase schedules (Ballard and Howell, 2003). These schedules constitute a basis for the Last Planner System. Phase schedules are formed by working back from a target completion date of a master schedule together with production teams, that are responsible for physical realization of a project. These teams interact with each other and decide on initial, rough sequences and quantities for the works that they are responsible for. Then, this basic phase plans are reviewed and reorganized taking into account scheduling imperatives. The final phase plans are presented to the approval of production teams again and they are asked to think ways to increase floats between activities. Once a phase schedule is approved by team members, the Last Planner System is initiated.

4.2.2 The Last Planner System

Production control is realized by the Last Planner System. In fact, Last Planner is one of the most concrete and innovative contributions of the lean construction efforts to the construction management body of knowledge. Although it is still developing, the idea was initiated by Glenn Ballard and Gregory Howell in 1997. Its main feature is that it aims at a workflow and production unit control in a “pull” manner (Ballard, 2000b). It is main metric is Percent Plan Complete (P. P. C.).

The conventional project control is based on determining deviations from a baseline and taking corrective actions if possible. Its main motives are time and cost. Time control is realized by monitoring work progress and cost control is realized by monitoring efficiency and productivity of the necessary resources. Planning means determining “should be done” activities. Tracking is performed by means of determining “did” activities. The difference between “should be done” activities and “did” activities is where some corrective actions are taken. It is rather a reactive approach. By the lean terminology, it is also a push planning system. Figure 4.9 depicts a “traditional” push planning system:

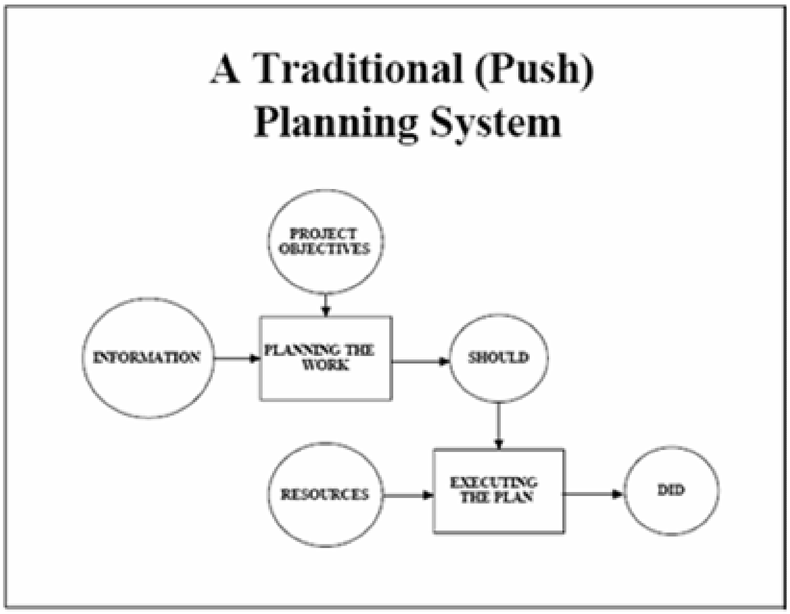


Fig. 4.9- A Push Planning System
(Source: Ballard, 2000b)

The Last Planner System transforms “should be done”, which surfaces from the requirements of a master schedule, into “can be done” (Ballard, 2000b). “Can be done”s are determined by considering the applicability of “should be done”s, taking the constraints into the account. From “can be done” activities, a weekly or daily “will be done” activity plan is formed. By proportioning “did” activities to “will be done” activities, P. P. C. is determined. The person, who decides whether the work is ready to be physically executed at the operational level, is the Last Planner. A Last Planner can be a construction or shop foreman or a design head. The point here is an attempt to create a more pull driven planning and control system in order to increase the flow reliability. Figure 4.10 shows the basic idea behind the Last Planner System.

Production control is sustained by P. P. C. and workflow control is realized by a lookahead system (Ballard, 2000b). The whole process is shown in Figure 4.11.

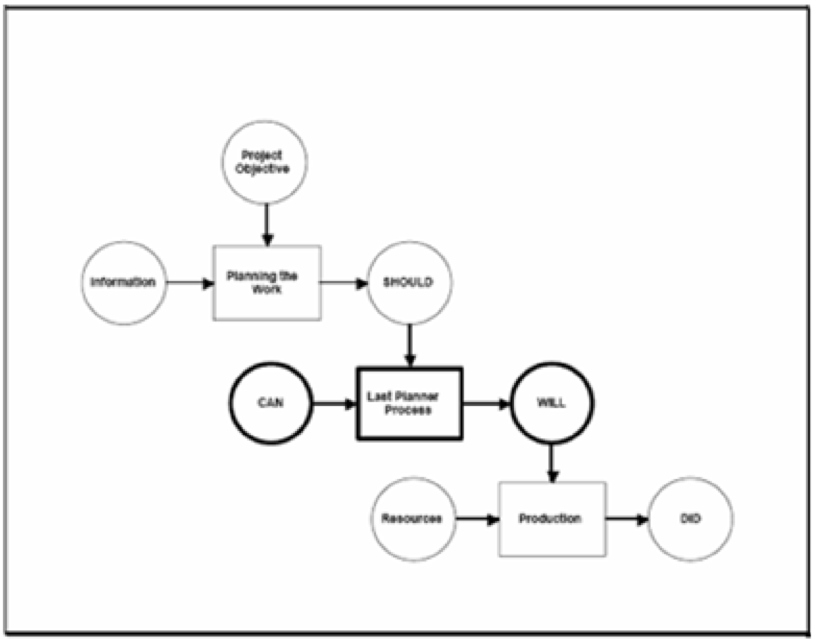


Figure 4.10- The Last Planner System (Source: Ballard, 2000b)

Master and phase schedules, based on design criteria and work structuring process, are determined.

Lookahed plans, a detailed thinking of assignments for production units, generally from 3 to 12 weeks ahead in terms of constraints, are constantly determined. If some assignments are thought to be inapplicable at an initially planned date, these assignments are not allowed to retain their originally planned durations.

"Can be done" assignments, determined in lookahead plans, are brought to another planning level which incorporates in the interconnections with other production units. At this stage, last planners of downstream and upstream production units decide together on a workable backlog for each production unit. This kind of planning constitutes a more "pull" planning practice. These workable backlogs generally consist of a several weeks of workload for a production unit.

From his/her workable backlog, a last planner constitutes his/her weekly work plan, again taking into account the applicability of the chosen assignments. This final work plan consists of “will be done assignments”.

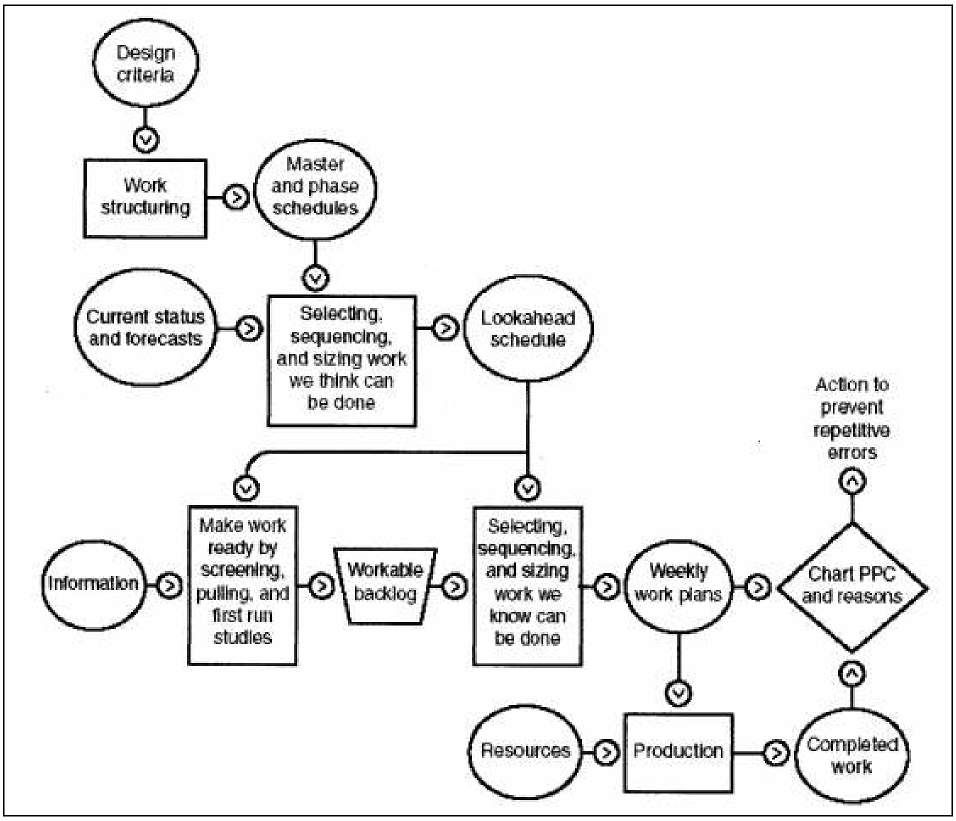


Figure 4.11- The Last Planner Process

(Source: Ballard and Howell, 2003)

At the end of each week, P. P. C, the ratio of “did” assignments to “will be done” assignments in a weekly work plan is calculated. A relatively small P. P. C. indicates a poor planning practice for a production unit. The reasons for deviations are investigated. That kind of investigation constitutes a learning atmosphere and enables better planning at the earlier stages of the process.

Up to this point, the main concepts, principles and the delivery system offered by the lean construction movement have been addressed. The remaining part of the lean construction topic will be on the techniques, methodologies and tools employed in the lean construction efforts.

4.3 Methodologies/Tools in Lean Construction

Paez et al. (2005) classified the operative techniques utilized in lean construction through three levels. The classification is summarized in Table 4.3:

1. Level One: Direct application of the techniques from lean manufacturing.
2. Level Two: Modification of the techniques taken from lean manufacturing.
3. Level Three: The all-in-all lean construction specific techniques.

Table 4.3- Classification of Methodologies/Tools

Levels	Lean Construction Technique	Related Lean Manufacturing Technique
Level One	- Material Kanban Cards	- Kanban System
Level Two	- Visual Inspection - Quality Management Tools - Concurrent Engineering	- Visual Inspection (Poka-Yoke Devices) - Multifunctional Layout - T.Q.M - Standard Operations - Single Minute Exchange of Dies (S. M. E. D.)
Level Three	- Last Planner - Plan Conditions of Work Environment (P. C. W. E.) - Daily Huddle Meetings	- Kanban System - Production Leveling - Toyota Verification of Assembly Line (T. V. A. L.)

(Source: Paez et al., 2005)

Salem et al. (2006) sorted the techniques employed in lean construction by their utilization goals through a real world case study. This classification is shown in Table 4.4:

Table 4.4- Utilization Goals of Methodologies/Techniques

Goal	Flow Variability	Process Variability	Transparency	Continuous Improvement
Lean Construction Technique	- Last Planner	- Fail Safe for Quality	- 5S - Increased Visualization	- Huddle Meetings - First Run Studies

(Source: Salem et al., 2006)

Although these techniques can be applied separately, their complementary nature proposes that a combined utilization of techniques will increase leanness of a construction organization. It would be explanatory to take a glance at these techniques.

4.3.1 Material Kanban Cards

Material kanban cards have the same functionality as the kanban system of lean manufacturing. It is used to supply necessary materials to the site just-in-time to avoid lack of materials, which seriously disturbs the flow of any construction site. They both aim at reducing inventory and promoting pull-driven production. Arbulu, Ballard and Harper (2003) presented the application of the kanban system to deliver consumables, personal protective equipment, hand tools, power tools and consumables for power tools from suppliers to a big (5000 workers at peak) and spread construction site on a just-in-time bases. The system includes marketplaces, satellite stores, internal and external “milk run” (predefined, constant routes) vehicles, supplier kanbans and an inventory management system. Marketplaces are the main warehouses, which are the main distribution area. Materials are distributed from marketplaces to various satellite stores on the site. These satellite stores function as collective points of materials for workers. Materials are transported from suppliers to marketplace by external “milk run” vehicles. These materials are delivered then from marketplace to satellite stores by internal “milk run” vehicles. Some standardized plastic bins are used as kanban cards to pull materials from suppliers. On the other hand, communication between satellite stores and marketplaces are maintained by written or verbal order forms. The case is important as it shows a direct application of the kanban system in manufacturing and challenges “the big batch” mentality of the construction industry.

4.3.2 Increased Visualization

Increased visualization is a technique that promotes transparency in lean construction. Salem et al. (2006) described some exemplary practices about visualization. One of them is commitment charts. In commitment charts visualization practice, the vice president of a construction company (or any other top senior) addresses to the staff about the importance of their health and safety for the company. At the end, all employees sign a commitment pledge and this pledge is posted on trailers. Another practice is employing safety and warning signs, that were designed with unusual expression by the construction staff itself to take more attention. One other way of improving visualization is to let employees know the milestones or the current situation of a project through visual apparatuses. This visualization approach can be applied to safety, schedule and quality related issues easily.

4.3.3 Daily Huddle Meetings

Daily huddle meetings refer to some systematical meetings with employees in order to increase employee involvement. Involvement has positive effects on self-esteem, job-meaningfulness and sense of growth (Salem et al., 2005). Employees share what they have done till the current phase of the project and what their thoughts and believes are towards the project at these meetings. People plan their own tasks and see the big picture, interacting with other people involved in their projects. Salem et al. (2006) gave two examples for these meetings: all-foreman meetings and start-of-the-day meetings.

4.3.4 First Run Studies

First run studies refer to the P. D. A. C (Plan, Do, Act, Check) cycle (Salem et al., 2005). That is to say, it is a continuous improvement tool that focuses on critical activities generally with high variability and/or high cost in a construction project. These critical activities are inspected and understood by mostly project manager, superintendent and foreman by means of photographs, videos, charts etc. Inspection, analysis, change and observation of the processes related to these critical activities are common practices.

4.3.5 Fail Safe for Quality

Fail safe for quality is about being constantly focused on quality and safety issues from the beginning till the end. Potential quality and safety improvement practices are constantly investigated. Quality is sought to be reached at the source of any failure before a mistake's taking place (Salem et al., 2005). This proactive approach resembles Poka-Yoke in the lean production system. Marosszeky et al. (2002) proposed a quality inspection model that is aimed at quality at the source. This model incorporates some task checklists, a completion matrix that gives a project overview and some motivational stimuli for employees. Saurin et al. (2002) proposed a comprehensive safety framework. This framework comprises of integration of safety in long term, short term and lookahead planning, risk identification and control cycle, based on employees' perceptions, development of safety performance indicators and monthly safety performance evaluation meetings. Plan conditions for work environment (P. C. W. E.) referred by Paez et al. (2005), actually corresponds to fail safe for quality.

4.3.6 Concurrent Engineering

Concurrent engineering is a multi disciplinary effort. According to Paez et al. (2005), concurrent engineering is "the parallel execution of different development tasks in multidisciplinary teams with the aim of obtaining an optimal product with respect to functionality, quality, and productivity.". Evbuomwan and Anumba (1998) defined concurrent engineering in construction as:

> An attempt to optimize the design of the project and its construction process to achieve reduced lead times, and improved quality and cost by the integration of design, fabrication, construction and erection activities and by maximizing concurrency and collaboration in working practices.

It is a combined effort that incorporates the parties involved in a product or a production system design with a strong client needs orientation.

While simultaneously executing their own tasks, multi disciplinary teams should sustain extensive communication and information sharing with customers and each other and some serious risk analysis and resource allocations under time pressure. Concurrently designed products and production systems are believed to present a more obstruction-free flow in construction. Jaafari (1997) mentioned the basic principles of an extended concurrent engineering/construction: integration of the design phases, simultaneous inclusion of the information related to the construction life cycle (design, procurement, commissioning and so on.), multi disciplinary composite teams, division of the work into smaller parts and proactive integration of the work and the information throughout a construction life cycle. There is an extensive amount of literature about concurrent engineering efforts in the construction industry.

These methodologies/tools, mentioned above, can be extended based on the concepts and the principles of lean construction.

4.4 Comparison between Traditional and Lean Construction

Up to this point, the lean construction term has been tried to be explained in terms of concepts, principles and methodologies/tools. There is also a need of a brief comparison between the widespread traditional construction management practices and lean construction, under the light of what has been mentioned up to this point. Kim (2002), based on the L. C. I seminar in Dallas, Texas, summarized the primary deviation points of lean construction from the traditional construction management practices. This summary is presented in Table 4.5:

Table 4.5- A Brief Comparison between Traditional and Lean Construction

Lean Construction	Traditional Construction
Control	
Causing events to conform to plan – Steering	Monitoring against schedule and budget projections – Tracking
Optimization	
The entire project	A specific activity
Scheduling Viewpoint	
• "PULL" work schedule • Based on when its completion is required by a successor activity	• "PUSH" work schedule • Based on emphasizing required start dates for activities
Production System	
Flow production system	Conversion production system
Production Process	
Effectiveness	Efficiency
Performance Measurement	
Percent Plan Complete (PPC)	WBS, CPM, Earned Value
Customer Satisfaction	
Successor process satisfaction	Owner or final consumer satisfaction
Planning	
Learning	Knowing
Uncertainty	
Internal	External
Coordination	
Keeping a promise	Following orders
Goal of Supervision	
Reduce variation & Manage flow	Point speed & Productivity

(Source: Kim, 2002)

4.5 The Importance of Measuring Lean Conformance

An extensive amount of literature about lean construction related topics has been accumulated since the early 1990s. As lean construction spreads among scholars and practitioners, a need for measuring lean conformance or degree of "leanness", at the level of basic concepts, has aroused. This measurement will provide us some idea about whether or not firms are ready for the applications of the lean construction methodologies and tools. This investigation can also display firms' lean characteristics, their strengths and drawbacks on the way of “leanness”. Shortly, lean conformance investigates lean attributes and applicability of lean construction at various firms. Since there is no one best way for improving every business, there can also be some firms that can benefit more from the lean construction ideal then the others. This difference can be based on the difference between their level of conformance and lean characteristics. A feasible application of the lean construction methodologies and tools is also expected to be directly related to this conformance level. Moreover, an inventory of lean conformance for the construction industry in a specific country can be developed to a certain degree. This limited inventory can act as some sort of a guide for the future studies. An analysis of the common practices within a construction firm, classified under the basic lean construction dimensions, is needed to measure this type of conformance.

In Turkey, there are also some studies on lean construction at a comparatively minor level. The author of this thesis expects an increase in the interest towards the subject in the near future, as the lean construction movement spreads and develops throughout the world. In the next chapter, a study for measuring lean conformance, with the aim of identifying the lean characteristics of some contractors, will be presented.

CHAPTER 5

MEASURING LEAN CONFORMANCE

A methodology for measuring lean conformance for contractors, with its limitations, is presented in the first part of this chapter. The sample data gathered by this methodology are displayed in detail and the analysis of this data is performed. This analysis includes displaying summary statistics of the data, finding the average lean conformance value the population, applying some inferential statistical tests based on the sample data and so on. As a conclusion, the necessary discussion of the analysis are presented and recommendations are made for future studies on lean construction and for increasing lean conformance of contractors.

5.1 Methodology

Measuring lean conformance or, in other words, lean characteristics is a demanding task due to the multi – dimensional nature of lean thinking and, eventually, lean construction. With the purpose of acquiring the necessary data from various construction firms, a questionnaire was prepared. The questionnaire contains a total of 35 questions. The first 4 questions aim at clarifying respondents' professional and occupational attributes. The questions from 5 to 10 are mainly related to operational characteristics of the firms interviewed. The remaining 25 questions measure the lean conformance of a construction firm. The lean conformance related questions were prepared from the model proposed by Diekmann et al. (2003). The model is presented in a wheel form as shown in Figure 5.1:

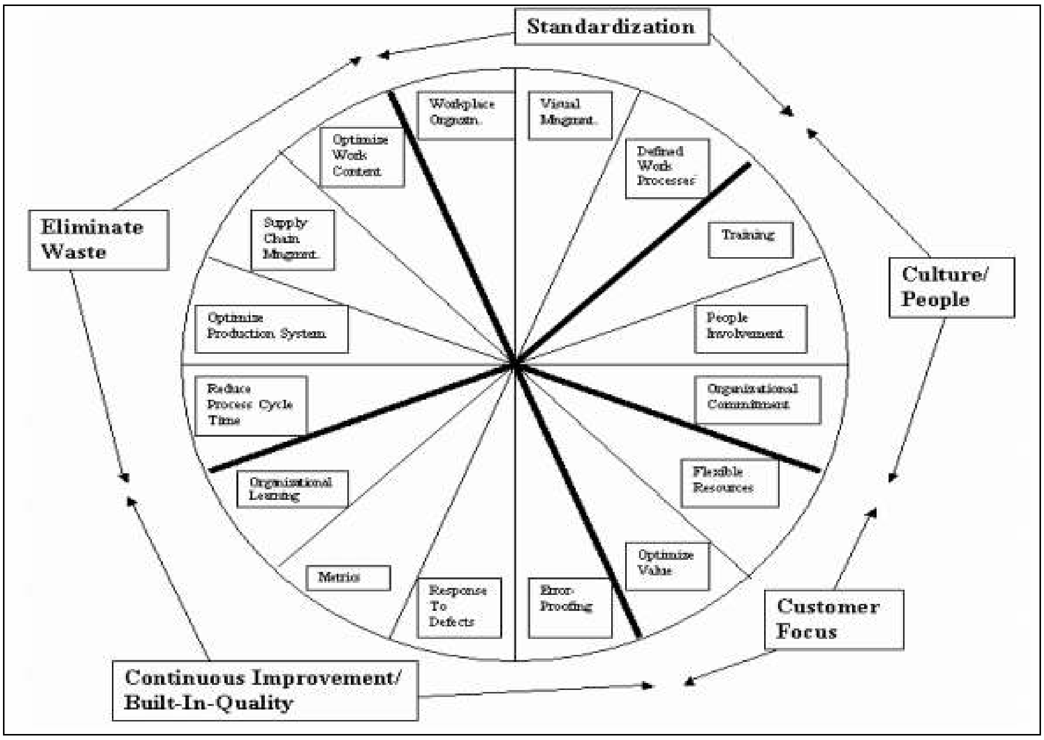


Figure 5.1- Lean Construction Wheel
(Source: Diekmann et al., 2003)

The model has 5 main principles and 16 sub – principles. The main principles are standardization, culture/people, customer focus, continuous improvement/built–in–quality and eliminate waste. Standardization contains workplace organization, visual management and defined work processes as its sub – principles. Culture/People contains training, people involvement and organizational commitments as its sub - principles. Customer focus contains flexible resources and optimize value as its sub – principles. Continuous Improvement/Built-in-Quality contains error – proofing, response to defects, metrics and organizational learning as its sub – principles. Eliminate Waste contains reduce process cycle time, optimize production system, supply chain management and optimize work content as its sub – principles.

In general, there is more than one question that correspond to each sub – principle. The metrics, flexible resources, optimize value, supply chain management and visual management sub – principles have two corresponding questions. The optimize production system and reduce process cycle time sub – principles have three corresponding questions. The rest of the sub – principles has one corresponding question for each in the questionnaire.

While answering the questions related to lean conformance, the respondents were asked to evaluate the practices within their firms. They were given two statements and asked to identify proximity or conformance of the practices to one of these two statements. A sample question was presented in Figure 5.2:

Employees do not share their ideas/point of views in the name of improving the firm's operations.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Employees share their ideas/point of views to improve the firm's processes and to reduce the waste within the firm. The firm has some mechanisms to provide this.

Figure 5.2- A Sample Question

If practices within their firm completely comply to the statement on the left, respondents ticked the box under the number 1. If practices within their firm are close to the statement on the left, respondents ticked the box under the number 2. If practices within their firm completely comply to the statement on the right, respondents ticked the box under the number 5. If practices within their firm are close to the statement on the right, respondents ticked the box under the number 4. For the practices between these two statements, they ticked the box under the number 3. If they had no idea or thought that these statements were irrelevant, they chose the box under N/A.

In principle, the statements on the right represent leaner practices. On the other hand, the statements on the left are believed to represent more conventional practices. Thus, the boxes under the numbers 5 and 4 are for leaner practices in different degrees and the boxes under the numbers 1 and 2 are for more conventional practices in different degrees. The questionnaire was prepared to be easily filled on computer and on paper. Therefore, some questionnaires were distributed by hand and some questionnaires were distributed via the internet. The English version of the questionnaire can be found in Appendix.

5.2 Limitations

There are some limitations on this study. Firstly, the questionnaire was prepared to be filled by only contractors. Secondly, all of the respondents were chosen among lower, mid or upper level managers. Thirdly, the questionnaire was only applied to either Turkish based contractors or foreign contractors operating in Turkey. The questionnaire is mainly focused on internal operational aspects of contractors, rather than environmental affects.

5.3 Presentation of Results

The questionnaire was distributed to 125 contractors. 63 of contractors were chosen among the members of the Turkish Contractors Association and the rest was determined by the personal connections of the author and the thesis advisor. Out of 125 attempts, 44 responses were collected. This number yields a response ratio of %35.2. 10 questionnaires were answered on paper and collected by hand. 34 questionnaires were answered on computer and collected via the internet. Therefore, the ratio of the questionnaires collected by hand is %22.72 and the ratio of the questionnaires collected via the internet is %77.28.

5.3.1 Respondents' Attributes

There are 4 questions in the questionnaire to identify respondent's attributes. These questions are about respondents';

1. Professions.
2. Levels of education.
3. Positions.
4. Levels of experience.

By profession, 23 of the respondents are civil engineers, which correspond to a ration of %52.27. 10 of the respondents are architects, which corresponds to a ratio of %22.72. 3 of the respondents are mechanical engineers, which corresponds to a ratio of %6.82. 2 of the respondents are geology engineers, which corresponds to a ratio of %4.55. There are also 1 chemical engineer, 1 electrical engineer, 1 industrial engineer, 1 manager with a degree in accountancy, 1 interior architect and 1 manager with a degree in international relations. Each one has a ratio of %2.72 among the whole respondents. Figure 5.3 shows these figures:

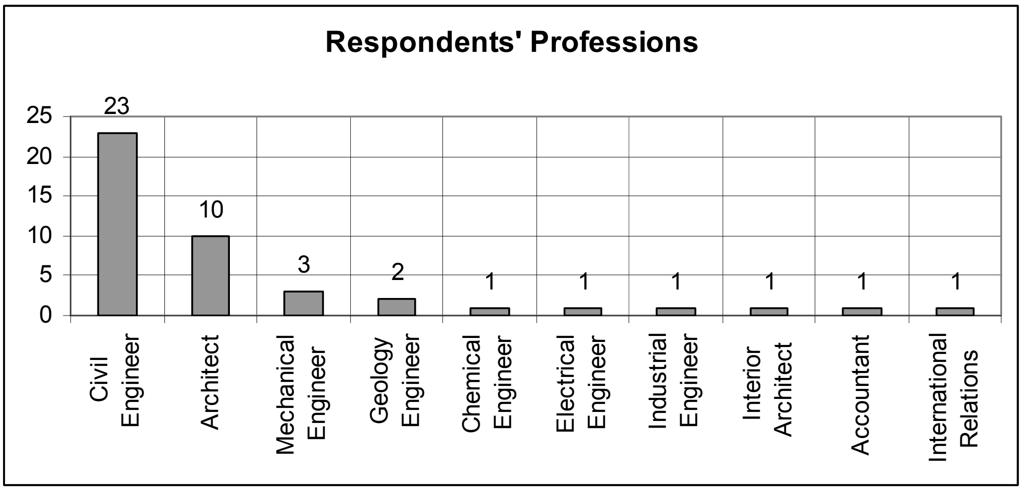


Figure 5.3- Respondents' Professions

As for level of education, 25 of the respondents have a B.Sc. degree, corresponding to a ratio of %56.82. 19 of the respondents have a M.Sc. degree, corresponding to a ratio of %43.18. There is no respondent with a doctorate degree.

As for position, 3 of the respondents are lower level managers. Lower level managers constitute a ratio of %6.82. 14 of the respondents are mid – level managers. Mid – level managers constitute a ratio of %31.82. 27 of the respondents are higher level managers. Higher level managers constitute a ratio of %61.37. Figure 5.4 shows these figures:

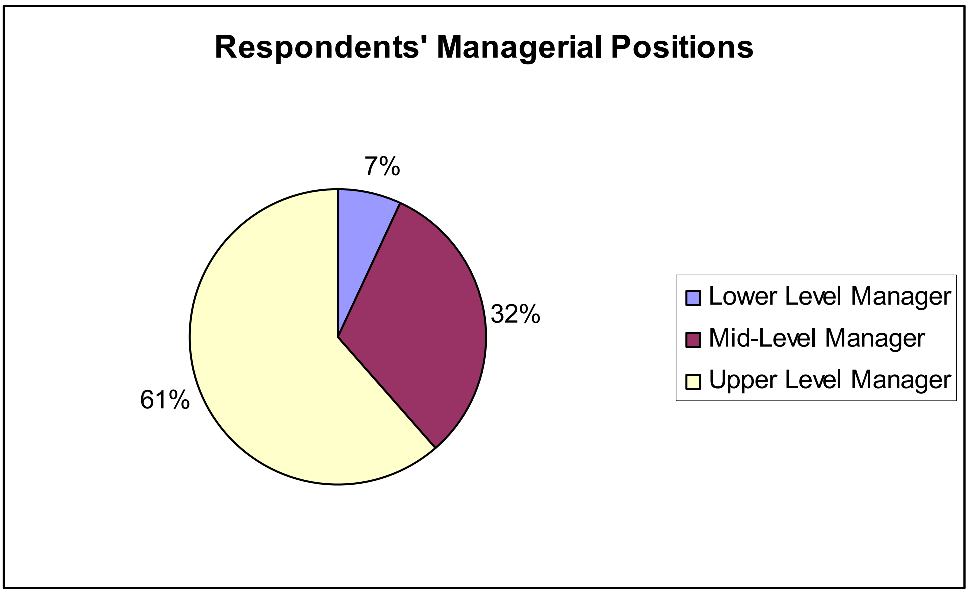


Figure 5.4- Respondents' Managerial Positions

By level of experience, 3 of the respondents have between 0 and 5 years of experience. These respondents constitute a ratio of %6.82. 5 of the respondents have between 5 and 10 years of experience. These respondents constitute a ratio of %11.36. 8 of the respondents have between 10 and 15 years of experience. These respondents constitute a ratio of %18.18. 4 of the respondents have between 15 and 20 years of experience. These respondents constitute a ratio of %9.09. 24 of the respondents have more than 20 years of experience. These respondents constitute a ratio of %54.54. The figures are shown in Figure 5.5. A summary of the respondents' attributes, with interrelations, is shown in Table 5.1.

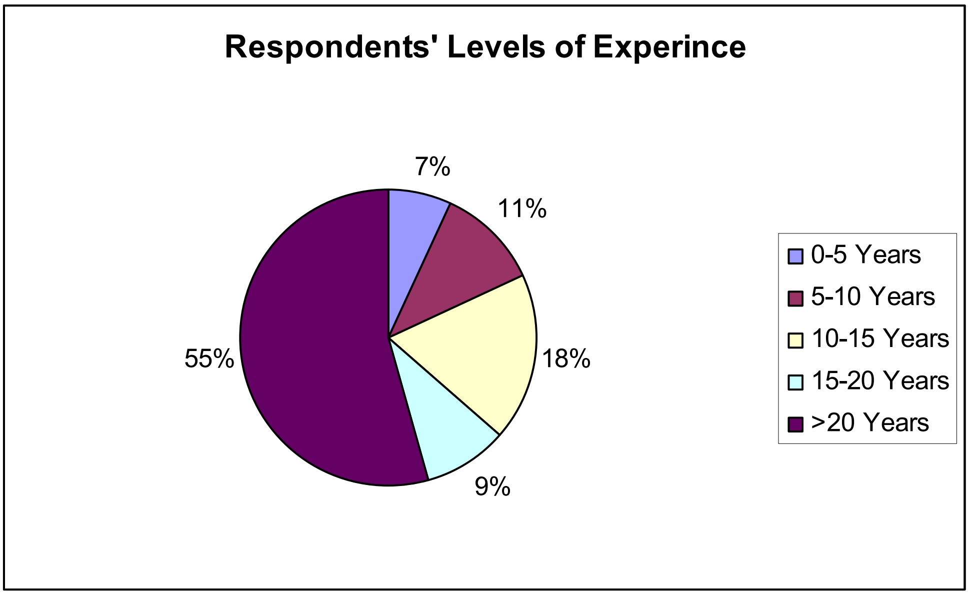


Figure 5.5- Respondents' Level of Experience

Table 5.1- Respondents' Attributes

Profession	Position	Level of Experience (In Years)	Level of Education: B.Sc.	Level of Education: M.Sc.	Total
Accountant	Upper Level Manager	15-20		1	1
Architect	Mid-Level Manager	>20	1		1
	Upper Level Manager	>20	6		6
		10-15	1		1
		5-10	1	1	2
Chemical Engineer	Upper Level Manager	>20		1	1
Civil Engineer	Lower Level Manager	10-15	2		2
		0-5		1	1
	Mid-Level Manager	>20	3	1	4
		10-15		1	1
		15-20		1	1
		0-5	1	1	2
	Upper Level Manager	>20	5	3	8
		10-15	1	1	2
		15-20	1		1
		5-10		1	1
Electrical Engineer	Upper Level Manager	>20		1	1
Geology Engineer	Mid-Level Manager	>20		1	1
	Upper Level Manager	>20	1		1
Interior Architect	Upper Level Manager	5-10	1		1
International Relations	Mid-Level Manager	10-15		1	1
Mechanical Engineer	Mid-Level Manager	>20		1	1
		5-10		1	1
	Upper Level Manager	15-20	1		1
Industrial Engineer	Mid-Level Manager	10-15		1	1
Grand Total			25	19	44

5.3.2 Firms' Attributes

There are 6 questions in the questionnaire to identify firms' attributes. These questions are about firms';

1. Areas of operation.
2. Operational times since their foundations.
3. Average numbers of employees.
4. Average annual turnovers.
5. Major clients
6. Geographical operational locations.

By areas of operation, 35 (%79.55) of the firms construct commercial and residential buildings. 29 (%65.91) of the firms construct infrastructural facilities. 25 (%56.82) of the firms construct highway and transportation facilities. 20 (%45,45) of the firms construct pipelines. 19 (%43.18) operate in the areas of project and design. 18 (%40.91) of the firms deal with tunnel works. 17 (%38.64) of the firms construct industrial facilities. 14 (%31.82) of the firms deal with industrial projects. 12 (%27.27) of the firms construct dams. 10 (%22.73) of the firms operate in the area of airport construction. 9 (%20.45) of the firms deal with marine and shore works and 8 (%18.18) of the firms operate in the area of strengthening – restoration. The visual display of these numbers can be found in Figure 5.6:

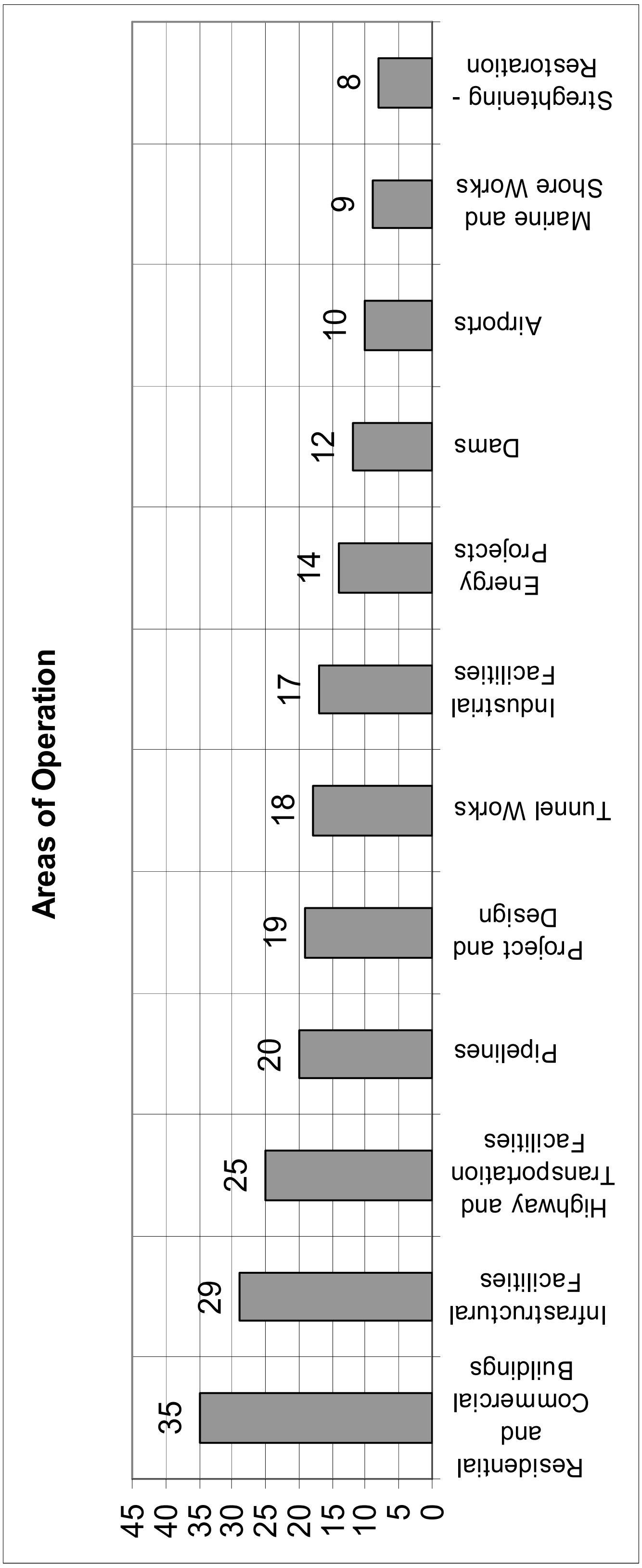


Figure 5.6- Firms' Areas of Operation

As for operational times since their foundations, 4 (%9.09) of the firms have been operating for between 0 and 5 years. 5 (%11.36) of the firms have been operating for between 5 and 10 years. 4 (%9.09) of the firms have been operating for between 10 and 15 years. 2 (%4.55) of the firms have been operating for between 15 and 20 years. 29 (%65.91) of the firms have been operating for more than 20 years. Figure 5.7 displays these figures:

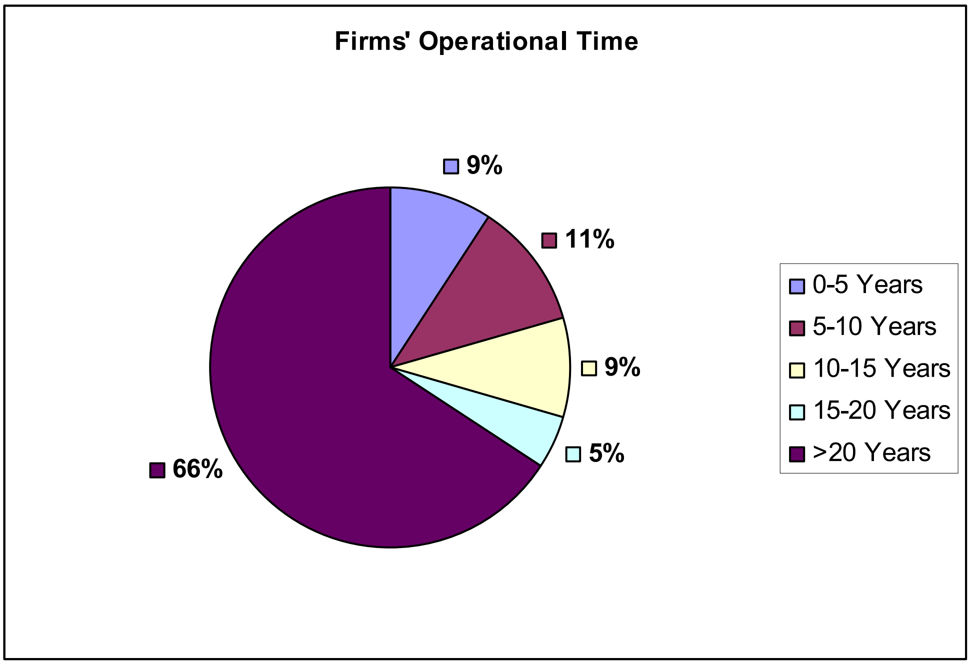


Figure 5.7- Firms' Operational Time

By average number of employees working in both offices and at construction sites, 18 (%40.91) of the firms employ between 10 and 100 employees. 5 (%11.36) of the firms employ between 100 and 500 employees. 8 (%18.18) of the firms employ between 500 and 1500 employees. 13 (%29.55) of the firms employ more than 1500 employees. Figure 5.8 displays these figures:

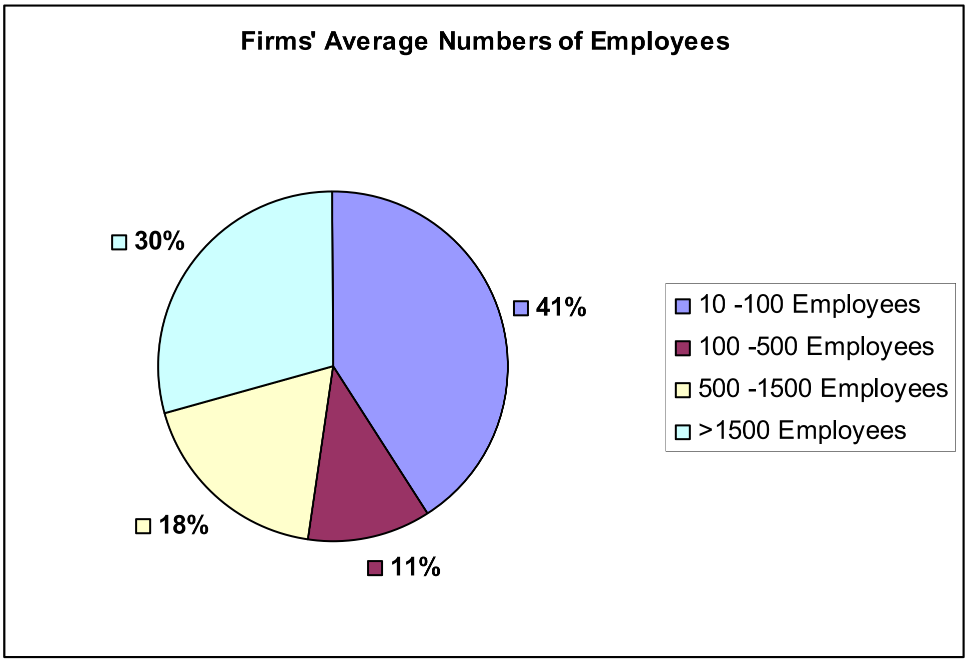


Figure 5.8- Firms' Average Numbers of Employees

As for average annual turnovers, 14 (%31.82) of the firms have average annual turnovers between 1 and 10 million American dollars. 15 (%34.09) of the firms have average annual turnovers between 10 and 100 million American dollars. 12 (%27.27) of the firms have average annual turnovers between 100 and 1000 million American dollars. 3 (%6.82) of the firms have average annual turnovers more than 1000 million American dollars. These figures are displayed in Figure 5.9:

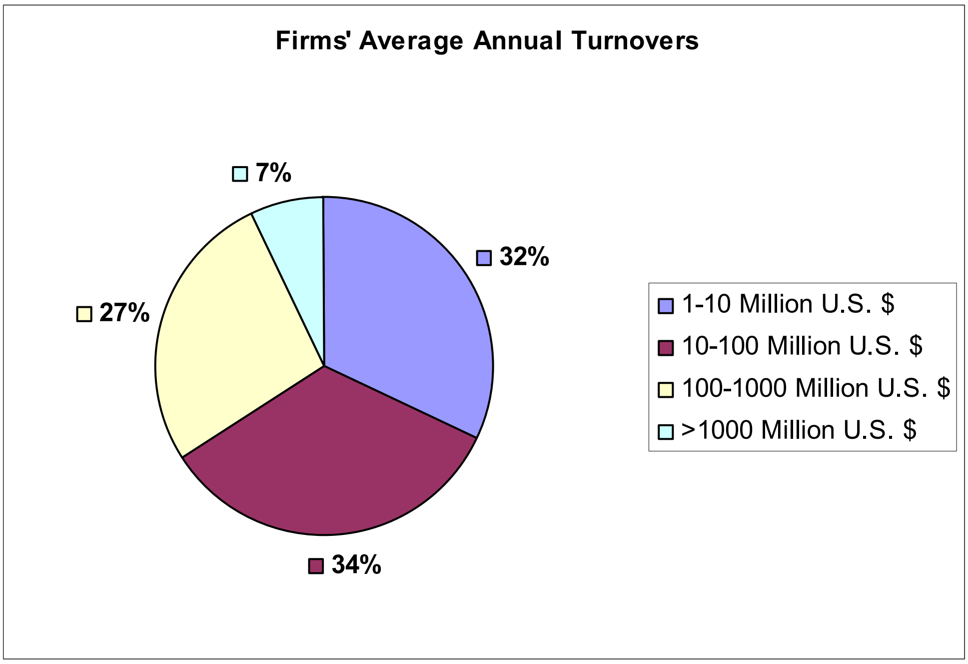


Figure 5.9- Firms' Average Annual Turnovers

Concerning major clients, 13 (%29.55) of the firms specified public organizations as their major clients. 12 (%27.27) of the firms specified private individuals and organizations as their major clients. 19 (%43.18) of the firms specified both public and private figures as their major clients.

Concerning geographical operational locations, 25 (%53.82) of the firms operate in both in Turkey and abroad. 19 (%43.18) of the firms operate in only in Turkey. There is no firm that operates only abroad. The visual display of these numbers can be found in Table 5.2:

Table 5.2- Firms' Attributes

				Major Clients			
Annual Turnover (In million U.S. $)	**Number of Employees**	**Operational Time (In years)**	**Operational Locations**	**Both Public and Private Figures**	**Private Individuals and Organ.**	**Public Organ.**	**Total**
>1000	>1500	>20	Spread in the Country and Abroad	2	1		3
100-1000	>1500	>20	Spread in the Country and Abroad	5	1	3	9
	500-1500	>20	All in the Country	1			1
			Spread in the Country and Abroad	1		1	2
10-100	>1500	>20	Spread in the Country and Abroad	1			1
	100-500	>20	All in the Country			2	2
			Spread in the Country and Abroad		2		2
		5-10	Spread in the Country and Abroad	1			1
	10-100	>20	All in the Country			1	1
			Spread in the Country and Abroad	1			1
		5-10	All in the Country		1	1	2
	500-1500	>20	Spread in the Country and Abroad	1		4	5
1-10	10-100	>20	All in the Country	2	1	1	4
		0-5	All in the Country	2	1		3
			Spread in the Country and Abroad	1			1
		10-15	All in the Country	1	3		4
		5-10	All in the Country		2		2
Grand Total				19	12	13	44

5.3.3 Lean Conformance Answers

There are 25 questions, that are related to measuring lean conformance, in each of the answered 44 questionnaires. Thus, 25 times 44 yields 1100 answers in total. As for answer frequencies, the answer 1 was chosen for 68 times (%6.18). The answer 2 was chosen for 121 times (%11). The answer 3 was chosen for 209 times (%19). The answer 4 was chosen for 344 times (%31.27). The answer 5 was chosen for 327 times (%29.73) and the answer N/A was chosen for 31 times (%2.82). A brief summary of the answer ratios is presented in Figure 5.10. A detailed summary of the answer frequencies can be found in Table 5.3:

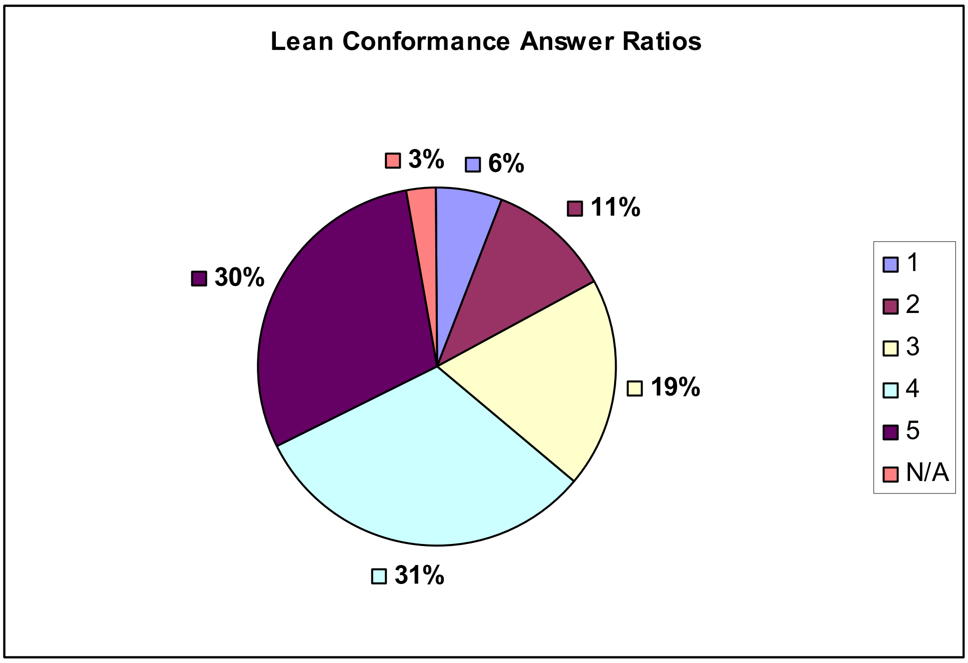


Figure 5.10- Lean Conformance Answer Ratios

Table 5.3- Lean Conformance Answer Frequencies

Type of Question	Answer Frequency					
	1	**2**	**3**	**4**	**5**	**N/A**
Culture/People						
People Involvement	2	4	7	23	8	
Organizational Commitment	5	6	7	12	14	
Training	4	8	6	12	13	1
Continuous Improvement/Build-in-Quality						
Metrics-1		10	10	12	11	1
Metrics-2	3	3	13	15	9	1
Response to Defects	1	3	10	13	17	
Error Proofing	1	5	14	15	8	1
Organizational Learning	1	5	10	17	10	1
Customer Focus						
Flexible Resources-1	7	6	4	15	11	1
Flexible Resources-2	1	7	10	18	6	2
Optimize Value-1		6	7	14	14	3
Optimize Value-2	2	4	13	7	11	7
Eliminate Waste						
Supply Chain Management-1	3	6	9	8	17	1
Supply Chain Management-2	2	6	3	11	22	
Optimize Production System-1	3	4	13	9	11	4
Optimize Production System-2	1	1	8	22	12	
Optimize Production System-3	4	4	9	9	18	
Reduce Process Cycle Time-1	6	3	7	11	17	
Reduce Process Cycle Time-2	2	4	8	18	12	
Reduce Process Cycle Time-3	7	3	9	18	6	1
Optimize Work Content	2	3	2	14	20	3
Standardization						
Visual Management-1	2	4	5	13	20	
Visual Management-2	1	5	12	10	14	2
Workplace Organization	4	4	7	13	15	1
Defined Work Processes	4	7	6	15	11	1
Total	68	121	209	344	327	31

5.4 Analysis of Results

In this section, lean conformance values, necessary descriptive statistics and statistical tests will be presented in order to make conclusive inferences.

5.4.1 Lean Conformance

For further analysis of the data, calculating lean conformance values is essential. The lean conformance values for the sample data set in hand were calculated in percentages. Each lean conformance question was assigned the same weight in terms of lean conformance. As we have 25 questions in total, the answer value for each question, which can be 1, 2, 3, 4, 5 or N/A, was multiplied by 0.8. The N/A answers were assumed as 1. It is because of the idea that all of the questions should be related to lean practices and symbolize essential activities in a construction firm. If a respondent answers N/A, It is to say either he/she has no idea about the practice in his/her firm or he/she has no idea about the lean statements motioned in the question. The N/A choice is believed to act also as a buffer against some unrealistic answers. The lean conformance calculation in percentage was performed by this formula:

$$\text{Lean Conformance}(\%) = \frac{\sum(\text{Answer Value}) \times 4}{5} \quad \textbf{(2)}$$

For every firm, the lean conformance percentage values were calculated by Formula 2. Moreover, the lean percentage values for each 4 sub – principles were also calculated. The summary descriptive statistics for the sample lean conformance values (%) can be seen in Table 5.4:

Table 5.4- Summary Descriptive Statistics for Sample Lean Conformance

Minimum	Maximum	Mean(ỹ)	Median	Mode	Standard Deviation(*s*)	Kurtosis	Skewness
34.40	96.00	72.35	74.00	92.00	15.70	-0.60	-0.45

The histogram for the sample lean conformance values in percentage, with normal curve, can be seen in Figure 5.11:

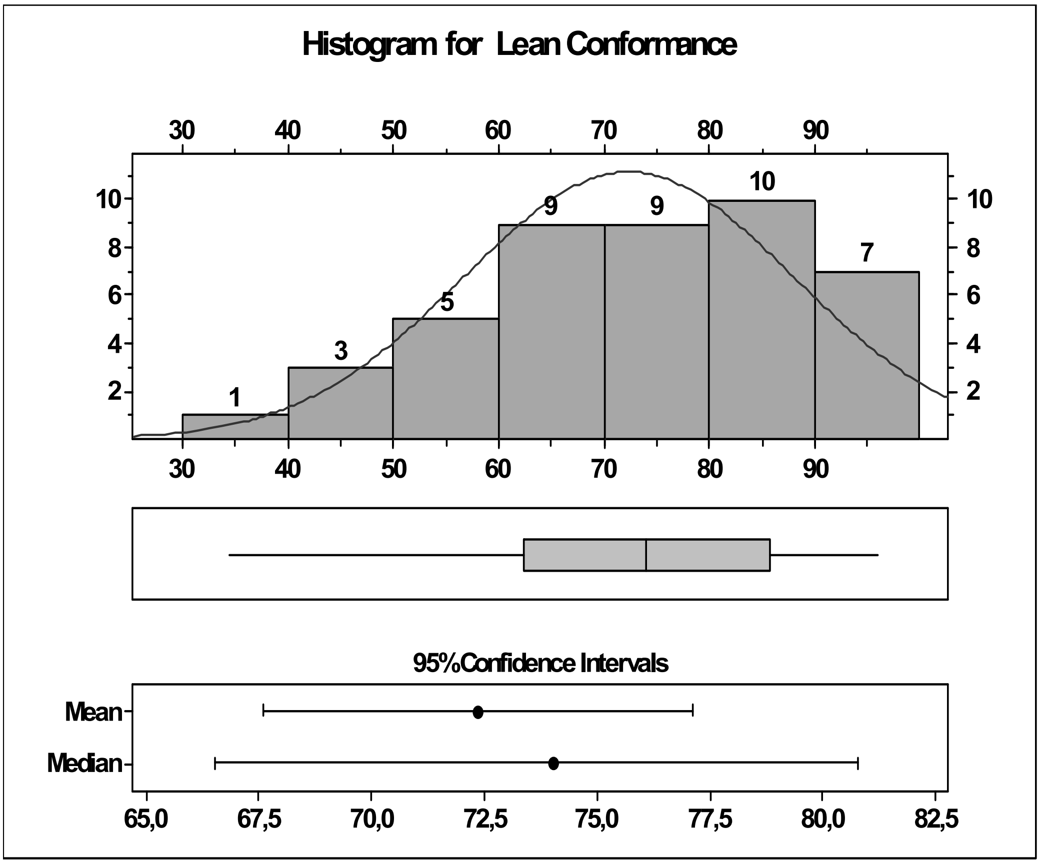


Figure 5.11- Histogram for Lean Conformance Values (%)

As there is an apparent negative skewness to the left in the sample data set, a search for normality was performed in order to correctly model the data set. While doing so, the statistical software Minitab® version 14.1 was utilized. The Anderson - Darling test was applied to test normality. The Anderson – Darling test (A – D test) assesses the degree of fit of a given data set to a distribution. It is a modified version of the Kolgomorov – Smirnov test (K – S test) with higher emphasis on the tails of a distribution. The Anderson Darling test is defined as (Engineering Statistics Handbook, 2006):

H_0: The data follow a specified distribution.
H_a: The data do not follow the specified distribution

The Anderson-Darling test statistic is defined as:

$$A^2 = -N - S \; ; \quad \textbf{(3)}$$

$$S = \sum_{i=1}^{N} \frac{(2i-1)}{N} \left[\ln F_c(Y_i) + \ln(1 - F_c(Y_{N+1-i})) \right] \; ; \quad \textbf{(4)}$$

N: Sample size;
F_c: The cumulative distribution function of the specified distribution;
Y: Data set in order $\{Y_i < \ldots\ldots\ldots < Y_N\}$

The Minitab® statistical software automates the procedure testing any given data set within any given confidence interval. The A - D goodness of fit test for the normal distribution with %95 confidence interval (α = 0.05) was applied to the lean conformance data set in hand. The results for this test were found as 0.471 for A^2 value and 0.234 for P value. Although 0.234 is bigger than 0.05 and therefore, the normal distribution could be assumed for the data set in hand, some arithmetical modifications were applied on the data set to increase its goodness of fit to the normal distribution. The normal distribution was sought because of the statistical opportunities it offers.

In order to increase the goodness of fit, every lean conformance value in the data set was first divided by 100 and then its square was taken. The descriptive statistics of the data after this modification can be seen in Table 5.5:

Table 5.5- Summary Descriptive Statistics for Modified Sample Lean Conformance

Minimum	Maximum	Mean($\tilde{y}$)	Median	Mode	Standard Deviation(s)	Kurtosis	Skewness
0.118	0.922	0.547	0.548	0.846	0.218	-1.000	-0.077

After this modification, the A - D goodness of fit test for the normal distribution with %95 confidence interval ($\alpha = 0.05$) was applied to the lean conformance data set in hand. The results for this test were found as 0.35 for A^2 value and 0.454 for P value. The P value for the modified sample has significantly increased. Thus, it can be said that the modification has a positive effect on the data set's goodness of fit to the normal distribution.

There is another way of more complex normal transformation method, which is called the Johnson's transformation. The Johnson's transformation module in Minitab® optimally selects one of the three families of distribution according to their A – D test values. Chou, Polansky and Mason (1998) described the Johnson's transformation distribution families and how to calculate their parameters in detail. In the end, the software identified the optimal transformation function as S_B type, which is defined as:

$\gamma + \eta \ln[(x - \varepsilon) / (\lambda + \varepsilon - x)]$; **(5)**

$\eta, \lambda > 0$;

$-\infty < \gamma < \infty$;

$-\infty < \varepsilon < \infty$;

$\varepsilon < x < \varepsilon + \lambda$

After the calculation of the parameters in Formula (5), the whole transformation function was defined as:

$$0.543864 + 0.860328 \ln\left[\left(x - 24.7117\right)/(100.507 - x)\right]; \quad \textbf{(6)}$$

$\gamma = 0.543864$;

$\eta = 0.860328$;

$\varepsilon = 24.7117$;

$\lambda = 75.7953$;

x: Values in the original data set

The original lean conformance values (x) was put into Formula (6) to make a modification towards the normal distribution. The descriptive statistics of the data after the Johnson's modification can be seen in Table 5.6:

Table 5.6- Summary Descriptive Statistics after Johnson's Modification

Minimum	Maximum	Mean($\tilde{y}$)	Median	Mode	Standard Deviation(*s*)	Kurtosis	Skewness
-2.289	1.819	-0.014	-0.027	1.222	0.910	-0.238	-0.123

After this modification, the A - D goodness of fit test for the normal distribution with %95 confidence interval ($\alpha = 0.05$) was applied to the lean conformance data set in hand. The results for this test were found as 0.135 for A^2 value and 0.977 for P value. This is quite a good normality fit. This modified results were used in the cases where normality was essential.

In order to make inferences for the whole population, we have to make some statistical tests on the data set. Since we only know sample mean ($\tilde{y}$), sample variance (s^2) and we have now a normalized data set in hand, we can apply t-test in order to define the confidence interval for the population average (μ). The formula to define the confidence interval for the t-test is :

$$\tilde{y} - t_{\alpha/2,N\text{-}1} \times \frac{s}{\sqrt{N}} \leq \mu \leq \tilde{y} + t_{\alpha/2,N\text{-}1} \times \frac{s}{\sqrt{N}} \qquad \textbf{(7)}$$

The sample size is 44 (N) and the level of confidence was chosen as %95 ($\alpha/2 = 0.025$). The $\tilde{y}$ and s values were taken from the data set modified by the Johnson's transformation. Since there is no $v = 43$ (N-1) value corresponding to %97.5 in the t-test table. A linear interpolation between $v = 40$ (2.021) and $v = 50$ (2.009) was performed. The values are as follows: $\tilde{y} = -0.014$, $s = 0.91$, N = 44, $t_{0.025,43} = 2.0174$. Therefore, for the modified values, the population average (μ), with %95 confidence, is :

$$-0.29106 \leq \mu \leq 0.26246$$

There is also a need for back transformation on the values found for the population average (μ). The back transformation function was derived from Formula (6) by taking its inverse with respect to x. The back transformation function is as follows:

$$\frac{100.507 \times k + 25.7117}{(1+k)}; \qquad \textbf{(8)}$$

$$k = e^{\left[\frac{z+0.543864}{0.860328}\right]}; \qquad \textbf{(9)}$$

z: Values in the modified data set

The modified values of -0.29106 and 0.26246 should be put into the back transformation formulae, Formula (8) and Formula (9), to get the real results for the population mean. By doing so, the following lean conformance result (%) was reached for the population average (μ) with %95 confidence:

$68.56 \leq \mu \leq 79.45$

5.4.2 Lean Conformance by Sub - Principles

There are 5 sub – principles for in the data set. Each has different contribution to the lean conformance value of a firm. The culture/people sub – principle can constitute %12 of the lean conformance value at its maximum. The continuous improvement/built – in – quality sub – principle can constitute %20 of the lean conformance value at its maximum. The customer focus sub – principle can constitute %16 of the lean conformance value at its maximum. The eliminate waste sub – principle can constitute %36 of the lean conformance value at its maximum. The standardization sub – principle can constitute %16 of the lean conformance value at its maximum. The summary descriptive statistics for each of the sub – principle were given in Table 5.7 and the summary descriptive statistics for each question can be seen in Table 5.8:

Table 5.7- Summary Descriptive Statistics for Sub – Principles

Sub - Principle	Minimum	Maximum	Mean	Median	Mode	Standard Deviation	Kurtosis	Skewness
Culture/People	2.40	12.00	8.56	8.80	9.60	2.35	-0.21	-0.64
Continuous Improvement/Built-in-Quality	8.00	20.00	14.47	14.00	13.60	3.30	-0.53	-0.24
Customer Focus	4.80	16.00	10.85	11.20	14.40	3.34	-1.00	-0.29
Eliminate Waste	12.00	35.20	26.65	26.80	28.80	5.85	-0.46	-0.44
Standardization	3.20	16.00	11.80	12.00	15.20	3.42	0.14	-0.72

Table 5.8- Summary Descriptive Statistics for Each Question

Type of Question	Summary Descriptive Statistics				
	Mean	Median	Mode	Standard Deviation	Skewness
Culture/People					
People Involvement	3.70	4.00	4.00	1.02	-0.99
Organizational Commitment	3.54	4.00	5.00	1.37	-0.58
Training	3.45	4.00	5.00	1.38	-0.44
Continuous Improvement/Built-in-Quality					
Metrics-1	3.50	4.00	4.00	1.17	-0.18
Metrics-2	3.50	4.00	4.00	1.17	-0.63
Response to Defects	3.95	4.00	5.00	1.05	-0.77
Error Proofing	3.50	4.00	4.00	1.06	-0.42
Organizational Learning	3.63	4.00	4.00	1.10	-0.63
Customer Focus					
Flexible Resources-1	3.34	4.00	4.00	1.43	-0.49
Flexible Resources-2	3.38	4.00	4.00	1.12	-0.52
Optimize Value-1	3.68	4.00	5.00	1.25	-0.69
Optimize Value-2	3.16	3.00	3.00	1.44	-0.19
Eliminate Waste					
Supply Chain Management-1	3.63	4.00	5.00	1.36	-0.55
Supply Chain Management-2	4.02	4.50	5.00	1.24	-1.09
Optimize Production System-1	3.29	3.00	3.00	1.37	-0.33
Optimize Production System-2	3.97	4.00	4.00	0.87	-1.04
Optimize Production System-3	3.75	4.00	5.00	1.33	-0.75
Reduce Process Cycle Time-1	3.68	4.00	5.00	1.41	-0.80
Reduce Process Cycle Time-2	3.77	4.00	4.00	1.09	-0.85
Reduce Process Cycle Time-3	3.25	4.00	4.00	1.31	-0.61
Optimize Work Content	3.93	4.00	5.00	1.35	-1.22
Standardization					
Visual Management-1	4.02	4.00	5.00	1.17	-1.13
Visual Management-2	3.61	4.00	5.00	1.24	-0.50
Workplace Organization	3.65	4.00	5.00	1.34	-0.77
Defined Work Processes	3.45	4.00	5.00	1.33	-0.54

The percent fulfillment for each sub – principle, which shows the real degree of realization for each sub – principle, can be calculated by this formula:

$$\text{Percent Difference}(\%) = \frac{\text{Real Value} \times 100}{\text{Maximum Possible Value}}; \qquad \textbf{(10)}$$

Maximum Possible Value: Maximum possible lean conformance value;
Real Value: Calculated mean value for the corresponding sub - principle

The calculated percent fulfillment for each sub – principle, by Formula (10), can be seen in Figure 5.12:

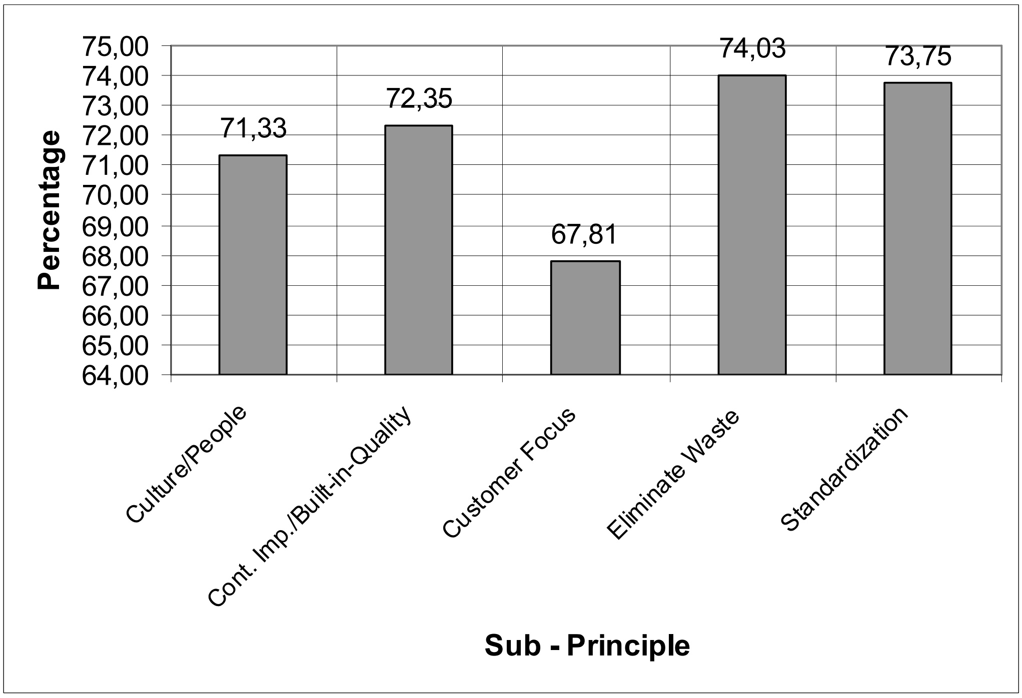


Figure 5.12- Percent Fulfillment(%) for Each Sub - Principle

We can classify the participated firms by their average annual turnovers. The firms, which have average annual turnovers between 1 – 10 U. S. dollars, can be classified as small firms. The firms, which have average annual turnovers between 10 – 100 U. S. dollars, can be classified as medium - small firms. The firms, which have average annual turnovers between 100 – 1000 U. S. dollars, can be classified as medium - large firms. The firms, which have average annual turnovers more than 1000 U. S. dollars, can be classified as large firms. The percent fulfillment of each classified group can be seen in Table 5.9:

Table 5.9- Percent Fulfillment of Classified Groups

	Percent Fulfillment				
Classified Group	Culture/ People	Cont. Imp./Built - in - Quality	Customer Focus	Eliminate Waste	Standard.
Small Firms (1 - 10 Mil. U. S. Dollars)	67.62	68.00	61.43	67.78	67.50
Medium - Small Firms (10 - 100 Mil. U. S. Dollars)	64.89	67.20	61.33	69.93	68.33
Medium - Large Firms (100 - 1000 Mil. U. S. Dollars)	82.78	79.67	78.75	82.41	85.42
Large Firms (>1000 Mil. U. S. Dollars)	75.56	89.33	86.67	90.37	83.33

5.4.3 Analysis of Variance

In this part, an analysis for statistically significant difference between data groups will be presented. For this kind of an analysis, the Analysis of Variance (ANOVA) method was employed. As the data was grouped and searched by only one factor, one – way ANOVA between groups was utilized. The ANOVA formulae are as follows (Dowdy, Weardon and Chilko, 2004):

ANOVA calculations between groups:

$$S.\ S_{\text{Between}} = \sum_{j=1}^{j} N_j(\overline{X}_j - \overline{X})^2\ ; \qquad \textbf{(11)}$$

Degree of freedom (d. f.)= j – 1 ; **(12)**

$$M.\ S_{\text{Between}} = \frac{S.\ S_{\text{Between}}}{j-1}\ ; \qquad \textbf{(13)}$$

ANOVA calculations within groups:

$$S.\ S_{\text{Within}} = \sum_{j=1}^{j}\sum_{i=1}^{N_j}(X_{ij} - \overline{X}_j)^2\ ; \qquad \textbf{(14)}$$

Degree of freedom (d. f.)= N – j ; **(15)**

$$M.\ S_{\text{Within}} = \frac{S.\ S_{\text{Within}}}{N-j}\ ; \qquad \textbf{(16)}$$

Total:

$$S.\ S_{\text{Total}} = \sum_{j=1}^{j}\sum_{i=1}^{N_j}(X_{ij} - \overline{X})^2 \qquad \textbf{(17)}$$

Degree of freedom = N – 1 **(18)**

$$F = \frac{M.\ S_{\text{Between}}}{M.\ S_{\text{Within}}}\ ; \qquad \textbf{(19)}$$

$\overline{X}$: Data set mean

$\overline{X}_j$: Group mean

j: Number of groups

N: Sample size

S. S: Sum of squares

M. S: Mean squares

F: F – test value

F critic values for every hypothesis test, by confidence level (α), (j – 1) and (N – j) degrees of freedom, are determined. If F – test value is smaller than F critic value, then H_0 is accepted at that confidence level.

After the brief explanation of the ANOVA method, the groups can be presented by their analysis factors. The lean conformance values will be tested by the average annual turnover of the firms. The tested data set can be seen in Table 5.10:

Table 5.10- Groups by Average Annual Turnover

	Average Annual Turnover (In Mil. U.S. $)			
	1 - 10	**10 - 100**	**100 - 1000**	**> 1000**
Lean Conformance (%)	76.8	73.6	72.8	88.8
	81.6	46.4	91.2	96.0
	65.6	54.4	84.0	75.2
	80.8	66.4	68.8	
	51.2	92.0	76.0	
	46.4	63.2	92.0	
	60.0	74.4	92.0	
	62.4	86.4	95.2	
	91.2	80.8	72.0	
	83.2	88.8	86.4	
	62.4	44.0	79.2	
	52.8	34.4	72.0	
	55.2	52.0		
	64.8	68.8		
		81.6		

The first ANOVA test was performed among the firms with average annual turnovers between 1 – 10 and 10 – 100 U. S. dollars. The hypothesis test, with %95 confidence, is as follows:

H_0: $\mu_1 = \mu_2$

H_1: $\mu_1 \neq \mu_2$

The first ANOVA test results can be seen in Table 5.11:

Table 5.11- First ANOVA Test Results

Groups	***Average***	***Variance***				
1 - 10	66.74	189.21				
10 - 100	67.14	314.00				
Source of Variation	***S. S.***	***d.f.***	***M. S.***	***F***	***P-value***	***F critic***
Between Groups	1.18	1	1.18	0.00465	0.94	4.21
Within Groups	6855.91	27	253.92			

Since the F value is smaller than the F critic value, the H_0 was accepted. No significant difference was found between these groups.

The second ANOVA test was performed among the firms with average annual turnovers between 1 – 10 and 100 – 1000 million U. S. dollars. The hypothesis test, with %95 confidence, is as follows:

H_0: $\mu_1 = \mu_2$

H_1: $\mu_1 \neq \mu_2$

The second ANOVA test results can be seen in Table 5.12:

Table 5.12- Second ANOVA Test Results

Groups	***Average***	***Variance***				
1 - 10	66.74	189.21				
100 - 1000	81.80	89.49				
Source of Variation	***S. S.***	***d.f.***	***M. S.***	***F***	***P-value***	***F critic***
Between Groups	1464.94	1	1464.94	10.20	0.0038	4.25
Within Groups	3444.27	24	143.51			

Since the F value is bigger than the F critic value, the H_0 was rejected. A significant difference was found between these groups.

The third ANOVA test was performed among the firms with average annual turnovers between 10 – 100 and 100 – 1000 million U. S. dollars. The hypothesis test, with %95 confidence, is as follows:

H_0: $\mu_1 = \mu_2$
H_1: $\mu_1 \neq \mu_2$
The third ANOVA test results can be seen in Table 5.13:

Table 5.13- Third ANOVA Test Results

Groups	***Average***	***Variance***				
10 - 100	67.14	314.00				
100 - 1000	81.80	89.49				
Source of Variation	***S. S.***	***d.f.***	***M. S.***	***F***	***P-value***	***F critic***
Between Groups	1431.46	1	1431.46	6.65	0.016	4.24
Within Groups	5380.59	25	215.22			

Since the F value is bigger than the F critic value, the H_0 was rejected. A significant difference was found between these groups.

No test was applied to the group that has average annual turnover more than 1000 million U. S. dollars. It is because its sample size is too small (N = 3). The average lean conformance of that group is %86.66 and this is the highest average of all groups.

5.4.4 Lean Conformance by Questions

There are 25 lean conformance related questions in the questionnaire. Each has the same weight and altogether constitute the sub – principles. The lined up mean values of each answer to the questions, in ascending order, can be seen in Table 5.14:

Table 5.14- Mean Values of Questions in Ascending Order

Type of Question	Mean
Optimize Value-2	3.16
Reduce Process Cycle Time-3	3.25
Optimize Production System-1	3.29
Flexible Resources-1	3.34
Flexible Resources-2	3.38
Training	3.45
Defined Work Processes	3.45
Metrics-1	3.50
Metrics-2	3.50
Error Proofing	3.50
Organizational Commitment	3.54
Visual Management-2	3.61
Organizational Learning	3.63
Supply Chain Management-1	3.63
Workplace Organization	3.65
Optimize Value-1	3.68
Reduce Process Cycle Time-1	3.68
People Involvement	3.70
Optimize Production System-3	3.75
Reduce Process Cycle Time-2	3.77
Optimize Work Content	3.93
Response to Defects	3.95
Optimize Production System-2	3.97
Supply Chain Management-2	4.02
Visual Management-1	4.02

We can classify the firms' answered to the questions by their average annual turnovers. The lined up mean values of each question, answered by the small firms (with average annual turnover between 1 – 10 million U. S. dollars), can be seen in Table 5.15:

Table 5.15- Mean Values of Questions Answered by Small Firms

Type of Question	Mean
Optimize Value-2	2.86
Metrics-2	2.93
Reduce Process Cycle Time-3	2.93
Training	3.00
Reduce Process Cycle Time-1	3.00
Optimize Work Content	3.00
Defined Work Processes	3.00
Flexible Resources-1	3.07
Optimize Value-1	3.07
Optimize Production System-1	3.14
Metrics-1	3.29
Flexible Resources-2	3.29
Optimize Production System-3	3.29
Workplace Organization	3.36
Organizational Commitment	3.43
Error Proofing	3.50
Visual Management-2	3.50
Response to Defects	3.57
Supply Chain Management-1	3.64
Visual Management-1	3.64
People Involvement	3.71
Organizational Learning	3.71
Optimize Production System-2	3.79
Reduce Process Cycle Time-2	3.79
Supply Chain Management-2	3.93

The lined up mean values of each question, answered by the medium – small firms (with average annual turnover between 10 – 100 million U. S. dollars), can be seen in Table 5.16:

Table 5.16- Mean Values of Questions Answered by Medium – Small Firms

Type of Question	Mean
Flexible Resources-1	2.80
Error Proofing	2.93
Optimize Value-2	2.93
Reduce Process Cycle Time-3	2.93
Flexible Resources-2	3.00
Optimize Production System-1	3.00
Metrics-1	3.07
Defined Work Processes	3.07
Organizational Commitment	3.13
Training	3.13
Workplace Organization	3.20
Supply Chain Management-1	3.27
Reduce Process Cycle Time-2	3.40
Visual Management-2	3.40
People Involvement	3.47
Metrics-2	3.47
Optimize Value-1	3.53
Reduce Process Cycle Time-1	3.53
Organizational Learning	3.60
Supply Chain Management-2	3.60
Optimize Production System-3	3.67
Response to Defects	3.73
Optimize Production System-2	4.00
Visual Management-1	4.00
Optimize Work Content	4.07

The lined up mean values of each question, answered by the medium – small firms (with average annual turnover between 100 – 1000 million U. S. dollars), can be seen in Table 5.17:

Table 5.17- Mean Values of Questions Answered by Medium – Large Firms

Type of Question	Mean
Organizational Learning	3.50
Optimize Value-2	3.58
Optimize Production System-1	3.67
Reduce Process Cycle Time-3	3.75
Flexible Resources-2	3.83
People Involvement	3.92
Metrics-2	3.92
Error Proofing	3.92
Reduce Process Cycle Time-2	3.92
Visual Management-2	3.92
Flexible Resources-1	4.00
Supply Chain Management-1	4.00
Metrics-1	4.08
Optimize Production System-3	4.08
Organizational Commitment	4.17
Optimize Production System-2	4.25
Training	4.33
Optimize Value-1	4.33
Reduce Process Cycle Time-1	4.33
Defined Work Processes	4.33
Visual Management-1	4.42
Workplace Organization	4.42
Response to Defects	4.50
Supply Chain Management-2	4.50
Optimize Work Content	4.58

The lined up mean values of each question, answered by the large firms (with average annual turnover more than 1000 million U. S. dollars), can be seen in Table 5.18:

Table 5.18- Mean Values of Questions Answered by Large Firms

Type of Question	Mean
Organizational Commitment	3.67
Training	3.67
Optimize Production System-2	3.67
People Involvement	4.00
Organizational Learning	4.00
Flexible Resources-2	4.00
Optimize Value-2	4.00
Supply Chain Management-1	4.00
Optimize Production System-1	4.00
Visual Management-2	4.00
Defined Work Processes	4.00
Metrics-1	4.33
Reduce Process Cycle Time-3	4.33
Visual Management-1	4.33
Workplace Organization	4.33
Metrics-2	4.67
Response to Defects	4.67
Error Proofing	4.67
Flexible Resources-1	4.67
Optimize Value-1	4.67
Supply Chain Management-2	4.67
Optimize Production System-3	5.00
Reduce Process Cycle Time-1	5.00
Reduce Process Cycle Time-2	5.00
Optimize Work Content	5.00

5.5 Discussion of Results

The discussion of the preceding analysis will be made in this section. Firstly, the comparatively high values of the sample average lean conformance (%72.35) and median (%74) promise a strong base for further lean construction studies and the applications of the lean methodologies/tools. Additionally, the population average (μ) of the contractors, which was found as lying in between %68.56 and %79.45 with %95 confidence interval, indicates a quite concrete lean character that is capable of internalize the major lean construction concepts and principles. The figures are promising for the future development of lean construction among the construction companies in Turkey. There is a potential in terms of firms' internal practices. Lean thinking and lean construction can systematically be introduced to and developed with contractors. These figures arguably indicate that the construction companies in Turkey have a lean foundation. This foundation is open to some developments and can enable the contractors to benefit from lean construction. It was also observed that contractors had no idea about the term lean construction yet.

Regarding sub – principles, the customer focus and culture/people sub – principles yielded relatively lesser values in terms of percent fulfillment from Figure 5.12. The customer focus sub – principle is about understanding changing customer needs and being flexible enough to easily adapt to these needs. The culture/people sub – principle focuses on systematically educating employees, listening to their ideas and commitment to joining every employee to the lean movement at a firm. The optimize value – 2 question under the customer focus sub – principle got the highest amount (7) of the N/A answers. This question searches for whether or not customers' needs are understood and agreed on by everyone. The somewhat terminological tongue of the question might have contributed to the number of the N/A answers. Shortly, customer focus and culture/people issues should get a little more attention by lean practitioners, according to the research.

The firms were classified by their average annual turnovers (Table 5.10). The firms, having average annual turnovers between 1 – 10 million U. S. dollars, were classified as small firms. The firms, having average annual turnovers between 10 – 100 million U. S. dollars, were classified as medium - small firms. The firms, having average annual turnovers between 100 – 1000 million U. S. dollars, were classified as medium -

large firms. The firms, having average annual turnovers more than 1000 million U. S. dollars, were classified as large firms.

The ANOVA test was applied between these classified firms, except for the large firms. As a result, no significant difference was found between the small and medium – small firms in terms of their average lean conformance values (Table 5.11). On the other hand, it was found that the medium – large firms had a significant difference from both the small and medium – small firms in terms of their average lean conformance values (Table 5.12 and Table 5.13). Because of its small sample size, no test was applied on the large firms. The large firms were observed to have the highest average lean conformance value though. The medium – large firms possess a higher average lean conformance value than the small and medium – small firms. The small and medium – small firms have very close average lean conformance values. It can be inferred from these tests that the medium – large and large firms can more easily adapt to and benefit from the lean construction methodologies/tools.

From Table 5.9, we can see that the small and medium – small firms have the least percent fulfillment in the customer focus and culture/people sub – principles. The medium – large firms have the least percent fulfillment in the customer focus and continuous improvement/built – in – quality sub – principles. The continuous improvement/built – in – quality sub – principle is related with making quality inherent in projects. This means to have metrics to measure the whole process, taking proactive measures to prevent improper construction, implementing organizational learning and having a clear roadmap in case of an under - quality production. The large firms have the least percent fulfillment in the culture/people and the standardization sub – principles. The standardization sub – principle mainly deals with management with visual assistance (graphs, illustrations etc.), workplace organization that is a reflection of 5S and defined work processes. All of the firms have comparatively high percent fulfillment values in the eliminate waste sub – principle. The eliminate waste sub – principle aims at reducing the waste defined by Ohno and elaborated by Womack et al. This seems logical as their reduction directly reduces the cost of a production process.

If we take a close look to the questions that have the least 5 average values from Table 5.14, we will see that the optimize value-2, reduce process cycle time-3, optimize production system-1, flexible resources-1, flexible resources-2 questions got the least mean values. The optimize value-2 question deals with understanding and clarifying the value that is created via any project. This understanding should be realized and shared with employees and customers. The expected value should be understood and agreed on. The reduce process cycle time-3 investigates whether or not the risk management techniques are utilized. The optimize production system-1 question focuses on the level of continuous flow in a production unit. The flexible resources-1 question investigates how customer focused firms are and how flexible they are to comply with changing customer expectations. The flexible resources-2 question focuses on the degree of flexibility of a firm mainly towards environmental changes. The construction companies in Turkey should be a little more careful with these issues.

The small firms have the least 5 average values at the optimize value-2, metrics-2, reduce process cycle time-3, training, reduce process cycle time-1, optimize work content, defined work processes, flexible resources-1, optimize value-1, optimize production system-1 questions (Table 5.15). The metrics-2 question focuses on the existence of some objective metrics about production. The training question investigates whether or not firms allocate resources for training of their employees.

The reduce process cycle time-1 question focuses on whether or not projects are evaluated in terms of their constructability in addition to their costs and conformities to the present codes and specifications. The optimize work content question measures the degree of utilization of standard, pre-fabricated, pre-assembled, repetitively usable construction elements. The defined work processes question deals with whether or not work processes are systematically mapped. The optimize value-1 question deals with systematic investigation of customer needs throughout a project. These specified points are seemed to demand the most attention from the small firms.

The medium - small firms have the least 5 average values at the flexible resources-1, error proofing, optimize value-2, reduce process cycle time-3, flexible resources-2, optimize production system-1, metrics-1 , defined work processes, organizational commitment and training questions (Table 5.16). The error proofing question investigates the existence of proactive measures against defects at a firm. The metrics-1 question focuses on the existence of some objective metrics about material waste. The defined work processes question focuses on whether or not processes are systematically uncovered. The organizational commitment question deals with how eager, open and committed upper management is to change.

The medium – large firms have the least 5 average values at the organizational learning, optimize value-2, optimize production system-1, reduce process cycle time-3, flexible resources-2 questions (Table 5.17). The organizational learning question deals with capturing, analyzing, distributing both implicit and explicit data from projects and making inferences from these data.

The large firms have the least average values at the organizational commitment, training, optimize production system-2, people involvement, organizational learning, flexible resources-2, optimize value-2, supply chain management-1, optimize production system-1, visual management-2, defined work processes questions (Table 5.18). The optimize production system-2 question measures the degree of flexibility of workforce. The people involvement question investigates whether or not employees' experiences and ideas are utilized. This can be hard for larger firms due to their sizes. The supply chain management-1 focuses on the existence of just – in – time delivery. The visual management-2 question deals with how up to date visual management tools are. Although the sample size of the large firms are small in this research, it can be said that the number of the large firms in the population is also minor. Therefore, some inferences can be made from the sample in hand.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Summary

There has been many calls for change in the construction industry. These calls are mainly because of the belief that the industry works in a comparatively wasteful manner and has remained “backward” compared to some other large industrial groups. Indeed, the manufacturing industry has witnessed dramatic changes since the 19th century. The rapidly changing global economy and the competitive pressure on organizations intensify discussion about the construction industry. In Turkey, there are in addition frequent issues with careless construction, which have been clearly uncovered during the severe consequences of earthquakes in the past. Such issues increase the expectations of change.

At this point, lean construction, which took its roots from lean manufacturing, has been pronounced to be a mean for change for the construction industry. Lean manufacturing emerged and developed in the car manufacturing industry. It is a method that has been proven to add a competitive advantage to its practitioners. Its main motive is to maintain continuous flow while reducing waste and improving quality. Various tools and methodologies have been developed to realize this motive.

Lean construction aims at adapting the lean manufacturing motives to the construction industry. In order to do that, a set of lean manufacturing concepts have been redefined for the construction industry. Based on these concepts, some methodologies and tools have been developed.

Lean construction advocates a combined transformation (conversion) – flow – value approach to construction projects. Lean construction claims that the conventional construction project management is only transformation oriented. Lean construction has been developing and is now globally widespread.

In Turkey, in spite of a need for change, there is relatively minor research in this field. Because of this fact, the lean characteristic of the construction industry in Turkey was not clearly known. A questionnaire was prepared, based on the model proposed by Diekmann et al. (2003), to measure the lean conformance of the construction companies in Turkey at the level of the lean construction concepts.

The questionnaire was distributed to 125 contractors and 44 responses from contractors of various sizes and different characteristics were collected. After the analysis of the questionnaire, it was found that the construction companies in Turkey had promising lean conformance values for future studies, suggesting potential for lean construction practices.

It can be inferred from this study that contractors should be more focused on customer needs and culture/people issues. These issues include commitment to change, training employees and utilizing from their ideas, thoughts and expectations.

Significantly higher lean conformance values for large and medium - large firms suggest that these have more potential to successfully implement a lean philosophy. The small and medium – small firms have no significant difference in terms of lean conformance and these firms should be more concentrated on improving their lean conformances by realizing the lean construction concepts more intensively.

In general, the contractors should clearly define the expected value from a project with every party involved, utilize the risk management techniques more efficiently, try to maintain continuous flow and should keep their resources flexible towards changing customer needs and environmental effects.

Detailed recommendations, the main points of improvement and the characteristic traits of the contractors will be mentioned in the next section.

6.2 Conclusion and Recommendations

Lean production has been benefiting many manufacturers throughout the world. Positive references catch the attention of construction management researchers and practitioners. There are some differences between manufacturing and construction though. These differences may hinder the penetration of some of the main lean production philosophies, like just-in-time (J. I. T.) production, to the construction industry. In order to increase J. I. T., the diffusion of standardized construction elements should be promoted in the industry. Thus, the construction industry needs to make substantial changes in its context to benefit fully from lean thinking.

On the other hand, lean construction addresses interconnections between transformation, flow and value management, the detrimental effects of variability and the high level of obvious and hidden waste in the construction industry. This type of view to construction project management can be helpful for easing some of the industry’s well known shortcomings, such as waste, excess materials on site and comparatively low productivity figures. Lean construction also comes up with some new methodologies/tools in the name of adapting lean thinking to the construction environment.

The Turkish construction industry has pros and cons but in general a dynamic and competitive nature. Provided that the lean construction concepts, principles and methodologies/tools are explained clearly to the contractors in the industry, they can take advantage of this movement. Especially the large and medium to large contractors display readiness for further implementation. It was observed that the contractors had no idea about either lean production or lean construction yet. The way forward is self examination and implementation in accordance with the lean philosophy as set out in this thesis. There are some recommendations to make at the end of this study. Firstly, the recommendations for future researches:

- There is room for research in sub – principles of lean. However, one should be careful not to expand his/her questionnaire or survey too much, as longer questionnaires or surveys may reduce the respond ratio.
- The research herein can be supported with increased sample size. The terminology should be as per normal construction practices as much in order to increase the sample size and the number of meaningful answers.
- One copy of the questionnaire or survey can be distributed to site supervisors or employees working at construction sites. This type of research will give an opportunity to compare the answers of management to the answers of people working at sites.
- Another type of questionnaire or survey, that measures environmental effects on contractors, can be prepared.
- Different questionnaires or survey forms can be prepared by contractors' sizes or operational areas.

The recommendations for researchers and managers of the construction companies in Turkey:

- The comparatively high values of the average lean conformance of the population indicates that the contractors give attention to waste and cost, thus having a lean construction base. This base is open to the lean development and the application of the lean methodologies/tools.
- In order to enable further applications and benefit from lean construction, the contractors should be informed about being “lean”, the lean construction philosophy and its application means.
- The introduction of lean construction can be started with the large and medium – large firms, as they were found to have higher lean conformance values. Their higher values can be interpreted as they are more ready to comply with the lean methodologies/tools
- No significant difference was found between the small and medium – small firms. Application of lean in this group will require study of the concepts and adoption for this particular size of firm.
- In general, the firms should be more customer focused and pay more attention to understanding and developing their employees. They should more carefully interpret their employees’ ideas, thoughts and experiences. Organizational commitment to change should be sustained. This can be realized by informing parties about the prospective benefits change offers
- In a little more detail, the contractors should clearly define the expected value from a project. This definition should be agreed by employees and customers. By doing so, contractor will make sure that every party know what is expected from a project.
- Risk management should be formalized. These techniques will add more flexibility and readiness to unexpected situations, in other words, the situations that cause some variability in flow.

- Maintaining continuous flow should be more carefully studied. This study compromises the rearrangement of time and the resources, like manpower, material and money. In order to do that, detailed maps of work processes should be uncovered.
- The contractors should try to keep their resources flexible towards changing environmental conditions and customer needs. The flexibility of these resources will contribute also to maintaining continuous flow. This flexibility can be realized by consciously training employees for their gaining additional skills, establishing long term relationships with more than one trusted material supplier. Financial flexibility should also be sought persistently.
- Some objective and general metrics about production and waste should be implemented in the firms. These metrics need to be monitored and interpreted constantly.

The general recommendations and the major improvement points for the small construction firms in Turkey are as follows:

- The small and medium – small firms have close average lean conformance values. These comparatively low values indicate that these type of firms should work more towards implementing the basic lean construction concepts before the application of any methodology/tool.
- These small firms should work to understand customer needs and expectations and position themselves accordingly. They also need to improve their employees' abilities, gather their ideas, thoughts and experiences more efficiently. Management of these firms should be convinced about the possible benefits of change. By doing so, a substantial commitment can be reached.

- The above-mentioned recommendations for researchers and managers of the construction companies in Turkey are totally valid for the small and medium – small firms.
- The small contractors should clearly define the expected value from a project.
- Because of the comparatively low mean value of the metrics- 2 question by Table 5.15, implementing some production metrics seem a little more essential for the small firms.
- The utilization of the risk management techniques should be increased among the small contractors.
- In addition to this, the need for training of employees seem more important and essential for the small contractors.
- The small firms should also evaluate projects not only by their costs and conformance to the present codes and specifications but also by their levels of constructability.
- The small firms should work more towards the common usage of standard and pre – fabricated, pre – assembled construction elements. Although pre-fabricated elements and components may initially cost more, they help firms prevent waste, enable time savings and reduce quality issues related to workmanship
- The small firms should also spare their resources and time to understand flow of construction processes throughout a project.
- The flexibility of resources issue, especially towards changing customer needs, is necessary.
- Maintaining flow should be an objective to increase the level of conformance of the small firms as well.

The general recommendations and the major improvement points for the medium - small construction firms in Turkey are as follows:

- The medium – small firms should work to understand customer needs and expectations and position themselves by these needs and expectations. They also need to improve their employees' abilities, gather their ideas, thoughts and experiences more efficiently. Management of these firms should be convinced about the possible benefits of change. By doing so, a substantial commitment can be reached.
- The flexibility of resources issue, especially towards changing customer needs, seems to have a priority in amendment.
- The medium – small firms should take proactive measures to prevent defective production. This measures can include check lists, guides, informative tools etc.
- The medium – small contractors should also clearly define the expected value from a project with every party involved.
- The medium – small firms should utilize the risk management techniques more efficiently.
- Maintaining continuous flow should be more carefully studied by the medium – small firms.
- The concept of production metrics should be implemented by the medium – small firms.
- Mapping of construction processes is necessary to increase the level of lean conformance of the medium – small firms.
- Upper – level management of the medium - small firms should be convinced to change these firms' organizational cultures.
- The need for training of employees have importance for increasing the level of lean conformance of the medium – small firms.

The general recommendations and the major improvement points for the medium - large construction firms in Turkey are as follows:

- The medium – large firms have a significant difference from the small and medium – small firms. This means that these firms can implement lean construction at a more detailed level. The methodologies/tools of lean construction can be implemented more easily at these firms. It is because of their relatively high lean conformance values. They are more ready in terms of concepts than the small and medium – small firms.
- The medium - large firms should increase their customer focus. They need to correctly understand customer needs and take the necessary precautions to fulfill these needs. These firms also should be a little more concentrated on forming metrics to measure production and waste, taking proactive steps to prevent improper construction, implementing organizational learning and having a clear roadmap in case of defective – low quality production.
- It is necessary for the medium – large firms to put more effort to increase their level of organizational learning. While capturing, analyzing and distributing data, information technologies can be helpful.
- The medium – large contractors also need to clearly define the expected value from a project with every party involved.
- Maintaining continuous flow, by rearranging time and the resources, should be carefully studied by the medium – large firms.
- The risk management techniques should be more effectively used by the medium – large firms.
- The resources should be kept flexible, especially towards changing environmental conditions.

The general recommendations and the major improvement points for the large construction firms in Turkey are as follows:

- The large firms have the highest average lean conformance value. This may mean that these firms can implement lean construction at a more detailed level and that methodologies/tools of lean construction can be implemented more easily at these firms.
- The large firms should work to understand customer needs and expectations. They also need to improve their employees' abilities, gather their ideas, thoughts and experiences more efficiently. Management of these firms should be convinced about the possible benefits of change.
- Upper – level management of the large firms should be convinced to change these firms' organizational cultures.
- The need for training of employees seem more important and essential for the large contractors to increase their level of lean conformance
- The workforce, especially at construction sites, should be trained to be able to work in more than one production unit. In other words, they should be multi – skilled to a degree.
- The ideas, thoughts and experiences of employees should be effectively gathered. Employees should be joined in some decision processes.
- It is necessary for the large firms to put more effort to increase their level of organizational learning. While capturing, analyzing and distributing data, information technologies can be helpful.
- The resources should be kept flexible, especially towards changing environmental conditions.
- The large contractors need to clearly define the expected value from a project with every party involved.
- Materials should arrive to construction sites as close to their time of usage as possible. This is to say, the just – in – time delivery should be sought. This can be realized to a degree with detailed

procurement plans, high level of communication and establishing long term and strong relationships with suppliers.

- Maintaining continuous flow, by rearranging time and the resources, is also important for the large firms.
- Frequent update of informative visual tools is necessary to increase the level of lean conformance of the large firms
- Work processes should be mapped and uncovered.

The companies should try to check and improve themselves by the points mentioned in this thesis.

The environmental conditions in the country that surrounds the contractors should also be taken into the account. Construction has a great number of different products and every construction environment is different. Therefore, further studies may include the environmental effects and/or the lean application practices - trials among the contractors.

Lean thinking is applicable not only to the value-added activities of constructors, but to the value chain of construction activity as a whole. Lean thinking can also be more easily adapted to the manufacturers of pre-fabricated elements, as their environment resembles highly of the manufacturing environment. A lean conformance study can be conducted among the architects, designers and in particular project management consultants which would integrate lean into their management of design, procurement, construction, time, cost and quality.

REFERENCES

Abdelhamid, T. S., "Lean Construction", http://www.msu.edu/user/tariq/Learn_Lean.html, Last Accessed Date: May, 2007.

Abdelhamid, T. S., 2003. "Six Sigma in Lean Construction Systems: Opportunities and Challenges.", Proceedings of the 11th Annual Conference of the International Group for Lean Construction, 2003, Blacksburg, Virginia, U. S. A.

Abdelhamid, T. S., 2004. "The Self-Destruction and Renewal of Lean Construction Theory: A Prediction From Boyd's Theory", Proceedings of the 12th Annual Conference of the International Group for Lean Construction, 2004, Elsinore, Denmark.

Abdelhamid, T. S., and Everett, J. G., 2002. "Physical Demands of Construction Work: A Source of Workflow Unreliability", Proceedings of the 10th Annual Conference of the International Group for Lean Construction, 2002, Gramado, Brazil.

American Production and Inventory Control Society (A. P. I. C. S.) Dictionary, 7th Ed., 1992, A. P. I. C. S. Educational and Research Foundation, Falls Church, Virginia.

Arbulu, R., Ballard, G., and Harper, N., 2003. "Kanban in Construction", Proceedings of the 11th Annual Conference of the International Group for Lean Construction, 2003, Blacksburg, Virginia, U. S. A.

Arditi, D., and Gunaydin, H. M., 1997. "Total Quality Management in the Construction Process", International Journal of Project Management, Vol. 15, No. 4, 1997, pp. 235 – 243.

Ballard, G., 1999. “Work Structuring”, L. C. I. White Paper, No. 5, Lean Construction Institute, Las Vegas, Nevada, http://www.leanconstruction.org/pdf/WP5-WorkStructuring_1.pdf, Last Accessed Date: May, 2007.

Ballard, G., 2000a. “Lean Project Delivery System”, L. C. I. White Paper, No. 8, Lean Construction Institute, Las Vegas, Nevada, www.leanconstruction.org/pdf/WP8-LPDS.pdf, Last Accessed Date: May, 2007.

Ballard, G. 2000b. *The Last Planner System of Production Control*, PhD Dissertation, University of Birmingham, U. K.

Ballard, G., and Howell, A. G., 2003. “Lean Project Management”, Building Research and Information, Vol. 31, No. 2, 2003, pp. 119 – 133.

Ballard, G., and Koskela, L., 1998. ‘‘On the Agenda of Design Management Research’’, Proceedings of the 6th Annual Conference of the International Group for Lean Construction, 1998, Guaruja, Sao Paulo, Brazil.

Ballard, G., Koskela, L., Howell, G., and Zabelle, T., 2001. “Production System Design in Construction”, Proceedings of the 9th Annual Conference of the International Group for Lean Construction, 2001, National University of Singapore, Singapore.

Bechtel Company, “Six Sigma: The Way We Work”, http://www.bechtel.com/sixsigma.htm, Last Accessed Date: May, 2007.

Bertelsen, S., 2003. “Construction as a Complex System”, Proceedings of the 11th Annual Conference of the International Group for Lean Construction, 2003, Blacksburg, Virginia, U. S. A.

Bertelsen, S., and Koskela, L., 2002. “Managing the Three Aspects of Production in Construction”, Proceedings of the 10th Annual Conference of the International Group for Lean Construction, 2002, Gramado, Brazil.

Bossink , B. A. G., and Brouwers, H. J. H., 1996. “Construction Waste: Qualification and Source Evaluation”, A. S. C. E. Journal of Construction Engineering and Management, Vol. 122, No. 1, 1996, pp. 55 – 60.

Buchanan, D., and Huczynski, A., 2004. *Organizational Behavior : An Introductory Text, 5th Ed.,* Prentice Hall, Harlow.

Burati, J. L., Mathews, M. F., and Kalidendi, S. N., 1991. “Quality Management in the Construction Industry”, A. S. C. E. Journal of Construction Engineering and Management, Vol. 117, No. 2, 1991, pp. 341 – 359.

Bruck, H., Gerber, P., and Maier, V., 2005. “Strategic Change Decisions: Doing the Right Change Right”, Journal of Change Management , Vol. 5, No. 1, 2005, pp. 97 -107.

Celep, Z., and Kumbasar. N., 2004. *Deprem Mühendisliğine Giriş ve Depreme Dayanıklı Yapı Tasarımı, 3rd Ed*., Beta Publications, İstanbul.

Chou, Y., Polansky, A. M., and Mason, R. L., 1998. “Transforming Non – Normal Data in Statistical Process Control”, Journal of Quality Technology, Vol. 30, No. 2, 1998, pp. 133 – 141.

Chryssolouris, G., 1992. *Manufacturing Systems: Theory and Practice*, Springer-Verlag, New York.

Cimorelli, S., and Chandler, G., 1996. *Handbook of Manufacturing Engineering*, Edited by Jack M. Walker, Marcel Dekker, New York.

Cooke, B., and Williams, P., 2004. *Construction Planning, Programming and Control*, Blackwell Publishing, Oxford.

Cornick, T., 1991. *Quality Management for Building Design,* Butterworth Architecture, Oxford.

Crowley, A., 1998. “Construction as a Manufacturing Process: Lessons from the Automotive Industry”, Computer and Structures, Vol. 67, No. 5, 1998, pp. 389 -400.

Deming, E. W., 1986. *Out of the Crisis* , The MIT Press, Cambridge, Massachusetts.

Deprem Bilgi Bankası, “Türkiye Deprem Kronolojisi”, http://www.afet.gen.tr/turkiye-deprem-kronolojisi.php, Last Accessed Date: May, 2007.

Diekmann, J. E., Balonick, J., Krewedl, M., and Troendle, L., 2003. “Measuring Lean Conformance”, Proceedings of the 11th Annual Conference of the International Group for Lean Construction, 2003, Virginia Tech, Blacksburg, Virginia, U. S. A.

Dikbas, A., 1995. *Türk İnsaat Firmalarının Teklif Verme Sürecinde Karar Vermelerini Etkileyen Faktörlerin Analizi*, PhD. Dissertation, Istanbul Technical University, Istanbul.

Dowdy, S., Wearden, S., and Chilko, D., 2004. *Statistics for Research*, *3rd Ed*., John Wiley and Sons Ltd., Hoboken, New Jersey.

Dubois, A., and Gadde, L.-E., 2002. “Construction Industry as a Loosely Coupled System”, Construction Management and Economics, Vol. 20, No. 7, 2002, pp. 621 - 631.

El-Higzi, A. F., 2002. “Examining International Trade Flows For Australian Construction Companies”, International Journal of Social Economics, Vol. 29, No. 6, 2002, pp. 491 – 507.

EMS Consulting Group, 2004. “Heijunka: Level Load Production”, http://www.emsstrategies.com/dm090804article.html, Last Accessed Date: May, 2007.

Engineering Statistics Handbook, 2006. “Anderson – Darling Test”, http://www.itl.nist.gov/div898/handbook/eda/section3/eda35e.htm, Last Accessed Date: July, 2007.

Esin, A., 2004. *ISO 9001:2000 Işığında Hizmette Toplam Kalite, 2nd Ed*., METU Press, Ankara.

Evbuomwan, N. F. O., and Anumba, C. J., 1998. “An Integrated Framework for Concurrent Life-cycle Design and Construction”, Advances in Engineering Software, Vol. 29, No. 7, 1998, pp. 587 - 597.

Flanagan, R., and Jewell, C. A., 2005. “International Competitiveness of the Finnish Construction Sector”, Finnish Research Council, www.tekes.fi, Last Accessed Date: May, 2007.

Flyvbjerg, B., Skamris, H. M., and Buhl, S. L., 2004. "What Causes Cost Overrun in Transport Infrastructure Projects?" *Transport Reviews,* Vol. 24, No. 1, 2004, pp. 3 - 18.

Formoso, C. T., Isatto, E. L., and Hirota, E. H., 1999. “Method for Waste Control in the Building Industry”, Proceedings of the 7th Annual Conference of the International Group for Lean Construction, 1999, The University of California, Berkeley, California, U. S. A., pp. 325 – 334.

Formoso, C. T., Soibelman, L., Cesare, C. D., and Isatto, E. L., 2002. “Material Waste in Building Industry: Main Causes and Prevention”, A. S. C. E. Journal of Construction Engineering and Management, Vol. 128, No. 4, 2002, pp. 316 – 325.

Gann, M. D., 1996. “Construction as a Manufacturing Process? Similarities and Differences between Industrialized Housing and Car Production in Japan”, Construction Management and Economics, Vol. 14, No. 5, 1996, pp. 437 – 450.

Garas, L. G., Anis, R. A., and Gammal, E. A., 2001. “Material Waste in te Egyptian Construction Industry”, Proceedings of the 9th Annual Conference of the International Group for Lean Construction, 2001, National University of Singapore, Singapore.

Garelli, S., 2006. *IMD World Competitiveness Year Book*, International Institute of Management Development, Lausanne.

George, L. M., 2002. *Lean Six Sigma: Combining Six Sigma Quality with Lean Speed*, McGraw-Hill, New York.

Ghiani, G., Laporte, G., and Musmanno, R., 2004. *Introduction to Logistic Systems Planning and Control*, John Wiley and Sons Ltd., Hoboken, New Jersey.

Gibb, A. G. F., and Isack, F., 2003. "Re-engineering through Pre-Assembly: Client Expectations and Drivers", Building Research and Information, Vol. 31, No. 2, pp. 146 - 160.

Green, S., 1999. "The Missing Arguments of Lean Construction", Construction Management and Economics , Vol. 17, No. 2, 1999, pp. 133 – 137.

Green, S., 2002. "The Human Resource Management Implications for Lean Construction: Critical Perspectives and Conceptual Chasms", Journal of Construction Research, Vol. 3, No. 1, pp. 147 – 166.

Green, S., and May, S., 2003. "Re-Engineering Construction: Going Against the Grain", Building Research and Information, Vol. 31, No. 2, 2003, pp. 97 – 106.

Green, S., and May, S., 2005. "Lean Construction: Arenas of Enactment, Models of Diffusion and the meaning of 'Leanness'", Building Research and Information, Vol. 33, No. 6, 2005, pp. 498 – 511.

Gross, M. J., and McInnis, R. K., 2003 *Kanban Made Simple—Demystifying and Applying Toyota's Legendary Manufacturing Process*, AMACOM, New York.

Halevi, G., 2001. *Handbook of Production Management Methods,* Butterworth-Heinemann, Oxford.

HC Online, 2006. "Lean Manufacturing: Heijunka", http://chohmann.free.fr/lean/heijunkabox_us.htm, Last Accessed: May, 2007.

Hobbs, J., 2003. *Lean Manufacturing Implementation: A Complete Execution Manual for Any Size Manufacturer,* J. Ross Publishing: APICS, Boca Raton, Florida.

Horman, M. J., and Kenley, R., 2005. "Quantifying Levels of Wasted Time in Construction with Meta-Analysis", A. S. C. E. Journal of Construction Engineering and Management, Vol. 131, No. 1, 2005, pp. 52 – 61.

Howell, A. G., 1999. "What Is Lean Construction", Proceedings of the 7th Annual Conference of the International Group for Lean Construction, 1999, Berkeley, California, U. S. A.

Imai, M., 1994. *Kaizen : Japonya'nın Rekabetteki Başarısının Anahtarı*, Brisa, İstanbul.

Istanbul Technical University, 1999. *17 Ağustos 1999 Kocaeli Depremi Ön Değerlendirme Raporu*, Technical Report, Istanbul Technical University, Istanbul.

Jaafari, A., 1997. "Concurrent Construction and Life Cycle Project Management", A. S. C. E. Journal of Construction Engineering and Management, Vol. 123, No. 4, 1997, pp. 427 – 436.

Jackson, B., 2001. *Management Gurus and Management Fashions: A Dramatistic Inquiry*, Routledge, London.

Juran, J. M., 1993. "Made in USA: A Renaissance in Quality," Harvard Business Review, Vol. 71, No. 4, 1993, pp. 42 - 50.

Kim, D., 2002. *Explanatory Study of Lean Construction: Assessment of Lean Implementation*, PhD Dissertation, The University of Texas at Austin, U. S.

Kline, D. H., and Coleman, G. B., 1992. "Four Propositions for Quality Management of Design Organizations". Journal of Management in Engineering, Vol. 8, No. 1, 1992, pp. 15 – 26.

Kocel, T., 2003. *İşletme Yöneticiliği : Yönetim ve Organizasyon, Organizasyonlarda Davranış, Klasik-Modern-Çağdaş Yaklaşımlar, 9th Ed*., Beta Publications, Istanbul.

Kondo, Y., 1998. “Hoshin Kanri: A Participative Way of Quality Management in Japan”, The TQM Magazine, Volume. 10, No. 6, 1998, pp. 425 – 431.

Koraltan, S., and Dikbas, A., 2002. “An Assessment Of The Applicability of Partnering in The Turkish Construction Sector”, Construction Management and Economics, Vol. 20, No. 4, 2002, pp. 315 – 321.

Koskela, L., 1992. *Application of the New Production Philosophy to Construction*, Technical Report No. 72, Center for Integrated Facility Engineering, Department of Civil Engineering, Stanford University, Palo Alto, California.

Koskela, L., 1993. "Lean Production in Construction", Proceedings of the 1st Annual Conference of the International Group for Lean Construction, Technical Research Centre of Finland (VTT), Espoo, Finland.

Koskela, L., 2000. *An Exploration Towards a Production Theory and its Application to Construction,* PhD. Dissertation, VTT Building Technology, Espoo, Finland.

Koskela, L., Howell, G., and Ballard, G., 2003. “Achieving Change in Construction”, Proceedings of the 11th Annual Conference of the International Group for Lean Construction, 2003, Virginia Tech, Blacksburg, Virginia, U. S. A., pp. 1 – 14.

Kovanci, A., 2001. *Toplam Kalite Yönetimi Fakat Nasıl? : Her Seviyedeki Yöneticiler için Toplam Kalite Uygulama Rehberi*, Sistem Publishing, Istanbul.

Krieg, G., 2005. *Kanban-Controlled Manufacturing Systems*, Springer - Verlag, New York.

Lanigan, M., 1992. *Engineers in Business: The Principles of Management and Product Design*, Addison-Wesley Publishing Co., Harlow.

Liker, K. J., 2004. *The Toyota Way : 14 Management Principles from the World Greatest Manufacturer*, McGraw - Hill, New York.

Liker, K. J., and Lamb, T., 2000. *Lean Manufacturing Principles Guide*: *Version 0.5. A Guide to Ship Building*, Technical Report, The University of Michigan, Ann Arbor, Michigan.

Marosszeky, M., Thomas, R., Karim, K., Davis, S., and McGeorge, D., 2002. “Quality Management Tools for Lean Production: From Enforcement to Empowerment.”, Proceedings of the 10th Annual Conference of the International Group for Lean Construction, 2002, Gramado, Brazil.

McCabe, S., Rooke, J., Seymour, D., and Brown, P., 1998. “Quality Managers, Authority and Leadership”, Construction Management and Economics, Vol. 16, No. 4, pp. 447 – 457.

McCarthy, D. and Rich, N., 2004. *Lean T.P.M: A Blueprint for Change*, Elsevier Butterworth-Heinemann, Oxford.

McGeorge, D., and Palmer, A., 1997. *Construction Management: New Directions*, Blackwell Science, Osney Mead, Oxford.

Ministry of Public Works and Settlement, 2000a. *17 Ağustos 1999 İzmit Körfezi Depremi Raporu*”, Technical Report, Ministry of Public Works and Settlement of the Turkish Republic, 2000, Ankara.

Ministry of Public Works and Settlement, 2000b. *17 Kasım 1999 Düzce Depremi Raporu*, Technical Report, Ministry of Public Works and Settlement of the Turkish Republic, 2000, Ankara.

Monden, Y., 1998. *Toyota Production System: An Integrated Approach to Just-In-Time*, 3rd Ed., Engineering & Management Press, Norcross, Georgia.

Moralioglu, E., 1999. *İnşaat Sektöründe Yalın Yönetim Yaklaşımının Uygulanabilirliği*, Msc. Thesis, Istanbul Technical University, Istanbul.

Myers, D., 2004. *Construction Economics: A New Approach*, Spon Press, New York.

National Audit Office, 2001. *Modernising Construction,* National Audit Office, Report by the Comptroller and Auditor General, HC87, Session 2000 – 2001, London.

National Earthquake Council, 2002. *Deprem Zararlarını Azaltma Ulusal Stratejisi*, Technical Report, The Scientific and Technological Research Council of Turkey (T. Ü. B. İ. T. A. K.), 2002, Ankara.

Ohno, T., 1998. *Toyota Ruhu : Toyota Üretim Sistemi'nin Doğuşu ve Evrimi, 2nd Ed.,* Scala Publishing, Istanbul.

Ouchi, W. G., 1981. *Theory Z: How American Firms Can Meet the Japanese Challenge*, Addison-Wesley, Reading, Massachusetts.

Oz, O., 2001. "Sources of Competitive Advantage of Turkish Construction Companies in International Markets", Construction Management and Economics, Vol. 19, No. 2, 2001, pp. 135 – 144.

Paez, O., Salem, S., Solomon, J., and Genaldy, A., 2005. "Moving from Lean Manufacturing to Lean Construction: Toward a Common Sociotechnical Framework", Human Factors and Ergonomics in Manufacturing, Vol. 15, No. 2, 2005, pp. 233 – 245.

Pande, P., Neuman, R., and Cavanagh, R., 2004. *Six Sigma Yolu*, Klan Publications, Istanbul.

Pheng, L. S., and Hui, M. S., 2004. "Implementing and Applying Six Sigma in Construction", A. S. C. E., Journal of Construction Engineering and Management, Vol. 130, No. 4, 2004, pp. 482 – 489.

Pheng, L. S., and Tan, S. K. L., 1998. “How `Just-In-Time’ Wastages Can Be Quantified: Case Study of a Private Condominium Project”, Construction Management and Economics, Vol. 16, No. 6, 1998, pp. 621 – 635.

Picchi, F. A., 2001 “System View of Lean Construction Application Opportunities”, Proceedings of the 9th Annual Conference of the International Group for Lean Construction, 2001, National University of Singapore, Singapore.

Polat, G., and Ballard, G., 2004. "Waste in Turkish Construction: Need for Lean Construction Techniques," 12th Annual Conference of the International Group for Lean Construction, 2004, Elsinore, Denmark, pp. 488-501.

Polat, G., and Ballard, G., 2006. “How to Promote Off-Site Fabrication Practice of Rebar in Turkey?”, 14th Annual Conference of the International Group for Lean Construction, 2006, Santiago, Chile, pp.279-290.

Porter, M. E., 1990. *The Competitive Advantage of Nations*, The Free Press, New York.

Rich, N., 2002. *Turning Japanese?*, PhD. Dissertation, Cardiff University, Cardiff.

Ross, E. J., 1999. *Total Quality Management: Text, Cases and Readings, 3rd Ed.,* St. Lucie Press, Boca Raton, Florida.

Russell, S. R., and Taylor III, W. B., 2000. *Operation’s Management: Multimedia Version*, 3rd Ed., Prentice-Hall, Upper Saddle River, New Jersey.

Salem, O., Solomon, J., Genaidy, A., and Luegring, M., 2005. “Site Implementation and Assessment of Lean Construction Techniques”, Lean Construction Journal Vol. 2, No. 2, pp. 1-21.

Salem, O., Solomon, J., Genaidy, A., and Minkarah, I., 2006. “Lean Construction: From Theory to Implementation”, A. S. C. E. Journal of Construction Engineering and Management, Vol. 22, No. 4, 2006, pp. 168 – 175.

Saurin, T., Formoso, C., Guimaraes, L., and Soares, A., 2002. “Safety and Production: An Integrated Planning and Control Model.”, Proceedings of the 10th Annual Conference of the International Group for Lean Construction, 2002, Gramado, Brazil.

Saylan, G., 1999. *Postmodernizm*, Imge Publishing Co., Ankara.

Schleifer T. C., 2002. “Degenerating Image of the Construction Industry”, Practice Periodical On Structural Design And Construction, Vol. 7, No. 3, 2002, pp. 99 -102.

Shingo, S., 1986. *Zero Quality Control: Source Inspection and the Poka-Yoke System*, Productivity Press, Stamford, Connecticut.

Simsek, S. M., 2002. *Yönetim ve Organizasyon*, Nobel Publishing Co., Ankara.

Society of Manufacturing Engineers, 2005. “Pull System Must Fit Your Production Needs”, http://www.sme.org/cgi-bin/get-newsletter.pl?LEAN&20051011&1&, Last Accessed Date: May, 2007.

Society of Manufacturing Engineers, 2006. “Strategy Deployment: Linking Lean to Business Strategy”, http://www.sme.org/cgi-bin/find-articles.pl?&ME06ART13&ME&20060312&PUBME-66.249.66.238&SME& , Last Accessed Date: May, 2007.

Sorguc, D., 1996. “Deneyimler Işığında İTÜ Yapı İsletmesi Programı”, Proceedings of the 1st Construction Management Congress, 1996, Izmir, Turkey, pp. 33 – 51.

Sorguc, D., 1997. ”İnşaat (Yapım) Yönetimi Sorunları ve İTÜ Yapı İşletmesi Programı”, Türkiye Mühendislik Haberleri, No. 387, 1997, pp. 14 – 21.

Spar, D., 2003. *Managing International Trade and Investment: Casebook*, Imperial College Press, London.

Stinchcombe, L. A., 1959. "Bureaucrats and Craft Administration of Production: A Comparative Study", Administrative Science Quarterly, Vol. 4, No. 2, 1959, pp. 168 – 187.

Sun M., and Aouad, G., 2000. “Integrating Technologies to Support Organizational Changes in the Construction Industry”, Proceedings of the 7th ISPE International Conference on Concurrent Engineering, 2000, Lyon, France, pp. 596 – 604.

Tapscott, D., Ticoll, D., and Lowy, A., 2000. *Digital Capital: Harnessing the Power of Business Webs,* Harvard Business School Press, Boston, Massachusetts.

Taylor, W. F., 1967. *The Principles of Scientific Management, by Frederick Winslow Taylor*, Norton Company, New York.

Thomas, R. H, and Horman, M. J., 2006. “Fundamental Principles of Workforce Management”, A. S. C. E. Journal of Construction Engineering and Management, Vol. 132, No. 1, 2006, pp. 97 – 104.

The Lean Construction Institute, 2004. “What Is Lean Construction?”, http://www.leanconstruction.org/whatis.htm, Last Accessed Date: May, 2007.

Thomas, R. H., Horman, M. J., Souza, L. E. U., and Zavrski, I., 2002. “Reducing Variability to Improve Performance as a Lean Construction Principle”, A. S. C. E. Journal of Construction Engineering and Management, Vol. 128, No. 2, 2002, pp. 144 – 154.

T. M. M. O. B. Chamber of City and Regional Planners, 1999. *Gölcük Depremi Raporu: Deprem Sonrası Büyük Yıkımın Tarihsel Süreç; Politikalar Ve Üst Ölçekli Planlama Açısından Değerlendirilmesi*, Technical Report, T. M. M. O. B. Chamber of City and Regional Planners, 1999, Istanbul.

T. M. M. O. B. Chamber of Civil Engineers, 2006. "Biz Yapı Denetimi İstemiyoruz Diyenler 14 Ekim'de Ankara TMMOB Mitinginde.", http://www.tmmob.org.tr/modules.php?op=modload&name=News&file=article&sid=1638&mode=thread, Last Accessed Date: May, 2007.

Toklu, Y. C., 1996. "Türkiye'de Yap-İşlet-Devret Uygulamaları ve Sorunlar", Proceedings of the 1st Construction Management Congress, 1996, Izmir, Turkey, pp. 69 – 78.

Tommelein, I., Riley, D., and Howell, G., 1999. ''Parade Game: Impact of Work Flow Variability on Trade Performance'', A. S. C. E. Journal of Construction Engineering and Management, Vol. 125, No. 5, 1999, pp. 304 – 310.

Toyota Motor Company, 2007a. "Toyota Production System: Just – in - Time",http://www.toyota.co.jp/en/vision/production_system/just.html, Last Accessed Date: May, 2007.

Toyota Motor Company, 2007b. "Toyota Production System: Jidoka", http://www.toyota.co.jp/en/vision/production_system/jidoka.html, Last Accessed Date: May, 2007.

Toyota Motor Company, 2007c. "Toyota Production System: Illustration",http://www.toyota.co.jp/en/vision/production_system/illustration.html, Last Accessed Date: May, 2007.

Tsao, C. C. Y., Tommelein, I., Swanlund, E. S., and Howell, G., 2004. "Work Structuring to Achieve Integrated Product–Process Design", A. S. C. E. Journal of Construction Engineering and Management, Vol. 130, No. 6, 2004, pp.780 – 789.

Tulacz, J. G., 2005. "World Construction Spending Nears $4 Trillion for 2004", Engineering News-Record (E. N. R.), McGraw-Hill Construction, Vol. 254, No. 1, 2005, pp. 12 - 13.

University of Cambridge, 2007. "Kanbans", http://www.ifm.eng.cam.ac.uk/dstools/process/kanban.html, Last Accessed Date: May, 2007.

U. S. Environmental Protection Agency, 2006a. "5S", http://www.epa.gov/lean/thinking/fives.htm, Last Accessed Date: May, 2007.

U. S. Environmental Protection Agency, 2006b. "Total Productive Maintenance (T. P. M.)", http://www.epa.gov/lean/thinking/tpm.htm, Last Accessed Date: May, 2007.

Van der Aalst, W., and Van Hee, K., 2002. *Workflow Management: Models, Methods and Systems*, The MIT Press, Cambridge, Massachusetts.

Willamette University, 2005. "Fordism and Postfordism", http://www.willamette.edu/~fthompso/MgmtCon/Fordism_&_Postfordism.html, Last Accessed Date: May, 2007.

Willmott, P., and McCarthy, D., 2001. *T.P.M: A Route to World-Class Performance*, Elsevier Butterworth-Heinemann, Oxford.

Winch, M. G., 2003. "Models of Manufacturing and the Construction Process: The Genesis of Re-Engineering Construction", Building Research and Information, Vol. 32, No. 2, 2003, pp.107 - 118.

Womack, P. J., and Jones, T. D., 1996. *Lean Thinking : Banish Waste and Create Wealth in Your Corporation*, Simon and Schuster, New York.

Womack, P. J., Jones, T. D., and Roos, D., 1991, *The Machine that Changed the World : How Japan's Secret Weapon in the Global Auto Wars Will Revolutionize Western Industry*, Harper-Perennial, New York.

Woodward, J., 1980. *Industrial Organization : Theory And Practice*, *2nd Ed.,* Oxford University Press, New York.

Zhao, Y., and Chua, D. K., 2003. “Relationship between Productivity and Non Value-Adding Activities”, Proceedings of the 11th Annual Conference of the International Group for Lean Construction, 2003, Blacksburg, Virginia, U. S. A.

APPENDIX

THE QUESTIONNAIRE

An English copy of the distributed questionnaire can be found in this section. Each section heading of the lean conformance wheel (Figure 5.1) was also displayed above the related question. This questionnaire was formed to be easily filled on a computer.

A Questionnaire Form Prepared for a Master's Thesis within the Civil Engineering Department at the Middle East Technical University

While Filling the Questionnaire ;

1. **Carefully read the instructions, question statements and choices.**
2. **Try to be objective and true as much as you can.**
3. **Unless stated otherwise, pick one choice for each question.**
4. **It is enough to click on the shape represented as; ☐ with your mouse to pick a choice. A *cross* will appear on the shape representing the picked choice. Click once more on the shape with your mouse to remove the cross on it (To undo your choice.).**
5. **Try to answer all of the questions in the questionnaire.**
6. **Check your answers at the end of the questionnaire.**
7. **When the questionnaire is finished, save the questionnaire (Click Ctrl and S buttons at the same time.).**
8. **Send the questionnaire to odtu.anket@gmail.com via electronic mail.**
9. **We guarantee that the all types of gathered corporate and personal information will be kept confidential and used solely for academic purposes.**
10. **Thank you for your help and cooperation.**

Respondent's;

1. Profession;

Architect	Civil Engineer	Construction Technician	Other
☐	☐	☐	☐

2. Level of Education;

Associate's Degree	Bachelor's Degree	Master's Degree	Doctorate
☐	☐	☐	☐

3. Position;

Lower Level Manager	Mid-Level Manager	Upper Level Manager
☐	☐	☐

4. Level of Experience (In Years);

0 – 5	5 – 10	10 – 15	15 – 20	>20
☐	☐	☐	☐	☐

Firm's;

5. Areas of Operation (More than one choice can be picked !);

Project and Design	☐	Airports	☐
Residential and Commercial Buildings	☐	Pipe Lines	☐
Industrial Facilities	☐	Marine and Shore Works	☐
Infrastructural Facilities	☐	Tunnel Works	☐
Dams	☐	Strengthening and Restoration	☐
Highway and Transportation Facilities	☐	Energy Projects	☐

6. Operational Time Since Its Foundation (In Years);

0 – 5	5 – 10	10 – 15	15 – 20	>20
☐	☐	☐	☐	☐

7. Average Number of Employees (Including Construction Sites and Offices);

10 – 100	100 – 500	500 – 1500	>1500
☐	☐	☐	☐

8. Average Annual Turnover (In Million American Dollars);

1 – 10	10 – 100	100 – 1000	>1000
☐	☐	☐	☐

9. Major Clients;

Public Organizations ☐

Private Individuals and Organizations ☐

Both Public and Private Figures ☐

10. Geographical Operational Locations;

All Abroad	Spread in the Country and Abroad	All in the Country
☐	☐	☐

Please carefully read the statements below. Determine, as objectively as possible, the conformity of the practices at your firm to the statements on the right or left. If you think that the practices perfectly conform to the statement on the left, then mark the box number 1. If you think that the practices perfectly conform to the statement on the right, then mark the box number 5. If you think that the practices are close to the statement on the left, then mark the box number 2. If you think that the practices are close to the statement on the right, then mark the box number 4. For the practices in the middle of these two statements, mark the box number 3. If you have no idea about the practice or if you think that the statements are irrelevant, mark the N/A box. Please make sure that you mark only one box for each question.

Culture/ People

People Involvement

Employees do not share their ideas/point of views in the name of improving the firm's operations.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Employees share their ideas/point of views to improve the firm's processes and to reduce the waste within the firm. The firm has some mechanisms to provide this.

Organizational Commitment

Upper-level management seems satisfied with the status quo.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Upper-level management endeavors to change the firm's culture in the name of increasing organizational effectiveness.

Training

The firm does not allocate time and money for the activities (seminars, educational meetings etc.) that enrich employees' present knowledge and capabilities.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The firm, consciously and systematically, sustains activities that enrich employees' present knowledge and capabilities, that cause employees gain new skills necessary for the changing needs of the firm.

Continuous Improvement/ Built – in – Quality

Metrics- 1

Unused and/or unnecessarily purchased materials and tools are frequently put aside. These materials and tools are either wasted or returned to the supplier at the end of the job.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	There is a concrete system at the firm that measures and evaluates the quantity of unused and/or unnecessarily purchased materials and tools .

Metrics- 2

Some metrics about production (Worker – machine productivity, production defect ratios, material waste ratios, the ratio of real time – cost performance to the planned figures and so on.) are not clearly, systematically and objectively measured.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Some metrics about production are clearly, systematically and objectively measured, recorded and analyzed. These metrics are clear enough for employees to understand them. These standard measures are taken into the account while evaluating project successes.

Response to Defects

Production defects are usually identified randomly. The decision of whether production will be stopped or not, after the identification of production defects, are completely left to the will of the crew that is responsible for that production.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	In the identification of defects, there is a guiding quality plan that defines the duties and the responsibilities of people within any project. Crews and individuals behave according to this quality plan in case of a production defect.

Error Proofing

The precautions against production defects are limited to defect correctors that are put into application after the occurrence of any defect. These precautions have a reactive nature.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The precautions against production defects are preventive measures that are put into application before the occurrence of any defect. These precautions have a proactive nature.

Organizational Learning

Each and every project is evaluated separately. An effective database, created from the objective and the subjective data of the past projects, has not been constituted. Some inferences are not driven from the past projects to use for the future projects.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	For the firm, effectively recording project data, employees' knowledge and ideas, analyzing these data, presenting these data to the related departments on time and applying necessary change by the inferences driven from these data are among priorities. During the realization of any future project, these data are extensively utilized.

Customer Focus

Flexible Resources- 1

Working by customer focus is not explicitly stated among the strategic goals of the firm. The features of the main resources, such as material, tools and man power, are in a static nature and predominantly determined by the management.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Being customer focused is one of the strategic goals of the firm. The features of the main resources, such as material, tools and man power and the elements, like the employed technology and the organizational structure within the firm, are in a dynamic nature and in a change according to the expectations of customers.

Flexible Resources- 2

The firm has to consume substantial amount of resources in order to comply to the environmental change, such as changing customer needs.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The firm is in a flexible nature. It can adapt to the environmental change consuming relatively lesser amount of resources.

Optimize Value- 1

Some problems are experienced about studying the customer needs throughout a project, understanding them correctly and producing by these needs.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	It can be said that the customer needs are studied throughout a project, understood correctly and the necessary production is executed by these needs.

Optimize Value- 2

The value created by means of a project is defined separately by each and every party involved.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The value created by means of a project is defined with the customer and for the whole of a project. It is ensured that this value is understood by every party involved.

Eliminate Waste

Supply Chain Management- 1

Materials, prior to their usage, are stored in somewhere near the construction site.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Materials predominantly arrive to the construction site just before their usage. Storage is at its minimum.

Supply Chain Management- 2

Materials stay at a specific place, no matter where their location of usage is at the construction site.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Materials stay at the possible closest place to their location of usage at the construction site.

Optimize Production System- 1

The output of a production unit gets into its successor production unit as an input, either in huge amounts or being totally completed. The production chain is discontinuous.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The output of a production unit gets into its successor production unit as an input, in a continuous manner and in lesser amounts.

Optimize Production System- 2

The number of employees in a production unit at the construction site is not changed. There is only one production unit for each individual, in which they can work efficiently.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The number of employees in a production unit at the construction site can be changed depending on the needs of their successor production units. Each individual can work in more than one production unit efficiently.

Optimize Production System- 3

There is no planning and control department in the firm.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	There is a planning and control department in the firm, with its authority and responsibilities clearly defined. This department is efficiently utilized within the firm.

Reduce Process Cycle Time- 1

Projects, prior to their starts, are evaluated according to their approximate costs and their conformances to the related codes and specifications.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Projects, in addition to their approximate costs and conformances to the related codes and specifications, are evaluated also according to their constructability. The points, that are believed to cause waste of resources and some discontinuity in the production line and that are believed not to contribute to meeting customer needs, are tried to be changed.

Reduce Process Cycle Time- 2

The departments (Civil, mechanical, electrical, architectural, environmental etc.) operate in their areas of responsibility. There is no intensive connection between each other.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Coordination and cooperation between the departments (Civil, mechanical, electrical, architectural, environmental etc.) are at a top level.

Reduce Process Cycle Time- 3

Risk management techniques are not utilized within projects.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Risk management techniques, according to the features of projects, are always utilized with different methods and scales.

Optimize Work Content

Standard, pre-fabricated, pre-assembled, repetitively usable construction elements have never been used by the firm.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Standard, pre-fabricated, pre-assembled, repetitively usable construction elements have been consciously preferred by the firm. The firm desires and works for the generalization of their usage.

Standardization

Visual Management- 1

Some visual tools, that inform employees about the matters like the production condition, schedule, safety, productivity, level of production quality and so on, have not been used.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Some visual tools, such as documents and pictures, about the matters like the production condition, schedule, safety, level of production quality and so on, have been used and are accessible to anyone at the offices and the construction sites.

Visual Management- 2

The informative tools are updated at different intervals. These updates are sometimes frequent and sometimes seldom.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The informative tools are updated frequently and prepared to be understandable for everyone.

Workplace Organization

There is no pre - defined order at the offices and the construction sites. The order and the cleaning at these places, depending on the conditions, are at the personal initiatives of the office and the site managers.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	The firm systematically pays attention to keeping the offices and the construction sites clean, materials and tools sorted orderly by their types and places of usage. There are firm – wide standards in order to keep this system running. Chaos and dirt are never allowed.

Defined Work Processes

There is no study on work processes at the firm-wide scale. Employees, within their responsibilities, are expected to manage their own work processes.	1 | 2 | 3 | 4 | 5 | N/A ☐ ☐ ☐ ☐ ☐ ☐	Work processes are systematically, consciously and continuously monitored. The visual maps of these processes, that show the flow of materials, equipments, man power and financial resources, are uncovered. Processes are identified.

The questionnaire is completed.