A GUIDE FOR CONSTRUCTION COMPANIES TO APPLY LEAN SIX SIGMA METHODOLOGY

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ABSTRACT

A GUIDE FOR CONSTRUCTION COMPANIES TO APPLY LEAN SIX SIGMA METHODOLOGY

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The construction sector is an immensely important industrial sector in terms of economic and social impact and also employment facilities. Nonetheless, much research has pointed out a gap in terms of labor productivity, quality, performance and responsiveness to customer needs when compared with other large industrial sectors; sectors that have recently experienced huge gains and cost reductions via methods like Lean Six Sigma.

In this study, the construction industry will be examined for determination of the potential Lean Six Sigma implementation level and expected benefits from its use.

The author conducted interviews with three companies in order to find out their readiness for such a management by innovation. One of the companies was selected for further study due to suitability of their organizational structure, innovative strategy and interest in this study.

By taking up this pilot study and Lean Six Sigma principles as references, five roadmaps are generated as a guidance to implement Lean Six Sigma methodology for companies indicating the general steps before and during the implementation.

The proposed roadmaps and applied questionnaire/interview questions developed in this thesis will also be helpful to construction companies to scrutinize their own structure and performance levels and as a guide on how to pursuit improvements through the proposed implementation of the Lean Six Sigma methodology.

Keywords: Construction Industry, Lean Construction, Six Sigma, Lean Six Sigma.

ÖZ

İNŞAAT ŞİRKETLERİNİN YALIN ALTI SİGMA YÖNTEMİNİ UYGULAMASI İÇİN REHBER

DÜĞME, Fatma Zehra
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Inşaat sektörü ekonomik ve sosyal etkisi ve de işverme olanakları açısından son derece önemli bir endüstriyel sektördür. Bununla birlikte, yapılan araştırmalar Yalın Altı Sigma gibi metotları kullanarak büyük kazanç elde eden ve maliyetlerini düşüren diğer endüstrilere göre İnşaat sektörünün iş gücü verimliliği, kalite, performans, ve müşteri beklentilerini karşılama gibi konularda yetersiz kaldığını göstermektedir.

Bu çalışmada, İnşaat endüstrisi, potansiyel Yalın Altı Sigma uygulama seviyesinin belirlenmesi ve bu uygulamadan beklenen faydaları açısından incelenecektir.

Bu amaçla 3 inşaat şirketi ile bu tür yenilikçi bir yönetim şekline uyumluluk seviyelerini bulmak için görüşmeler gerçekleştirildi. Bu şirketlerden bir tanesi organizasyon yapısının uygunluğu, yenilikçi stratejileri ve çalışmaya gösterdikleri ilgi nedeniyle daha detaylı çalışma yapmak için seçildi.

Gerçekleştirilen pilot çalışma ve Yalın Altı Sigma prensipleri referans alınarak, İnşaat şirketlerinin Yalın Altı Sigma metodolojisini uygulayabilmesi için uygulamadan önce ve uygulama sürecinde takip edilmesi önerilen aşamaları gösteren beş yol haritası oluşturuldu.

Bu tez çalışmasında, uygulanan anket/ görüşme sorularının analizi ve önerilen yol haritaları, inşaat şirketlerinin kendi altyapılarını ve başarı seviyelerini gözden geçirmelerine yardımcı olacaktır. Ayrıca bu çalışma, İnşaat şirketlerine Yalın Altı Sigma metodolojisinin uygulama alanları, uygulamada takip edilecek yollar ve böyle bir yenilikçi uygulamanın faydaları konularında rehberlik edecektir.

Anahtar kelimeler: İnşaat sektörü, Yalın İnşaat, Altı Sigma, Yalın Altı Sigma

To My Husband and My Family

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A.D.	Axiomatic Design
A.N.O.V.A.	Analysis of Variance
A.N.S.I.	American National Standards Institute
A.S.C.E.	American Society of Civil Engineers
A.S.Q.	American Society for Quality
B.B.	Black Belt
B.C.A.	Building and Construction Authority
B.Q.C.	Business Quality Council
C.I.D.B.	Construction Industry Development Board
C.O.C.	Costs of Conformance
C.O.N.C.	Costs of Non-Conformance
C.O.N.Q.U.A.S.	Construction Quality Assessment System
C.O.P.Q.	Cost of Poor Quality
C.O.R.B.E.R.	Costain, O'Rouke, Bechey and Emcor Rail
C.R.	Capability Ratio
C.S.M.	Current State Map
C.T.Q.	Critical to Quality
C.T.Q.C.	Critical to Quality Characteristics
C.T.R.L.	Channel Tunnel Rail Link
CPI	Continuous Process Improvement
D.C.E.	Defect Containment Effectiveness
D.F.M.O.	Defects for Million Opportunities
D.F.S.S.	Design for Six Sigma
D.M.A.D.V.	Define, Measure, Analyze, Design, Verify
D.M.A.I.C.	Define, Measure, Analyze, Improve, Control
D.O.E.	Design of Experiment
D.P.U.	Defects per Unit
E.C.I.	European Construction Institute
F.M.E.A.	Failure Mode Effect Analysis
F.S.M.	Future State Map
G.B.	Green Belt
G.D.P.	Gross Domestic Product
H.D.B.	Housing and Development Board
I.S.O.	International Organization for Standardization
J.I.T.	Just in Time

K.I.A.	Key Improvement Areas
L.C.	Lean Construction
L.C.I.	Lean Construction Institute
L.C.L.	Lower Control Limits
L.C.N.	Lean Construction Network
L.P.D.S.	Lean Project Delivery System
L.P.S.	Last Planner System
L.S.S.	Lean Six Sigma
M.B.B.	Master Black Belt
M.S.A.	Measurement System Analysis
P.A.F.	Prevention, Appraisal, and Failure
P.C.M.	Process Cost Model
P.D.C.A.	Plan, Do, Check, Act
P.I.P.	Process Improvement Project
P.P.C.	Percent Plan Complete
Q.A.	Quality Assurance
Q.C.	Quality Cost
Q.F.D.	Quality Function Deployment
Q.I.P.	Quality Improvement Program
Q.M.	Quality Management
R.P.S.	Reverse Phase Schedules
R.R.	Repeatability and Reproducibility
S.I.P.O.C.	Supplier, Input, Process, Output, Customer
S.M.E.D.	Set up Time Reduction
S.P.C.	Statistical Process Control
S.S.	Six Sigma
S.W.L.A.	Six Week Look Ahead
T.P.M.	Total Productive Maintenance
T.Q.M.	Total Quality Management
T.R.I.Z.	Theory of Inventive Problem Solving
U.C.L.	Upper Control Limits
V.O.C.	Voice of the Customer
V.S.A.	Value Stream Analysis
V.S.M.	Value Stream Mapping
W.B.S.	Work Breakdown Structure
W.I.P.	Work in Progress
W.W.P.	Weekly Work Plan
Y.B.	Yellow Belt
Y.R.T.	Rolled Throughput Yield

CHAPTER 1

GENERAL INFORMATION

1.1. INTRODUCTION

The construction industry accounts for around one-tenth of the world's gross domestic product, seven percent of employment, half of all resource usage and up to 40% of energy consumption. This industry has a profound impact on our daily lives: the buildings we live and work in, the roads and bridges we drive on, the utility distributions systems we use, the railways, airports and harbours we travel and trade from are all products of this vital industry.

The construction industry is also a key indicator and driver of economic activity and wealth creation. It plays a substantial role in many economies (Stewart and Spencer 2005). The global construction industry is worth, conservatively, US$3.4 trillion in 2003 (International Construction, 2003) and it is essential in the vast majority of national economies.

Although construction sector is an immensely important industry in terms of economic impact, much research has pointed out a gap in terms of staff productivity, quality, performance and responsiveness to customer needs when compared with other large industries. The construction process does not inherently allow for mechanization, atomization and refinement with the same ease as in manufacturing.

The vast majority of enterprises in construction are small and medium-size, and although the market for large projects must be considered a global playground, most construction activity is domestic.

Apart from this, construction environments are characterized by problems related to variation, non value adding activities, and waste. Construction managers have for a long time focused their attention on conversion processes, with little attention given to flow activities, leading to uncertain flow processes, expansion of non value-adding activities, and reduction of output value (Alwi et al., 2002).

Waste has been considered to be a major problem in the construction industry. Industry researchers and practitioners acknowledge that there are many wasteful activities during the design and construction process with the majority of these consuming time and effort without adding value for the client (Love, 1996).

It is obvious that the identification of waste, non-value added activities, their causes, and a measurement of their level of importance, would provide useful information that would allow management to actively reduce their negative effects in advance. (Alwi et al., 2002)

Variation in construction is also one of the most important problems in construction sector. Schonberger (1986) emphatically states that "variability is the universal enemy" and that reducing variability increases predictability and reduces cycle times. Koskela (1992) also adds that reducing process variability will also increase customer satisfaction and decreases the volume of non value-adding activities.

Other large industries have reached far better levels of organizational maturity ,enabling them to consistently deliver high quality and low cost products, services and to focus on growing customer expectations, by adopting new technologies and management principles such as TQM, Lean and Six Sigma necessitated by increasing global competition. However, construction industry used its structural differences as an excuse for not adopting these new technologies and management techniques (Ferng and Price, 2005).

Many organizations have reported upon the successful implementation of a process known as Six Sigma (6σ). Six Sigma is in essence a 'zero defects' philosophy aiming at production and quality perfection through improvement projects having specific steps and use of statistical tools. The Six Sigma process originated in Motorola's strive for reaching better levels of product reliability when they started to measure defects as presented by six standard deviation (6σ) between the upper and lower specification limits.

Motorola reported that they have saved US$11 billion in manufacturing costs since its introduction. Other organizations such as General Electric and Sony have reported similar results and today Six Sigma has become a way of life in many leading organizations as well as in the service industry.

For decades there have been calls for construction to improve productivity, quality and responsiveness to customer needs and such results have encouraged the use of Six Sigma as a business strategy in construction. However due to various misconceptions and lack of adjustment to the character of the construction industry, the adaptation of Six Sigma has not been widespread.

So far, research looking at the applicability of Six Sigma in construction has emphasized that application of 'generic' Six Sigma may be problematic and that modifications may be needed to make the approach more suitable for construction. Such modifications have concentrated on the synergy with other approaches, in particular value management and 'lean' (construction/manufacturing) philosophies. Breyfogle et al. (2001), for example, stated that: "in a system that combines the two philosophies, Lean creates the standard and Six Sigma investigates and resolves any variation from the standard.

Whereas Six Sigma will help to fight and control variation from construction process with the help of the Six Sigma toolkit such as DOE (design of experiment), regression, correlation, hypothesis testing etc., Lean management will focus on continuous incremental improvement of processes through relentless elimination of waste and non value adding operations and also reduction of cycle time in the processes with the help of many techniques and tools such as value stream map analysis, mistake proofing (poke-yoke), total productive maintenance (TPM), production smoothing (Heijunka), cycle time reduction, and inventory reductions using the now-famous Just-In- Time. (Womack and Jones, 1996) So process speed and value added activities will be supplied by Lean Construction, variation control with Six Sigma make construction process more productive and profitable.

Whatever combination of Six Sigma and Lean is adopted, it is critical that care is taken to define and prioritize those process/products that are to be improved in order to ensure appropriate application of Six Sigma. Six Sigma is a quality/production improvement philosophy aimed squarely at timely, monetary results. Items with highest cost are therefore logical targets for Six Sigma projects – the higher cost saving potential the higher chance of success for Six Sigma projects.

As a result, all researches show that the construction industry unfortunately has tended to lag behind other industries in the adaptation of new technologies and management techniques for the performance, quality and quality improvement and also better customer focus. Therefore, construction industry should continuously review and improve its success and deliverables in the light of every changing perception of quality and performance.

According to the recent literature, Lean Six Sigma (combination of Lean construction and Six Sigma) could have the potential to push the agenda forward by reducing process and product defects, minimizing waste, non value adding activities, and variability in the processes, thus improving quality, productivity, performance and profitability within the construction.

1. 2. GOALS AND OBJECTIVES

The first aim of this study is measuring the current performance and infrastructure of company in terms of its compatibility to Lean Six Sigma principles in a selected company as a case study. The second aim is identifying and quantifying general construction industry problems in terms of quality, waste, variability, productivity, performance, and responsiveness to customer needs in this company. Third and major aim is forming a general guide for construction companies to start implementing Lean Six Sigma.

Expected gains from Lean Six Sigma implementation can be summarized as:

- To increase productivity and performance of employees;
- To increase process cycle efficiency and remove waste;
- To eliminate iterations due to rework;

- To decrease money loss due to rework, scrap, employees' mistakes, etc…;
- To decrease cost intensity of process due to improvement in inputs, outputs, and operations;
- To increase competitive advantages and market share;
- To generate drastic improvements in profit, productivity, quality, performance, and customer satisfaction.

To attain the above gains the following objectives were defined:

- To determine the conformance level of the construction industry infrastructure (from i.e. economic, i.e. strategic, i.e. cultural, i.e. organizational aspects) for the Lean Six Sigma implementation;
- To determine the quality, productivity, and performance gaps that need to be closed;
- To determine the critical problems, its effects, and financial implications;
- Identifying cost intensity of construction main processes and sub-processes;
- To prioritize key improvement areas/processes where Lean Six Sigma projects can have the greatest monetary impact;
- To form an optimum framework for improvement;
- To identify and map actionable problems and areas for improvement that could be candidates for Lean Six Sigma projects in construction;
- To determine the unique or shared elements and principles of Six Sigma and Lean Construction, Lean Six Sigma, appropriate for construction industry focusing on the results obtained from the case study.

To achieve the above objectives following studies were carried out:

- Literature survey in construction quality;
- Literature survey of construction waste;
- Literature survey of construction quality cost;
- Literature survey of Six Sigma and Lean Construction;
- A questionnaire for industry survey;
- Interviews with a construction firm as a case study to identify problems related to productivity, performance, quality, variability, waste, and customer satisfaction;
- Analyzing the interview results to determine current performance and infrastructure of the company
- Comparison of the results with proposed Lean Six Sigma principles and methodologies and evaluating the problems in implementation.
- Forming a general Lean Six Sigma Guide to lead construction companies in Lean Six Sigma implementation to gain benefits.

CHAPTER 2

CONSTRUCTION INDUSTRY RELATED PROBLEMS

2.1. THE CONSTRUTION INDUSTRY

Construction activity has been a central feature of civilization since the presence of human settlement. Construction is as old as any civilization and construction of structures is considered as a symbol of civilizations' prosperity. Therefore construction sector as having immense importance to the society is a fundamental industry to the quality of human life.

Construction industry is a business sector that plays a substantial role in many economies with its contribution to economy in terms of GDP (Gross Domestic Product) and a great employment potential (Stewart and Spencer, 2005). The construction sector has traditionally been a significant source of economic activity and the motor for a number of other industries, including iron and steel, wholly privatized cement sector, glass, ceramics and paint (The Economist Intelligence Unit Limited 2007, www.eiu.com). Consequently, construction is considered unique in that it can stimulate the growth of other industrial sectors.

According to the statistical results on countries' economy, the growth of construction industry in terms of its contribution to GDP in isolation plays a crucial role in the economy of a country. Therefore, improving construction efficiency by means of cost-effectiveness and timeliness would certainly contribute to cost savings for the country as a whole.

Although the construction sector is an immensely important industry in terms of economic impact and employment, research has often pointed out a gap in terms of performance, staff productivity, quality, and responsiveness to customer needs when compared with other large industries. Therefore, construction industry has traditionally experienced relatively low levels of efficiency, productivity, performance, quality, and also caused considerable wastage of resources.

To achieve improvements in terms of quality, performance, productivity, and customer satisfaction, many construction organizations have embraced a wide variety of management strategies. However, much research has shown that the construction industry has tended to lag behind other industries in achieving expected benefits through the implementation of these management strategies.

Constructions' lagging behind other industries arises from the characteristics that differentiate construction from other large industrial groups. In their research, Fheng and Price (2005) conclude that these characteristics are used as an excuse for not adopting management strategies.

Therefore construction industry needs to make radical changes to the processes through which it delivers its projects and these processes should be explicit and transparent to the industry and its clients to facilitate a quick and smooth progression (Egan Report, 1998). It is vital that that construction industry should improve its success and deliverables in the light of every changing perception of quality and performance by continuously reviewing its processes.

2.1.1. KEY CHARACTERISTICS OF THE CONSTRUCTION INDUSTRY

The construction industry has a number of different characteristics from other industrial sectors in terms of structure and mode of operation. The characteristics obtained from different researches and papers are as follows (Kanji and Wong, 1998; Serpell et. al., 2002; Fheng and Price, 2005; Harris and McCaffer, 2001; Riley and Brown, 2001; ILO, 2003):

- It is a project based industry composed of many different organizations having diverse performance and quality approaches;
- It employs a significant proportion of workforce who are transient and self employed, thus making it difficult to generate long term cultural perspectives;
- Its products have tended to be unique, thus making it difficult to learn through repeatability,
- Products of construction are large in scale and varied in kind;
- Unlike manufacturing industries, which have a fixed factory site, each construction site is unique in terms of environment and conditions;
- Construction projects require construction firms to set up temporary organizational structures at dispersed geographical locations, most often at a distance from central management;
- There is no clear, uniform evaluation standard in overall construction quality as there is in manufactured items and materials; thus, construction projects usually are evaluated subjectively;
- Since construction projects are single order design products, the owner usually directly influences the production. Moreover, excessive changes to the details of the design of a project are typical throughout the construction process;
- The participants in both the design and construction stages are likely to change from project to project;
- Lack of education and training of people especially the construction workers' that do not have a favorable attitude with respect to active participation in quality improvement;
- Virtual lack of research and development;

- Low investment in information technology;
- Various parties are involved in the same area at the same time;
- If not designed or built correctly, there is usually little that can be done to put things right at a later stage. The reworks at site cost much higher than in factory;
- Fragmented value chain,
- Changing project organizations,
- A hectic business climate,
- Adversarial contractual relationships.
- Construction core activities are dependent on manual labor and can only to a very limited extent be automated.
- Works are subject to the environments, weather.
- Construction companies have very high turnover compared to their asset base, i.e. very high budget construction projects can be completed with comparatively small amount of plant and machinery;
- Compared to other sectors, profit in relation to turnover is low;
- The use of hired plant is widespread, and the tendency is growing. Approximately 50-60% of site plant used on projects is hired;
- Cyclical fluctuations in the volume of work.

2.2. DEFINING QUALITY IN THE CONSTRUCTION INDUSTRY

Numerous expressions have been adopted to define quality in the construction industry. Crosby (1979) defined quality as “conformance to requirements”. Juran’s definition pointed to quality as “fitness for use” in terms of design, conformance, availability, safety, and field use (Omachonu and Ross, 1994).

Other definitions are also available and include: “customer satisfaction”, as indicated in Burati et al. (1991); “conformance to predetermined requirements”, as defined by the American Society of Civil Engineers (ASCE); “an organizational wide effort to continuously improve products and services delivered to customers by developing supporting organizational culture and implementing statistical and management tools” as explained by Madu(1998) and “the totality of factors and characteristics of a product or service that bears on its ability to satisfy given needs” as defined by the American National Standards Institute (ANSI), the American Society for Quality (ASQ), and the International Organization for Standardization (ISO) (as listed in Parti, 1996). Battikha (2002) declares that these definitions are interdependent and the choice of one depends on the domain and the purpose of its use.

A general graphical interpretation of the foregoing definitions is depicted in Figure 2.1 (Battikha, 2002). It illustrates, based on a quality level scale, the conformance of the product/service to the design requirements and the conformance of these requirements to the client needs/expectations, in the execution and the design stages respectively. This reflects the quality of each of the product/service and the requirements (i.e. design output). Client needs/expectations are at the base for varying the quality of the product/service (i.e. degree of goodness). The higher the standards levels to which the needs/expectations conform, the higher the degree of goodness (i.e. quality) (Battikha, 2002).

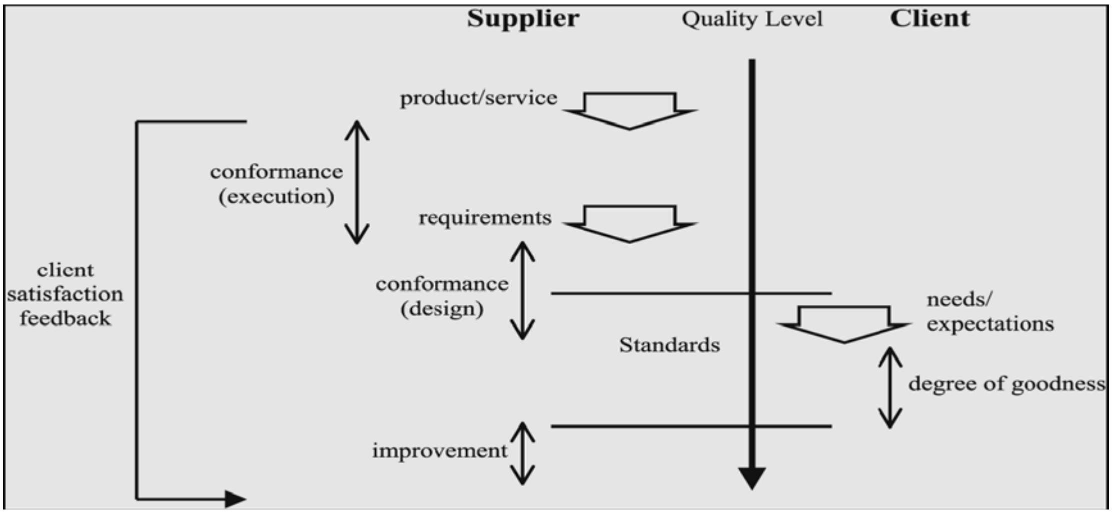


Figure 2.1- A general graphical interpretation of the foregoing definitions of quality (Battikha, 2002)

For the above figure, Battikha (2002) also encloses the followings:

- Standards can improve in time with the advancement of technology and innovation.
- The advancement process can benefit from the feedback provided by clients since their satisfaction in the product/service is also a reflection of its quality.

2.2.1. CONSTRUCTION QUALITY

Perceptions of quality have changed dramatically over past ten years and the importance of value for money has become a key dimension to performance measurement (Ferng and Price 2005).

The construction industry has become more competitive and recognized the importance of quality, performance, productivity, achieving excellence, and focusing on the customers' growing expectations. However, managing quality in construction projects has always been more difficult than in the manufacturing environment where the quality management concept was born. The researchers explain the reasons of this difficulty as followings:

- The project based nature of work,
- The fragmented value chain,
- The uniqueness of each project,
- Changing project organizations,
- A hectic business climate,
- Adversarial contractual relationships,
- The extreme difficulty of obtaining statistical data which is a must for the quality revolution,
- Defying automation in construction works due to the intensive labor component.

In the construction sector, quality is understood as the ability to meet the requirements contracted with clients. Achieving high quality is a fundamental way of meeting the needs of customers and reducing non-conformance. Producing quality products and services is cost effective, and auditing the cost of quality is one of the most important parameters of achieving quality (Kazaz et al., 2005). High quality is therefore always more cost effective than poor quality in the long term.

Quality management is a critical component to the successful management of construction projects. The construction industry lacks exposure to the tools and methods which have been applied successfully in the manufacturing industry to promote the management of quality. Quality in construction is directly related to time and cost, and vice-versa. A poor quality managed project can result in extra cost and time extensions, a poor time and cost controlled project can affect the conformance of requirements, i.e. quality (Abdul Rahman, 1995). It is therefore vital for project managers to understand the client's requirements in terms of cost, quality and time.

In a construction project, quality management should start from the inception right up to the commission stage. The earlier one recognizes the importance of better management of quality in a project, the more likely problems can be recognized and savings realized. Unfortunately the lack of attention to quality in construction has meant that quality failures have become endemic features of the construction process (Love and Heng, 2000).

The respondents of the survey made by Abdul Rahman (1997) observed that an emphasis on quality management in projects will eventually create opportunities for improvements in future, in terms of teamwork, better value for money, less dispute and in meeting the requirements of internal and external customers.

Significant expenditures of time, money and resources, both human and material, are wasted each year as a result of inefficient or non-existent quality management procedures (Arditi and Gunaydin 1997).

Although the attainment of acceptable levels quality in the construction industry has long been a problem, there exist a great potential for quality improvements in the construction industry (Steward and Spencer 2005).

Many of the quality management and production process improvement principles that have improved the performance, quality of manufacturing in terms of error free processes, customer satisfaction, and bottom line results also have potential for specific adaptation to suit construction management and production systems (Ferng and Price, 2005). Construction companies can implement such strategies with benefit and thereby achieve higher levels of quality, process capability, process maturity and profit.

2.2.2. FACTORS INFLUENCING CONSTRUCTION QUALITY

The factors which have an effect on the quality of construction were identified by Low and Goh (1993). These are ranked below in their order of importance:

1. Poor workmanship by the contractors in completing the works results from low tender prices.
2. Drawings and specifications do not specify clearly the intentions of the designers. Discrepancies are found between different consultants' drawings which have resulted in poor co-ordination during construction.
3. Contractors pay more attention to completing the works on schedule and controlling the costs to within budget than to achieving quality in construction.
4. Poor co-ordination exists between the contractors and the subcontractors as well as the nominated subcontractors.
5. Designers do not consider the "buildability" problems in design. For example, designers do not consider the use of special construction methods to achieve the tight tolerance caused by site constraints.
6. Contractors cannot plan and control the works. Contractors lack the skills to interpret the design and cannot provide the end products on site in accordance with the design and specifications.
7. Completion periods fixed by the client and consultants are not realistic.
8. Design does not satisfy the relevant codes and standards. This has resulted in a large amount of remedial work for the contractors and delay in the completion of projects.
9. Contractors do not know how to establish a quality system to control the works.
10. Materials chosen by the consultants do not satisfy the standards or the Building Control Authority.

From the above rankings, it would appear that the quality of construction work is dependent to a large extent on the attitudes of the contractors and consultants. Hence, the quality of the products is adversely affected if the parties to the contract do not carry out their duties properly. Therefore it is necessary to adopt a total quality approach in all construction projects in order to eliminate all factors which have an adverse effect on the quality of construction works (Pheng and Ke-Wei, 1996).

2.3. THE COST OF QUALITY IN CONSTRUCTION

Quality costs are a measure of costs specifically associated with the achievement or non-achievement of product quality, as defined by all product requirements established by the company and its contracts with customers and society (ASQC Quality Costs Committee, 1974).

Quality costs can be used to identify the causes of poor quality and to develop estimates of their direct and indirect costs. Then this obtained information can be used to determine quality improvement initiatives, which can be oriented at achieving significant cost savings and quality breakthroughs for organizations (Love and Heng, 2000).

It is accepted that quality cost is a useful indicator of performance. However, according to analysis of survey results made by Abdul Rahman (1997), the concept of quality cost in construction is ambiguous, making the cost of quality failure relatively unknown during construction.

According to Kazaz et all (2005), the advantages of measuring and classifying quality costs are as follows:

- It ensures that the project tasks are completed correctly from the beginning, and warrant the effort required.
- It helps to identify the problems that reduce the overall cost of quality.
- It allows cost quantification of failure events and thus helps to reveal the anomalies in cost allocation, which might otherwise remain undetected

Love et. al. (1998) defined quality costs as the total cost derived from problems occurring before and after a product or service is delivered. Figure 2.2 (Feigenbaum, 1991) identifies quality costs in terms of control and failure. Costs associated with failure arise from both internal and external sources. Internal poor quality costs increase an organizations cost of operations, for example, rework, material waste, and other avoidable process losses. However, external poor quality costs result in loss of profits: for example, contractual claims, defect rectification (rework), and the loss of future business.

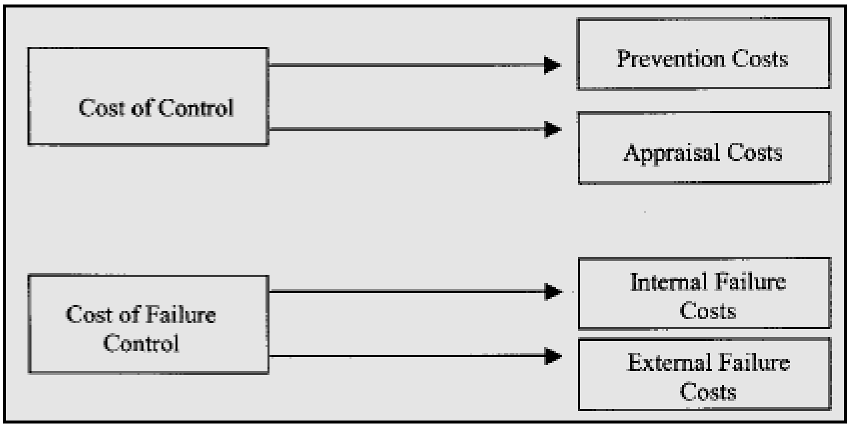


Figure 2.2- Quality costs: cost of control and failure (Feigenbaum, 1991)

Quality costs is just one type of measurement that can provide management with information about process failures and the activities that need to be designed to prevent their occurrence (Love and Heng, 2000). With this in mind, the measurement of quality costs taken throughout a project can be used to help transfer lessons learned to the next.

To improve the performance of construction organizations and reduce costs, Davis et al. (1989), Abdul- Rahman (1993) and Low and Yeo (1998), have stressed the need to measure quality costs. Without an effective quality cost system in place, performance improvements can be very difficult to identify and measure.

There are numerous methods for calculating quality costs. For example, costs can be classified as the 'cost of conformance' and the 'cost of non-conformance' (Love and Heng, 2000). Conformance costs include items such as training, indoctrination, verification, validation, testing, inspection, maintenance, and audits. Non-conforming costs, on the other hand, include items such as rework, material waste, and warranty repairs.

The most widely accepted method for measuring and classifying quality costs is the prevention, appraisal, and failure (PAF) model.

Prevention cost resulting from quality activities used to avoid deviations and errors (Oberlender, 1993). Examples of such costs are design reviews, education, training, supplier selection, process study, capability reviews, and process improvement projects. Prevention efforts also try to determine the causes of problems and eliminate them at the source, because an organization can determine when and where it wants to implement such efforts.

Appraisal costs include all costs associated with measuring, evaluating, or auditing products to determine whether they conform to their requirements (Crosby, 1979). Examples of appraisal costs include checks and grading to ensure specifications have been met, inspections, material reviews, and calibration of measuring and testing equipment. Appraisal costs are that they are associated with managing the outcome, whereas prevention costs are associated with managing the intent. Appraisal costs can be reduced when the quality of the product reaches high levels.

Failure costs are incurred when it is necessary to correct the products that fail to satisfy the customer or do not meet company quality specifications. Internal failure costs customer such as scrap and rework costs for the materials and defective product, labor, overhead associated with production, and compensation for delays in delivery. External failure costs are the costs that occur when a non-conforming product reaches the customer such as those due to customer complaints and those associated with receipt, handling, repair, returns, dealing with complaints and compensation, and replacement of non-conforming products. Warranty charges and product liability costs are also external failure costs. External failures can include loss of future business through customer dissatisfaction.

According to Tang et. all (2004), the PAF (prevent appraisal and failure) approach for capturing quality costs is in fact not suitable for construction projects, as they are usually big and complex. Then a new approach called Process Cost Model (PCM) which is suitable for use in construction projects, regardless of the sizes of the projects has been developed by the authors.

The quality costs in the PCM are called process costs, which can be divided into two parts: the costs of conformance (COC) and the costs of non-conformance (CONC) (Aoieong et al., 2002). COC is the intrinsic costs involved for providing the finished concrete product as required in good order, and the CONC is the costs of wasted time, materials and resources and any costs associated with the rectification of the unsatisfactory concrete product (Tang et. all, 2004).

The reduction in the cost of non-conformance is a popular motive for quality cost implementation since this leads to enhanced profit and competition (Dale and Plunkett, 1991). Similarly, reductions in the cost of quality failure or in cost of non-conformance in construction would provide the same effects – improved profit margin, competitiveness and client satisfaction (Abdul Rahman et al., 1996).

While Figure 2.3 shows the typical process cost model for construction processes, Figure 2.4 illustrates PCM for specific concreting process (Tang et. all, 2004).

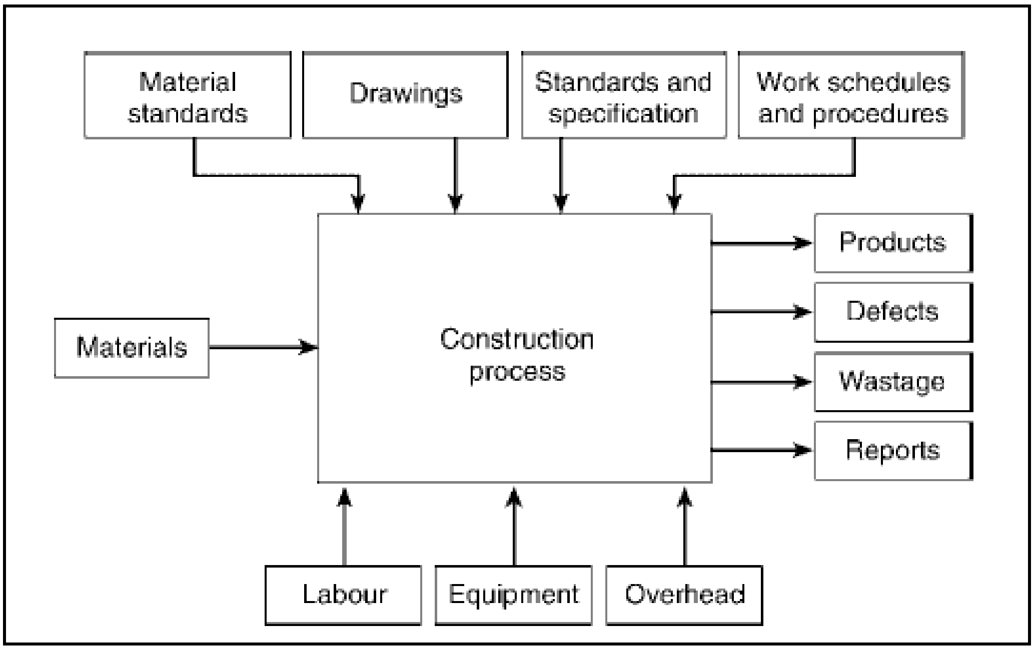


Figure 2.3- Typical cost model for construction processes (Tang et. all, 2004)

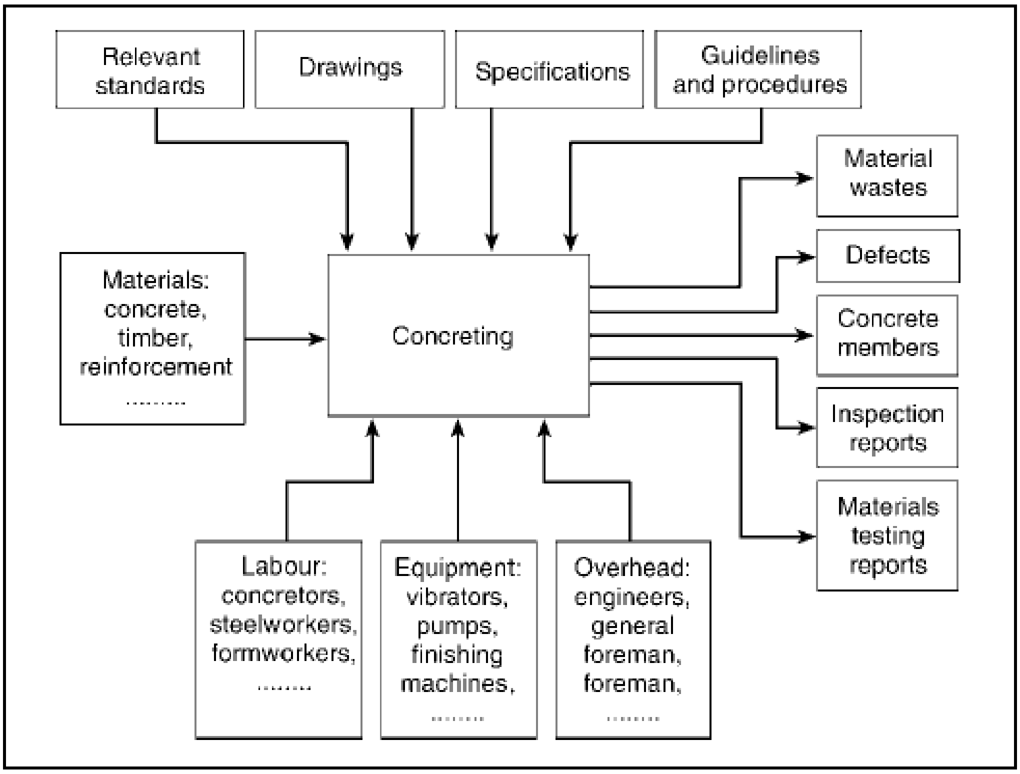


Figure 2.4- Process cost model for 'concreting process' (Tang et. all, 2004)

Due to the absence of a simple method for the acquisition of non-conformance information on construction sites (Abdul Rahman, 1993), Abdul Rahman and Thompson and Whyte (1996) developed the quality matrix specifically to seek answers to the following questions on non-conformance information:

- What category of non-conformance should be used and which construction activity is affected?
- What is the specific problem?
- What is the cause of non-conformance?
- How long will it take to rectify the problem?
- What will be the cost of rectification?
- Are there any other costs spread elsewhere?

On the following Table 2.1, there exists an example of quality matrix used to capture non-conformance events during construction.

Table 2.1- Example of Quality Matrix

Problem Category A	Specific Problem B	When problem is discovered C	Causes of Problem D	E	F	G	H	I
Construction related								
Sub-contractor								
Planning								
Buildability								
Design/ Information of temporary works								

• E = additional time needed to remedy the problem, i.e. actual duration minus estimated duration.

• F = the extra cost of resources incurred by the activity in putting things right using normal production rates.

• G = the additional time-related cost of extra time needed to complete the activity or additional costs required to speed up work as a result of the problem.

• H = any other additional remedial costs not associated with categories F and G, but adding to the activity cost indirectly.
• I = the expected or incurred cost of preventing the problem and/or inspection costs in performing the activity.

An example of expected quality costs for an organization can be seen in the following Figure 2.5 (BRE, 1982). As shown in Figure 2.5 (BRE, 1982), at least 15 per cent savings on total costs of construction can be achieved through eliminating re-work and wasted work. By looking the figure, it can be also concluded that as processes improve over a period of time, appraisal costs should reduce, as the need for inspection is no longer necessary. Thus, the greatest savings could be derived from reducing internal failure areas. The figure also illustrates the importance of prevention costs.

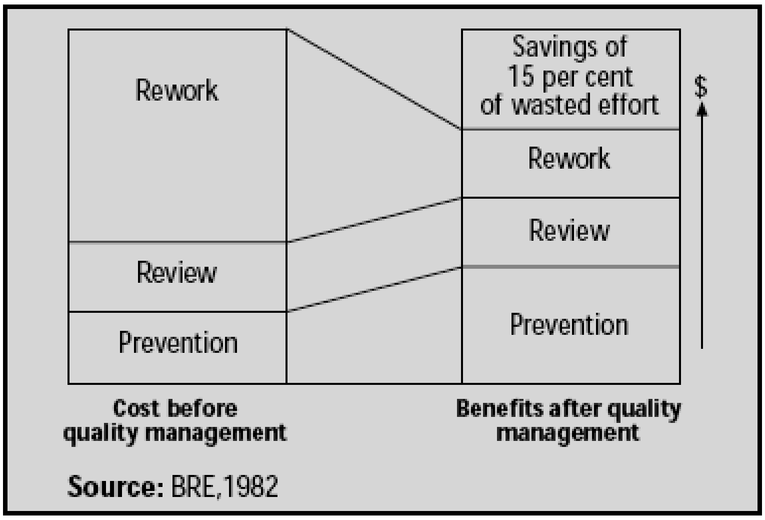


Figure 2.5-Costs and Benefits of Quality Management

According to Banks (1992), actual prevention costs are expected to rise, as more time is spent on prevention activities throughout the organization. Banks (1992) also points out that costs will rise as more time is spent on prevention. As processes improve, appraisal costs should then reduce, as inspection is no longer necessary. Thus, the greatest savings could be derived from reducing internal failure areas.

Campanella and Corcoran (1983) suggest that increases in expenditures will not show immediate reductions in failure costs, primarily because of the time lag between cause and effect. Appraisal and prevention costs are unavoidable costs that must be borne by design and construction organizations if their products/services are to be delivered 'right' the first time. Failure costs, on the other hand, are almost avoidable in construction, as most originate from ineffective management practices (Love and Irani, 2003).

Notably, quality costs can account for 8–15% of total construction costs. The Construction Industry Development Board (CIDB) in Singapore, for example, stated that an average contractor was estimated to spend 5–10% of the project costs doing things wrong and rectifying them. They concluded that an effective quality management would cost about 0.1–0.5% of total construction cost and produce a saving of at least 3% of total project cost (about five times the original outlay). Studies have shown that more than 25% of the costs can be cut through the use of an effective quality program. This clearly points to the importance of knowing how to prevent recurrence, not only benefiting the contractor, but also the client and end-users. Roberts in Australia found that by spending 1% more on prevention, failure costs could be reduced by a factor of five (Love and Irani, 2003).

Direct costs are readily measurable, often quoted in evaluating quality of workmanship, and represent a significant proportion of total project costs. Indirect costs are not directly measurable and include loss of schedule and productivity, litigation and claims, and low operational efficiency. In addition, labor costs for quality management (QM), which include full-time QM personnel and others occasionally involved with quality-related activities, need to be identified (Love and Irani, 2003).

Whatever the method is chosen, to enhance understanding of construction delays and cost overruns, the variables influencing construction time, performance, quality, and productivity should be identified, grouped into factors and finally the relations of these variables should be analyzed.

2.4. WASTE IN CONSTRUCTION INDUSTRY

Construction is characterized by complex communication and coordination environments involving a large number of individuals and interacting functions (Hampson, 1997). There exist various problems which cause considerable decrease in performance, productivity, quality, and customer satisfaction in the construction industry.

Waste has been considered to be a major problem in the construction industry. Not only does waste have an impact on the efficiency of the construction industry but also on the overall state of the economy of the country.

Industry researchers and practitioners acknowledge that there are many wasteful activities during the design and construction process with the majority of these consuming time and effort without adding value for the client (Love, 1996).

The term non value-adding activity is used to differentiate between physical construction waste found on-site, and other waste which occurs during the construction process. A number of definitions of waste are available in the literature. Waste definitions from different researchers are given on the following Table 2.2:

Table 2.2- Waste Definitions from different researchers

Researchers	Waste definition
Koskela, 1992	Any inefficiency that results in the use of equipment, materials, labor or capital in larger quantities than those considered as necessary in the production of a building.
Polat and Ballard, 2004	A simple way to define waste is that which can be eliminated without reducing customer value. It can be activities, resources, rules, etc.
Pheng and Tan, 1998	The difference between the value of those materials delivered and accepted on site and those used properly as specified and accurately measured in the work, after the deducting cost saving of substituted materials and those transferred elsewhere.
Koskela, 1992	Non value adding activities
Koskela, 1992 Alarcon, 1994 Love et al., 1997(a)	All those activities that produce costs, direct or indirect, and take time, resources or require storage but do not add value or progress to the product can be called waste.

According to the research made by Mastroianni and Abdelhamid (2003), for select construction activities the value added portion is about 5% and the remaining 95% is both non-value added and non-value added activities, also known as “waste”.

Alwi et al. (2002) adopted a quantitative approach for the research utilizing the results of a questionnaire survey involving 53 variables that relate to non value-adding activities. The variables were then separated into two classifications: waste variables that contribute to a reduction in the value of construction productivity and waste causes variables that could be defined as factors producing waste. The following Table 2.3 shows the details of these classifications.

Table 2.3- Alwi et al. (2002) Waste Classifications

Significant Waste Variables:	• Waiting for instructions • Repair on finishing works • Waste of raw materials on site • Unnecessary material handling • Tradesman slow/ineffective • Damaged materials on site • Delays to schedule • Waiting for materials • Waiting for equipment to arrive • Waiting for equipment repair • Lack of supervision/poor quality • Loss of materials on site • Waiting for labor • Repair on structural works • Idle tradesmen • Repair on formwork/false work • Repair on foundation works • Material does not meet specification • Too much material inventory on site • Equipment frequently breakdown • Unreliable equipment • Excessive accident on site

Table 2.3- Alwi et al. (2002) Waste Classifications (continued)

Key Waste Causes Variables:	• Poor quality site documentation • Weather • Unclear site drawings supplied • Poor design • Design changes • Slow drawing revision and distribution • Unclear specifications • Poor provision of information to project participants • Poor coordination among project participants • Poor planning and scheduling • Slow in making decisions • Lack of subcontractor's skill • Supervision too late • Site condition • Lack of trades' skill • Delay of material delivery to site • Poor distribution of labor • Inappropriate construction methods • Poor quality of materials • Poor material handling on site • Inappropriate/misuse of material • Poor equipment choice/ineffective equipment • Damage by other participants • Inexperienced inspectors • Too much overtime of labor • Poor site layout • Equipment shortage • Poor storage of material • Outdated equipment

Waste in construction is not only focused on the quantity of waste of materials on-site, but also related to several activities such as overproduction, waiting time, material handling, processing, inventories and movement of workers (Formoso et al. 1999; Alarcon 1994).

Consolidating research from authors (Alarcon 1995; Alwi 1995; Koskela 1993; Robinson 1991; Lee et al. 1999; Pheng and Hui 1999), the main categories of waste during the construction process can be described as: reworks/repairs, defects, material waste, delays, waiting, poor material allocation, unnecessary material handling and material waste.

Kaming et al. (1997) identified lack of material, rework/repair, and lack of equipment and supervision delays as factors influencing productivity in the construction industry.

Graham and Smithers (1996) believed that construction waste could occur during different project phases:

- Design (plan errors, detail errors and design changes),
- Procurement (shipping error and ordering error),
- Materials Handling (improper storage, deterioration and improper handling on and off site),
- Operation (human error, trades person, labour, equipment error, accidents and weather),
- Residual (leftover and unreclaimable non-consumables), and
- Other (theft, vandals and clients actions).

The study of material management in Malaysia (Abdul-Rahman and Alidrisyi 1994) identified the nature of problems such as delay in the delivery of materials, lack of planning and material variances.

Researches also indicated that clients could be a source of waste through careless inspection procedures and variation orders during the process. Initially, carelessness at the design stage can also lead to excessive waste which creates a need to over order to avoid a shortage of materials on site (Graham and Smithers, 1996).

Walbridge Aldinger (WA), who is in response to a challenge from Ford Motor Company to utilize "Lean" production principles in WA's construction delivery process, defined 8 forms of construction waste by using and adding to Ohno's famous seven (Womack and Jones 1996). The eight forms of waste are shown in Table 2.4 adopted by WA.

Table 2.4- The eight forms of waste adopted by WA.

	Form of Waste	Example
1	**Over-Production:** Producing over the customer requirements, producing unnecessary materials/products	Producing more pipe spools than required
2	**Inventory:** Holding or purchasing unnecessary raw supplies, work-in-progress inventory, finishing goods	Stockpiling too much dry wall in area well before it is needed and in the way of other trades
3	**Transportation:** Multiple handling, delay in material handling, unnecessary handling	Locating materials to far from the point of installation
4	**Waiting:** Time delays, idle time	Crew B waiting for an activity to be completed as promised by Crew A
5	**Motion:** Actions of people or equipment that do not add value to the product	Double and triple handling of material when planning could have reduced it to one move
6	**Over Processing:** Unnecessary processing steps or work elements	Rubbing a concrete foundation wall to well when it will be backfilled or covered
7	**Correction:** Producing a part that is scrapped or requires rework /procedures	Punchlist items or items of work that are deficient and do not meet requirements which require rework
8	**Not Utilizing Human Resources:** Not following-up/implementing ideas/suggestions	Not considering someone's idea to improve a process or work task particularly if that person performs that work

The eight basic types of waste in production defined by Taiichi Ohno (1988) and Womack and Jones (1996) are demonstrated in Table 2.5 as follows:

Table 2.5- The eight basic types of waste in production

Researchers	Sources	Classifications
Taiichi Ohno, 1988	Production	1. Defects in products 2. Overproduction (production more or doing more than needed) 3. Excess inventories 4. Unnecessary processing steps 5. Motion of employees with no purpose 6. Transportation of materials with no purpose 7. Waiting time (waiting by employees for process equipment too finish its work or for an upstream activity to complete)
Womack and Jones, 1996 (added one waste to Ohno's classification)	Production	8. Design of goods and services that fails to meet the customers' needs.

Formoso et al. (1999) classified waste as unavoidable waste, in which the investment necessary to its reduction is higher than the economy produced, and avoidable waste, in which the cost of waste is higher than the cost to prevent it.

Bossink and Brouwers (1996) classified the main waste causes in construction in six sources, which are;

1. Design
2. Procurement
3. Material handling
4. Operation
5. Residual
6. Other

Lee et al. (1999) classified construction waste in 8 groups, which are;

- Delay times,
- Quality cost,
- Lack of safety,
- Rework,
- Unnecessary transportation trips,
- Long distances,
- Improper choice or management methods or equipment,
- Poor constructability.

The evidence gives a clear indication that waste is not only associated with waste of materials in the construction process, but also other activities that do not add value such as repair, waiting time and delays. Another investigation showed that 25 per cent time savings is achievable in a typical construction work package without increasing allocated resources (Mohamed and Tucker, 1996).

Garas et al. (2001) grouped construction waste into two principal components:

1. Time wastes including waiting periods, stoppages, clarifications, variation in information, rework, ineffective work, interaction between various specialists, delays in plan activities, and abnormal wear of equipment.
2. Material wastes comprising over ordering, overproduction, wrong handling, wrong storage, manufacturing defects, and theft or vandalism.

The main causes of material and time waste identified by the respondents having sufficient background and qualifications are represented in the following Table 2.6 (Polat and Ballard, 2004). Polat and Ballard (2004) also organized the answers of respondents in respect of the classification proposed by Bossink and Browers (1996).

Table 2.6- The main causes of material and time waste

Construction Design	1. Material waste: • Lack of information about types and sizes of materials on design documents • Design changes and revisions • Errors in information about types and sizes of materials on design documents • Determination of types and dimensions of materials without considering waste 2. Time waste: • Interaction between various specialists • Rework due to design changes and revisions • Lack of information about types and sizes of materials on design documents • Errors in information about types and sizes of materials on design documents • Contradictions in design documents • Delays in approval of drawings
Construction Procurement	1. Material waste: • Ordering of materials that do not fulfill project requirements defined on design documents • Over ordering or under ordering due to mistakes in quantity survey • Over ordering or under ordering due to lack of coordination between warehouse and construction crews 2. Time waste: • Delay in material supply • Receiving material that do not fulfill the requirements defined on design documents, and waiting for replacement • Delay in transportation and/or installation of equipment

Table 2.6- The main causes of material and time waste (continued)

Construction Material Handling	1. Material waste: • Damage of material due to deficient stockpiling and handling of materials
Construction Operation	1. Material waste: • Imperfect planning of construction • Workers' mistakes • Damaged caused by subsequent trades 2. Time waste: • Scarcity of crews • Unrealistic master schedule • Rework due to workers' mistakes • Scarcity of equipment • Waiting for design documents and drawings • Lack of coordination among crews • Choice of wrong construction method • Accidents due to lack of safety
Construction Residual	1. Material waste • Conversion waste from cutting uneconomical shapes
Construction, others	1. Material waste: • Lack of on site materials control • Lack of waste management plans 2. Time waste: • Irregular cash flow • Severe weather conditions • Bureaucracy and red tape • Unpredictable local conditions • Acts of God

2.5. OTHER CRITICAL PROBLEMS IN CONSTRUCTION INDUSTRY

Apart from the waste problems, construction environments are also characterized by other problems related to production, general quality of work, design changes, material quality and availability and capacity utilization (Akintoye, 1995). Koskela (1993, 2000), Alarcon (1993) and Chan et al., (1997) identified low productivity, poor safety, inferior working conditions and insufficient quality as chronic problems of construction.

Other problems in the construction industry included equipment shortages, inefficiencies in using materials, imbalances in organizational structure, unfair competition, limited funds, planning uncertainties and a lack of human resource development (Alwi et al., 2002).

According to the numerous reports and studies performed by Love (1995) in the Australian construction industry, various problems related to construction performance are given below:

- The fragmented nature of the industry
- The phasing and sequencing of functions
- Lack of coordination between participants and trades
- Excessive subcontracting
- Unsatisfactory competitive tendering

Business Roundtable (1982a) identified the lack of adequate planning, scheduling, materials management, quality control, and quality assurance as critical problems during the construction process.

Alwi et al. (2002) concluded that major failures in construction was caused by cost overruns, delays in planned schedule, quality problems, and an increase in the number of disputes and resultant litigations.

Kaming et al. (1997) conducted a questionnaire survey on high rise projects in Indonesia to determine the variables having impact on construction cost and time overruns. In his corresponding paper, these variables were grouped into factors and their relationships were analyzed to enhance understanding of construction delays and cost overruns in developing countries. The following Table 2.7 illustrates these variables:

Table 2.7- The causes of time and cost overruns (Kaming et al., 1997)

Causes of time overruns	• Unpredictable weather conditions • Inaccuracy of materials estimate • Inaccurate prediction of craftsmen production rate • Inaccurate prediction of equipment production rate • Materials and equipment shortage • Skilled labor shortage • Locational restriction of the project • Inadequate planning • Poor labor productivity • Design changes

Table 2.7- The causes of time and cost overruns (Kaming et al., 1997)(continued)

Causes of cost overruns	• Unpredictable weather conditions • Material cost increased by inflation • Inaccurate quantity take off • Labor cost increase due to environment restrictions • Lack of experience of project location • Lack of experience of project type • Lack of experience of local regulation

According to the survey analysis performed by Kaming et al. (1997), the following results were obtained:

- It would seem that cost overruns occur more frequently and are thus a more severe problem than time overruns on high-rise construction in Indonesia.
- The predominant factors influencing time overruns/delays are design changes, poor labor productivity, inadequate planning and resource shortages.
- In the case of cost overruns, the most important factors are material cost increases due to inflation, inaccurate materials estimating and degree of project complexity.
- Considering both time and cost overruns together, the most important factors that influence them are: materials cost increases due to inflation, inaccuracy of estimates, and lack of experience of project type.

In addition to these results, Kaming et al. (1997) agreed that by reducing the influences of the identified factors, time and cost overruns on high-rise construction projects in developing countries can be carefully controlled.

According to the final report about measurement of construction processes for continuous improvement developed by Syed (2003), the critical problems in each section related to client dissatisfaction are shown on the following Table 2.8:

Table 2.8- Critical factors related to customer dissatisfaction

Sections	Critical factors related to client dissatisfaction
Administrative	Relationship between parties
	Adequacy of office personnel
	Project cost within the budget
	Knowledge of client needs
	Attention to client priorities
	Adequacy of supervision
	Coordination with regularity agencies
	Adequacy of planning
	Adequacy of training
	Customer satisfaction
Project Management And Engineering	Progress review meetings
	Adequacy of project control
	Adequacy of safety program
	Estimating
	Interaction with architect/engineer
	Scheduling
	Adequacy of supervision
	Shop drawing review
	Adequacy of planning
	Adequacy of subcontractor selection
Logistical	Adequacy of storage
	Adequacy of warehousing
	Adequacy of delivery
	Adequacy of maintenance
Construction	Project quality
	Adequacy of job site personnel
	Material quality
	Quality of workmanship
	Equipment quality
	Timely completion of project phases
	Knowledge of the project
	Site cleanliness
	Adequacy of processing change orders
	Project closeout

Variation is also one of the critical problems in construction processes. In the construction industry, sources of variability include late delivery of material and equipment, design errors, change orders, equipment breakdowns, tool malfunctions, improper crew utilization, labor strikes, environmental effects, poorly designed production systems, accidents, and physical demands of work (Abdelhamid and Everett 2002). Reducing or eliminating the variability that plague production processes requires the removal of the root causes of variability –a difficult but not impossible task.

Finally, the Egan report (1998) identified several problems with the construction industry, and they are as follows:

- Under-achievement of the industry as a whole
- Unacceptable level of defects
- Lack of predictability within the industry as a whole
- Lack of contractor profit
- Need for customer feed-back
- Lack of investment in capital, research, development and training
- Level of dissatisfaction amongst the industry's clients

Apparently, there are waste and other major problems in the construction industry. One form of waste or problem can cause another form of waste or problem to occur. Therefore, prevention of waste or problems must start at project inception. The focus therefore should be on both identification and elimination of material and time waste, and chronicle construction problems with the aim of improving project performance, productivity, quality, and namely increasing value for the customer, reducing consumption of resources in society. It is also commonly accepted that eliminating or reducing waste could yield great cost savings to society.

CHAPTER 3

TOTAL QUALITY MANAGEMENT

3.1. TOTAL QUALITY MANAGEMENT

In the 1950s, the Japanese asked W. Edwards Deming, an American statistician and management theorist, to help them improve their war torn economy. By implementing Deming's principles of total quality management (TQM), Japan experienced dramatic economic growth. In the 1980s, when the United States began to see a reduction in its own world market share in relation to Japan, American business rediscovered Deming. Total quality management experts or gurus, Joseph Juran and Philip Crosby, also contributed to the development of TQM theories, models, and tools. TQM is now practiced in business as well as in government, the military, education, and in non-profit organizations.

TQM is "a system of continuous improvement employing participative management and centered on the needs of customers". Key components of TQM are employee involvement and training, problem solving teams, statistical methods, long-term goals and thinking, and recognition that the system, not people, produces inefficiencies. TQM is seen as primarily a management-led approach in which top management commitment is essential (Anderson, 2004). The emphasis is on quality in all aspects and functions of the company operation, company-wide, not just the manufacturing function or provision of a major service to the external end-customer. Employee awareness and motivation are essential. The below Figure 3.1 depicts how the management process constantly strives for continuous improvement, deliver customer value, and excellence. (Anderson, 2004)

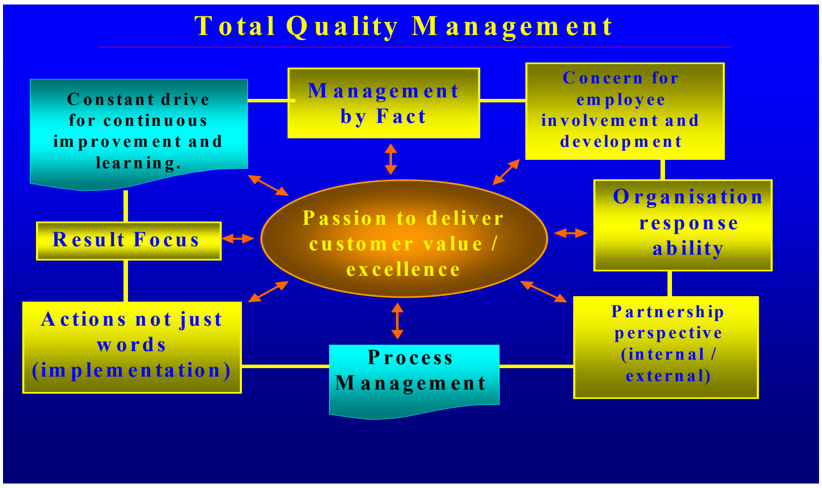


Figure 3.1- Total Quality Management adopted by Anderson (2004)

TQM is defined as a management approach that tries to achieve and sustain long-term organizational success by encouraging employee feedback and participation, satisfying customer needs and expectations, respecting societal values and beliefs, and obeying governmental statutes and regulations**.** Basic TQM principles assist management by fact and not by myth, no process without data collection, no data without analysis, no analysis without a decision, and avoid paralysis by analysis. (Arnheiter and Maleyeff, 2005)

TQM includes the following concepts:

- Strong customer focus
- Continual improvement
- Top management involvement
- Improvement in the quality of everything
- Cultural change
- Empowerment of employees

The main tools of TQM include the seven tools of quality: control charts, histograms, check sheets, scatter plots, cause-and-effect diagrams, flowcharts, and pareto charts; and the seven management tools of quality: affinity diagrams, interrelationship digraphs, tree diagrams, matrix diagrams, prioritization matrices, process decision program charts, and activity network diagrams (Sower et al., 1999).

As a summary, Total Quality Management (TQM) is a structured system for satisfying internal and external customers and suppliers by integrating the business environment, continuous improvement, and breakthroughs with development, improvement, and maintenance cycles while changing organizational culture. TQM provides the culture and climate essential for innovation and for technology advancement (Arditi and Gunaydin, 1997). TQM aims for quality principles to be applied broadly throughout an organization or set of business processes.

3.2. TOTAL QUALITY MANAGEMENT IN CONSTRUCTION

In construction, indirect learning and transfer of knowledge from one project to the next may work well, particularly at the time of construction master planning, integration of design and construction, and broad balancing of the construction sequence. At a given project site with a given workforce, once construction gets underway, the opportunity to apply TQM principles is normally limited due to the fact that construction operations are typically short lived, diverse, and subject to situational limiting factors and statutory requirements. (Jaafari, 2000)

Total Quality Management (TQM) concepts, developed by the manufacturing industry and first applied in Japan, in recent years were used in the United States, which have increased productivity, decreased product cost and improved product reliability. These concepts are also applicable to the construction industry. For example, Japanese construction companies, benefiting from the experiences of Japanese manufacturers, began implementing TQM during the 1970s. Even though construction is a creative, one-time process, the Japanese construction industry embraced the TQM concepts that some argued could only apply to mass production. (Arditi and Gunaydin, 1997)

TQM is increasingly being adopted by construction companies as an initiative to solve quality problems in the construction industry and to meet the needs of the internal customer (Kanji & Wong, 1998). As suggested by Oakland and Aldridge (1995), if ever an industry needed to take up the concept of TQM it is the construction industry. Alfeld (1988) advances the view that construction very probably promises a greater payback for performance improvement than any other service industry because of its magnitude.

TQM is an effort that involves every organization in the construction industry in the effort to improve performance. It permeates every aspect of a company and makes quality a strategic objective.

TQM is achieved through an integrated effort among personnel at all levels to increase customer satisfaction by continuously improving performance. TQM focuses on process improvement, customer and supplier involvement, teamwork, and training and education in an effort to achieve customer satisfaction, cost effectiveness, and defect-free work.

Project requirements are the key factors that define quality in the process of construction. The process of construction can be broken down into three main phases, namely, (1) the planning and design phase, (2) the construction phase, and (3) the maintenance and operation phase.

Figure 3.2 adopted by Arditi and Gunaydin (1997) shows generally accepted elements of TQM and construction industry-specific factors that affect quality of the process of a building project.

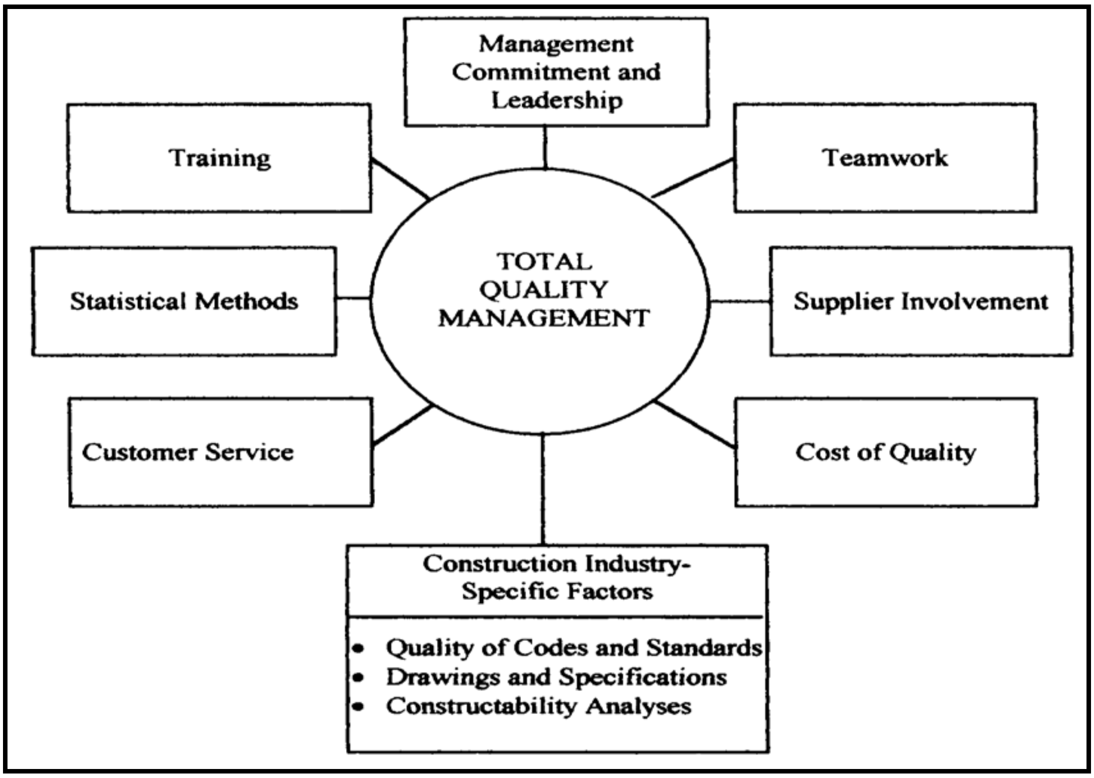


Figure 3.2- Elements of Total Quality Management in Construction Process (Arditi and Gunaydin, 1997)

Project managers and company administrators should consider the following points in developing their quality systems (Arditi and Gunaydin, 1997):

- Management commitment to quality and to continuous quality improvement is very important in each phase of the building process. Management must participate in the implementation process and be fully committed to it if TQM is to succeed.
- Construction industry professionals are aware of the importance of quality training. Engineering, architecture and construction management students who eventually become the industry's future leaders must be instructed in the basics of quality management. Education and training in TQM theory and practice at all levels (management as well as operative levels) and in all phases (design, construction, and operation phases) are essential to enhance competitiveness.
- Teamwork is necessary to allow each person to get the assistance required to be successful individually, and collectively as a team. The whole construction industry is project oriented; so improved quality performance must be project-related and must include the whole project team such as professional designers, project managers and above all, the owner.

- Manufacturer, subcontractors, main contractor, vendors, and suppliers should be also involved in the construction process. It is obvious that partnering arrangements between these parties will enhance total quality.
- Statistical methods are essential problem solving tools and are very important in monitoring quality in manufacturing industries. But they are not perceived as very useful by construction professionals; yet, there appears to be potential for a feedback system in the construction process. As the project is being completed, feedback loops originating at the end of each phase could be used to upgrade the original quality standards adopted at the beginning of the project.
- Taking measures to achieve high quality cost money. This cost should not be considered an expense but an investment. Construction organizations that achieve reputation for high quality can maximize their competitiveness and increase their business opportunities.
- The construction project should be considered as a process where all customers must be satisfied. These customers include internal customers (employees, units, departments within an organization) and external customers (owner, designer, contractor, etc.).
- The requirements of the owner, codes, and specifications must be clearly defined at the beginning of the project and be agreed to by both the owner and design firm. The more time and effort are spent at the beginning in defining requirements, the more smoothly the project will progress. Objective setting is important because it provides a focus for scope definition, guides the design process, controls the construction process, and influences the motivation of the project team.
- Drawings and specifications received from the designer affect the quality of the construction. Drawings are the only documents given to the constructor that show the design concept, size and scope of the job. It is critical that drawings and specifications be clear, concise, and uniform.
- The project must be constructible by those retained to build the project. Design professionals must be familiar with construction materials and techniques that constructors will be using in the project.

TQM is perceived as not only a means of improving quality, but also as an issue paramount in ensuring competitive edge in a fiercely competitive market. Consequently, according to Sommerville and Robertson (2000), considerable benefits are seen as a corollary to successful implementation of the TQM program, including:

- A quality product/service, without compromise;
- Repeat and new business (due to the product and service quality);
- A reduction in the cost of waste, with a clear shift in emphasis from waste's cost build up, i.e. in inspection and failures (QC/QA), towards prevention (TQM);
- Increased job security, through increased competitiveness, coupled with greater job-satisfaction through individual commitment to common goals.

The proposed framework for implementing TQM for the construction industry can be rationalized as shown in Figure 3.3. (Pheng and Ke-Wei, 1996)

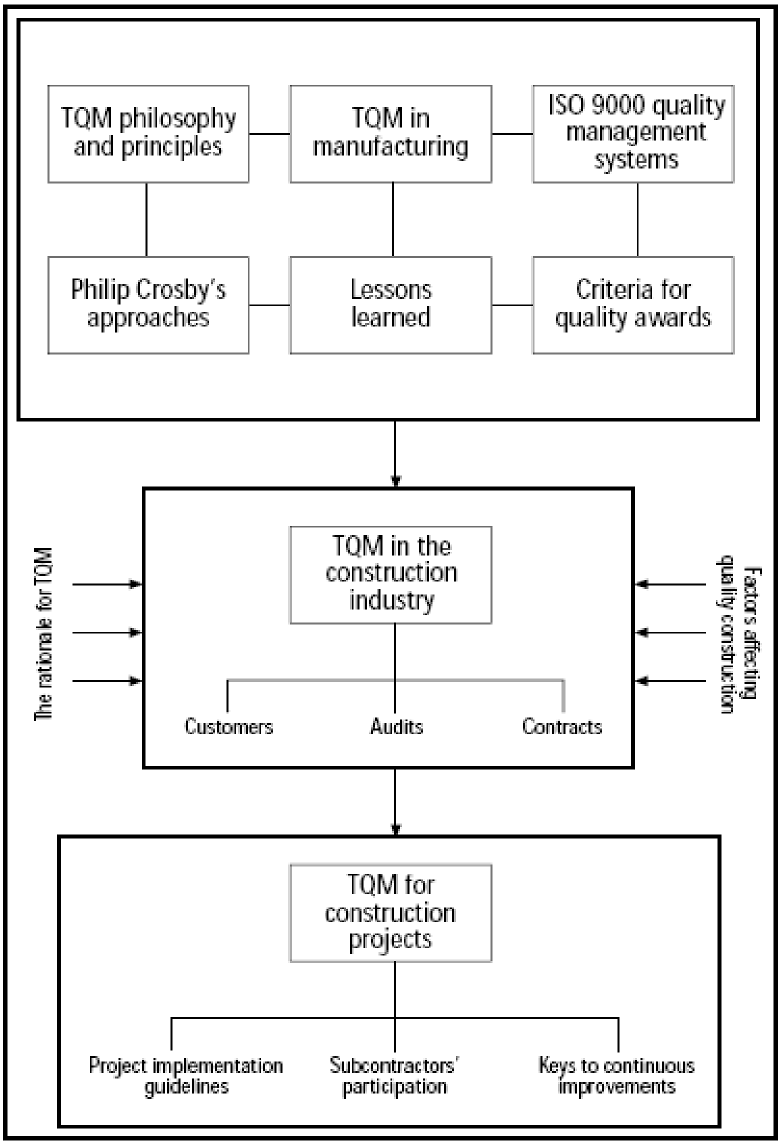


Figure 3.3- Proposed Framework for Implementing TQM in Construction by Pheng and Ke-Wei, 1996

In essence, there is a stress on collaboration and social cohesion among all employees with TQM ideas and TQM encourages: (Pheng and Ke-Wei, 1996)

- Greater harmonization of terms and conditions, thereby creating a powerful sense of belonging;
- A collaborative community-like spirit, with emphasis on customer service orientation between departments, divisions or individuals;
- Project teams to pursue a "company-wide policy" and dominant shared values;

- A mutual sense of belonging when all employees are part of a quality culture focusing on customer satisfaction as the super ordinate goal;
- Certain practices to be deemed normal and desirable;
- A shared language, i.e. a "total quality" language.

TQM aims to improve processes and eliminate non value-added activities, primarily through empowering individuals and teams to discuss these issues within their own area or across organizational boundaries.

TQM is a continuous process of incremental improvements. It may take years to put it in place within a construction organization but a start could be made with fruitful short-term successes. It should be remembered at this stage that TQM is process-oriented and not so much result-oriented. If the processes are right, the results (i.e. quality improvements) are likely to follow. TQM gives an organization the competitive edge. It refines the quality of work life by getting management and employees involved in identifying and solving work problems.

CHAPTER 4

LEAN CONSTRUCTION

4.1. LEAN THINKING AND LEAN PRODUCTION

Lean is a management philosophy focusing on reduction of process waste to improve overall customer value. Lean thinking aims to improve competitiveness and profitability through the removal of waste and it considers the whole system and involves employees in the value creation process. Waste generally results in failure to meet customer requirements with respect to time, cost, and quality. Therefore, Lean Production has taken waste reduction approach as the cornerstone to the production systems. The approach considered a flow based production management for the whole production system a rather than just focusing on worker and machine productivity (Ferng and Price 2005).

The primary focus of Lean initiatives in organizations is to eliminate waste in the form of scrap, non-value added activities, excessive inventory, etc and reduce costs associated with storage and floor space.

Lean manufacturing is a philosophy with a whole set of approaches, tools and characteristics that lead an organization to reduce waste and add value to its products and processes. There are some principles that can be used to define the main characteristics of Lean strategy (Womack and Jones, 1997). These are:

1. Value: It is important to identify which features of a product or service create value and can be obtained from the internal and external customer perspectives. Value is expressed in terms of how the specific product or service meets the expectations of customers. Having determined the value, we need to identify the processes or sub-processes that add value to the final product or service. All non-value added processes should be eliminated from the system.
2. Flow: Flow in this case is the uninterrupted movement of product or service through the system to the customer. Work in queue, batch processing and transportation are the bottlenecks of flow. Improvement efforts should be sought for to make activities within the system flow.
3. Pull: Once the non-value added activities are removed and flow within the system is established, we need to make the process responsive to providing the product or service only when the customer needs it.

4. Perfection: This is the repeated effort to remove waste from the processes, improve work flow, and meet delivery needs of customers. It is important to make a note that by accomplishing the above three characteristics, variation in the processes may be reduced and thereby product or service quality is improved.

Womack and Jones (2003) also developed the set of integrated principles and methods of Lean Thinking:

- Specify value in terms of the customer's needs;
- Identify the value stream for each product or service;
- Create continuous flow through the value stream;
- Produce goods or services according to the pull from the customer;
- Continue to always improve and seek perfection.

An effective implementation of Lean principles could result in reduced set-up times for machines, improved machine uptime, organized house keeping, reduced waste (material waste, waste from excess inventory, waste from over production, waste from over-processing, etc.). It emphasizes continuous improvement, inventory reduction, cycle time reduction, quality improvement, so on and so forth. The potential benefits from the effective implementation of a Lean Production System may include: (Antony et al., 2003)

- Reduction of inventory requirements
- Reduction of floor space requirements
- Reduced waste due to waiting, movement, etc.
- Reduced cycle time of processes, etc.

Lean Production principles have evolved since the 1940s, and Toyoto Motor Company implemented it successfully. These lean principles are being increasingly employed in many other industrial sectors after popularized by the 1990 book "The Machine That Changed the World" (Abdelhamid and Salem, 2005).

The adaptation of Lean Production concepts in the construction industry has been going on since 1992, as mentioned in by Koskela's technical report (1992).

4.2. LEAN CONSTRUCTION

Lean construction is a production management based approach to project that expands 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" (LCI, 2004).

Lean construction is a new way to manage construction. The objective, principles and techniques of lean construction taken together form the basis for a new project delivery process. Unlike existing approaches to managing construction (including design-build) and programmatic improvement efforts (partnering and TQM), lean construction supplies the foundation for an operations based project delivery system (Howell and Ballard, 1997).

The authors Abdelhamid and Salem (2005) define Lean Construction as:

“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.”

According to both the Lean Construction Network (LCN, 2004) and Lean Construction Institute (LCI, 2004):

“Lean construction has the goal of better meeting customer needs while using less of everything. But unlike current practice, lean construction rests on production management principles which results in a new project delivery system that can be applied to any kind of construction but is particularly suited for complex, uncertain, and quick projects”.

LCI also developed the “Lean project delivery system (LPDS)” by applying the concepts of lean production to lean construction resulting in confidential and rapid delivery of value. Lean construction is described as a new way to design and build capital facilities.

The aim of LCI for developing LPDS is to develop a new and better way to design and build capital facilities. The LPDS framework, Figure 4.1, developed by Ballard (2000) is given below:

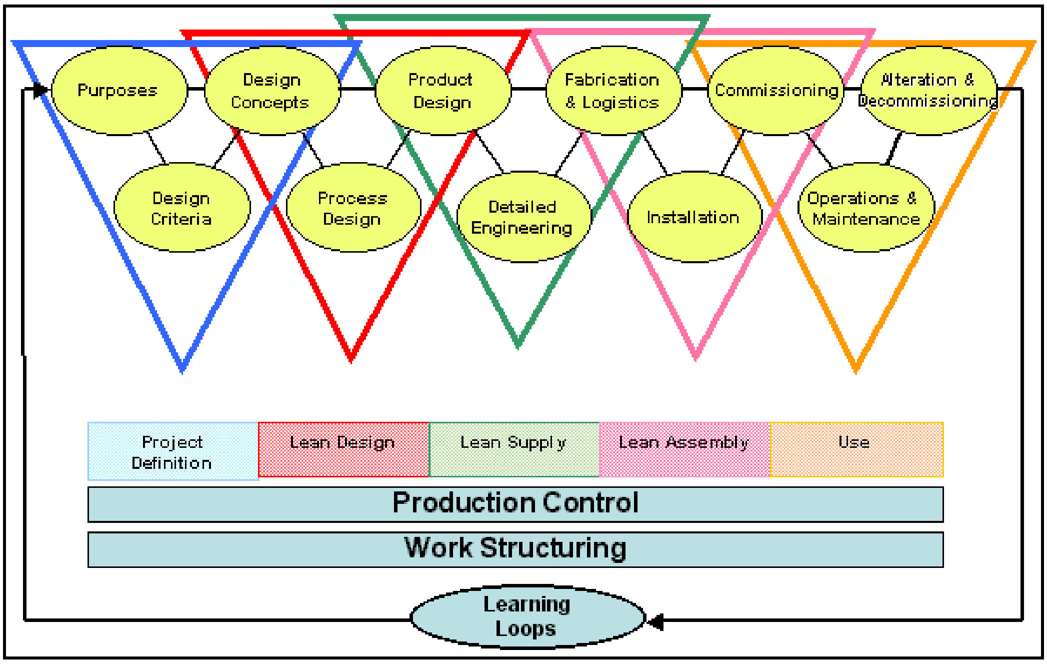


Figure 4.1- The Lean Project Delivery System (LPDS) framework (Ballard, 2000)

LPDS model consists of 13 modules, 9 organized in 4 interconnecting triads or phases extending from project definition to design to supply and assembly, plus 2 production control modules and the work structuring module, both conceived to extend through all project phases, and the post-occupancy evaluation module, which links the end of one project to the beginning of the next.

Essential features of LPDS (developed by Ballard, 2000) include:

- The project is structured and managed as a value generating process,
- Downstream stakeholders are involved in front end planning and design through cross functional teams,
- Project control has the job of execution as opposed to reliance on after-the-fact 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 are incorporated at every level, dedicated to rapid system adjustment; i.e., learning.

In their study, Ballard and Howell (1994) also developed a framework for the application of Lean production to construction. The first step is to shield direct production from variation and uncertainty in the flows of directives and resources. The second step is to reduce flow variation and the final step is to improve performance behind the shield; i.e., to improve operations within the context of managed flows.

The application of Lean Construction principles and techniques remarks the adoption of a new organization design that can make Project Management systems feasible in the construction sector. In Construction the application of the lean production model originates from a discussion of Koskela's work (1992), which emphasized the importance of the production process flow, as well as aspects related to converting inputs into finished products as an important element to the creation of value over the life of the project.

Lean construction uses partnering to reduce tendering costs and intensify the speed of implementation through team working and mutual confidence and the techniques: (Ferng and Price, 2005)

- Value management with function analysis as the core technique
- Supply chain management to link the flow of material and processes

According to Lean Construction Institute (LCI, 2004), the main features of Lean Construction can be summarized as:

- The facility and its delivery process are designed together to better reveal and support customer purposes. Positive iteration within the process is supported and negative iteration reduced.
- Work is structured throughout the process to maximize value and to reduce waste at the project delivery level.
- Efforts to manage and improve performance are aimed at improving total project performance because it is more important than reducing the cost or increasing the speed of any activity.
- "Control" is redefined from "monitoring results" to "making things happen." The performance of the planning and control systems is measured and improved.

LCI (2004) identify the key differences between Lean construction and traditional form of construction project management as:

- Simultaneously designed product and delivery processes that identify and support customer needs and encourage increased customer pull;
- Value driven performance, as defined by stakeholders and customers throughout the whole life of the project;
- A total project approach to performance maximization and waste reduction that recognizes that there does not always have to be a trade off between time, cost, and quality;
- A more proactive approach taken to planning and control systems that are continuously improved; and

- Decentralization of decision making through increased transparency and empowerment.

Howell and Ballard (1997) also defined the differences between Lean Construction and current construction management as follows:

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

Lean is a new way to think about and do work in construction. Identifying a change agent, getting the knowledge, mapping processes and installing reliable planning are the first steps to becoming lean. The transformation takes time as each new action in support of the optimum objectives creates new problems, benefits and understanding. (Howell and Ballard, 1997) Therefore, implementation of lean production concepts and techniques in the construction industry is the way to the future, but following that path requires allowing go of traditional thinking. (Ballard and Howell, 1994)

In conclusion, Lean Construction aims to reduce waste throughout the whole project life cycle by improving predictability, reliability and certainty by means of specified value and eliminating non value adding activities.

4.3. LEAN CONSTRUCTION TOOLS

Due to the fundamental differences between construction and production processes, the tools of lean production can't be directly used to manage construction processes and a new set of tools is required (Salem et al., 2005). Therefore, Lean based tools have developed and have been successfully applied to simple and complex construction projects. Consequently, construction projects have become easier to manage, safer, completed sooner, cost less, and are of higher quality via these tools (Abdelhamid and Salem, 2005).

According the study of Salem et al., (2005) the major lean construction tools and their measure items are given on below Table 4.1:

Table 4.1- The major Lean Construction Tools and their Measure Items (Salem et al., 2005)

Tools	Measure Items
Last Planner	Reverse Phase Scheduling, Six Week Look-ahead, Weekly work Plan, PPC Charts and reasons for variances
Visualization	Commitment Charts, Safety signs, Mobile signs, Project milestones and PPC Charts
Daily Huddle Meetings	All foreman meeting and start of the day meeting
First Run Studies	Plan, Do, Check, Act and Productivity Studies
The 5s Process	Sort, Straighten, Standardize, Shine and Sustain (5 S's)
Fail Safe for quality and Safety	Quality, Safety and SPA

These tools are also briefly described in the below sections.

4.3.1. THE LAST PLANNER SYSTEM OF PRODUCTION PLANNING AND CONTROL

The Last planner system of production control is the most completely developed lean construction tool to apply for the control of workflow unreliability on simple and complex construction projects. Ballard (2000) indicates that Last Planner System (LPS) is a technique that shapes workflow and directs project variability in construction.

The goals of Last Planner are to pull activities by reverse phase scheduling through team planning and optimize resources in the long-term. In the last planner system, the sequences of implementation are: (Salem et al., 2005)

1. Master schedule,
2. Reverse phase schedules (RPS),
3. Six-week look ahead,
4. Weekly work plan (WWP),
5. Percent plan complete (PPC),
6. Constraint analysis, and
7. Variances analysis

Master Schedule: The master schedule is an overall project schedule, with milestones, that is usually generated for use in the bid package.

Reverse Phase Scheduling: A pull technique is used to develop a schedule that works backwards from the completion date by team planning; it is also called Reverse Phase Scheduling (RPS). (Ballard and Howell, 2003) It is closer to reality than master schedule.

Six Week Look Ahead (SWLA): According to Ballard (2000), the tool for work flow control is look ahead schedules. SWLA shows what kinds of work a supposed to be done in the future. All six week look ahead durations and schedules were estimated based on the results of the RPS, and constraints are indicated in order to solve the problems before the actual production takes place. Lean look ahead planning is the process to reduce uncertainty to achieve possible constraint free assignments (Koskela et al. 2000).

Weekly Work Plan: Weekly Work Plan (WWP) is produced based on SWLA, the actual schedule, and the field condition before the weekly meeting. It can improve safety, quality, the work flow, material flow, productivity, and the relationship among team members. Ballard and Howell (2003) indicates that WWP should emphasize the learning process more by investigating the causes of delays on the WWP instead of assigning blames and only focusing on PPC values. Variance analysis is conducted based on the work performance plan from the previous week. The causes of variance should be documented within the WWP schedule.

Percent Plan Complete: The measurement metric of Last Planner is the percent plan complete (PPC) values (the number of activities that are completed as planned divided by the total number of planned activities). To achieve higher values (i.e., 70% and above), additional lean construction tools such as first run studies have to be implemented.

This implementation sequences sets up an efficient schedule planning framework through a pull technique, which shapes work flow, sequence, and rate; matches work flow and capacity; develops methods for executing work; and improves communication between trades (Salem et al., 2005).
The Last Planner System usage as a planning tool uncovers a great number of constraints that threaten the execution of assignments related to engineering, owner decision, pre-requisite, labor, materials, contract, submittals, equipment, and coordination (Abdelhamid and Salem, 2005).

As a result, all the researches indicate that utilization of Last Planner System provides to maintain projects on time and at budget, as well as having a stress free production planning and control processes and leads to higher system throughput.

4.3.2. INCREASED VISUALIZATION

Visual control is the ability too control processes through visual techniques. The increased visualization lean tool is about communicating key information effectively to the workforce by means of posting various signs and labels (related to safety, schedule, and quality) around the construction site (Salem et al., 2005). Workers can remember elements such as workflow, performance targets, and specific required actions if they visualize them (Moser and Dos Santos 2003).

4.3.3. VALUE STREAM MAPPING AND ANALYSIS

A lean transformation needs a complete assessment of the current situation and performance, a significant model for improvement and a plan to get there.

A relatively recent tool to support implementation of a lean philosophy is Value Stream Mapping (VSM) (Rother and Shook, 1999), used to define and analyze the current state for a product value stream and design a future aspect focused on reducing waste, improving lead-time, and improving workflow. One of the unique characteristics of VSM in comparison with other process analysis techniques is that one map describes both material and information flow that controls the material flow (Goubergen et al., 2003).

A complete value stream map will rapidly provide visibility as well as train company personnel in seeing the interaction among departments, suppliers and everything that interacts with the product at every part of value stream.

The Value Stream Mapping (VSM) process identifies all the steps in a process showing how the product or service is being altered from activity to activity. All the actual time durations are recorded (snap shots in time). Time delay between activities as well as how data and information are transmitted is identified. In general, the steps involved in a VSM include the following: (Mastroianni and Abdelhamid, 2003)

1. Current State Map: When the value stream map is developed based on current information, it’s usually referred to as the current state map. A current state map (CSM) documents how work flows throughout the design, procurement, and construction. Analysis of this current state map highlights value added and non value added times and lead times.
2. Opportunities for Improvement: After creating the current state map (CSM), the next step is to look for opportunities to reduce or eliminate waste in the process.
3. Future State Map: The group decides to make changes to the current state to define how they want to operate in the future. This is the process of defining the future state map (FSM). A future state map illustrates process improvements that can be obtained by applying various management tactics.
4. Work Plan to the Future State: A work plan is developed to get to the future state map.
5. Define Measurable(s) to gage performance: A measurable is defined to help understand when the future state is attained.
6. Analyze Cost Savings: Cost savings are analyzed between the CSM and FSM using conservative numbers.

As a result, Value Stream Map assists the company to find waste, identify its root cause and prepare strategic plans for its elimination through value stream mapping. The earnings of having a VSM are the following:

- A complete map of your value stream
- Includes material, process and information flows
- From raw material and components through finished goods
- Graphic 'current' and 'future state' maps
- Strategic improvement plan
- Optional software with company database of value stream

Value stream analysis (VSA) is a tool to determine the amount of waste in the supply chain of any construction process, and then identifies the most relevant causes of waste for this supply chain in particular. The aim of this approach is the achievement of performance improvement based on a flow perspective rather than an activity-based perspective.

Mapping and value stream analysis are valuable tools when trying to improve supply chain performance. It is possible, through the application of VSA, to directly assault the most visible waste.

Moravec and Associates consultants provide an assessment of the total value stream. This assessment includes:

- Identifying processes that matter within your organization or across organizations (e.g., suppliers and customers)
- Mapping the current flows of information, materials, and capital
- Identifying the core competencies being had today and those being planed to have tomorrow
- Selecting process and output measurements
- Collecting data
- Gauging performance of each step
- Defining potential future states
- Implementing changes
- Tracking success

Value stream assessment identifies significant opportunities for process improvement by pinpointing where delays occur, what causes them, whether schedules are reliable, and where the core competencies lie.

As a conclusion, mapping, modeling and analysis of the value stream includes product, process, logistics and information flow maps with the following analysis:

- Information flow efficiency and constraints
- Interface enabler analysis
- Time based / logistic based movement
- Six-sigma/eLean analysis
- Inventory and resource measurement
- Support department analysis
- Key supplier analysis
- Current, target and ideal state analysis

It also allows for visual simulation and what-if testing of target and future states. Therefore, dramatic savings in time, cost and quality can be realized by applying the value stream mapping principles to all aspects of the enterprise.

4.3.4. DAILY HUDDLE MEETINGS (TOOLBOX MEETINGS)

Two-way communication is the key of the daily huddle meeting process in order to succeed the employee involvement. Daily Huddle Meetings ensure quick back flash to problems through empowerment of workers, and continuous open communication through the tool box meetings (Salem et al., 2005).

4.3.5. FIRST RUN STUDIES

First Run Studies are used to redesign critical assignments which are part of continuous improvement efforts; and include productivity studies and review work methods by redesigning and streamlining the different functions involved (Ballard and Howell 1997). These studies commonly use video files, photos, or graphics to show the processes and illustrate the work instructions. A PDCA cycle (plan, do, check, act) is suggested by Salem et al. (2005) to develop the study: Plan refers to select work process to study, assemble people, analyze process steps, brainstorm how to eliminate steps, check for safety, quality and productivity. Do means to try out ideas on the first run. Check is to describe and measure what actually happens. Act refers to reconvene the team, and communicate the improved method and performance as the standard to meet.

4.3.6. THE 5S PROCESS (VISIUAL WORK PLACE)

Lean construction visualizes the project as a flow of activities that must generate value to the customer (Dos Santos et al. 1998). It has five levels of housekeeping that can help in eliminating wasteful resources (Kobayashi 1995; Hirano 1996):

1. Seiri (Sort) refers to separate needed tools / parts and remove unneeded materials (trash).
2. Seiton (Straighten or set in order) is to neatly arrange tools and materials for ease of use (stacks/bundles).

3. Seiso (shine) means to clean up.
4. Seiketsu (standardize) is to maintain the first 3Ss. (Development of a standard 5S's work process with expectation for the system improvement)
5. Shitsuke (sustain) refers to create the habit of conforming to the rules.

The recorded benefits from implementation of 5S include improved safety, productivity, quality, and set-up-times improvement, creation of space, reduced lead times, cycle times, increased machine uptime, improved morale, teamwork, and continuous improvement (kaizen activities).

The 5s can also be converted into construction operations as used by Walbridge Aldinger (WA) (Mastroianni and Abdelhamid, 2003). The following Table 4.2, developed by Walbridge Aldinger, shows this conversion.

Table 4.2- Construction 5S Implementation

	5S Description	5S Example
1	Separate/Scrap	Separate like materials and equipment and remove or dispose of that which is no longer needed.
2	Straighten	Put material into bundles or racks so there is order. Equipment locations can be outlined to show where it is to be stored.
3	Scrub	Broom swept areas. Put trash in designated trash bins. Clean equipment.
4	Sustain/Standardize	Develop standards for 5S expectations and audit those standards on a weekly basis.
5	Systematize	A system is in place to communicate the 5S expectations on a regular basis. The 5S audit process is done regularly. The labor forces understand the expectations and follow them. The system goes into "autopilot".

4.3.7. FAIL SAFE FOR QUALITY AND SAFETY

Fail safe for quality depends on the generation of ideas that alarm for potential defects. This approach is opposed to the traditional concept of quality control, in which only a sample size is inspected and decisions are taken after defective parts have already been processed. Fail safe can be extended to safety but there are potential hazards instead of potential defects, and it is related to the safety risk assessment tool from traditional manufacturing practice. Both elements require action plans that prevent bad outcomes (Salem et al., 2005).

CHAPTER 5

SIX SIGMA

5.1. WHAT IS SIX SIGMA?

Six Sigma is a systematic framework for quality improvement and business excellence has been popularized for more than a decade (Goh, 2002). It is a system of practices originally developed by Motorola to systematically improve processes by eliminating defects. Six Sigma uses extremely rigorous data collection and statistical analysis to ferret out sources of errors in work processes and to find ways to eliminate them (Paul, 1999).

Six Sigma is a problem solving methodology that provides a quick and effective approach for improving cost, quality and schedule. Six Sigma is a systematic procedure for improving methods and processes by focusing on correction and preventing defects. It focuses on the quantification and elimination of the cost of poor quality driven in current processes. It achieves this through the use of qualitative and advanced quantitative tools and techniques (a five-step improvement strategy called DMAIC). The result is improved work processes, enhanced performance, and therefore tangible cost savings and increased competencies.

Six Sigma is a project-driven method aimed at sustainable business performance improvement. It focuses on better understanding of changing customer requirements, improving processes throughout the organization, and enhancing the organization's financial performance (Anbari and Kwak, 2004).

Various authors have defined Six Sigma in the following ways:

- Harry and Schroeder (2000), who are the key developers and proponents of the Six Sigma program at Motorola, defined Six Sigma as ''a disciplined method of using extremely rigorous data gathering and statistical analysis to pinpoint sources of errors and ways of eliminating them.''
- Snee (2000) indicated that ''Six Sigma should be a strategic approach that works across all processes, products, company functions and industries.''
- Chowdhury (2001) explained that Six Sigma represents a statistical measure and a management philosophy that teaches employees how to improve the way they do business, scientifically and fundamentally, and how to maintain their new performance level. It gives discipline, structure, and a foundation for solid decision-making based on simple statistics.

- Pande et al. (2000) defined Six Sigma as (1) a way of measuring processes, a goal of near perfection represented by 3.4 defects per million opportunities (DPMO); and more accurately, (2) a comprehensive and flexible system for achieving, sustaining, and maximizing business success. It is uniquely driven by a close understanding of customer needs, disciplined use of facts, data, and statistical analysis, and diligent attention to managing, improving, and reinventing business processes.
- Pande and Holpp (2002) defined Six Sigma as (1) a statistical measure of the performance of a process or a product; (2) a goal that reaches near perfection for performance improvement; and (3) a system of management to achieve lasting business leadership and world-class performance.
- Tang et al. (2007) defined "Six Sigma is a systematic, highly disciplined, customer-centric and profit-driven organization-wide strategic business improvement initiative that is based on a rigorous process-focused and measurement driven methodology. Six Sigma makes use of sound statistical methods and quality management principles to improve processes and products via the Define–Measure–Analyze–Improve–Control (DMAIC) quality improvement framework to meet customer needs on a project-by-project basis".

The following definition, suggested by Linderman et al. (2003), also embodies the concepts and principles underlying Six Sigma:

"Six-Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates."

More recently, The European Construction Institute (ECI, 2004) defined Six Sigma as:

"A powerful management tool that assists companies to achieve breakthrough improvements in quality, eliminate defects, streamline operations, and thus dramatically improve profits. It works by measuring the variability in everyday business processes. By redesigning and improving these processes, errors and waste are minimized leading to dramatic reductions in variability."

However, Primavera (2004) defined Six Sigma as:

"A process improvement strategy that drives operational and financial improvements to positively impact Revenue, Cost Reduction, Customer Satisfaction, Productivity Improvement, and Innovation" and provide organizations with the project portfolio management software tools that help select, plan, execute, and control the Six Sigma process:

- Identification, analysis, and selection of 'Key Improvement Areas' (KIAs).
- Improving existing processes through DMAIC methods.
- Providing Six Sigma Products and Services through DFSS methods.

- Ensuring lasting and continuous improvement through CPI.

In general, the above definitions of Six Sigma may be summarized into the following two aspects: (Pheng and Hui, 2004)

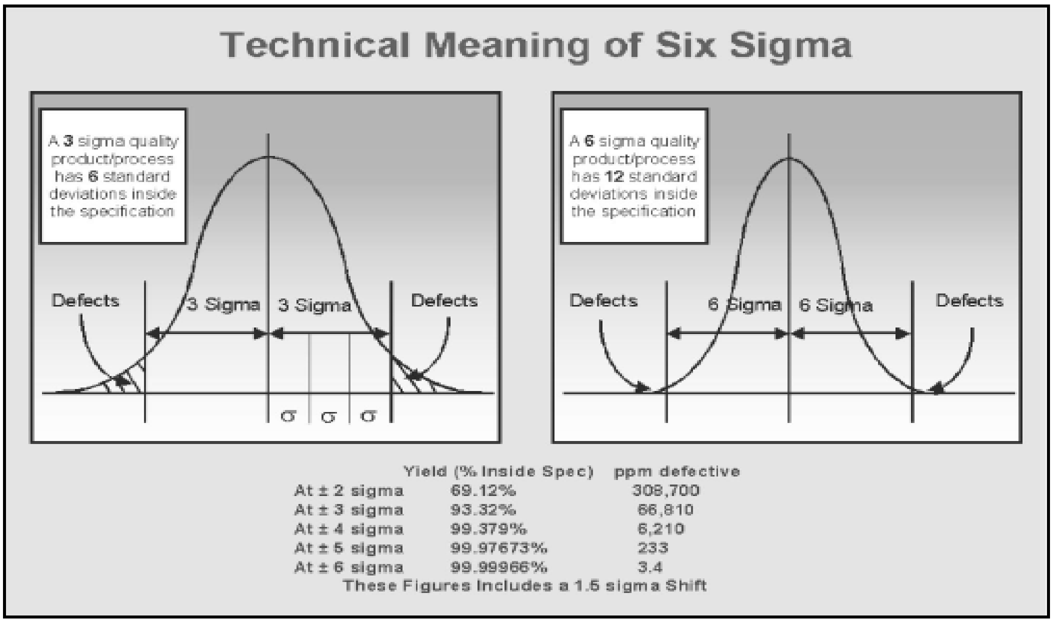
- Six Sigma is a statistical measure used to measure the performance of processes or products against customer requirements.

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.

Six Sigma method has two major perspectives:

From the statistical point of view, Six Sigma refers to a process in which the range between the mean of a process quality measurement and the nearest specification limit is at least six times the standard deviation of the process where sigma is a term used to represent the variation about the process average. The below Figur 5.1 illustrates this technical definition of Six Sigma.



Figur 5.1- Technical Definition of Six Sigma

The term Six Sigma is defined by convention as having less than 3.4 defects per million opportunities (DPMO) or a success rate of 99.9997 percent, where the term sigma is used to represent the variation about the process average. The simplified sigma conversion table is shown in the following Table 5.1 (Anbari and Kwak, 2004).

Table 5.1- Simplified Sigma Conversion Table

Yield=percentage of items without defects	Defects per million opportunities (DPMO)	Sigma level
30.9	690,000	1
69.2	308,000	2
93.3	66,800	3
99.4	6,210	4
99.98	320	5
99.9997	3.4	6

Through Six Sigma, every measurable can be compared on the reasonable platform by converting yields or DPMO to sigma level. Higher sigma values indicate better processes with fewer numbers of defects per unit of product or service (Pheng and Hui, 2004).

In business terms, Six Sigma is a business strategy and a disciplined methodology, effective use of which leads to breakthrough in profitability through huge gains in product/service quality, product's functional performance, process capability, customer satisfaction and productivity (Antony and Banuelas, 2002).

Six Sigma is used to improve the organization's products, services and processes across various disciplines, including production, new product development, marketing, sales, finance, information systems, and administration. It is achieved through understanding the fundamental processes, and reducing or eliminating defects and waste in these processes.

Fundamentally, Six Sigma is a disciplined, measurement based strategy for eliminating defects that focuses on systematic and project-based process improvement and variation reduction – driving towards achieving a process that does not produce more than 3.4 defects per million opportunities (Lee- Mortimer 2006).

One of the objective of this thesis is therefore to examine the strategies, principles, and concepts of Six Sigma and to explore if Six Sigma can be applied to the construction industry to overcome the problems related to productivity, performance, quality, waste, and customer satisfaction and to achieve the many benefits it has brought to the organizations that have implemented it successfully.

5.2. THE HISTORICAL BACKGROUND AND EVALUATION OF SIX SIGMA

Over the past half-century various industries focused their attention to the quality of products. A large number of systems/methods have been developed in an attempt to improve the product quality in various industries. One of these methods is Six Sigma that was introduced in the late 1980's.

The concept of sigma was originated by Carl Fredrick Gauss who formulated the normal distribution curve. Therefore Six Sigma roots have been introduced more than 100 years ago.

In 1920, Walter Shewhart, an employee of Bell Telephone Laboratories developed the tools that provided statistical quality control and development of quality assurance which provide the foundation to quality management in Japan and USA. He also showed that three sigma from the mean is the location where a process still requires correction. (Pathmaker, 2004)

In the early 1980's, many industries started to require substantially better degrees of product reliability. In their strive for excellence, industries decided that measuring defects in rates of 3 sigma, i.e. defect per thousand had become unacceptable.

Deming (1982) emphasized that quality management is a management philosophy that requires commitment and involvement throughout the company. At the time, Motorola was facing the threat of Japanese competition in the electronics industry and needed to make drastic improvements in their quality levels. Motorola was losing market share to foreign competitors who had better quality and lower cost. A Japanese firm took over a Motorola television factory. After implementing changes, the factory was producing with 1/20th the defect rate with same people, same equipment, and same designs but with different management and different processes.

In 1985, Bill Smith of Motorola developed and implemented an approach to achieve near perfection in product manufacturing called Six Sigma (Breyfogle et al., 2001). Then Motorola started to measure defects per million as represented by six sigma which equates to 3.4 defects per million. The term six sigma subsequently became a registered trademark of Motorola. Motorola has saved over US $ 11 billion in manufacturing costs since its production. Therefore, it is accepted that Six Sigma is a concept originated by Motorola Inc. in the USA in about 1985 and the term Six Sigma subsequently became a registered trademark of Motorola.

For making a chronological order, it can be said that by the mid-1980s, Bob Galvin, Motorola CEO, has the company focused on improving quality; 1988, Motorola wins the first Malcolm Baldridge Quality Award. Part of winning this national quality award is the agreement to share the methods used to achieve the high levels of quality. Several companies followed by initiating Six Sigma programs:

1. Motorola (1987)
2. Texas Instruments (1988)

3. IBM (1990)
4. ABB (1993)
5. AlliedSignal / Kodak (1994)
6. General Electric (1995)
7. Lockheed Martin, Bombardier, & Navistar (1996/97)
8. PACCAR (1998)
9. Amazon.com (1999)
10. Ford Motor Company (2000)

Today, Six Sigma has evolved from its roots as a measure of quality to an overall business improvement methodology over time and it became a way of doing business. It's more than just a statistical tool; it is a major quality system.

5.3. THE PRINCIPLES OF SIX SIGMA

The fundamental principle of Six Sigma is to 'take an organization to an improved level of sigma capability through the rigorous application of statistical tools and techniques' (Antony et al., 2003).

The general principles of Six Sigma can be distilled into the following six themes (Pande et al., 2000; Pande and Holpp, 2002):

1. Genuine focus on the customer: While profits and statistical tools seem to get the most publicity, the emphasis on customers is the most remarkable element of Six Sigma.
2. Data and fact-driven management or metrics for decision making: Six Sigma takes the concept of ''management by facts'' to a new and more powerful level. Instead of basing business decisions on opinions and assumptions, Six Sigma builds the foundation of decision making by using metrics (i.e., numbers) in building up key measures that represent and calculate the success of everything an organization does.
3. Process focus, management, and improvement: Six Sigma positions the process as the key vehicle of success, be it in design of products and services, measuring performance, improving efficiency and customer satisfaction, etc.
4. Proactive management: Proactive means action in advance of events rather than reacting to them. An example of proactive management in Six Sigma is the focus on eliminating defects at the source instead of trying to manage the defect or problem after it has occurred. It tries to solve why the bad results are occurring.
5. Boundless collaboration: Boundless means working to break down corporate barriers and to improve teamwork up, down, and across organizational lines.
6. Drive for perfection, tolerate failure: Although these two ideas sound contradictory, they are actually complementary. The bottom line is that any company that makes Six Sigma its goal will have to keep pushing to be more perfect while being willing to accept and manage occasional setbacks.

5.4. SIX SIGMA AND VARIATION

Schonberger (1986) emphatically states that “variability is the universal enemy” and that reducing variability increases predictability and reduces cycle times. Koskela (1992) adds that reducing process variability will also increase customer satisfaction and decreases the volume of non value-adding activities.

The statistical theory of variation for Six Sigma is based on the supposition that all things, when measured fine enough, vary and that is called “natural variation.” Six Sigma emphasizes identifying and avoiding variation. But what also makes Six Sigma unique is the explicit recognition of the correlation among the number of product defects, wasted operating costs, and the level of customer satisfaction (Abdelhamid 2003).

Six Sigma primarily focuses on variation in processes and determines the possible solutions which will minimize or even eliminate variation, which often results in inconsistent product performance, high scrap rate, rework, warranty costs, customer dissatisfaction, etc. Six Sigma entails the use of simple and advanced statistical tools and techniques to bring about radical improvements by eliminating or minimizing variability (Anthony et all., 2003).

Statistical thinking and statistical methodologies constitute the backbone of Six Sigma (Goh, 2002). Understanding the statistical origins of the Six Sigma methodology requires an understanding of variability and the characteristics of the normal distribution, which represents many data sets in real life (Abdelhamid 2003).

According to Deming (1986), since all things vary, statistical methods are required to control quality or defect rates. He also stated that there are two types of variation: common cause and special cause variation. Common cause variation is an inherently random source of variation and addressing it involves a major change in the basic process and operating procedures. Special cause variation is an unusual but controllable source of variation that requires a correction to bring the process or procedures back to its normal levels.

Deming (1986) asserts that “the difference between these is one of the most difficult things to comprehend” and that it is a worthless attempt to address quality problems without understanding the two types of variations. Therefore, Deming recommended that special cause variation be addressed first before addressing common cause variation. To illustrate common cause and special cause variation, a manufacturer who produces a product using a single stage or one step process is considered as shown on Figure 5.2: (Abdelhamid 2003)

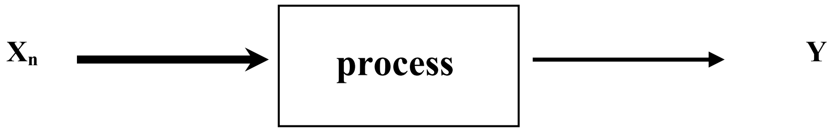


Figure 5.2- A Single (One Step) Process

In the figure $\mathbf{X_n}$ represents the inputs and **Y** represents the output. Due to the variations in the inputs, the resulting Y will also be variable.

The output is assumed to follow a normal distribution where the ideal target is represented by the mean value as shown on Figure 5.3 (Abdelhamid 2003).

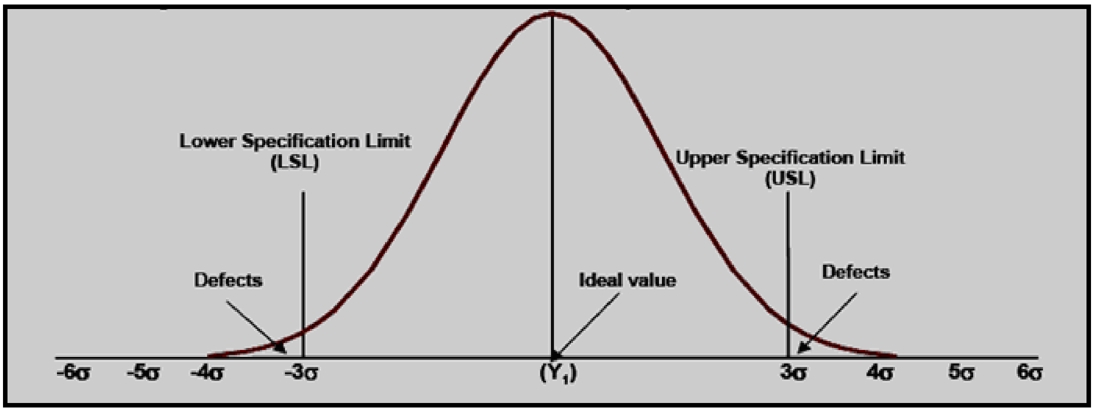


Figure 5.3- Normal Distribution with Specification Limits set at ± Three Sigma (Abdelhamid 2003)

The use of lower and upper specification limits, which are usually reflection of the customers' inputs and requirements to accept the product Y, for the purposes of explaining the six sigma statistical origin. Abdelhamid (2003) evidences that in real life; customers choose specification limits independent of the normal or any other distribution.

A statistical control chart is also used to isolate common from special cause variation. The Figure 5.4 shows hypothetical dimension figures for the product Y plotted against time and there are also the upper and lower control limits (UCL, LCL; respectively) which are a function of the process mean, process range, and the standard deviation of the measured data (Breyfogle 2003).

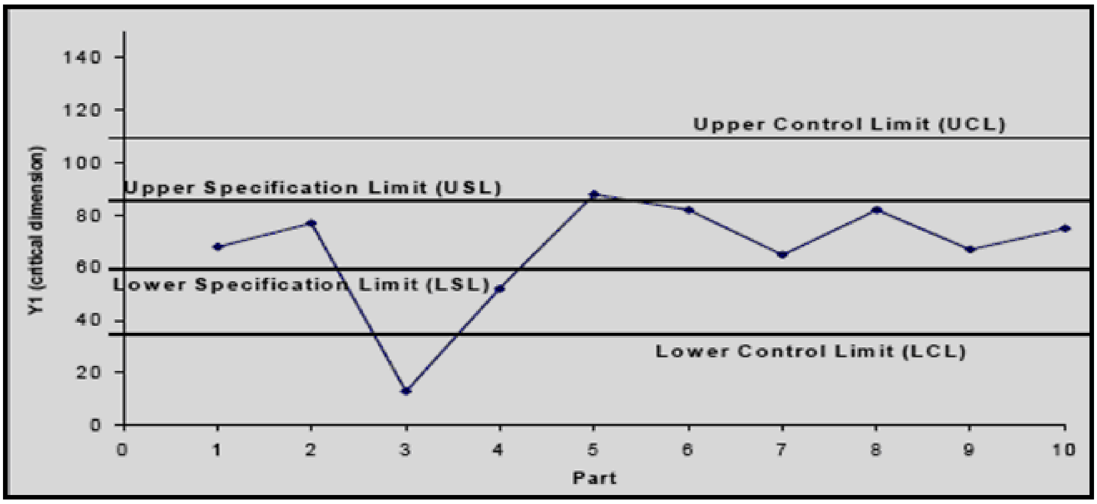


Figure 5.4- Statistical Control Chart (Breyfogle 2003)

By considering the position of the data points on the control chart relative to the upper and lower control limits, the manufacturer can determine whether the process is under statistical control. A process is considered under statistical control if all the data points fall within the LCL and UCL. Data points falling outside the LCL and UCL are caused by special cause variation. The variation of data points within the same bounds indicates common cause variation, which is inheritably inevitable (Abdelhamid 2003).

5.5. SIX SIGMA AND METRICS

In an enterprise, Six Sigma implementation requires selection of metrics against which progress and improvements can be assessed. Examples of these metrics are as follows:

- Rolled throughput yield (Y_{RT})
- Defects per million opportunities (DPMO)
- Process capability (C_k and C_{pk})
- Process performance (P_k and P_{pk}) (4)

Since the study of author does not involve the application of Six Sigma, the review of the technical concept of Six-Sigma has not covered this issue which includes more complex methods of calculating sigma using the discrete method or the continuous method such as capability ratio (CR), capability index (Cp), and capability index compared to some constant (Cpk).

5.6. SIX SIGMA YIELD

Different definition of yield can be given as follows:

- For most organizations, yield (Y) represents the percentage of units that pass final inspection relative to the number of units that were processed.

- Mathematically, the yield represents the area under the probability density curve between design specification limits (Breyfogle 2003).
- Using the Poisson distribution as an approximation of the normal distribution, as it is seen on the Figure 5.5, the yield denotes the probability of having zero defects.
- Breyfogle (2003) shows yield in equation form as follows:

$$Y = P(x = 0) = \frac{e^{-\lambda} \lambda^{x}}{x!} = e^{-\lambda} = e^{-DPU}$$

Where λ is the mean of the distribution equal in this case to the defects per unit, DPU. Note also that x represents the number of failures.

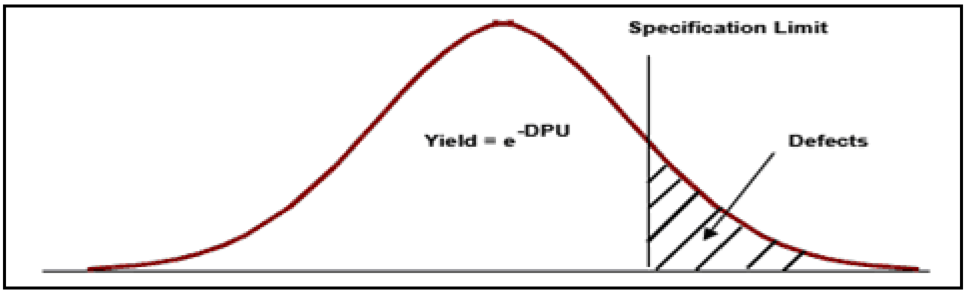


Figure 5.5- Process Yield and Defects (Breyfogle 2003)

Although a process yield can be defined in any industry, this type of representation can mask the rework that takes place prior to final release, which is the metaphoric ‘hidden factory’ that Lean and Six Sigma advocate identifying and eliminating (Abdelhamid 2003). Exposing the ‘hidden factory’ is facilitated in Six Sigma projects through the use of rolled throughput yield (YRT). YRT is the product of the yield of each process (or sub-process) required to produce a unit or a service. To illustrate the difference between Y and YRT, Figure 5.6 shows a 3-stage process with the yield, rework, and scrap at each stage (Abdelhamid 2003).

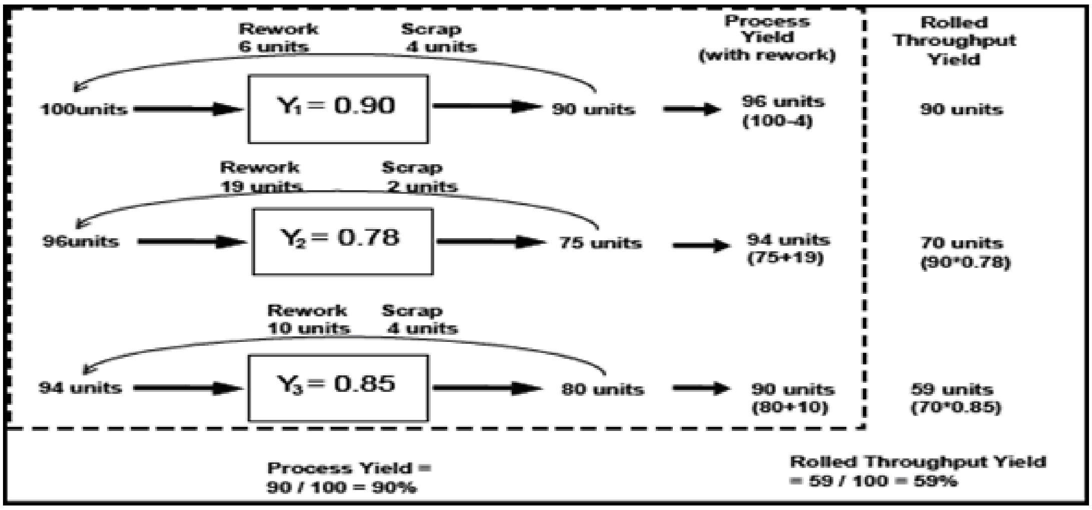


Figure 5.6- Conventional Process Yields vs. Six Sigma's Rolled Throughout Yield

The study of Abdelhamid (2003) shows that using the Six Sigma rolled throughput yield metric gives an entirely different perspective on the yield. The use of rolled throughput yield indicates that the 3-stage process has a 59% yield and not the 90% reported by conventional yield calculations. This exposes the hidden factory and gives more insights into process performance.

To facilitate comparison of processes performed at different locations, e.g., by peer companies or even across industries, the rolled throughput yield is normalized and a sigma quality level and then apart per million rate are calculated.
As it was mentioned in the previous section, the author does not either go into details of this issue because the application of Six Sigma will not be performed for this study and requires extensive knowledge.

5.7. ASSUMPTIONS OF SIX SIGMA

Sigma is the lower case Greek letter that denotes a statistical unit of measurement used to define the standard deviation of a population. It measures the variability or spread of the data. The name Six Sigma comes from the value of the standard deviation of the process output. Six is the sigma level of perfection that companies should be aiming for. The statistical theory of variation for Six Sigma is based on the supposition that all things, when measured fine enough, vary and this is called ''natural variation.''

As a result, it is called 'Six Sigma' because Sigma or standard deviation is a statistical term used by statisticians and it is a measure of process performance. For Six Sigma process the following assumptions are made:

- Normal distribution
- Nominal shift of 1.5σ

- μ and σ are known
- Defects randomly distributed
- Parts and process steps independent

5.8. METHODOLOGY AND TECNIQUES OF SIX SIGMA

Six Sigma projects require a clearly written and approved Project Charter, Scope Statement, and a basic Work Breakdown Structure (WBS). The Six Sigma method includes measured and reported financial results, uses additional, more advanced data analysis tools, focuses on customer concerns, and uses project management tools and methodology.

The Six Sigma method integrates immense knowledge of systems, processes, engineering, statistics, and project management, to improve quality and delivery, reduce waste, reduce cost, develop steady products and processes, to enhance and sustain the organization's competitive advantage through contiguous improvement of systems in the organization (Anbari and Kwak, 2004).

Six Sigma refers to a body of statistical and process-based (e.g., process mapping, value stream mapping, etc.) methodologies and techniques used as part of a structured approach for solving production and business process problems caused by variability in execution (Harry and Schroeder 2000, Pande et al. 2000).

Six Sigma utilizes a disciplined and rigorous methodology for tackling variability related problems in manufacturing or service processes (Anthony et all., 2003).

There are two main complementary methodologies that can be used in the implementation of Six Sigma in an organization:

1. DMAIC: Define, Measure, Analyze, Improve, Control
2. DMADV (DFSS): Define, Measure, Analyze, Design, Verify

In the following sections, these methodologies will be explained briefly.

5.8.1. DMAIC METHODOLOGY

DMAIC is "a closed-loop process" that eliminates inefficient steps, often focuses on new measurements, and applies technology for continuous improvement (Kwak and Anbari, 2004). The DMAIC approach is suited for investigating and improving existing processes and it can help in identifying and eliminating the root causes behind the problems in the processes.

DMAIC should be used to reduce the variability of processes and to solve the problems when the product or process is in existence but it is not performing well enough or not meeting customer's expectations (Ferng and Price, 2005).

The DMAIC approach involves (Henderson and Evans, 2000; Harry and Schroeder, 2000; Pheng and Hui, 2004; Rath and Strong, 2000):

1. **Define:** The objectives and scope of the new development project are defined and the problem is understood. Relevant information about the process, key factors affecting the process output, and critical customer requirements are collected. The team charter is also defined. Designed to help answer the questions ``who are the customers and what are their priorities?" by means of:

- Six Sigma overview;
- Process mapping;
- Data gathering;
- Risk management;
- Team and leadership skills;

More briefly;

- ➢ A Six Sigma project team identifies a project suitable for Six Sigma efforts based on business objectives as well as customer needs and feedback.
- ➢ As part of the definition phase, the team identifies those attributes, called CTQs (critical to quality characteristics), that the customer considers having the most impact on quality.

2. Measure: Identification of the key measures, the data collection plan or the plan for measurement for the process in question, and execute the plan for data collection on the current situation and process metrics. Then measurement of relevant data to the problem through Six Sigma metrics is performed. Designed to help answer the question ``how is the process performing and how is it measured?" by means of:

- Process measurements (definition of unit, data types, probability distributions);
- Process performance (first time yield, defects per unit, defects per opportunity, Z long term, Z bench, Z shift, sub-grouping);
- In-class exercises; and
- Introduction PC-based recommended statistical tool.

Briefly;

- ➢ The team identifies the key internal processes that influence CTQs and measures the defects currently generated relative to those processes.

3. Analyze: Analyze the data collected as well as the process to determine the root causes of the problem that need improvement by using statistical quality control tools. Then alternatives and tradeoffs are understood. Designed to help answer the question ``what are the most important causes of the defects?" by means of:

- Overview define/measure;
- Graphical tools;
- Quality tools;
- Stable operations;
- Types and terms;
- Hypothesis testing;
- Group dynamics;
- Benchmarking;
- High-level design;
- Simple linear regression;
- Multiple regression; and
- Binary logistic regression.

Briefly;

- ➢ The team discovers why defects are generated by identifying the key variables that are most likely to create process variation.

4. Improve: Generate and determine the potential solutions and plot them on a small scale to determine if they positively improve the process performance. Successful improvement methods are then implemented on a wider scale by using the alternatives derived in the analysis phase. Designed to help answer the question ``how to remove the causes of the defects?" by means of:

- overview define/measure/analyze;
- design of experiments;
- smart simple design;
- detailed design;
- failure mode and effect analysis;
- simulation;
- workout;

In a more brief sense;

- ➢ The team confirms the key variables and quantifies their effects on the CTQs.
- ➢ It also identifies the maximum acceptable ranges of the key variables and validates a system for measuring deviations of the variables.
- ➢ The team modifies the process to stay within the acceptable range.

5. Control: Develop, document, and implement a plan to ensure that performance improvement remains at the desired level (Pande et al. 2000; Eckes 2001). It means that the implemented solution(s) are evaluated and the mechanisms are implemented to hold the gains, which may include standardization. Design to help answer the question ``how to maintain the improvements?" by means of:

- Control plans;
- Error proofing and checklists;
- SPC; and
- Project closure.

Briefly;

- Tools are put in place to ensure that under the modified process the key variables remain within the maximum acceptable ranges over time.

Table 5.2 also presents the key steps of six sigma using DMAIC process developed by Kwak and Anbari (2004) (adopted from McClusky, 2000).

Table 5.2- Key Steps of Six Sigma using DMAIC Process (Anbari 2004, adapted from McClusky, 2000)

Six sigma steps	Key processes
Define	Define the requirements and expectations of the customer Define the project boundaries Define the process by mapping the business flow
Measure	Measure the process to satisfy customer's needs Develop a data collection plan Collect and compare data to determine issues and shortfalls
Analyze	Analyze the causes of defects and sources of variation Determine the variations in the process Prioritize opportunities for future improvement
Improve	Improve the process to eliminate variations Develop creative alternatives and implement enhanced plan
Control	Control process variations to meet customer requirements Develop a strategy to monitor and control the improved process Implement the improvements of systems and structures

The Six Sigma DMAIC methodology can be thought of as a roadmap for problem solving and product/process improvement. Although DMAIC approach may appear linear and explicitly defined, it should be noted that an iterative approach may be necessary. For example, during analyzing the data it can be realized that gathered data is not enough and relevant for the determination of the root cause of the problem. At this point, the Measure phase may be iterated to back. (Bertel, 2006)

As a result all 'sigmaists' know the framework used to achieve Six Sigma goals as DMAIC (Define, Measure, Analyze, Improve, Control). In its formative years, the DMAIC was practiced and perfected on performance improvement initiatives directed at existing processes that resulted in manufacturing defects. Nowadays, the DMAIC methodology is generally accepted for managing Six Sigma projects aimed at process improvement (Rath and Strong 2000), such as reduction of defects or increasing system availability and used for many business processes that fail to meet customer requirements. It is commonly believed that the real power of Six Sigma lies in the integration of various tools, techniques, and methodologies within the DMAIC model.

5.8.2. DMADV (DFSS) METHODOLOGY

DMADV should be used to improve the design of products when a product or process is not in existence but it is required, or when product or process is in existence but needs to be optimized. (Ferng and Price, 2005)

The following five phases make up the commonly accepted methodology for managing Six Sigma projects aimed at new product or system development (Hayes 2003), such as developing a new industrial product or a software application, and has usually been mentioned by its initials DMADV:

- **Define:** The objectives and scope of the process improvement project are defined. Relevant information about the process and customer are collected.
- **Measure*:*** Data on the current situation and process metrics are collected. This may include data mining and cost of poor quality analysis.
- **Analyze*:*** Collected data are analyzed to understand alternatives and tradeoffs. This may include quality function deployment (QFD) and critical-to-quality (CTQ) analysis.
- **Design/Build*:*** The voice of the customer is translated into prioritized development and construction deliverables. Meaningful reviews and walk-throughs are conducted and may use measures such as Defect Containment Effectiveness (DCE). The system is developed and implemented.
- **Verify/Control*:*** The implemented solution(s) are evaluated and the procedures are implemented to maintain the new system, which may include measures of success defined by the customer and the business.

Another emerging set of steps called Design for Six Sigma (DFSS) is used when a product or a process does not exist or when incremental changes need to be embodied into existing products or processes (Breyfogle et al. 2001). DFSS uses existing techniques, such as Quality Function Deployment (QFD), the Axiomatic Design (AD) method, and the theory of inventive problem-solving (TRIZ), to arrive at designs that consider a great number of issues; performance, assembly, manufacturability, ergonomics, recyclability, reliability, and maintainability (Breyfogle 2003).

Design for Six Sigma (DFSS) is a systematic methodology that utilizes tools, training, and measurements to allow the organization to design products and processes that meet customer expectations and can be produced at Six Sigma quality levels (Mader 2002). DFSS can improve new product and systems development processes, and can reduce their risks with the use of tools such as quantitative tollgate reviews, and deployment of a measurement-based process (Hayes 2003).

DFSS aims to develop new products or services with Six Sigma criteria and capability (Tennant 2002). The following Figure 5.7 (adopted by Kwak and Anbari (2004) from De Feo and Bar-El, 2002) depicts the five step DFSS process. The goal of DFSS is to achieve minimum defect rates, six sigma level, and maximize positive impact during the development stage of products.

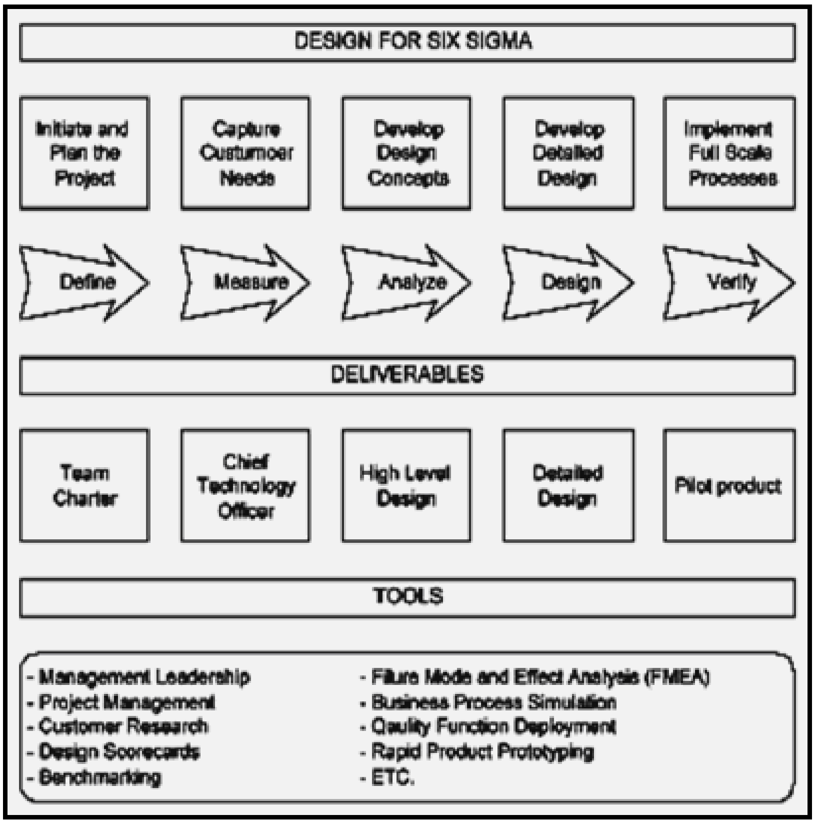


Figure 5.7- Five Step DFSS (Adopted by Kwak and Anbari (2004) from De Feo and Bar-El, 2002)

DFSS utilizes a variety of quality oriented tools and techniques to meet customer requirements (Kwak and Anbari, 2004). Treichler et al. (2002) noted that the essence of DFSS is "predicting design quality up front and driving quality measurement and predictability improvement during the early design phases". The DFSS process is focused on new or innovative designs that yield higher level of performance. De Feo and Bar-El (2002) summarized seven elements of DFSS:

- Drives the customer-oriented design process with Six Sigma capability;
- Predicts design quality at the outset;

- Matches top-down requirements flow down with capability flow up;
- Integrates cross-functional design involvement;
- Drives quality measurement and predictability improvement in early design phases;
- Uses process capabilities in making final decisions;
- Monitors process variances to verify that customer requirements are met.

It can be concluded that the methods used in DFSS are an extension of those used in DMAIC for existing (repetitive) processes. The goal of DFSS is to meet customer (internal and external) requirements from the start. This is especially important for project-based production systems where a customer requirement is usually met under a tight budget and schedule constraints.

5.9. NECESSARY TOOLS FOR THE IMPLEMENTATION OF SIX SIGMA

Six Sigma projects are monitored and controlled using basic project planning and control tools, including Gantt charts, milestone charts, project reporting, project closeout, and post project evaluation methods. Other tools include effective communications and team development methods (Anbari and Kwak, 2004). In addition to the above methodologies, a wide array of tools is necessary to the Six Sigma approach. Some illustrations of the tools used in Six Sigma analyses can be shown as follows: (Kwak and Anbari, 2004)

- Process analysis tools: Benchmarking, Cause and effect, Cycle time, etc.
- Project management tools: Cost benefit, Gantt chart, Risk analysis, etc.
- Data analysis tools: ANOVA, DoE, Regression, Control charts, etc.
- Change management tools: Resistance analysis, Communication plan, Rewards and measures, etc.

The following Table 5.3 adopted by Kwak and Anbari (2004) (from Anthony et al., 2003) briefly summarizes Six Sigma business strategies, tools, techniques, and principles.

Table 5.3- Six Sigma Strategies, Principles, tools, and techniques (Adapted from Anthony et al., 2003 by Kwak and Anbari, 2004)

Six sigma business strategies and principles	Six sigma tools and techniques
Project management	Statistical process control
Data-based decision making	Process capability analysis
Knowledge discovery	Measurement system analysis
Process control planning	Design of experiments
Data collection tools and techniques	Robust design
Variability reduction	Quality function deployment
Belt system (Master, Black, Green, Yellow)	Failure mode and effects analysis
DMAIC process	Regression analysis
Change management tools	Analysis of means and variances
	Hypothesis testing
	Root cause analysis
	Process mapping

Recognizing the role that Six Sigma initiatives are playing and will play in the future, the Primavera group has developed software called Team Play which provides organizations with the tools to select and implement Six Sigma projects. Team Play has a host of tools that allow the identification of 'key improvement areas', and applying the DMAIC and the DFSS method (Abdelhamid, 2003).

A good Six Sigma business strategy involves the measurement of how well business processes meet their objectives and offers strategies to make required improvements (Breyfogle, 1999). The application of the techniques and tools to all functions results in improved profitability, a competitive advantage, and a very high level of quality at reduced costs with a reduction in cycle time. It should be emphasized that organizations do not need to use all the measurement units associated with Six Sigma. The most important thing is to choose the best set of measurements for their situation and focus their emphasis on the wise integration of statistical and other improvement tools (Breyfogle, 1999).

In addition, prior knowledge of the tools and techniques is necessary in determining which tools are useful in each phase. Before the presentation of the tools and techniques, it is very important not to forget that the appropriate application of tools becomes more critical for effectiveness than correctness, and all the tools are not needed to use all the time. The following Table 5.4 prepared by Thomas Bertel (Six Sigma DMAIC Roadmap) shows the necessary tools and techniques for each phase in detail.

Table 5.4- The necessary Six Sigma Tools and Techniques for each DMAIC Phase (Bertel, Six Sigma DMAIC Roadmap)

DMAIC Phase Steps	Tools Used
D - Define Phase: Define the project goals and customer (internal and external) deliverables.	
☐ Define Customers and Requirements (CTQs) ☐ Develop Problem Statement, Goals and Benefits ☐ Identify Champion, Process Owner and Team ☐ Define Resources ☐ Evaluate Key Organizational Support ☐ Develop Project Plan and Milestones ☐ Develop High Level Process Map	☐ Project Charter ☐ Process Flowchart ☐ SIPOC Diagram ☐ Stakeholder Analysis ☐ DMAIC Work Breakdown Structure ☐ CTQ Definitions ☐ Voice of the Customer Gathering
M - Measure Phase: Measure the process to determine current performance; quantify the problem.	
☐ Define Defect, Opportunity, Unit and Metrics ☐ Detailed Process Map of Appropriate Areas ☐ Develop Data Collection Plan ☐ Validate the Measurement System ☐ Collect the Data ☐ Begin Developing Y=f(x) Relationship ☐ Determine Process Capability and Sigma Baseline	☐ Process Flowchart ☐ Data Collection Plan/Example ☐ Benchmarking ☐ Measurement System Analysis/Gage R&R ☐ Voice of the Customer Gathering ☐ Process Sigma Calculation
A - Analyze Phase: Analyze and determine the root cause(s) of the defects.	
☐ Define Performance Objectives ☐ Identify Value/Non-Value Added Process Steps ☐ Identify Sources of Variation ☐ Determine Root Cause(s) ☐ Determine Vital Few x's, Y=f(x) Relationship	☐ Histogram ☐ Pareto Chart ☐ Time Series/Run Chart ☐ Scatter Plot ☐ Regression Analysis ☐ Cause and Effect/Fishbone Diagram ☐ 5 Whys ☐ Process Map Review and Analysis ☐ Statistical Analysis ☐ Hypothesis Testing (Continuous and Discrete) ☐ Non-Normal Data Analysis
I - Improve Phase: Improve the process by eliminating defects.	
☐ Perform Design of Experiments ☐ Develop Potential Solutions ☐ Define Operating Tolerances of Potential System ☐ Assess Failure Modes of Potential Solutions ☐ Validate Potential Improvement by Pilot Studies ☐ Correct/Re-Evaluate Potential Solution	☐ Brainstorming ☐ Mistake Proofing ☐ Design of Experiments ☐ Pugh Matrix ☐ House of Quality ☐ Failure Modes and Effects Analysis (FMEA) ☐ Simulation Software
C - Control Phase: Control future process performance.	
☐ Define and Validate Monitoring and Control System ☐ Develop Standards and Procedures ☐ Implement Statistical Process Control ☐ Determine Process Capability ☐ Develop Transfer Plan, Handoff to Process Owner ☐ Verify Benefits, Cost Savings/Avoidance, Profit Growth ☐ Close Project, Finalize Documentation ☐ Communicate to Business, Celebrate	☐ Process Sigma Calculation ☐ Control Charts (Variable and Attribute) ☐ Cost Savings Calculations ☐ Control Plan

Some of these tools will be explained briefly in the following sections.

5.9.1. PROCESS CHARTER

A project charter is the first step in the Six Sigma methodology. It takes place in the Define phase of DMAIC, and the project charter can make or break a successful project. It can make this success by specifying necessary resources and boundaries (Swinney, "Departments").

Here are the major project charter areas that are necessary:

- Project title,
- Black belt/ Green Belt,
- Mentor/Master Black Belt,
- Project start date
- Anticipated project end date
- Cost of poor quality
- Process importance
- Process problem
- Process start-stop points
- Project goals
- Process measurements
- Team members
- Project time frame
- Template

5.9.2. PROCESS MAPPING

Process mapping is a well-known technique for creating a common vision and shared language for improving business results (Webb, "Process Mapping and Flowcharting"). It is a technique for making work visible since it is difficult to work on a process without having a clear picture of it. A process map shows "who is doing what, with whom, when and for how long". It also shows decisions that are made, the sequence of events and any wait times or delays inherent in the process.

Process maps are good for streamlining work activities and telling new people, as well as internal and external customers, "what they do around there." They also can help in the effort to reduce cycle time, avoid rework, eliminate some inspections or quality control steps, and prevent errors.

Process mapping is also one of the basic quality or process improvement tools used in Six Sigma. It has acquired more importance in recent times since it has given the complexities of processes and the need to capture and visualize knowledge that resides with the people performing the task.

Process mapping is becoming widely recognized as important management tool to understand how value is delivered for customers. Process mapping usage in the construction industry is also growing rapidly.

5.9.3. FLOWCHARTS

A flowchart is a graphical representation of a process, depicting inputs, outputs and units of activity. It represents the entire process from start to finish, showing inputs, pathways and circuits, action or decision points, and ultimately, completion at a high or detailed (depending on the usage purpose) level of observation, allowing analysis and optimization of workflow. It can function as an instruction manual or a tool for facilitating detailed analysis, optimization of workflow and service delivery (Smith, "Process Mapping and Flowcharting").

5.9.4. THE CAUSE AND EFFECT DIAGRAM (FISHBONE DIAGRAM)

To solve a problem by utilizing a team approach, there are often many opinions suggested as to be the problem's root cause. One method to capture these different ideas and stimulate the team's brainstorming on root causes is the cause and effect diagram, commonly called a fishbone. The fishbone will help to visually display the many potential causes for a specific problem or effect. It is particularly useful in a group setting and for conditions in which there exists little quantitative data to be available for analysis (Simon, "The Cause and Effect Diagram (a.k.a. Fishbone)").

The fishbone has an ancillary benefit as well. Because people by nature often like to get right to determining what to do about a problem, this can help bring out a more thorough exploration of the issues behind the problem - which will lead to a more robust solution.

The fishbone diagram consists of one line drawn across the page, attached to the problem statement, and several lines, or 'bones,' coming out vertically from the main line. These branches are labeled with different categories according your project and subject matter.

Once the branches are labeled, brainstorming sessions are begun to find possible causes and attach them to the appropriate branches. For each cause identified, the question that is 'why does that happen?' is continuously asked. Then that information is attached as another bone of the category branch. This procedure will help get to the true causes of a problem. The following Figure 5.8 illustrates the framework of a fishbone diagram (Simon, "The Cause and Effect Diagram (a.k.a. Fishbone)").

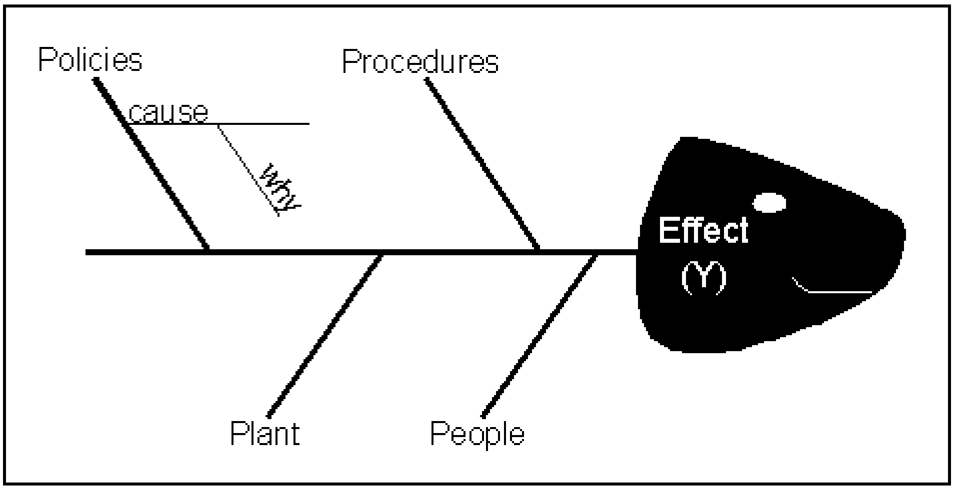


Figure 5.8- The General Framework of A Fishbone Diagram (Simon, "The Cause and Effect Diagram (a.k.a. Fishbone)")

5.9.5. BRAINSTORMING

A brainstorming session is a tool for generating as many ideas or solutions as possible to a problem or issue. It is not a tool for determining the best solution to a problem or issue.

Before beginning any effective brainstorming session, major rules must be set Simon (2006; isixsigma.com). He is suggested four key ground rules that are useful when conducting a brainstorming session: (Simon, "Effective Brainstorming")

- There are no dumb ideas. It's a brainstorming session, not a serious matter that requires only serious solutions.
- Don't criticize other people's ideas. This isn't a debate, discussion or forum for one person to display superiority over another.
- Build on other people's ideas. An idea suggested by one person can trigger a bigger and/or better idea by another person. Or a variation of an idea on the board could be the next 'Velcro' idea. It is this building of ideas that leads to out of the box thinking and fantastic ideas.
- Reverse the thought of 'quality over quantity.' Here quantity is the wanted item; the more creative ideas the better. As a facilitator, one can even make it a challenge to come up with as many ideas as possible and compare this team's performance to the last brainstorming session conducted.

5.9.6. AFFINITY DIAGRAM

The affinity diagram wasn't originally intended for quality management. Nonetheless, it has become one of the most widely used of the Japanese management and planning tools. The affinity diagram was developed to discover meaningful groups of ideas within a raw list. An affinity diagram is usually used to refine a brainstorm into something that makes sense and can be dealt with more easily. Briefly, it is a tool to organize large group of data complex ideas or issues.

5.9.7. SIPOC DIAGRAM

A SIPOC diagram is a tool used by a team to identify all relevant elements of a process improvement project before beginning the work. It helps to define a complex project that may not be well scoped, and is generally employed at the Measure phase of the Six Sigma DMAIC methodology. It is similar and related to Process Mapping and 'In/Out of Scope' tools, but provides additional detail (Simon, “SIPOC Diagram”).

The tool name prompts the team to consider the Suppliers (the 'S' in SIPOC) of the process, the Inputs (the 'I') to the process, the Process (the 'P') the team is improving, the Outputs (the 'O') of the process, and the Customers (the 'C') that receive the process outputs. In some cases, Requirements of the Customers can be appended to the end of the SIPOC for further detail. The SIPOC tool is particularly useful when it is not clear:

- Who supplies Inputs to the process?
- What specifications are placed on the Inputs?
- Who are the true Customers of the process?
- What are the Requirements of the customers?

SIPOC diagrams are very easy to complete. The following steps given below should be kept abreast of: (Simon, “SIPOC Diagram”)

1. Create an area that will allow the team to post additions to the SIPOC diagram. This could be a transparency (to be projected by an overhead) made of the provided template, flip charts with headings (S-I-P-O-C) written on each, or headings written on post-it notes posted to a wall.
2. Begin with the Process. Map it in four to five high level steps.
3. Identify the Outputs of this Process.
4. Identify the Customers that will receive the Outputs of this Process.
5. Identify the Inputs required for the Process to function properly.
6. Identify the Suppliers of the Inputs that are required by the Process.
7. Optional: Identify the preliminary requirements of the Customers. This will be verified during a later step of the Six Sigma measurement phase.
8. Discuss with Project Sponsor, Champion, and other involved stakeholders for verification.

5.9.8. SCATTER DIGRAMS

Scatter diagram is a graph used to understand the relation between two variables. Six-Sigma scatter diagrams and their correlation analyses often confute management myths. Knowing which factors do and don't vary together improves forecasting accuracy so that improved forecasts can reduce decision risk (Sloan, "Scatter Diagram"). It's quite simple to check the assumption of statistical independence with a scatter diagram (Cleary, "Statistical Process Control"). For scatter plots, the following statistics are calculated as shown in Table 5.5:

Table 5.5- Definitions of Common Statistics

Mean X and Y:	The average of all the data points in the series.
Maximum X and Y:	The maximum value in the series.
Minimum X and Y	The minimum value in the series.
Sample Size	The number of values in the series.
X Range and Y Range	The maximum value minus the minimum value.
Standard Deviations for X and Y values	Indicates how widely data is spread around the mean.
Line of Best Fit - Slope	The slope of the line which fits the data most closely (generally using the least squares method).
Line of Best Fit - Y Intercept	The point at which the line of best fit crosses the Y axis.

5.9.9. STATISTICAL PROCESS CONTROL (SPC)

Statistical process control uses one of the basic quality improvement tools, a control chart, to monitor a process to identify special causes of variation (mentioned in 5.4) and signal the need to take corrective action (Evans and Lindsay, 2002).

5.9.10. FAILURE MODE AND EFFECT ANALYSIS (FMEA)

Failure mode and effect analysis is a procedure and tools that help to identify every possible failure mode of a process or product, to determine its effect on other sub-processes and on the required function of the product or process. The FMEA is also used to rank and give priority the possible causes of failures. It also provides opportunities to develop and implement preventative actions, with responsible persons assigned to carry out these actions (Browning, "Failure Mode Effect Analysis (FMEA)").

Failure modes and effects analysis (FMEA) is a disciplined approach used to identify possible failures of a product or service and then determine the frequency and impact of the failure.

Failure mode and effect analysis is an easy to use and yet powerful pro-active engineering quality method that helps to identify and counter weak points in the early conception phase of all kinds of products and processes. The structured approach makes it easy to use and even for non-specialist a valuable tool (Browning, "Failure Mode Effect Analysis (FMEA)").

FMEA's basic idea is to spot risks and to initiate dedicated efforts to control or minimize risks. Knowing all risks can make their project plan more realistic. FMEA seems to work best, when a team documents its known knowledge about known cause- and effect-relationships (Schlueter, "Failure Mode Effect Analysis (FMEA)").

FMEA is a team-based problem solving tool that helps users identify and eliminate, or reduce the negative effects and potential failures before they occur in systems. The FMEA is typically performed during product and process design.

5.9.11. QUALITY FUNCTION DEPLOYMENT (QFD)

Quality Function Deployment (QFD) is a set of matrices used to gather and understand the voice of the customer (VOC) and relate the VOC to the product's technical requirements, component requirements, process control plans, and manufacturing operations. It is a customer-driven planning process to guide the design, manufacture and marketing of products and services (Evans and Lindsay, 2002).

5.9.12. REGRESION ANALYSIS

Regression analysis is a statistical tool for finding estimates of the parameters in a regression model. The regression model is used to predict future observations of the mean response variable (Montgomery, Runger, and Hubele, 2001).

5.9.13. PARETO CHARTS

The Pareto charts are bar charts in which each bars represent the relative contribution of each cause or component to the total problem. These bars are arranged in descending order of importance.

It is a graphical tool based on the Pareto 80/20 principle asserted by the Italian Statistician that most effects result from only a few causes. It means that 80% of the problem can be explained by just 20% of the causes.

This tool helps to categorize and summarize the causes for further investigation and it is really simple to construct and clarify. Therefore every team members can use it easily in their every project.

5.9.14. MEASUREMENT SYSTEM ASSESSMENT

Measurement system assessment studies that measure the accuracy, repeatability and reproducibility (R&R) of a measurement system (Evans, and Lindsay, 2002).

5.9.15. DESIGN OF EXPERIMENT (DOE)

Design of experiment is a test or series of tests designed to understand the factors that effect the outcome or response variable of a process.

5.9.16. ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance is typically used in conjunction with Design of Experiments to analyze the impact of variables on a process.

5.9.17. HISTOGRAM

Histogram is a statistical tool used to understand the nature of a process' distribution.

5.9.18. CHECK SHEETS

Check sheets are tools used to collect data pertaining to a process to understand process problems, and measure the impact of process improvements. They are simply one of data recording methods and they are commonly required at the beginning of a project.

5.9.19. CAPABILIY ANALYSIS AND CAPABILITY INDICES (Cp and Cpk)

A capability analysis involves performing a process capability study to understand whether the process is capable of producing products within specifications. Two capability indices that are generally produced after the process is found to be in control with respect to the variation are the process capability index, Cp and Cpk.

Cp measures the capability in relation to specification limits. (Evans and Lindsay, 2002)

The formula is $C_p = (USL - LSL) / 6\sigma$;
Where USL = Upper Specification Limit; LSL = Lower Specification Limit; and σ = measure of standard deviation.

Cpk measures shifts in the process mean. The formula is Cpk = min (CPU, CPL)
Where CPU = $(USL - x) / 3\sigma$ and CPL = $(x - LSL) / 3\sigma$,
Where ere x = process mean.

5.9.20. PROCESS LEAD TIME AND CYCLE EFFICIENCY

Process lead time can be accurately estimated. Firstly work in progress (WIP) and number of completions per day should be measured by accurate observation and recording. Then process lead time can be calculated by comparing work in progress (WIP) with number of completions per day:

Process Lead Time = (WIP) / (# of Completions)

Process cycle efficiency can be calculated by comparing value added time in a process with total lead time. Therefore value added times and non value added times in the process should be detected by using value stream mapping which is one of the tools of Six Sigma. After obtaining value added times and lead times, Process cycle efficiency is:

Process Cycle Efficiency = (Value added time) / (Total Lead Time)

It is suggested that for an ideal process, Process Cycle efficiency should be more than 25% of Total Lead Time.

5.10. TRAINING PROGRAM OF SIX SIGMA

The Six Sigma training program is a part of communication methods. It gives a clear vision to better understand the fundamentals, tools, and techniques of the Six Sigma approach and also makes sure that people apply these complex Six Sigma tools and techniques effectively. The main objective of this training program is grounding managers and employees how to define what process variables are critical to product quality, how to define the gaps between goals and current performance that will become Six Sigma projects, and how to select appropriate tools and techniques for an effective Six Sigma implementation.

Implementing a typical Six Sigma program begins at top management level with training in fact-based decision-making and evaluation of a company's strategic goals, describing a typical implementation process promoted by Six Sigma Academy (Harry, 1998). Training should also cover both qualitative and quantitative measures and metrics, leadership, and project management practices and skills (Pheng and Hui, 2004).

Because Six Sigma is a relatively new concept for many organizations, relevant training is essential for those involved. This typically lasts for 4 weeks and may spread over a few months. After each week of training, the Black Belts (it will be explained thereafter) go back to the workplace and put into practice what they have just learned. The purpose is to allow trainees to practice what they have learned so that the learning curve sinks in better.

There are four core phases of training to match the four main points of the Six Sigma strategy: How to measure, analysis, improve, and control the processes that produce increased customer satisfaction, company savings, and a healthier bottom line. These four phases of training would include statistics, quantitative benchmarking, and design of experiments.

In the literal sense for an effective training program, participants need to continuously follow up and adapt the latest methods and techniques outside the Six Sigma domain that might be useful in complementing the Six Sigma approach and communicate with actual data analysis (Anbari and Kwak, 2004).

As a result, training is a key success factor in implementing six sigma projects successfully and should be part of an integrated approach. The training curriculum is customized and needs to be provided by identifying key roles and responsibilities of individuals implementing Six Sigma projects (Anthony and Banuelas 2002).

5.11. KEY PLAYERS OF SIX SIGMA

Companies implementing Six Sigma provide its employees with intensive and differentiated levels of training in Six Sigma methods since it is a new concept (Pande et al 2000, Breyfogle et al . 2001, Linderman et al. 2003). Effective Six Sigma management requires commitment and active participation by senior executives, and leadership and communications by organizational champions (Lee-Mortimer, 2006).

The role everyone plays is one of leading fact of Six Sigma approach. Every player must have clearly defined roles and responsibilities, with rewards for good performance and consequences for not performing well enough (Pheng and Hui, 2004).

Six Sigma projects are managed by using the “Belt” system in a strong matrix organizational structure (Anbari and Kwak, 2004). The belt program should start from the top and be applied to the entire organization. The curriculum of the belt program should reflect the organization’s needs and requirements. It has to be customized to incorporate economical and managerial benefits. Chowdhury (2001) describes the roles and responsibilities of Six Sigma team members during implementation to include the following:

1. **Executive leadership:** This has to be the driving force behind adopting the Six Sigma philosophy and inspiring the organization from day one.
2. **Executive champion:** The executive champion is appointed by the CEO to oversee and support the entire mission. This sends the signal to everyone that the management of the company is serious about implementing Six Sigma.
3. **Deployment champions:** The deployment champions provide leadership and commitment and work to implement Six Sigma throughout their business and work closely with the project champions. They set and maintain broad goals for projects and ensure that they are aligned

with business priorities, negotiate resources for projects and may undertake the administrative and logistics roles in Six Sigma such as preparing and executing training plans (Pande et al. 2000).

4. **Project champions or Team sponsor:** Project champions oversee, support, and fund the Six Sigma projects and the personnel necessary to get the job done. They will typically be the process owner of the projects selected by management.

5. **Master Black Belts:** These are the project managers of the Six Sigma projects and are the people most responsible for creating lasting, fundamental changes in the way the company operates from top to bottom. The role of the Master Black Belts is usually played by outside consultants who act as in-house experts on Six Sigma during the initial stages of implementation. These consultants serve as coach and mentor and will help the champions to select good projects and the people to run them at the top end. They will also teach the core points of Six Sigma to Black Belt candidates throughout the company at the lower end. When the people they have trained are ready, they will take over the job of Master Black Belts from the consultants.

6. **Black Belts:** The Black Belts are the people who really work. They are the ones, apart from the Master Black Belts, who work full-time on the job (Hoerl 1998). The Six Sigma project management structure is centered on the Black Belt who is also called as the Six Sigma project leader. The Black Belt works on Six Sigma projects full time, and may lead four to six projects per year. Black Belts are carefully selected and receive extensive training in Six Sigma methodology includes Six Sigma strategies, tactics, tools, and statistical methods. The selection of Black Belts focuses on technically oriented individuals, who are highly regarded in their discipline area, and "have the potential to realize a synergistic proficiency between their respective discipline and the Six Sigma strategies, tactics, and tools" (Harry, 1997). The Black Belt plays the role of a project manager in a strong matrix organization. Full-time 'black-belts' receive extensive training, usually 4-6 weeks, on the DMAIC or DFSS approaches and are prepared to lead Six Sigma improvement projects (Abdelhamid, 2003).

7. Green Belts: Project team members who work on Six Sigma projects on a part time basis are called Yellow Belts. They provide the Black Belts with the support they need to get the projects done. Their job scope is identical to that of the Black Belts except that they maintain a ''real'' job in the organization and work part-time on Six Sigma projects (Pheng and Hui, 2004). They receive about two to three full days of training in the fundamentals of Six Sigma methodology.

Table 5.6 provides a comparison of the roles played by main participants in Six Sigma projects to the roles played by participants in traditional projects (Anbari and Kwak, 2004).

Table 5.6- Roles of Participants in Six-Sigma Projects

Six Sigma Projects	Traditional Projects
Black Belts	Project Managers
Yellow Belts	Project Team Members
Green Belts	Specialized Project Team Members
Master Black Belts	Project Management Office
Champions	Project Sponsors

As a result we can say that the key players of Six Sigma:

- Senior Champion – Owns Six Sigma for the Business.
- Champion – Identifies and resources projects.
- Master Black Belt – Serves as coach to the Black Belt and project team.
- Black Belt – Leads the project team, full time.
- Green Belts – Team members (part-time) from the organization sponsoring the project
- Project Sponsors – Team leaders.
- Process Owners – Owns the process / workflow.
- Executive Six Sigma Steering Committee – Oversees progress, resolves issues, ensures success enterprise-wide.

For the successful implementation of Six Sigma in construction sector, all of players in the organizations should focus on the comprehensive training of Six Sigma methodologies, techniques, tools, and their applications.

5.12. SIX SIGMA PROJECT SELECTION AND MANAGEMENT

Six Sigma projects have to be carefully reviewed, planned, and selected to maximize the benefits of implementation. After selected carefully, Six Sigma projects are evaluated rigorously to ensure that they achieve their financial objectives. Cost/benefit analysis provides the basis for selection among proposed Six Sigma projects.

Pande et al. (200) informs that potential benefits include reduction in cost of poor quality as manifested by cost of rework, scrap, repairs, field service, lost customers, and reduction in cost of similar internal and external failures. He also adds that cost of Six Sigma projects covers direct and indirect payroll cost of participants in these projects, training, consulting, and the cost of implementing the solution generated by the Six Sigma project team, which may include equipment, process redesign, and information technology driven solutions.

As a result, the Six Sigma project has to be feasible, organizationally and financially beneficial, and customer oriented. The project should be well documented to track project constraints, mainly cost, schedule, and scope. There has to be a clear set of measures and metrics to incorporate customer requirements. The project has to be reviewed periodically to evaluate the status of the project as well as the performance of Six Sigma tools and techniques being implemented. There should also be a lessons learned mechanism to capture the key issues of previous projects since common methodologies for Six Sigma implementation, DMAIC and DMADV, simplifies the application and learning and allows lessons learned to be communicated effectively across projects, organizational units, and as appropriate in the profession (Kwak and Anbari, 2004).

5.13. KEY FACTORS FOR THE SUCCESSFULL SIX SIGMA IMPLEMENTATION

There are several key elements that are necessary for successfully implementing Six Sigma. A number of authors defined key factors of successful Six Sigma implementation through own perspectives.

The prerequisites for successful implementation of Six Sigma would include the following attributes:

1. Leaders who take quality personally. Organizations that are successful in their quality efforts have vibrant, vocal, knowledgeable, and most importantly, involved management (Eckes 2001). Hoerl (1998) also cited continued top management support and enthusiasm as essential ingredients for success.
2. Six Sigma works best when everybody is involved. Good companies focus on not making mistakes: not wasting time or materials, not making errors in production or service delivery, and not getting sloppy in doing what they do best (Chowdhury 2001).
3. The value that companies place on understanding and satisfying customer needs (Hoerl 1998). Companies that truly value customer needs would spend precious resources to understand them.
4. The manner that combines the right projects with the right people and tools (Hoerl 1998).

Anthony and Banuelas (2002) and Banuelas Coronado and Anthony (2002) presented the key ingredients for the effective introduction and implementation of Six Sigma program in UK manufacturing and services organizations as:

- Management commitment and involvement
- Understanding of Six Sigma methodology, tool, and techniques
- Linking Six Sigma to business strategy
- Linking Six Sigma to customers
- Project selection, reviews and tracking
- Organizational infrastructure
- Cultural change
- Project management skills
- Liking Six Sigma to suppliers

• Training

• Linking Six Sigma to human resources (Wyper and Harrison 2000)

Johnson and Swisher (2003) provided useful implementation tips for successful Six Sigma applications:

• Sustained and visible management commitment

• Continuing Education and training of managers and participants

• Set clear expectations and select project leaders carefully for leadership skills

• Pick and select strategically important projects

Starbird (2002) argued that the Six Sigma process is part of a management system to achieve business excellence in the organizations and presented keys to Six Sigma success:

• Start process management: Identify core processes, customer needs, and measures

• Drive performance through reporting: Leaders must maintain and report opportunity lists, status of active projects/resources, and results from finished projects

• Integrate championing of active projects: Select and charter projects and require updates during existing staff meetings

According to the findings of Anbari and Kwak (2004), success factors in Six Sigma Projects can be summarized as follows:

- Management Commitment, Organizational Involvement, and Project Governance: Six Sigma requires top management commitment and contribution of required resources and effort. Implementation of Six Sigma projects means commitment of resources, time, money, and effort by the entire organization, based on clear mandates from senior executives.
- Project Selection, Planning, and Implementation Methodology: Six Sigma projects have to be carefully selected, planned, and reviewed, to maximize the benefits of implementation. The project has to be feasible, organizationally and financially beneficial, and customer oriented by means of clear set of measures and metrics to incorporate customer requirements. Each project should be well documented to track the various project constraints and has to be reviewed periodically to evaluate the status of the project as well as the performance of Six Sigma tools and techniques being implemented.
- Six Sigma Project Management and Control: A Six Sigma project should have a duration target, well defined project scope, expected financial impact and benefits per six sigma project. Scheduling, control, and progress reporting of six sigma projects for the management and control are accomplished using basic scheduling tools such as milestones and Gantt charts.
- Encouraging and Accepting Cultural Change: People facing organizational change and cultural challenges due to implementation of Six Sigma must first understand the nature and aim of the change. This requires having a clear communication plan and channels, motivating

individuals to overcome resistance, and educating senior managers, employees, and customers on the benefits of Six Sigma.

- Continuous Education and Training: Education and training give a clear vision to people to better understand the fundamentals, tools, and techniques of the Six Sigma approach. Training is part of the communications techniques used to make sure that managers and employees apply complex Six Sigma tools effectively. The training curriculum is customized and needs to be provided by identifying key roles and responsibilities of individuals implementing Six Sigma projects (Anthony and Banuelas 2002). Organizations need to continuously learn and adapt the latest methods and techniques outside the Six Sigma domain that might be useful in complementing the Six Sigma approach.

5.14. SIX SIGMA ROADMAP

Six Sigma provides an overall road map to assist practitioners to integrate the appropriate statistical and non-statistical tools and techniques into an overall approach towards improvement.

Where implementation is concerned, some of the key ideas can be drawn from the Six Sigma Roadmap (Harry and Schroeder 2000; Pande et al. 2000) and the Business Process Management model (Eckes 2001). The steps to an ideal roadmap for establishing the Six Sigma system and launching improvements are to: (Pheng and Hui, 2004)

1. Create and agree on strategic business objectives;
2. Identify key customers, core, key sub- and enabling processes, and owners of these processes;
3. Define customer requirements;
4. Measure current performance;
5. Prioritize, analyze, and implement improvements; and
6. Expand and integrate the Six Sigma system.

Briefly, if we want to describe a roadmap for the implementation of Six Sigma, it is necessary to follow these steps:

- Appoint a Champion
- Select a Cross-functional team
- Develop quantifiable goals
- Develop an implementation plan
    - Establish a training program
    - Address data collection requirements and issues
    - Develop a change control and maintenance program
- Coordinate your road map

5.15. THE BENEFITS AND REWARDS OF SIX SIGMA

The observed main rewards of Six Sigma:

- Improved reliability and predictability of software products and services.
- Increased value to the customers and shareholders.
- Improvements in organizational morale.
- Increased marketplace viability.
- Organizational recognition.
- Significant reduction in defects.
- Institutionalization of a "process" mindset.

The potential benefits from the effective implementation of Six Sigma projects may include: (Anthony et al. 2003)

- Better understanding of customer needs and expectations for today and tomorrow
- Development of robust products, processes and services
- Reduction of costs due to poor quality
- Reduction of product/service design and development time
- Improvement of process yield, stability and capability, etc.

It is very clear that Six Sigma is a considerable success because Six Sigma means that:

- Actions are in line with the strategy
- Meet or exceed customer expectations
- Meet management expectations
- Adding value to the processes
- Doing the right thing
- A clear and well defined strategy

In addition to these successes and rewards; by using the obtained knowledge from the literature, it can be said that Six Sigma has benefits on the organization and staff as follows:

<u>ORGANIZATION:</u>

- Bottom line cost savings (5 - 20% turnover)
- Improved quality as perceived by customer
- Cycle time reduction
- Common language throughout the organization
- World class standard (image)

<u>STAFF:</u>

- Improved knowledge and skills
- Wide range of tools and techniques

“Successful Stories” of Motorola and general Electric (GE) resulting from the implementation of Six Sigma are given as follows:

For more than a decade Motorola has implemented the six sigma process with dramatic results:

- Increased productivity an average of 12.3% per year.
- Reduced the cost of poor quality by more than 84%.
- Eliminated 99.7% of in-process defects.
- Saved more than $11 Billion in manufacturing costs.
- Realized an average annual compounded growth rate of 17% in revenues, earnings, and stock price.

GE also listed in their annual report (GE 1997) the following to exemplify these Six Sigma benefits (Breyfogle, 1999):

- Six Sigma designs have produced a 10-fold increase in the life of CT scanner x-ray tubes.
- The plastics business, through rigorous Six Sigma process work, added 300 million pounds of new capacity (equivalent to a "free plant"), saved $400 million in investment and will save another $400 million by 2000.

Benefits and savings of implementing the project-driven Six Sigma method have been widely reported. Table 5.7 prepared by Anbari and Kwak (2004) summarizes the organizations, projects, benefits, improvements, and savings achieved by implementing the Six Sigma method in the manufacturing sector, based on extensive investigation of literature on Six Sigma (Weiner 2004, De Feo and Bar-El 2002, Anthony and Banuelas 2002, Buss and Ivey 2001, and McClusky 2000).

Table 5.7- Reported Benefits and Savings from Six Sigma in the Manufacturing Sector (Data compiled from Weiner 2004, De Feo and Bar-El 2002, Anthony and Banuelas 2002, Buss and Ivey 2001, and McClusky 2000)

Company/Project	Metric/Measures	Benefit/Savings
Motorola (1992)	In-process defect levels	150 times reduction
Raytheon/Aircraft Integration Systems	Depot maintenance inspection time	Reduced 88% as measured in days
GE/Railcar leasing business	Turnaround time at repair shops	62% reduction
Allied Signal/Laminates plant in South Carolina	Capacity Cycle time Inventory On-time delivery	Up 50% Down 50% Down 50% Increased to near 100%
Allied Signal/Bendix IQ brake pads	Concept-to-shipment cycle time	Reduced from 18 months to 8 months
Hughes Aircraft's Missiles Systems Group/Wave soldering operations	Quality Productivity	Improved 1000% Improved 500%
General Electric	Financial	$2 billion in 1999
Motorola (1999)	Financial	$15 billion over 11 years
Dow Chemical/Rail delivery project	Financial	Savings of $2.45 million in capital expenditures
DuPont/Yerkes Plant in New York (2000)	Financial	Savings of more than $2 million
Telefonica de Espana (2001)	Financial	Savings and increases in revenue 30 million euro in the first 10 months
Texas Instruments	Financial	$ 600 million
Johnson & Johnson	Financial	$ 500 million
Honeywell	Financial	$1.2 billion

To conclude, there are lots of encouraging reasons for the companies to adopt Six Sigma and the most important ones are those:

- Concept has been around for 16 years; isn't just a fad.
- Six Sigma is the latest name for a comprehensive set of philosophies, tools, methods, and fundamental concepts.
- Six Sigma continues to evolve at all organizational levels; from CEO and CFO to the Black Belts and Green Belts.
- Six Sigma has shown the most endurance and return on investment of any such "program" till now.

5.16. THE CHALLENGES OF SIX SIGMA

Although Six Sigma is a very successful process to improve quality, profit, customer satisfaction, and etc., it can fail due to the following recorded reasons:

1. Inadequate Information
2. Poor Project Selection
3. Creating Solution-Caused Problems

4. Serving the Wrong Customer
5. Leaping to the Fix
6. Faulty Implementation
7. Failing to Consider the Human Side

There are also some challenges of Six Sigma in the literature to which are paid attention for the complete success of the program. These challenges are:

- The perception of "Six Sigma"
- Culture change
- Understanding the DFSS (Design For Six Sigma)
- It is neither a quick fix nor a recipe.
- Consultants can't make it happen.
- Training – especially management level
- Takes careful preparation and a commitment to the foundational change efforts required.
- Statistical analysis is not generally part of the engineering discipline in most IT shops.
- Implementation tends to be uneven and lapses occur frequently.
- Not everything has to be Six Sigma; this was our downfall on reengineering efforts!
- Lack of discipline and accountability.
- Reliability of data from the field.
- People must not fear giving "bad news".
- Design is critical and yet many IT organizations continue to go straight from poor requirements into coding without the benefits of even one design review.

5.17. IMPLEMENTATION FRAMEWOK OF SIX SIGMA

Implementation of Six Sigma projects means commitment of resources, time, money, and effort by the entire organization, based on clear mandates from senior executives (Anbari and Young, 2004). Six Sigma, if deployed properly, will infuse intellectual capital into the company and produce considerable knowledge gains that translate directly into bottom line results (Kiemele, 1998).

Ferng and Price (2005) were developed the following framework for the Six Sigma implementation. There are two key stages to the implementation process: Executive Vision, and Project/Process Implementation.

Stage I: Executive Vision

The executive vision stage involves the following steps:

- Review of the organization' s overall business strategy that may result revising its vision and mission statement to reflect the company' s new approach to Six Sigma and demonstrate executive vision and senior management commitment.

- Establishment of a set of objectives and guiding principles to clearly formalize the organization's approach to business and quality and to provide a focus for Six Sigma efforts, such as a project cost savings focus; a process focus; or a focus on a specific problem.
- Constitution of a group called as Business Quality Council (BQC) to lead the way forward.

Under the executive vision there are two phases:

1. The assessment and kick off phase
2. The deployment strategy phase

Phase I: The assessment and kick off phase

- Select project for assessment workshop
- Conduct executive assessment workshop
- Select champions

Phase II: The deployment phase

- Conduct executive training
- Conduct champion training
- Select black belt candidates
- Create intra- support

The Figure 5.9 (Ferng and Price, 2005) illustrates this stage and its phases schematically.

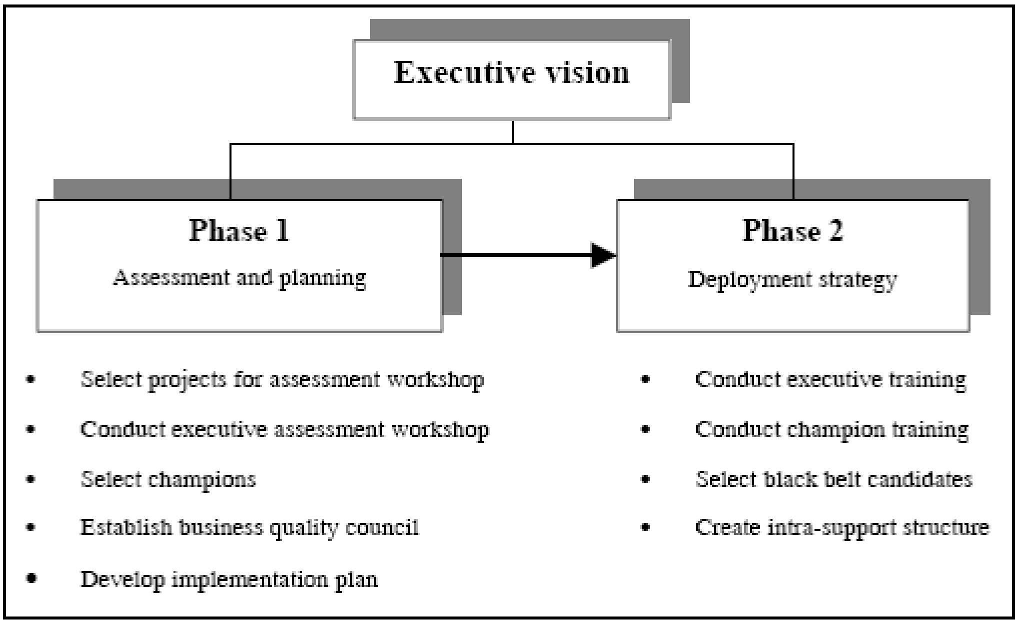


Figure 5.9- Executive Vision- Assessment, planning, and deployment strategy phase (Ferng and Price, 2005)

Stage II: Project/ Process Implementation

There are two different approaches for the Project / Process Implementation stage:

- DMAIC: Define; Measure; Analyze; Improve; and Control
- DMADV: Define; Measure; Analyze; Design; and Verify

Detailed information about DMAIC and DMADV will be given in pertinent part.

The Figure 5.10 shows the construction project/process implementation stage of adopting the five-step methodology. (Ferng and Price, 2005)

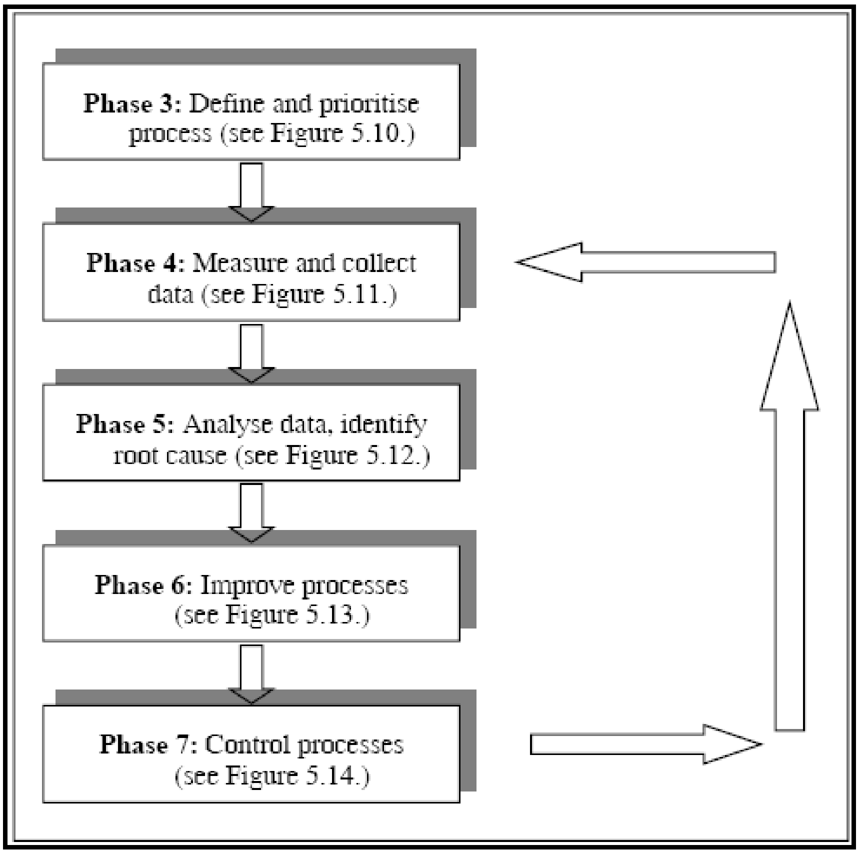


Figure 5.10- Adopting the five step methodology in the construction project/ process implementation stage (Ferng and Price, 2005)

Phase 3: Define and Prioritize Process

In most construction projects, the key resources are labor, materials, and time. Priorities for reducing waste vary from project to project depending upon the success criteria for each individual projects that are usually measured in terms of Quality, Cost, and Time. (Ferng and Price, 2005) This phase of implementation includes the following steps:

- Identify processes includes labor, materials, and time based on Cost, Quality, Time, and Customer Service Level in terms of waste.
- Prioritize processes using Pareto Chart, which makes a rank order in terms of relative frequency of defects, and FMEA, which makes a rank order in terms of severity, probability of occurrence, and detection.
- Create value added flow chart for steps.
- Define the selected process using Process Flow Chart (SIPOC) which has been shown to be an effective way of defining processes and can be used to identify and eliminate waste, and effective communicate the optimized process.

The Figure 5.11 illustrates the sketch of the phase 3 (Ferng and Price, 2005)

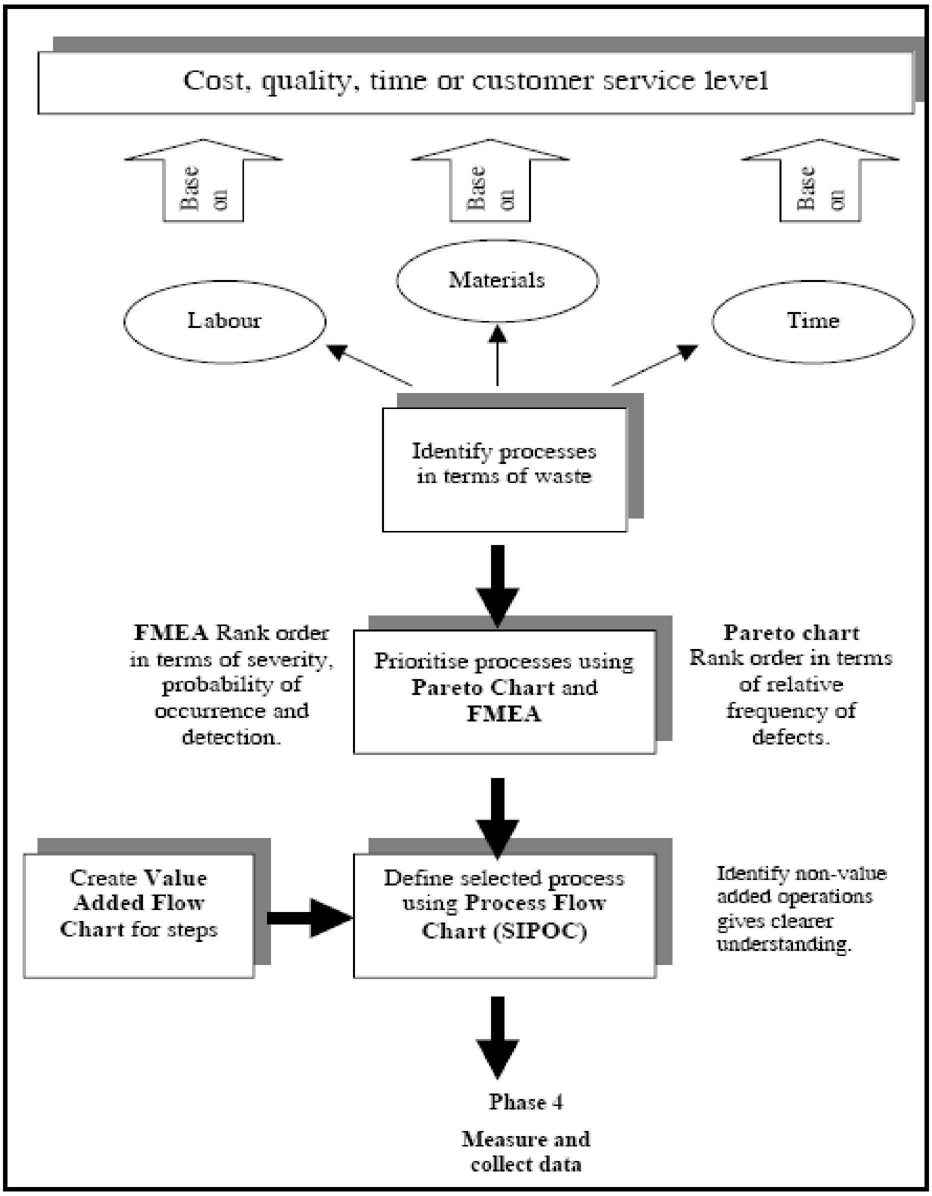


Figure 5.11- Phase 3- Define and Prioritize Phase

It is important to appreciate that drives to reduce defects to a Six Sigma level could result in excessive costs. Consequently, Phase 3 is perhaps the most important when considering the application of Six Sigma in construction industry. As a result, identifying non value added operations gives a better understanding (Ferng and Price, 2005). Then the framework can continue with the forth phase.

Phase 4: Measurement and Data Collection Phase

The results from phase 3 provide inputs to the measurement and data collection phase (phase 4). Phase 4 includes the following steps: (Ferng and Price, 2005)

- Phase 3 establish critical to quality characteristics (CTQC)
- Establish performance standards with operational definitions
- Establish measurement system by using Statistical Process Control (SPC) chart which is used to develop a baseline for performance in terms of defects per million opportunities (DPMO) that can be expressed a sigma value. For this step, firstly initiate data collection and then plot this data on SPC chart.
- Establish a baseline for performance in terms of DPMO
- Translate DPMO into a sigma value using a sigma conversation table.

The Figure 5.12 includes the sketch of the phase 4. (Ferng and Price, 2005)

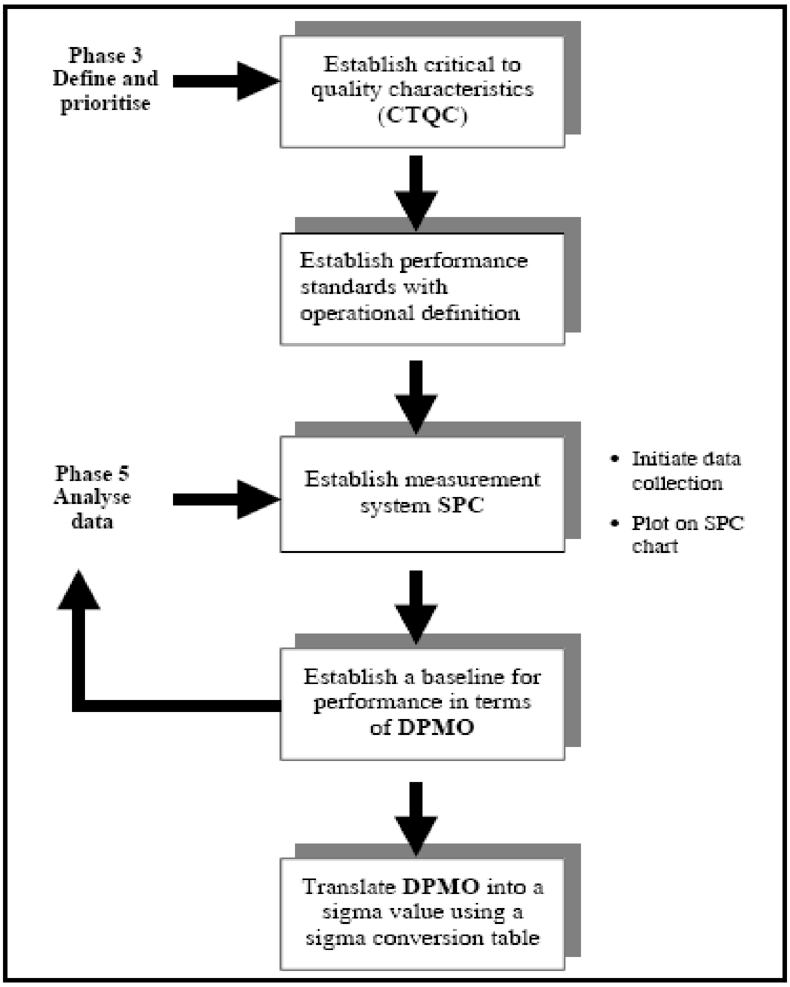


Figure 5.12- Phase 4 - Measure and Collect Data

Phase 5: Analyze Data and Identify Root Causes

The results obtained during phase 4 are analyzed in phase 5 using a range of tools to establish process capability and identify root causes of process variations. (Ferng and Price, 2005) This phase includes establishing process capability and identifying root causes of process variation by using the following tools:

- Fishbone Diagram
- 5- Why analysis
- Regression Analysis
- Design of Experiment
- Brain- Storming
- System Analysis

The Figure 5.13 illustrates the sketch of the phase 5. (Ferng and Price, 2005)

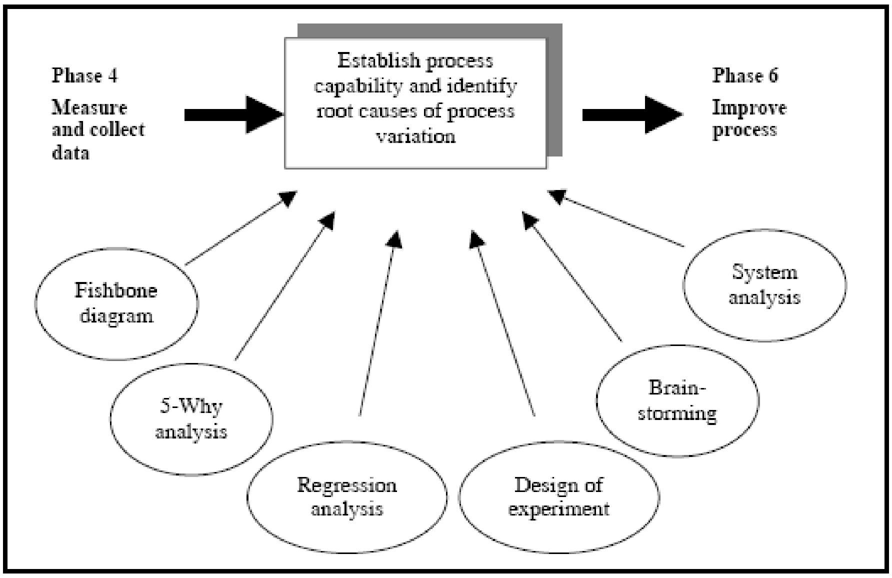


Figure 5.13- Phase 5 – Analyze data and Identify root causes

Phase 6: Improve Project/ Process

Once the root causes have been identified, corrective action may be taken in the form of short term countermeasures, which addresses symptoms or long-term countermeasure (Ferng and Price, 2005).

- Firstly, establishing corrective actions from the output of phase 5
- Establish short term countermeasures, which addresses symptoms
- Establish long-term countermeasure, which address root causes.

The Figure 5.14 shows the sketch of the phase 6. (Ferng and Price, 2005)

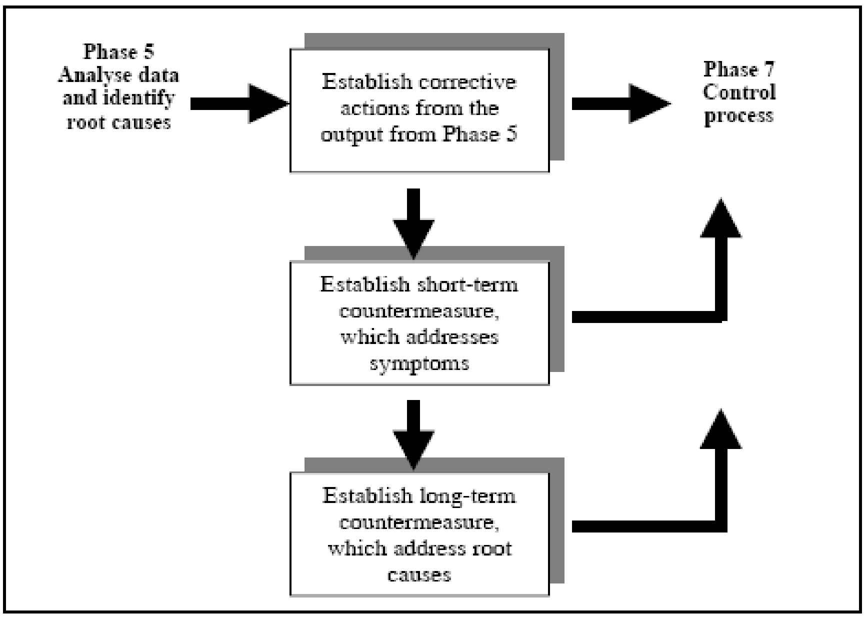


Figure 5.14- Phase 6 – Improve process/project (Ferng and Price, 2005)

Phase 7: Control Process/ Project

This phase includes establishing a control plan based on the corrective measures and new processes by using the tools such as: (Ferng and Price, 2005)

- SPC Charts
- Check Process
- 5S Housekeeping
- FMEA (failure mode and effect analysis)

The Figure 5.15 illustrates the sketch of the phase 7 (Ferng and Price, 2005)

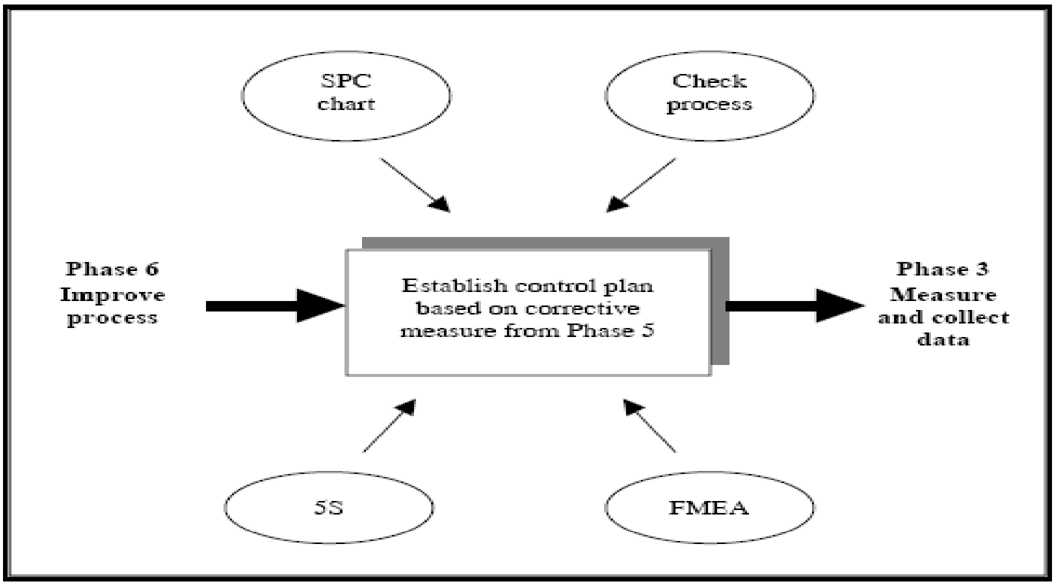


Figure 5.15- Phase 7 – Control process/project

In this section, common Six Sigma framework used for construction industry is illustrated. The aim of this study is also to develop a general Six Sigma framework that covers general construction processes by using necessary and suitable Six Sigma tools and methodologies.

5.18. SIX SIGMA IN CONSTRUCTION

Significant expenditures of time, money and resources, both human and material, are wasted each year as a result of inefficient or non-existent quality management procedures. Some construction companies start monitoring the internal and external engineering and construction processes to improve their performance, productivity, quality, and customer satisfaction. To achieve their aims, these construction organizations tend to other industries such as manufacturing to examine the effectiveness of measuring and monitoring tools and new management strategies such as Six Sigma.

In the recent years, only some of the major players of construction industry, such as Bechtel, utilized the Six Sigma methodology.

The principles of Six Sigma have been derived from TQM and it has found wide acceptance in the manufacturing sector by such firms as General Electric and Motorola. However, its structured and systematic framework, combined with the employment of statistical techniques, makes it an excellent tool for process diagnostics, which is an integral task of modern construction managers (Stewart and Spencer, 2006). The methodology has led to significant improvements in the manufacturing sector and it is believed that it should also assist construction firms to deliver projects on time, at the right cost and of superior quality for higher performance and customer satisfaction (Wantanakorn et al., 1999).

Six Sigma is a new way of managing business processes. While traditional quality programs have focused on detecting and correcting mistakes, Six Sigma surrounds something broader: it provides specific methods to re-create the process itself so that the defects are never produced in the first place. The concept seeks to continually reduce variation in processes with the aim of eliminating defects from every piece of business (Hahn et al., 1999; Tennant, 2001).

Ferng and Price (2005) indicate that the greatest challenge for Six Sigma in practice is to be found in non manufacturing environment where the difficulties lies in bridging the gap between subjective issues such as what actually constitute a defect and subsequently defining measurable and actionable variables for improvements. Therefore successful implementation in construction thus depends upon being able to realistically quantify defects.

According to Linderman et al. (2003), there is a misconception of Six Sigma philosophy that Six Sigma approach for construction is not about being totally defect free or having all processes and products at Six Sigma levels of performance. Brue (2002) adds that the appropriate level will depend on the strategic importance of the process and the cost of its improvement relative to the benefit.

In the application of Six Sigma in construction, according to Stewart and Spencer (2006), the common features are as follows:

- It is a top down rather than bottom up approach;
- It is a highly disciplined approach that includes five stages i.e. DMAIC. DMAIC methodology simplifies the process improvement project because it acts like a road map for improvement team;
- It is a data oriented approach using various statistical and non statistical decision tools (Klefsjo et al., 2001).

Applying Six Sigma in construction typically involves breaking down large tasks into smaller ones that can be re-engineered and improved (Stewart and Spencer, 2006). This structured approach usage to improving processes in construction helps to reduce task complexity while increasing performance and commitment from team members (Linderman et al., 2003).

By using the conclusion drawn from the literature review about the synergies between Six Sigma, TQM, and Lean Construction approaches already being widely used within construction, a postal questionnaire survey was developed by Ferng and Price (2005). The findings from the questionnaire survey and interviews have been summarized as follows:

The identification of several potential applications of Six Sigma within various processes related with construction, also the potential barriers to development and application are obtained as follows:

1. Most of the interviewees agreed that the application should be process focused, although some of them said that it should be product driven, depending on the type organization and final product.
2. The key is to identify the function variables within a process; the type of process is not much relevance hence it will be applicable in any industry.
3. Success depends upon the ability to define the correct functional variables within each of the construction process.

4. The main issues to be considered during the implementation of Six Sigma:
    - Adequate training to be provided
    - Ensure sufficient resources available such as finance, manpower, software, and hardware, i. e. and perform a feasible study
    - Top management driven, working towards a single goal, and mission
    - Selection of the choice of the tools, which are familiar to the organizations
    - Establish an adequate data collection system for measurement.

5. The main barriers to the development and application of Six Sigma:
    - Lack of resources
    - Difficulty in data collection
    - Difficulty in accurately translating client's needs in terms of CTQC
    - Implementation will be at the expense of day to day business
    - General perception that small organization will not benefit significantly
    - Complexity
    - Human factors such as resistance to chance
    - Lack of general information pertaining to Six Sigma in construction
    - General perception that is more for production industry
    - Projects are unique and one off with different clients
    - Needs to be tailored for each project-inflexibility.

6. The followings can help to overcome some of these barriers:

- Allow more time for training and implementation
- More publicity such as the information provided by isixsigma.com (2004) and government led initiatives
- Customer/ client must drive the process and incorporate it as an integral part of supply chain improvements
- Take a project driven approach through the project team member as part of a supply chain improvement
- Create more awareness that Six Sigma is for any size organization support to SMEs
- Provide easy access to information on Six Sigma and distinguish between misconceptions and facts.

The adaptation of Six Sigma in construction has not been rapid as in other industries, although there has been some interest within construction about the reported successful implementation of Six Sigma in other industries. However, after finding the characteristics of the generic Six Sigma approaches associated with the construction industry; Six Sigma can be applied in construction by assessing the modifications that may be required to make the approach more suitable for the sector.

5.19. EXAMPLES OF SIX SIGMA APPLICATION

In this section, four examples of Six Sigma application will be explained.

5.19.1. FIRST EXAMPLE OF APPLICATION

The author has mentioned about the framework for the Six Sigma implementation developed by Ferng and Price (2005) in the implementation of Six Sigma section.

Ferng and Price (2005) applied their two phased Six Sigma implementation framework to the painting process in the construction stage.

To select the painting process as the most critical process to initiate the Six Sigma process implementation, ranking is carried out using Pareto chart and FMEA.

For implementation of Six Sigma to painting process, the required steps are presented below:

- Firstly, establish the measurement methods to collect the data for the identification of paint defects
- Make an analysis to identify the root causes for improvement plans
- Calculate the control limits
- Decide whether the problem is controllable or uncontrollable.
- If it is not controllable identify the sources of special cause variation
- If it is controllable then calculate Cpk (normal distribution)
- If Cpk is greater than 2 then monitor

- If it is smaller than 2 then identify sources of common cause variation and design improvement plans.

The related figure of this process can be examined on the Figure 5.16 (Ferng and Price, 2005)

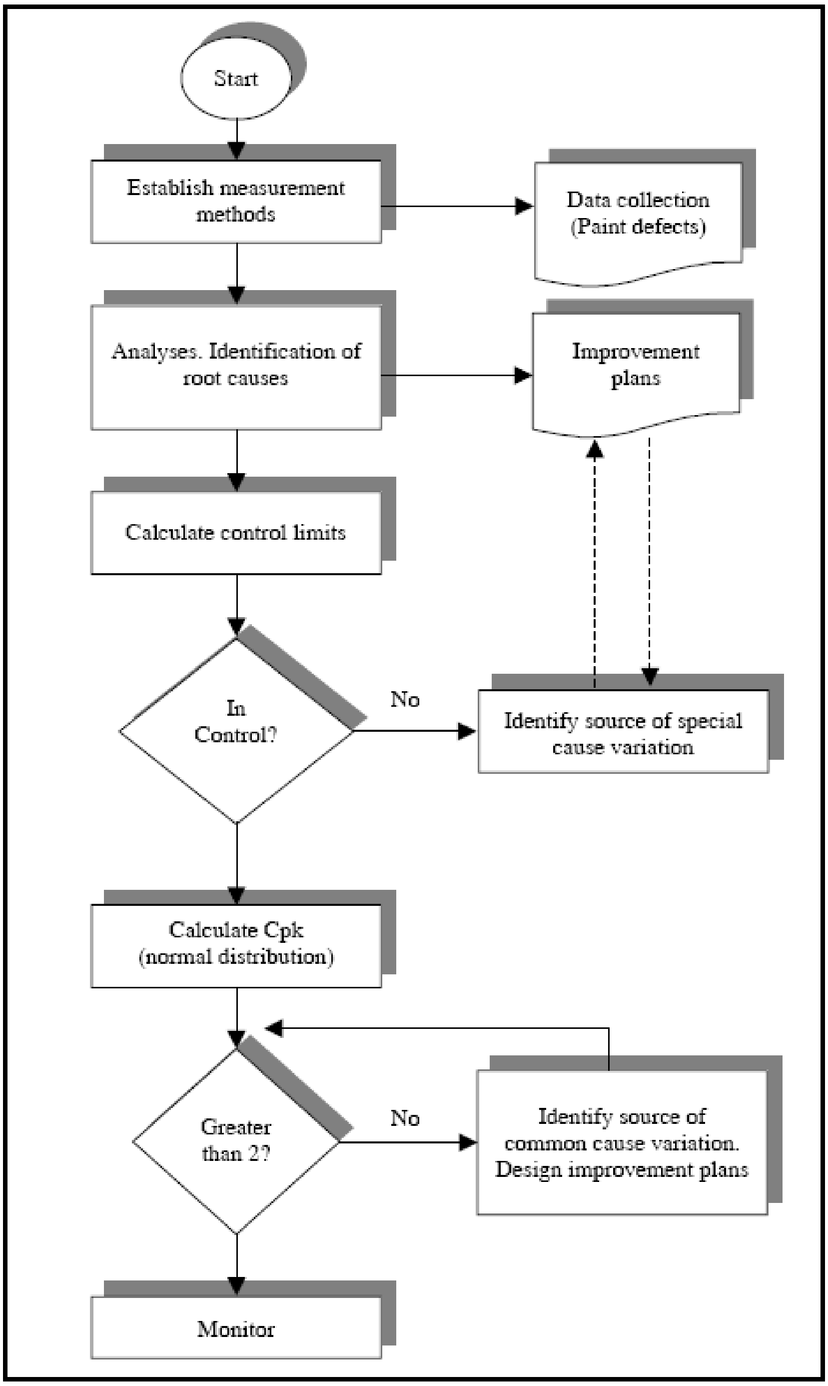


Figure 5.16- SIPOC Process Flow Chart

5.19.2. SECOND EXAMPLE OF APPLICATION

Another case study on the implementation of Six Sigma program is performed for the paper written by Pheng and Hui (2004) by the Housing and Development Board (HDB) of Singapore. The objectives for implementing Six Sigma are to improve the products and services that the HDB provides the public, and to help resolve some of its recurring problems. The training strategy involves the following steps:

1. Introduce senior management or champions to the principles and concepts of Six Sigma.
2. Training would be providing for the ten- member task force to become certificate black belts.
3. The black belts would conduct in- house training to the green belts, using the materials provided by the outside consultants.

As most of the Six Sigma initiatives are in the manufacturing, health care, and services industries, there were initial problems finding master black belts who have experience in the building industry. In addition, there were problems for the master black belts to find suitable information and case studies on how Six Sigma can be implemented in the building industry.

To resolve this problem, the HDB requested the master black belts to include the examples of how the various tools could be used in environments that are similar to the building industry. Apart from this, there were little modifications to the black belt training program. The training program includes:

1. Champions program which gives champions an overview of Six Sigma, what results can be expected from the Six Sigma projects, and their roles and responsibilities as champions during the implementation of Six Sigma within their departments.
2. Black belts program
3. Green belt program

A half- day in house seminar was conducted by the task force to introduce all interesting staff to the Six Sigma initiatives. This seminar was aimed at improving the level of awareness of Six Sigma within the HDB.

The selection criteria for the task force members include the ability to think innovatively, ability to work effectively, efficiently and independently, have good communication skills and a good knowledge of departmental processes, possess leadership qualities, including substantial experience with the quality initiatives such as ISO 9000 and ISO 14000, ability to handle additional workload without any compromise on normal responsibilities, and the ability to be a good trainer in the future.

The criterias for choosing the pilot projects are that being representative of the diverse operations of HDB and being the identified areas that recorded the highest number of unsatisfactory feedback of customer.

Contrary to common recommendation given by Six Sigma experts, the Black Belts in the HDB do not work on these pilot projects on a full time basis because of the fact that it was not cost efficient to have staff that does nothing but six sigma projects, especially this is only a pilot implementation.

Master Black belts that had no sufficient data and experience about the building industry were not involved in the pilot projects because the task force felt that no one else was able to give better knowledge of the processes and operations of the HDB than itself. The task force got assistance from the six sigma experts on more technical issues such as the correct usage of the tools in Six Sigma.

In Six Sigma, measuring current performance is necessary before initiatives can be taken for the Six Sigma improvement projects.

The Construction Quality Assessment System (CONQUAS), developed by Singapore's Building and Construction Authority (BCA) [formerly the Construction Industry Development Board (CIDB)], is the national yardstick for measuring the quality level achieved in completed buildings. And in this case study quality control was made according to these standards.

Over a period of 10 months, special attention was paid to ensure that its on-going building projects were closely supervised to meet the quality standards specified in CONQUAS for internal finishes. In addition, measures were taken to ensure that only skilled tradesmen were employed in the works.

Initial performance of company was found around 2,66 sigma level. Following the completion of the on-going projects at the end of 10 months, the internal finishes were assessed for the specified standards in CONQUAS. This assessment exercise also provided the data for computing the sigma of completed works to ascertain if the improvement measures taken by Contractor have indeed helped to raise the sigma to at least 3.8s. As a result, the new sigma level was approximately 3.95s. This was higher than the 3.8s set earlier for Contractor to achieve. By achieving a higher 3.95s, the corresponding CONQUAS scores for internal finishes were expected to rise accordingly. With improvements in both sigma and CONQUAS scores, the probability of HDB flat-dwellers to complain about defects relating to internal finishes was further eliminated.

The entire exercise showed that the initial sigma (2.66s) was enabling to provide a warning sign that the quality standards of internal finishes achieved initially by Contractor A were found lacking. The higher sigma (3.95s) achieved at the end of the 10- month period showed that the improvement measures taken by Contractor were effective.

An example of how Six Sigma was applied to improve the quality of internal finishes was also presented where improvement measures taken by contractor have helped to raise the Sigma from 2.66s to 3.95s. The operational principles that can be derived from this example can equally be applied by other design and/or construction firms. (Pheng and Hui, 2004)

In the recent years, only some of the major players of construction industry, such as Bechtel, utilized the Six Sigma methodology. Bechtel is the first major engineering and construction company to embrace Six Sigma, a methodology that uses statistics to identify and eliminate errors in work processes. In conjunction with their Performance-Based Leadership program, Six Sigma has made them more efficient while saving their customers and them time and money.

5.19.3. THIRD EXAMPLE OF APPLICATION

Bechtel launched Six Sigma in 2000, when the company was experiencing unprecedented growth and facing corresponding process challenges. Bechtel have now implemented Six Sigma in their key offices and business units around the world. About half of their employees have had Six Sigma training, and most of their major projects employ its methods from start to finish.

Bechtel offers the benefits of continuous improvement derived from their Six Sigma program since Bechtel is the first company in their field to adopt Six Sigma into all of its business practices. This benefits their customers by reducing schedule and process cycle time and by reducing the cost of poor quality. Bechtel emphasizes that Six Sigma has improved every aspect of their business, from construction projects to regional offices, saving time and money for their customers and them.

Bechtel's investment in Six Sigma reached the break-even point in less than three years, and their overall savings have added substantially to their bottom line, while also benefiting customers. Some examples:

- On a big rail modernization project in the UK, a Bechtel team used Six Sigma to minimize costly train delays caused by project work and reduced the "break in" period for renovated high-speed tracks.
- At a U.S. Department of Defense site in Maryland, Six Sigma helped achieve significant cost savings by streamlining the analysis of neutralized mustard gas at a project to eliminate chemical weapons.
- To speed up the location of new cellular sites in big cities, Bechtel developed a way to let planners use computers to view video surveys of streets and buildings, making it easier to pick the best spots.
- In a mountainous region of Chile, Six Sigma led to more efficient use of equipment in a massive mine expansion, with significant cost savings.

Bechtel explains one of its applications in details as follows:

The Channel Tunnel Rail Link project in the UK will complete a seamless, high-speed rail connection between London and Paris. The project includes more than a hundred kilometers of new track and many new bridges and tunnels. On one of the tunneling jobs, work productivity was lagging. To solve this problem, the project director decided to use Six Sigma, a statistical approach to improving processes that Bechtel has rolled out throughout the company. He formed a Six Sigma process improvement project (PIP) team from various departments working on the tunneling contract. To lead the PIP, he brought in a Six Sigma technical expert—called a black belt—to help facilitate the investigation. Using their combined experiences and perspectives, and following the five-step process of Six Sigma analysis and improvement depicted here, the team uncovered a way to save hundreds of job hours on the tunneling project. The members of the Process Improvement Project and the step processes of six Sigma analyses are illustrated in more detail in the following sketches (Figure 5.17 - 5.18 - 5.19 - 5.20 - 5.21 - 5.22).

Bechtel declares that Six Sigma is the most important initiative for change they have ever undertaken and they are happy to report that it's becoming "the way they work."

(Bechtel Company, 2004) (http://www.bechtel.com/sixsigma.htm, Last Accessed Date: May, 2007)

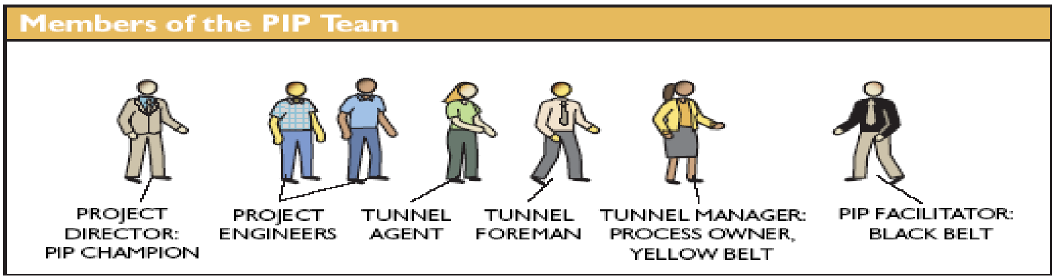


Figure 5.17- Members of the PIP Team

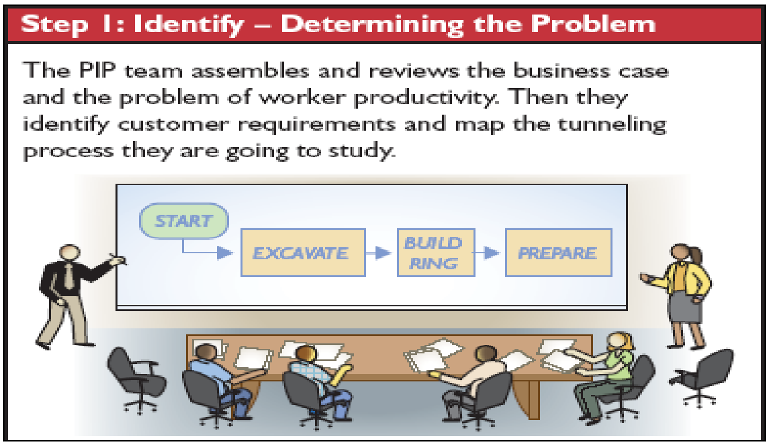


Figure 5.18- Step 1: Identify – Determining the Problem

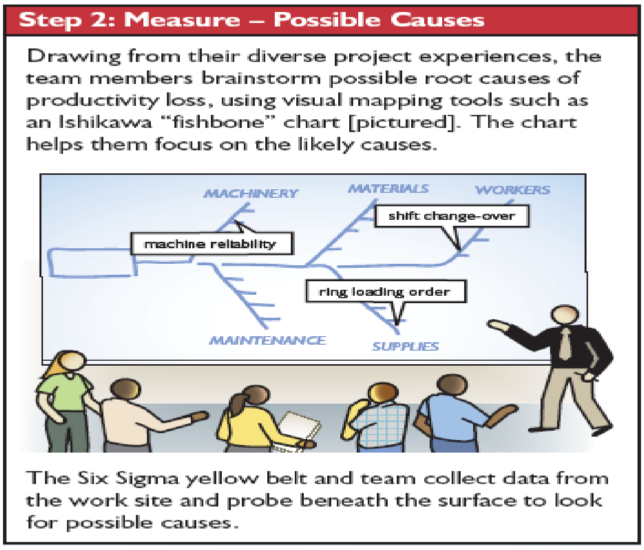


Figure 5.19- Step 2: Measure – Possible Causes

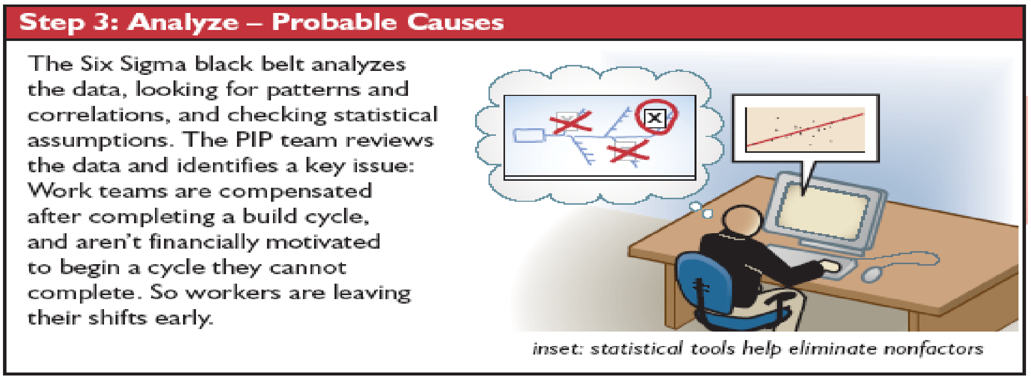


Figure 5.20- Step 3: Analyze – Probable Causes

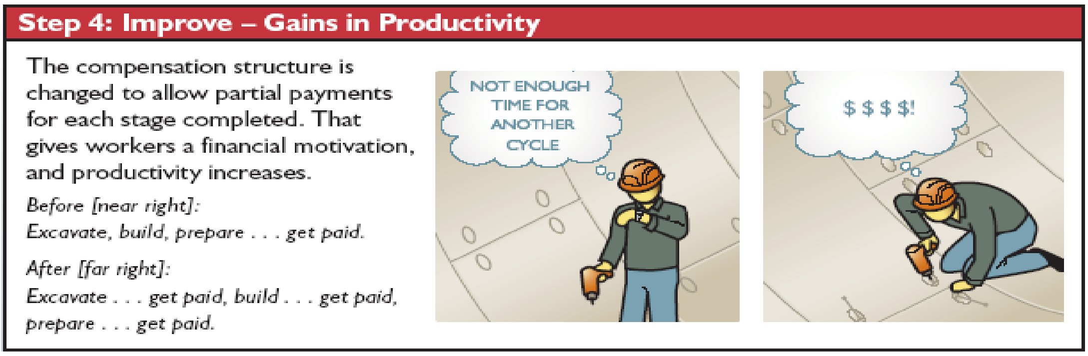


Figure 5.21- Step 4: Improve – Gains in Productivity

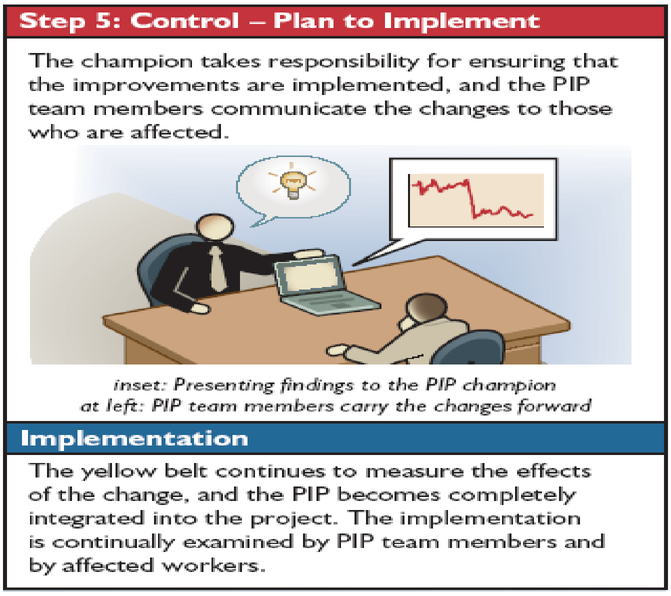


Figure 5.22- Step 5: Control – Plan to Implement

5.19.4. FORTH EXAMPLE OF APPLICATION

Another case study was conducted by Stewart and Spencer (2006) to demonstrate the potential of Six Sigma to achieve continuous process improvement (CPI) in construction and to highlight the benefits of introducing a structured assembly line discipline to construction processes. Their paper describes the outcomes of a Six Sigma process improvement project (PIP) conducted for the construction of concrete longitudinal beams on the St Pancras raised railway station in London, UK.

The case study was based on a PIP for a contract in the United Kingdom. The contract, Contract 105 (C105) of the Channel Tunnel Rail Link (CTRL) includes the construction of an extension to the existing St Pancras Station, London. The contract for construction included participants from the following companies: Costain, O'Rouke, Bechey and Emcor Rail (CORBER). Following completion, this station will become the main London terminal for international rail passengers using the Eurostar service in 2007. The platform extension was built in two halves, the east and west deck. This paper examines the construction of the east deck, which comprises the following major civil engineering activities: diversion of underground services (utilities); demolition of existing road and rail infrastructure; construction of piles, pile caps and columns to support the station extension platforms; and construction of beams that will comprise the new station platforms and tracks. This research project was conducted to achieve two primary objectives:

1. Describe the application of the Six Sigma method on a construction project; and
2. Evaluate the effectiveness of this method for achieving CPI in the construction sector. The research method adopted to achieve these objectives consisted of two parts.

Firstly, the decisions made and their outcomes for two PIPs were recorded under the five stages of the Six Sigma philosophy – define, measure, analyze, improve and control. Secondly, six of the PIP team members (i.e. six-sigma black belt consultant, site engineer, site foreman, design manager, construction coordinator and station extension manager) were interviewed to determine their perceptions of the barriers, critical success factors and suitability of Six Sigma in the construction sector. The five stages of Six Sigma were executed as follows:

Define Phase: The Six Sigma PIP was initiated to improve the construction of raised platform beams with the explicit aim of identifying particular activities that were causing defects. Define phase steps are the following:

- The main features of the platform construction were determined such as piles, pile caps, support columns, pre-cast T-beams and platform beams;
- PIP team concluded that the construction of the platform beams was dependent on a number of other activities that subsequently had the potential to impede their progress;
- The business case for this PIP was built around the additional cost incurred to the project due to delays in the construction of the platform beams;
- The cost of poor quality (COPQ) associated with delays caused by the beams include the following:
    1. The cost (above budget) of additional equipment and labor required to accelerate the construction (i.e. crash the project) to meet the program;
    2. The cost of maintaining equipment and labor on site beyond the planned completion to work off the deficit;
    3. The impact of the above two factors on follow-on activities such as roof construction and fit-out; and
    4. The £54k per day penalty for delay to opening the interim station.

- The review of past performance showed that the rate of beam production was 2.3 beams per week;
- The target beam production rate was determined as 2.9 beams per week to catch the contract program and avoid time and cost overrun;
- The metrics of the gap in the beam performance (number planned to date versus number actual to date) and the gap in the cost performance (the difference in the planned and actual cost to date) measured on a weekly basis were developed respectively;
- These metrics were monitored to highlight whether increased performance was due to excessive resources being deployed.

Measure Phase: In this phase of the beam construction process the team initially took a broad project-wide approach when searching for potential problem areas and associated measures in pre-beam activities. Measure phase included the following steps:

- A cause-and-effect analysis (i.e. mapping the beam construction process and examining the impact of different scenarios and/or production rates on the process's efficiency) was carried out with the process owners to establish the more general causes (i.e. pre-beam activities) of delays to the beam construction process;

- One of the results of cause effect matrix showed that the success of the beams was heavily reliant on preceding activities such as site access, utilities and road diversions, demolition, piling, pile caps, and columns;
- Other result was that poor coordination had caused significant delays and cost overruns to the beams or preceding processes;
- The PIP team realized that they needed to motivate workers to take ownership of what they do, through emphasizing the importance and contribution of their task to the overall success of the project;
- A technique used to help coordination gather data to further measure the construction process was the constructability workshop;
- This analysis also demonstrated that there was diminishing return from the procurement of further additional equipment.

Improve Phase: The previous phases drew the PIP team's attention to three areas relating to the construction of platform beams where improvements could be made and subsequent time/cost savings realized. The first area of improvement related to the pre-beam activities. The second area of improvement targeted gaps in the construction process which was about efficiency of beam construction based on the duration of construction. Finally, an analysis on the current levels of equipment used was conducted and it was recommended to purchase an additional set of false work and formwork.

Control Phase: To sustain improvements, the PIP team monitored the construction of the beams with the charts developed in the measure and analysis phases of the improvement process. A review of these charts indicated that there had been noticeable improvements in most of the activities – specifically, less variability in activity durations. The control charts allowed the PIP team to identify problems with the potential to cause significant delays to timely project completion.

The primary outcome of the study was a number of contributions to the planning and management of the beam construction process. Moreover, an increase in efficiency resulted from the development of a coordinated construction program that reduced the amount of piecemeal construction. The major findings and recommendations from the case study developed by Stewart and Spencer (2006) are as follows:

1. The most significant factor influencing the performance of beam construction is the availability of the site;
2. Coordination of the construction activities through the use of monitoring and projection tools enabled the teams to work together, rather than independently;
3. Continued collection of performance data (i.e. control phase) helped to highlight areas where future process improvements could be made; and

4. Project teams should be measured in a different way, whereby they were rewarded for the handover of a defect-free structure to the next team.

To conclude, the outcome of the Six Sigma Process Improvement Project (PIP) was the improved productivity of beam construction, enhanced interaction between project teams and reduced project delays.

As the author mentioned earlier, there have been limited number of Six Sigma application in the construction industry. These applications were also made for a specific construction process and did not involve all common problems of construction processes.

CHAPTER 6

SYNERGIES AND DIFFERENCES BETWEEN SIX SIGMA, TQM, AND LEAN CONSTRUCTION

6.1. SYNERGIES AND DIFFERENCES BETWEEN SIX SIGMA AND TQM

The roots of Six Sigma can be traced to two primary sources: total quality management (TQM) and the Six Sigma statistical metric originating at Motorola Corporation (Arnheiter and Maleyeff, 2005). Today, Six Sigma is a broad long-term decision-making business strategy rather than a narrowly focused quality management program.

The experience of TQM practice and its tools could form an effective foundation to many construction industries for successful implementation of Six Sigma.

The tools of TQM were heavily oriented towards brainstorming, communications and simple data analysis. However, after several years of application, the problems that needed to be tackled next, did not lend themselves easily to simple data analysis, and required more investment in resources and time than what was viewed as appropriate involvement in TQM activities. Significant business results were no longer achievable through TQM initiatives, and organizational strategic commitment to these initiatives came to an end.

The Six Sigma's Breakthrough Strategy is a disciplined method of using extremely precise data-gathering and statistical analysis to determine exactly sources of errors and ways of eliminating them. Six Sigma depends on the voice of the consumer to set the standard of acceptable performance. Six Sigma has a systematic approach to both validate data and to focus on the critical few inputs that will have the greatest potential to effect meaningful improvement. Six Sigma focuses on reducing defects in management and problematic process; it uses statistical analysis to find the most defective part of the process, and exact control procedures to sustain improvement. While Six Sigma is a long-term strategy, it is designed to generate immediate improvements to profit margins too.

Compared to traditional quality management programs such as TQM that project three or more years into the future, Six Sigma focuses on achieving financial targets in twelve-month increments.

TQM and Six Sigma have a number of similarities including the following:

- A customer orientation and focus

- A process view of work
- A continuous improvement mindset
- A goal of improving all aspects and functions of the organizations
- Data based decision-making
- Benefits depend highly on effective implementation

Six Sigma is more comprehensive than prior process improvement initiatives, such as Total Quality Management (TQM) and Six Sigma method overcomes the limitations of TQM (or CQI) by using additional, more advanced data analysis tools, applying project selection, evaluation, and relevant project management methodologies, tools and techniques, and including measurements of financial results which ensure sustained commitment to the initiative by senior executives (Kwak 2003).

Anbari (2002b) summarizes Six Sigma management method as follows:

Six Sigma = TQM (or CQI) + Additional Data Analysis Tools + Stronger Customer Focus + Project Management (i.e. managed as Six Sigma projects) + Clear focus on Financial Results
(Anbari and Kwak, 2004)

Many Six Sigma tools have also been used extensively within TQM. Some argue that Six Sigma is just uplift of TQM; however, others disagree because, when compared to TQM, Six Sigma does not appear to attach the same degree of focus on quality at the expense of all other business aspects. Although Six Sigma and TQM have been using the same tools, Six Sigma introduces a few essential ingredients that can act as a catalyst to the mixture of customer quality and process improvement. Six Sigma is able to overcome two disadvantages of TQM: (Fheng and Price, 2005)

1. Lack of common aims for supply chain
2. The lack measure by which progress can be monitored.

Perhaps the most common mischaracterization of Six Sigma is that it is “TQM on steroids” and that it is nothing new. Breyfogle et al. (2001) quotes Tom Pyzdek (2000) saying: “Six Sigma is such a drastic extension of the old idea of statistical quality control as to be an entirely different subject….In short, Six Sigma is ….an entirely new way to mange an organization…Six Sigma is not primarily a technical program; it’s a management program”.

Total Quality Management (TQM) programs focus on improvement in individual operations with unrelated processes; as a consequence, it takes many years before all operations within a given process are improved. Six Sigma focuses on making improvements in all operations within a process that produce results more rapidly and effectively. In the general literature lots of key differences are mentioned.

One of the key differences between TQM and Six Sigma is that Six Sigma focuses on prioritizing and solving specific problems which are selected based on the strategic priorities of the company and the problems which are causing the most defects whereas TQM employs a more broad based application of quality measures to all of the company's business processes.

Another difference is that TQM tends to apply quality initiatives within specific departments whereas Six Sigma is cross-functional meaning that in penetrates every department, which is involved in a particular business process that is subject to a Six Sigma project.

Other is that TQM provides less methodology in terms of the deployment process whereas Six Sigma's DMAIC framework provides a stronger platform for deployment and execution. For example, Six Sigma has a much stronger focus on measurement and statistics, which helps the company, define and achieve specific objectives.

According to Harry and Schroeder (2000), the basic differences of TQM and Six Sigma can be summarized as following:

- Traditional quality programs have focused on detecting and correcting mistakes; on the other hand Six Sigma provides specific methods to recreate the process itself so that the defects are never produced in the first place. Thus Six Sigma is a real move towards zero defects.
- While TQM have tended to focus on improving individual operations with unrelated processes, Six Sigma has tended to focus on making improvements in all operations within a process thus producing results far more rapidly and effectively through improved supply chain management.
- Six Sigma is a much more customer centric process oriented focus supported business functionality ensuring that changes in external customer requirements for and adapted to as required; and the organization as a whole becomes more responsive and adaptable to external and critical factors that directly influence the overall success.

According to the findings from the questionnaire survey and interviews conducted by Ferng and Price (2005), the potential benefits of having already adopted TQM as a support to the implementation of Six Sigma within construction are:

1. TQM compliments Six Sigma and provides a focus on continuous improvement
2. Six Sigma and many features of Six Sigma have previously appeared as TQM statistical tools before Six Sigma developed into its own philosophy and set of tools
3. Having an existing TQM will help an organization to implement Six Sigma by:
    - Reducing the employment during the deployment stage
    - Reducing the duration of implementation hence results are produced at an earlier stage
    - Providing familiarity with common deployment and measurement tools.

4. Construction is a project based and has developed some good TQM practices that provide a good platform for Six Sigma implementation.
5. Although TQM provides a good platform, it is not necessarily a prerequisite for the implementation of Six Sigma.
6. There needs to be a consensus drawn on the acceptable levels of defects to construction.

As a consequence, although both measurements of quality control within an organization have brought true success to companies who have applied their policies and procedures (Anderson, 2004), Six Sigma is complementary to TQM because it can help to prioritize issues within a broader TQM program and provides the DMAIC framework, which can be used to meet TQM objectives.

6.2. SYNERGIES AND DIFFERENCES BETWEEN SIX SIGMA AND LEAN CONSTRUCTION

According to Bertels (2004); Six Sigma focused on variance reduction and process yield improvement by following problem solving approach using statistical tools however lean is concerned with eliminating waste and improving flow by following the Lean principles and a defined approach to implement each of these principles.

Lean strategy brings a set of proven tools and techniques to reduce cycle times, inventories, set up times, equipment downtime, scrap, rework and other wastes of the hidden factory. The focus is on value from a customer perspective and flowing this through the entire supply chain. The statistically based problem solving methodology of Six Sigma delivers data to drive solutions, delivering dramatic bottom-line results (Anthony et al., 2003).
Abdelhamid (2003) denoted that Six Sigma eliminates defects but does not always address how the process flow is to be optimized. On the other hand Lean principles exclude the advanced statistical tools often required to achieve truly lean process. Hence, Six Sigma is suited to the problems that are "hard to find but easy to fix", whereas problems that are "easy to find but hard to fix" are better resolved using lean production tools.

Thomas Pyzdek (2000) has developed a very useful table (see Table 6.1) to identify his view of the synergies of Six Sigma and Lean Production.

Table 6.1- Synergies of Lean Production Strategy and Six Sigma Business strategy

Lean Production Strategy	**Six Sigma Business Strategy**
Use a project based implementation	Project management skills
Collect product and production data	Data collection
Understand current conditions	Knowledge discovery
Create standard work combination sheets	Process stability and control planning
Time the process	Data collection tools and techniques (Statistical Process Control)
Optimal value flow is achieved through aggressive elimination of waste and non-value added activities	Provides the 'how to' template for eliminating process variation
Reduce cycle times, set up times, equipment downtime, changeover time, etc.	Seven basic tools, modern management tools of quality, etc.

Abdelhamid (2003) also summarizes the basic synergies between Six Sigma and Lean Construction follows:

- Identifying a series of criteria that are controlled within defined customer limits;
- Understanding the issues lead to customer satisfaction through the value adding services and products.

In the Six Sigma methodology, root causes are identified, metrics are developed, process capability evaluated and various solutions tried out until a suitable solution is derived. On the other hand, in lean strategy, the problem is typically some form of waste (Antony et al., 2003). Table 6.2 arranged by Antony et al. (2003) briefly presents some of the fundamental differences between the two methods.

Table 6.2- Some fundamental differences between Six Sigma and Lean Production methodologies

Issues/Problems/objectives	Six Sigma	Lean Production
Focuses on customer value stream	✕	✔
Focuses on creating a visual workplace	✕	✔
Creates standard work sheets	✕	✔
Attacks work-in-process inventory	✕	✔
Focuses on good house keeping	✕	✔
Process control planning and monitoring	✔	✕
Focuses on reducing variation and achieve uniform process outputs	✔	✕
Focuses heavily on the application of statistical tools and techniques	✔	✕
Employs a structured, rigorous and well planned problem solving methodology	✔	✕
Attacks waste due to waiting, over processing, motion, over production, etc.	✕	✔

The results of this survey performed by Ferng and Price (2005) clearly show that the implementation of Six Sigma principles would make a significant improvement in the Lean Construction. The related findings can be summarized as follows:

1. Most of the construction respondents were familiar with the concepts of sustainable development and Lean Construction.
2. Wastages of resources were considered to be equivalent to the additional cost incurred onto the product.
3. Lean production and construction, the process of cycle time reduction and wastage reduction can be combined with the variability reduction tools from Six-Sigma to achieve operational and financial improvements.
4. Value management is an attempt to add value by reducing wastage and is thus a subset of Six Sigma philosophy.
5. Supply chain management, partnering, and value management make important contributions to sustainable development and were found to have parallel concepts with Six Sigma.

CHAPTER 7

LEAN SIX SIGMA

7.1. THE INTEGRATION OF SIX SIGMA AND LEAN CONSTRUCTION

Lean and Six Sigma are two widely acknowledged business process improvement strategies available to organizations today for achieving dramatic results in cost, quality and time by focusing on process performance. However it is clearly realized by many organizations that the integration of Lean construction and Six Sigma provides a rapid process improvement strategy for attaining organization goals.

Six Sigma as their process improvement and problem solving approach or Lean Manufacturing for improving speed to respond to customer needs and overall cost can be adopted as part of management strategy to increase the market share and maximize profit. According to Kumar et al. (2006); Lean strategy brings a set of proven tools and techniques to reduce lead times, inventories, set up times, equipment downtime, scrap, rework and other wastes of the hidden factory. On the other hand, the statistically based problem solving methodology of Six Sigma delivers data to drive solutions, delivering dramatic bottom-line results. The integration of the two systems can achieve much better results than either system can achieve alone (Kumar et al., 2006).

Both the Lean and the Six Sigma methodologies have proven over the last twenty years that it is possible to achieve dramatic improvements in cost, quality, and time by focusing on process performance. Whereas Six Sigma is focused on reducing variation and improving process yield by following a problem-solving approach using statistical tools, Lean is primarily concerned with eliminating waste and improving flow by following the Lean principles and a defined approach to implement each of these principles (Thomas Bertels, "Integrating Lean and Six Sigma: The Power of an Integrated Roadmap").

However, it is indicated that using either one of them alone has limitations: Six Sigma will eliminate defects but it will not address the question of how to optimize process flow; and the Lean principles exclude the advanced statistical tools often required to achieve the process capabilities needed to be truly 'lean'.

Six Sigma and Lean Production are not considered as an alternative for each other. In other words, they are complimentary to each other in that Lean identifies non value added steps in a process and looks at ways to eliminate waste and reduce cycle time on the other hand Six Sigma focuses on identifying variability and it seeks to standardize processes and reduce the cost of poor quality, always focusing on customer expectations.

The comparison of two methods is illustrated on the following Table 7.1: (Thomas Bertels, “Integrating Lean and Six Sigma: The Power of an Integrated Roadmap”)

Table 7.1- Comparing Lean and Six Sigma

	Lean	**Six Sigma**
Goal	Create flow and eliminate waste	Improve process capability and eliminate variation
Application	Primarily manufacturing processes	All business processes
Approach	Teaching principles and "cookbook style" implementation based on best practice	Teaching a generic problem-solving approach relying on statistics
Project Selection	Driven by Value Stream Map	Various approaches
Length of Project	1 week to 3 months	2 to 6 months
Infrastructure	Mostly ad-hoc, no or little formal training	Dedicated resources, broad-based training
Training	Learning by doing	Learning by doing

The integrated approach developed by Thomas Bertels (2006; isixsigma.com) to process improvement using Lean and Six Sigma will include:

- Using Value Stream Mapping to develop a pipeline of projects that lend themselves either to applying Six Sigma or Lean tools.
- Teaching Lean principles first to increase momentum, introducing the Six Sigma process later on to tackle the more advanced problems.
- Adjusting the content of the training to the needs of the specific organization - while some manufacturing locations could benefit from implementing the Lean principles with respect to housekeeping, others will have these basics already in place and will be ready for advanced tools.

While, Lean strategies play an important role in eliminating waste and non-value added activities across the organization, Six Sigma, through the use of statistical tools and techniques, takes an organization to an improved level of process performance and capability. Most companies using the integrated approach apply basic Lean tools and techniques to gain speed at the beginning of their program, such as current state map, basic housekeeping using 5S practice, standardized work, etc. After implementing the Lean tools and techniques some wastes are eliminated from the system. Then, the tools and techniques of Six Sigma are used to offer powerful solutions to chronic problems (Kumar et al., 2006)

As a result, the use of the comprehensive set of tools of Six Sigma and Lean can help to reduce all kinds of waste (rework, over production, waiting, material, human skills, transportation and unnecessary movement) from the organization (Ohno 1988, Womack et al. 1990, Shingo 1992, Hines et al. 1998, Liker 1998).

Developing an integrated improvement program that incorporates both Lean and Six Sigma tools requires more than including a few Lean principles in a Six Sigma curriculum or training Lean Experts as Black Belts. An integrated improvement strategy has to take into consideration the differences and use them effectively: (Thomas Bertels, "Integrating Lean and Six Sigma: The Power of an Integrated Roadmap")

- Lean projects are very tangible, visible, and can be completed within a few days (whereas Six Sigma projects typically require a few months). An integrated approach should emphasize Lean projects during the initial phase of the deployment to increase momentum.
- Lean emphasizes broad principles coupled with practical recommendations to achieve improvements. For example, Lean suggests a technique to analyze and reduce changeover time that does not require sophisticated analysis and tools. However, Lean principles are oftentimes inadequate to solve some of the more complicated problems that require advanced analysis. Therefore, Six Sigma needs to be introduced during the first year of the deployment to ensure that the improvement roadmap includes a generic problem-solving approach.
- An integrated improvement program needs to be fueled by a vision of the future state and by a pipeline of specific projects that will help close the gap between current and future state. Lean introduced Value Stream Mapping as the central tool to identify the gaps and to develop a list of projects that can be tackled using Lean or Six Sigma methodology.
- Whereas the Six Sigma process and tools can be applied to virtually every process and industry, the Lean approach is much more specific and the content needs to be adjusted to industry needs: For example, reducing set-up time in a plant that has lines dedicated to a single product is pointless. Therefore, the Lean curriculum needs to be adjusted to meet the needs of the specific business.
- Training is effective but only when combined with application. Lean principles are typically taught as separate workshops, with each workshop combining a short training session on the principle with direct application on the shop floor. Six Sigma training is broken down into the phases of the DMAIC process with time between each training session to apply the tools learned to the project. The extensive analysis required for Six Sigma projects suggests that a workshop structure as used for Lean training would not be effective.

The companies practicing integrated approach will gain four major benefits: (Antony et al., 2003)

- Become faster and more responsive to customers
- Strive for Six Sigma capability level
- Operate at lowest costs of poor quality
- Achieve greater flexibility throughout the business

The following Figure 7.1 summarizes the nature of improvements that may occur in organizations that practice lean management or Six Sigma, and the corresponding improvements that an integrated program could offer (Arnheiter and Maleyeff, 2005).

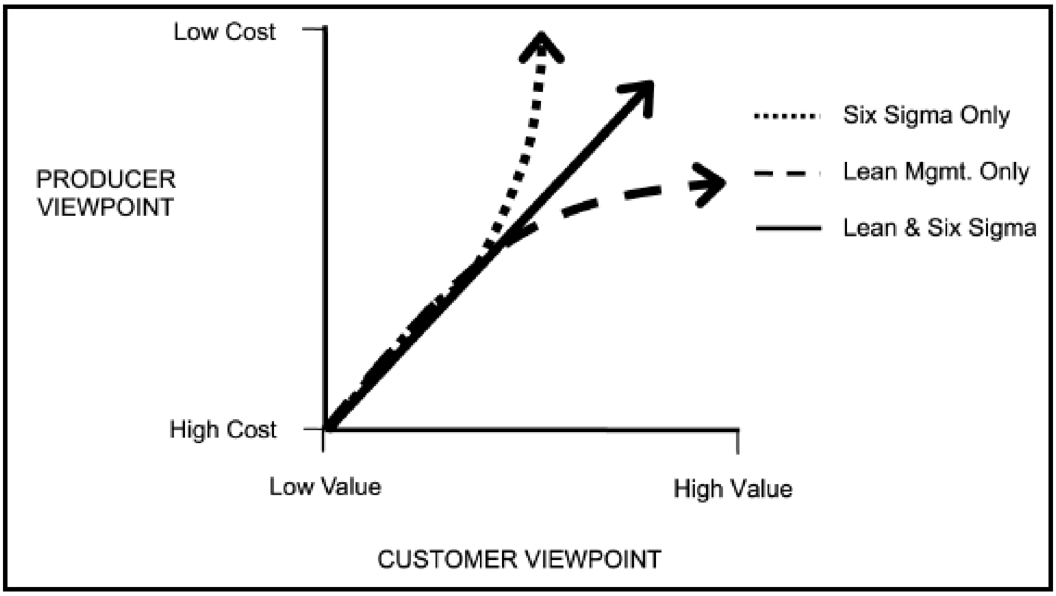


Figure 7.1- Nature of Competitive Advantage

A Lean Six Sigma organization would capitalize on the strengths of lean management and Six Sigma. The authors, Arnheiter and Maleyeff (2005), determined the principles of Lean Management and Six Sigma used for Lean Six Sigma organizations as indicating below.

A Lean Six Sigma organization would include following primary tenets of lean management:

1. It would incorporate an overriding philosophy that seeks to maximize the value-added content of all operations.
2. It would constantly evaluate all incentive systems in place to ensure that they result in global optimization instead of local optimization.
3. It would incorporate a management decision-making process that bases every decision on its relative impact on the customer.

A Lean Six Sigma organization would include the following primary tenets of Six Sigma:

1. It would stress data-driven methodologies in all decision making, so that changes are based on scientific rather than ad hoc studies.
2. It would promote methodologies that strive to minimize variation of quality characteristics.
3. It would design and implement a company-wide and highly structured education and training regimen.

The Figure 7.2 given below also illustrates the combined power of Six Sigma and Lean as a Lean Six Sigma methodology. (George, 2002)

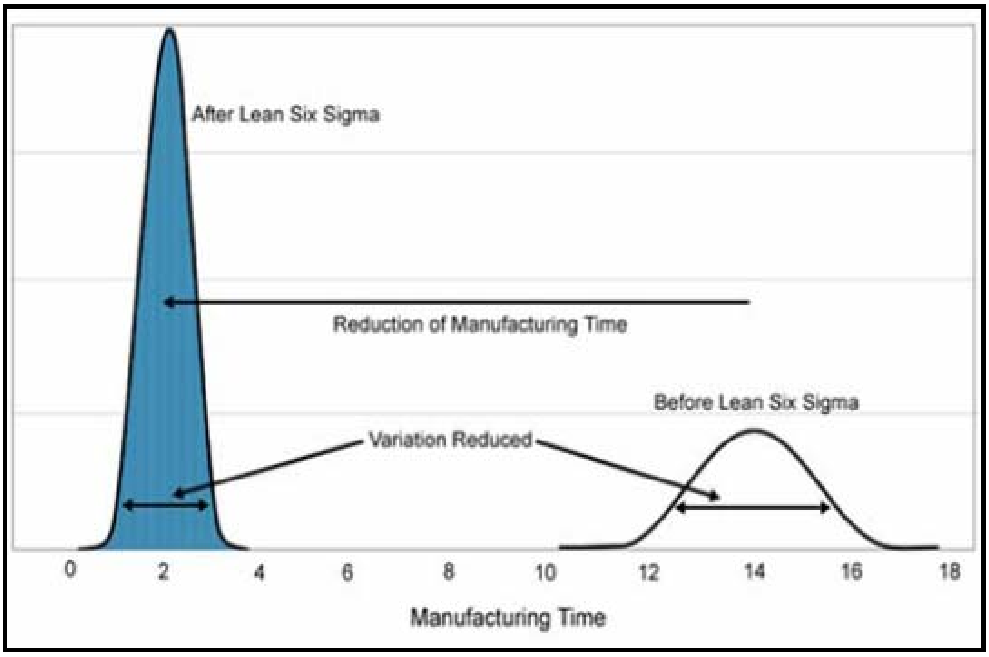


Figure 7.2- Combined Power of Six Sigma and Lean as a Lean Six Sigma

To conclude, the integrated approach of Six Sigma and Lean strategy will offer a complete, holistic approach to moving your business forward on the road to achieve the best competitive position because of the fact that the application of Six Sigma principles combined with the speed and agility of Lean strategy will produce solutions in the never-ending quest for better, faster, cheaper business processes (Antony et al., 2003). M. L. George (2002) describes Lean Six Sigma as a “Lean Six Sigma is a methodology that maximizes shareholder value by achieving the fastest rate of improvement in customer satisfaction, cost, quality, process speed, and invested capital.

7.2. LEAN SIX SIGMA FRAMEWORK

Lean and Six Sigma represent a potent framework in eliminating process variation. George (2002) described Lean Six Sigma as a combination of: "making work better by using Six Sigma and making work faster using lean principles". Breyfogle et al. (2001) states: "In a system that combines the two philosophies, lean creates the standard and Six Sigma investigates and resolves any variation from the standard". Six Sigma is considered a great tool for problems that are "hard to find but easy to fix". Problems of the "easy to find and hard to fix" category are better addressed using lean production tools (Hammer and Goding 2001).

Lean and Six Sigma practitioners are integrating the two strategies into a more powerful and effective hybrid, addressing many of the weaknesses and retaining most of the strengths of each strategy. Lean Sigma combines the variability reduction tools and techniques from Six Sigma with the waste and non-value added elimination tools and techniques from Lean Manufacturing, to generate savings to the bottom-line of an organization. The proposed framework integrates Lean tools (current state map, 5S System, and Total Productive Maintenance (TPM)) within Six Sigma DMAIC methodology to enhance the bottom-line results and win customer loyalty (Kumar et al., 2006).

The following roadmap (Figure 7.3) provides an example for how one could approach the integration of Lean and Six Sigma into a comprehensive roadmap (Thomas Bertels, "Integrating Lean and Six Sigma: The Power of an Integrated Roadmap").

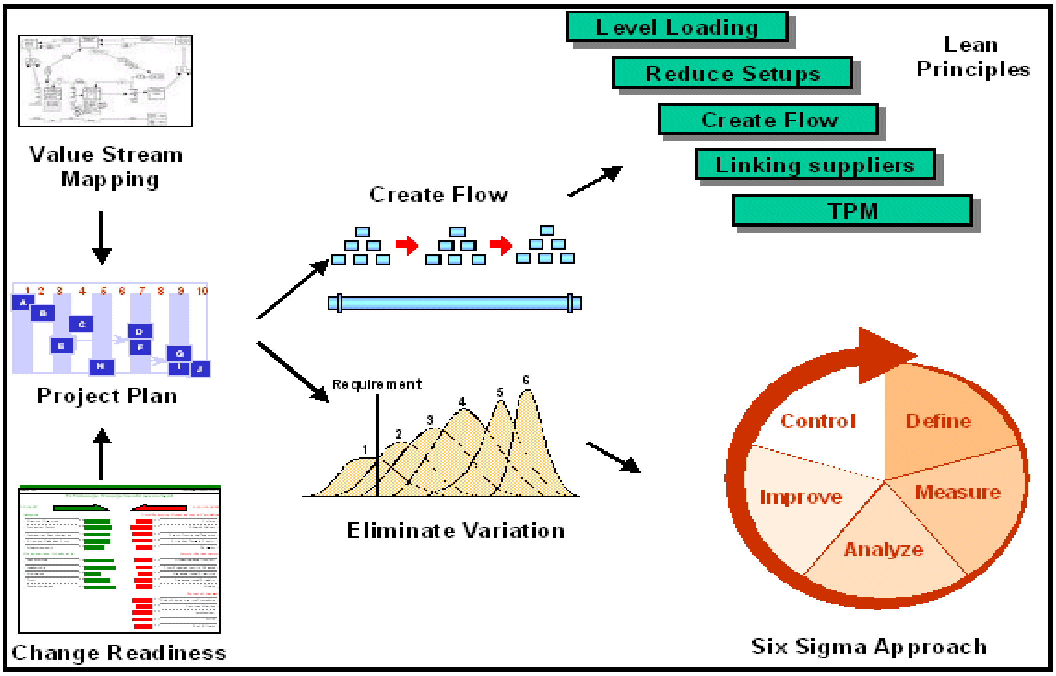


Figure 7.3- Integrating Lean and Six Sigma Roadmap (Thomas Bertels, "Integrating Lean and Six Sigma: The Power of an Integrated Roadmap")

According to this framework prepared by Bertels (2006, "Integrating Lean and Six Sigma: The Power of an Integrated Roadmap"), from a training perspective, the Lean principles would be taught first, using the simpler projects identified through the Value Stream Map as training projects for the Lean workshops. A Black Belt therefore would learn how to apply these lean principles working on a real life problem. A Lean Black Belt would complete a large Lean project over the course of the training to become certified. The Six Sigma process will be introduced once the Lean principles have been taught. Again, the training participants would work on one specific project identified by Value Stream Mapping.

As a result, a Lean Black Belt would receive in total 30 days of classroom training, would participate in five Lean workshops, and complete one large Lean and one large Six Sigma project over the course of one year. Such a Black Belt would be capable of applying Lean and Six Sigma tools to a variety of business problems and choosing the appropriate approach to address the problem at hand.

Tarıq S. Abdelhamid (2003) adapted the following framework (Figure 7.4) by using Ballard's model (2000) for the implementation of the Lean Six Sigma methodology.

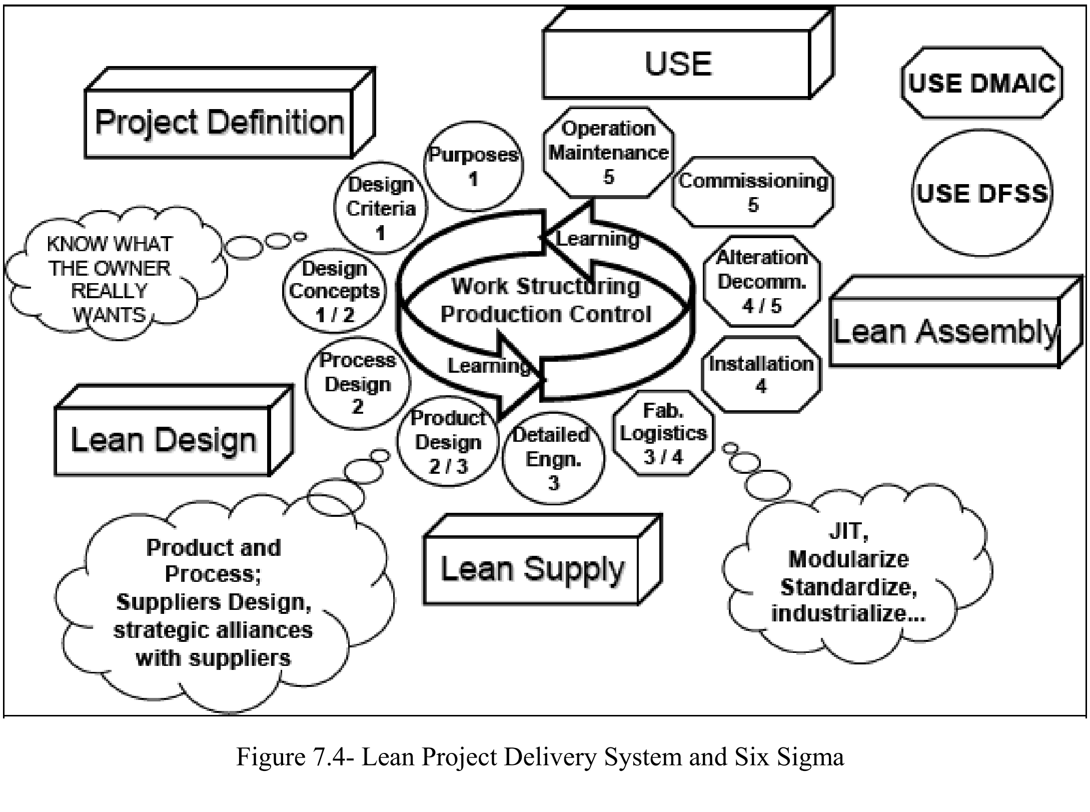


Figure 7.4- Lean Project Delivery System and Six Sigma

For the implementation of the Lean Six Sigma methodology, Tarıq S. Abdelhamid (2003) used the Lean Project Delivery System (LPDS). LPDS is a conceptual framework developed by Ballard (2000) to guide the implementation of Lean Construction on project- based production systems, i.e., the structures they build. LPDS and Six Sigma framework was depicted as a model with 5 main phases, where each phase is comprised of 3 modules.

LPDS and Six Sigma framework phases:

1. Project definition: Knowing what the owner really wants
    - Purposes
    - Design criteria
    - Design concepts

2. Lean design: product and processes; Supplier design, strategic alliances with suppliers
    - Design concept
    - Process design
    - Product design
3. Lean supply: JIT, modularize, standardize, industrialize…..
    - Product design
    - Detailed engineering
    - Fabricator Logistics

4. Lean assembly:
    - Fabricator Logistics
    - Installation
    - Alteration, decommission

5. Use: Use DMAIC and DFSS
    - Alteration, decommission
    - Commissioning
    - Operation and maintenance

In this figure, the numbers in the encircled and octagon bound modules represent the phase that the module belongs to. The modules with two numbers represent the modules that are shared between two different phases. For example, the module 'Product Design' is part of both the 'Lean Design' and the 'Lean Supply' phases.

In Figure, modules bounded by an octagon are candidates for the DMAIC approach because this approach is this approach is suited for investigating and improving existing processes. For example, fabricators can utilize this approach to investigate and improve processes that exceed the allowable tolerances (the Doors and Frames case study in Tsao et al. 2000). Another example is on-site assembly or installation processes suffering from variability in performance due to late delivery of material and equipment, design errors, change orders, machine breakdowns, environmental effects, occupational accidents, and poorly designed production systems. The DMAIC approach can help in identifying and eliminating the root causes behind these problems.

Similarly, encircled modules in the figure are candidates for the DFSS approach which is most suited for new products or processes or when incremental changes need to be incorporated into existing products or processes. The methods used in DFSS are an extension of those used in DMAIC for existing (repetitive) processes. The goal of DFSS is to meet customer (internal and external) requirements from the start. This is especially important for project-based production systems where a customer requirement is usually met under a tight budget and schedule constraints.

In general there is no standard framework for Lean Six Sigma implementation as it can be concluded above frameworks. It has also been observed by the author that there is no clear guidance within the framework as to which strategy should be selected at the early stages of a project. Therefore, the proposed framework for Lean Six Sigma implementation needs to be validated in different scenarios for establishing its validity.

7.3. LEAN SIX SIGMA TOOLS

When the two approaches are integrated, it becomes apparent that the role of various tools and techniques need to be understood. Most companies using the integrated approach began by applying the basic lean production tools and techniques such as basic housekeeping using 5S practice, standardized work, Total Productive Maintenance, etc. Once lean tools and techniques eliminate much of the noise from a process, Six Sigma then offers powerful solutions to chronic problems (Drickhamer, 2002).

The comprehensive set of tools, techniques and principles that can be employed in the integrated approach of Lean and Six Sigma business strategies is delineated in Figure 7.4. Figure 7.5 is based on the previous works of experts in Lean and Six Sigma (Womack and Jones 1996, James-Moore and Gibbons 1997, Hoerl 1998, Rother 1998, Breyfogle III 1999, Harry and Schroeder 1999, Emiliani 2000, Hines and Taylore 2000, Pyzdek 2000, Antony et al. 2003, Snee and Hoerl 2003).

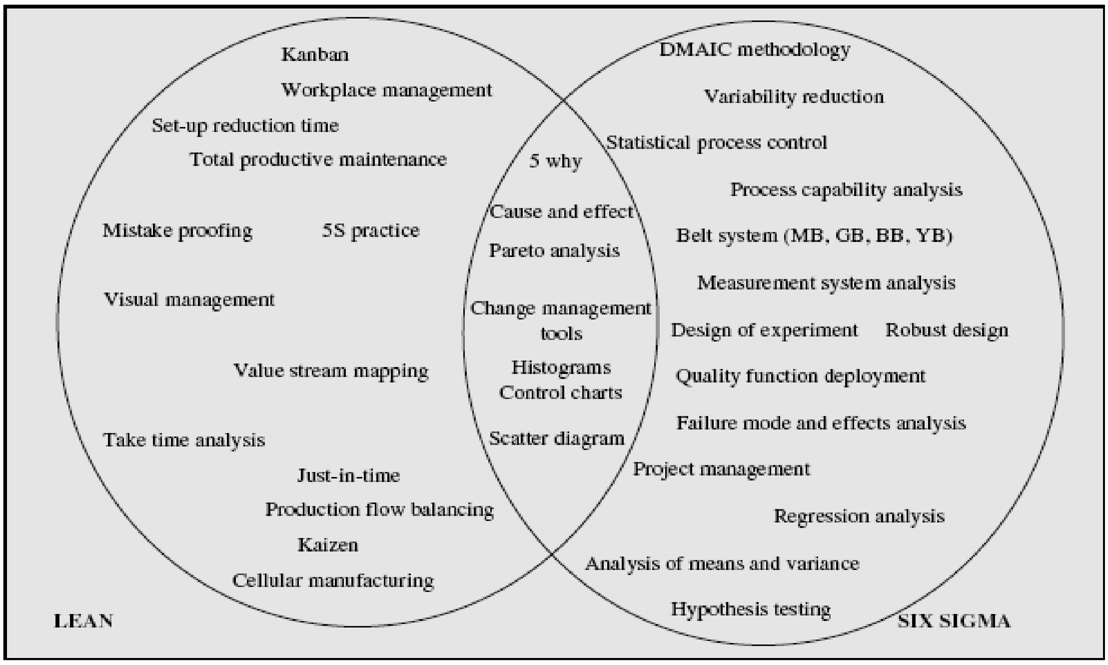


Figure 7.5- The Tools and Techniques of Lean and Six Sigma

Table 7.2 also provides a comprehensive set of tools, techniques and principles which can be employed in the integrated approach of Lean Production and Six Sigma business strategies (Antony et al., 2003).

Table 7.2- Tools, Techniques and principles of the integrated approach

Six Sigma (Tools, Techniques, Principles)	**Lean Production (Tools, Techniques, Principles)**
Variability reduction	Workplace management
Belt system (MB, BB, GB, YB)	Set-up time reduction (SMED)
DMAIC methodology	Pull system (Kanban)
Statistical Process Control (SPC)	Total Productive Maintenance (TPM)
Process Capability Analysis	Mistake Proofing (Poka Yoke)
Measurement System Analysis (MSA)	5S Practice
Design Of Experiments (DOE)	Value Stream Mapping
Robust Design	SIPOC process diagram
Quality Function Deployment (QFD)	Just-in-Time (JIT)
Failure Mode Effects and Criticality Analysis (FMECA)	Visual Management
Project Management	One Piece flow (Takt time)
Regression Analysis	Standardized procedures/work
Analysis of Means and Variance (ANOM & ANOVA)	Production flow balancing
Hypothesis tests	Waste identification and elimination (7 elements of waste)
Root Cause Analysis	Kaizen
Process Mapping	Cellular manufacturing
Change management tools	Change management tools

More new tools and techniques will also be added to the given ones according the requirement of the developed Lean Six Sigma framework since there is no clear understanding on the usage of tools and techniques within the Lean Sigma framework.

CHAPTER 8

CASE STUDY

8.1. INTRODUCTION

The purpose of this case study is to determine the deficiencies of the construction companies in quality, productivity, and performance; to identify the critical problems and the associated effects and financial implications; and to find out the cost intensity of construction processes. The specific objectives of the study were:

- To determine the conformance level of the construction industry infrastructure (from i.e. economic, i.e. strategic, i.e. cultural, i.e. organizational aspects) for the Lean Six Sigma implementation;
- To prioritize key improvement areas/processes where Lean Six Sigma projects can have the greatest monetary impact;
- To form an optimum framework for improvement;
- To identify problem areas for improvement that could be candidates for Lean Six Sigma implementation in construction;
- To determine the unique or shared elements and principles of Six Sigma and Lean Construction, Lean Six Sigma, appropriate for construction industry focusing on the obtained results of the case study.

To collect the required data for the above purposes, a questionnaire survey and interviews were conducted (Appendix). The detailed information related to questionnaire and interview is presented in the following sections.

8.2. QUESTIONNAIRE AND INTERVIEW METHODOLOGY

The questionnaire and interview included very comprehensive questions. The author aimed to obtain as much data as possible from the companies. This study does not aim to approach a general understanding of the Construction Industry through a questionnaire but examining the selected companies extensively through meetings, interviews and a questionnaire in order to draw a more accurate map for the companies with similar nature. For this purpose three construction firms were interviewed. One of these companies was selected as a pilot study for further research due to their organizational structure and management strategy open to innovation, and interest in this study.

The pilot company formed a team composed of staff from different departments except site personnel in order to answer the questions in a meeting organized by the top management. The president also attended all sessions of the meeting. Also individual meetings with the key personnel were held in order to discuss different aspects of the interview questions.

Interview results were examined to understand the characteristic features of the company's strategy, quality perception, financial situation, etc.; and to find the compatibility and incompatibility between the answers of different questions.

Finally, in the light of the answers given during the interviews and meetings; the general problems of the construction companies within the scope of this study were analyzed, compatibility of the organizational structure with Lean Six Sigma methodologies and possible implementation areas were detected and road maps for different levels of organizations for future implementations of the Lean Six Sigma methodology as a solution to the detected problems were offered.

8.2.1. INSTRUCTIONS FOR THE QUESTIONS

Interview questions were composed of three parts.

Part one was composed of 14 Questions. These questions were soliciting general information about the company such as:

- Name and age of the company
- Expert areas and associated employees
- Turnover and turnover control system
- Percentage of self-performed work
- Experience of respondent
- Quality system accreditation

Part two was composed of 28 questions. These questions were related to:

- Company and top management strategies
- Strategy deployment and control policy
- Company objectives and principles
- Quality perception of the company, including:
    - Quality goals
    - Quality improvement program (QIP)
    - QIP objectives
    - Management support to QIP
- Measurement systems
- Records
- Updated historical background

- Problem solving techniques
- Use of tools such as flowchart, process mapping
- Customer and employee satisfaction
- Motivation factors of top management, including:
    - Employee reward policy
    - Employee training
- Supplier relations of top management
- Self assessment method
- Critical factors for success and success rates for these critical factors
- Investments in recent years and their success rate
- Areas of improvement and improvement rate in the past five years

Part three was composed of 7 questions about the construction process life cycle to collect information related to:

- Time and budget extensions
- Additional expenses
- Time components of processes such as value/non value adding time, rework time, move time
- Variability and other critical problems in processes, their associated effects on money, quality, time, performance, productivity, and customer loss
- Quality cost components (prevention, appraisal, and failure costs) and their contribution to additional expense

Multiple choice questions had more than one option, and the respondent was encouraged to add his/her ideas in the additional space provided. For the questions which were required to be answered in 0-9 scale, values referred to as below:

"0" means "Not Applicable"
"1" means "very low"
"9" means "very high"

8.3. LIMITATIONS OF THE QUESTIONNAIRE AND THE INTERVIEW

The questionnaire was composed of very detailed and comprehensive questions which were required to be answered by experienced staff members.

The characteristic of construction industry mentioned in previous chapters and the factors indicated below were the main limitations of the conducted interviews:

- Due to the organizational structure of construction companies, in order to answer the questions; experience, information and knowledge of more than one individual were needed.
- The executed projects vary in type inhibiting the organizations in giving general answers to process related questions.
- They may not have available data in the specific area.

8.4. RESULTS OF THE QUESTIONNAIRE AND THE INTERVIEW

8.4.1. BACKGROUND INFORMATION ABOUT THE PILOT COMPANY

The author interviewed the pilot company through meetings organized by top management in the presence of key personnel from different departments and the president of the company. However there were no site personnel in the team. The average experience level of the respondent team which is also referred as the discussion group in this study was 11-20 years. Main features of the pilot company are given below:

- The company was a private organization and it had been working in the construction industry over 20 years. There were 50 to 500 technical and administrative personnel working in the firm. The company had 112 permanent and 10 temporary site personnel (technical personnel) and 196 permanent office personnel.
- Clients of the company were private companies, property developers, and government.
- Domestic and overseas annual turnover of the company was 42.228.449, 00-YTL, 691.821, 44-USD, respectively. The company did not have a system or tendering strategy to control the increase and decrease in their turnover.
- The quality system of the company was ISO 90001 and it does not have TQM.
- The company undertook infrastructure, industrial, building, housing, highway, and public works projects. This showed that the company had been working in a wide field and performing all kinds of construction works without considering the required knowledge to perform that corresponding projects. During the interview, the respondents explained that their firm had preferred being worked on the projects in which their staffs did not have any experience. They also added that although they floundered during these projects, they learned a lot for the future works and they accepted the risks coming with them.
- The company self-performed 50-75 % of their works instead of subcontracting. As they had the required resources because of the fact that they wanted to minimize the risks caused by sub-contracting they performed majority of their works without subcontractors.

8.4.2. STRATEGIC APPROACHES OF THE COMPANY

8.4.2.1. Main Strategy Components

The company strategy included vision, mission, company objectives, and customer satisfaction components at the highest weight (9). The other selected components were benefit (8) (added value by the company) and profit (7), respectively. The last ones were innovation and research and development according to given weights by the company. These results showed that this company had given full weight to vision, mission statement, customer satisfaction, and company objectives and principles rather than gaining profit.

Table 8.1 shows the strategy components of the company in ascending order of weight:

Table 8.1- Strategy components of company

Strategy Components	Weight(0-9)
Vision	9
Mission statement	9
Company objectives and principles	9
Customer satisfaction	9
Benefit (added value)	8
Profit	7
Innovation	6
Research and development	6

8.4.2.2. Strategy Deployment Actions

The company implemented their strategy by the actions such as in-house training, site coordination meetings, vertical integration meetings, and strategy deployment by setting individual targets. The effectiveness and management involvement to these actions are indicated in the Table 8.2 and bar chart, Figure 8.1:

Table 8.2- Strategy Deployment Actions

Action	Effectiveness (0-9)	Management Involvement (0-9)
No formal implementation		
In house training	5	8
Site coordination meetings	7	3
Involvement in Annual Board Meetings		
Involvement in Executive Committee Meetings		
Vertical integration meetings	2	8
Strategy deployment by setting individual targets	4	8

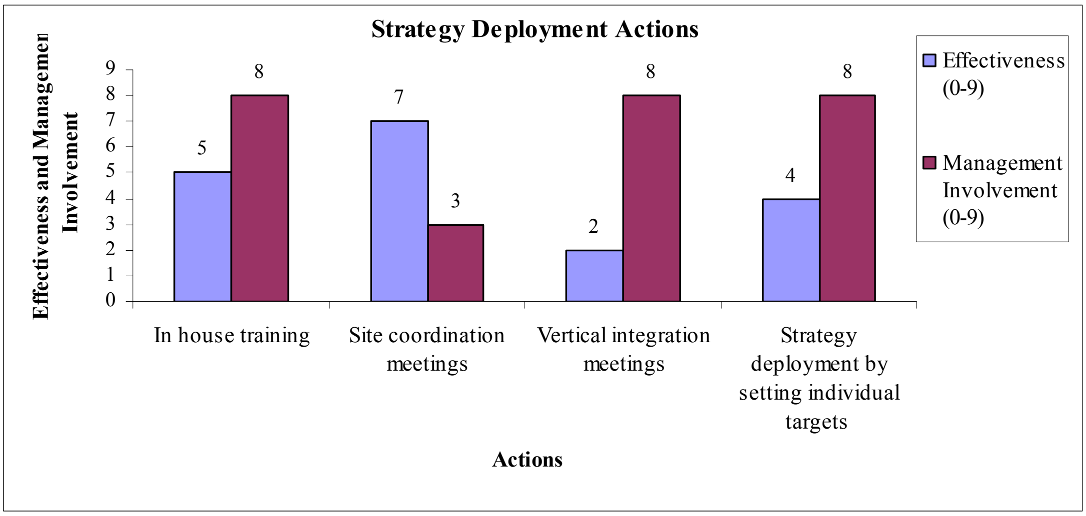


Figure 8.1- Strategy Deployment Actions

As it appears in both Table 8.2 and Figure 8.1, management involvement was high in all of the actions except site coordination meetings. The strategy deployment actions in descending order of effectiveness were site coordination meetings (7), in house training (5), strategy deployment by setting individual targets (4), and vertical integration meetings (2). On the basis of these results, it can be said that although management involvement was mostly high, strategy deployment to employees could not be done effectively except site coordination meeting.

8.4.2.3. Strategy Deployment Control

The control of how the company had deployed its strategy to employees was being made by progress meetings, process audits, and control meetings in descending order of effectiveness. The management involvement in the control actions was highest at the control meetings (9) and almost high at the process meetings (8) and process audits (8). According to these result; control was made properly to detect the problems related to strategy deployment. All the given values are also illustrated in the Table 8.3 and bar chart, Figure 8.2:

Table 8.3- Strategy Deployment Control Actions

Control Action	Effectiveness (0-9)	Management Involvement (0-9)
No control		
Control meetings	6	9
Progress meetings	7	8
Process audits	7	8
Performance evaluation		

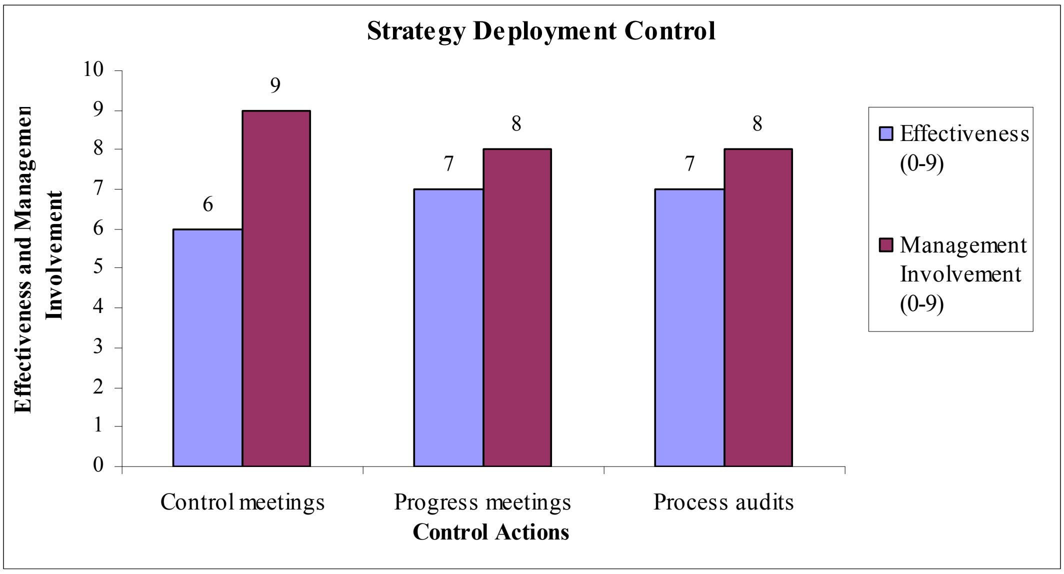


Figure 8.2- Strategy Deployment Control Actions

8.4.2.4. Company Objectives and Principles

Company objectives and principles, which were indicated by the company as one of their most important strategy components included process, specific problems, quality, and customer satisfaction at the same highest weight (9). The other components of company objectives and principles were new investments (7) and project cost savings (6) in descending order of importance. The results show that the company gave more importance to quality and customer satisfaction than project cost savings. The results are illustrated below, as Table 8.4:

Table 8.4- Components of The Company Objectives and Principles

Concepts	Weight (0-9)
Process	9
Specific problems	9
Quality	9
Customer satisfaction	9
New investments	7
Project cost savings	6
Vertical integration	0

8.4.2.5. Company Success Factors

The company agreed that the success of the company depended on quality, safety, duration, cost, and scope in descending order of importance. Quality was selected as the most important factor for the success of the company. The results are tabulated in the Table 8.5:

Table 8.5- Components of The Company Success Factors

Quality	Safety	Duration	Cost	Scope
5	4	3	2	1

8.4.3. QUALITY APPROACHES IN THE COMPANY

8.4.3.1. Quality Definition of The Company

The organization defined quality as both the elimination of defects and a competitive advantage with the highest importance(9), then as a customer satisfaction factor at a weight of 8, and finally as a tool to increase profit and formality at the weights of 5 and 1, respectively.

The organization set their quality goals internally by looking at the competition in general. The corresponding tables, Table 8.6 and Table 8.7 are given below:

Table 8.6- Quality Definition Concepts

Quality Definition concepts	**Weight (0-9)**
Elimination of defects	9
A competitive advantage	9
Customer satisfaction	8
A tool to increase profit	5
A formality	1

Table 8.7- Level of Quality Goals of The Company

Be the leading company in your sector	
To a level set internally	**X**
The competition in general	**X**
To increase profit range	

8.4.3.2. Quality Improvement Program in The Company

The company had a Quality Improvement Program (QIP) which covered the following objectives in descending order of importance in the following Table 8.8:

Table 8.8- The Objectives of Quality Improvement Program in The Company

Objective	Importance Weight (0-9)
Compliance with statutory	9
Customer satisfaction	9
Become a preferred bidder for	9
Increase quality	9
Decrease arbitration	9
Increase performance	8
Fulfill a strategic decision	7
Increase profit range by cost reduction	7
Fulfill a formality	5

As it is understood from the Table 8.8, compliance with statutory, customer satisfaction, become a preferred bidder for, increase quality and decrease arbitration were the main objectives of the QIP since these were given the highest importance weight of 9. Other objectives were increase performance (8), fulfill a strategic decision (7), increase profit range by cost reduction (7), and fulfill a formality (5) in descending order of importance weight.

8.4.3.3. Management Support for QIP

Top management support to QIP was high according to the answers of respondent team. The supportive activities in descending order of weight were conducting regular meetings (9); training (9), performance review meetings (9), research and development (9), and IT support (7). The effectiveness and management involvement weights of these supportive actions are given in the Table 8.9 and corresponding bar chart, Figure 8.3.

Table 8.9- Management Support Activities for QIP

Support Activity	Weight (0-9)	Effectiveness (0-9)	Management Involvement (0-9)
Conducting regular meetings	9	9	9
Training	9	6	7
Performance review meetings	9	6	9
Research and development	9	7	7
IT support	7	7	7

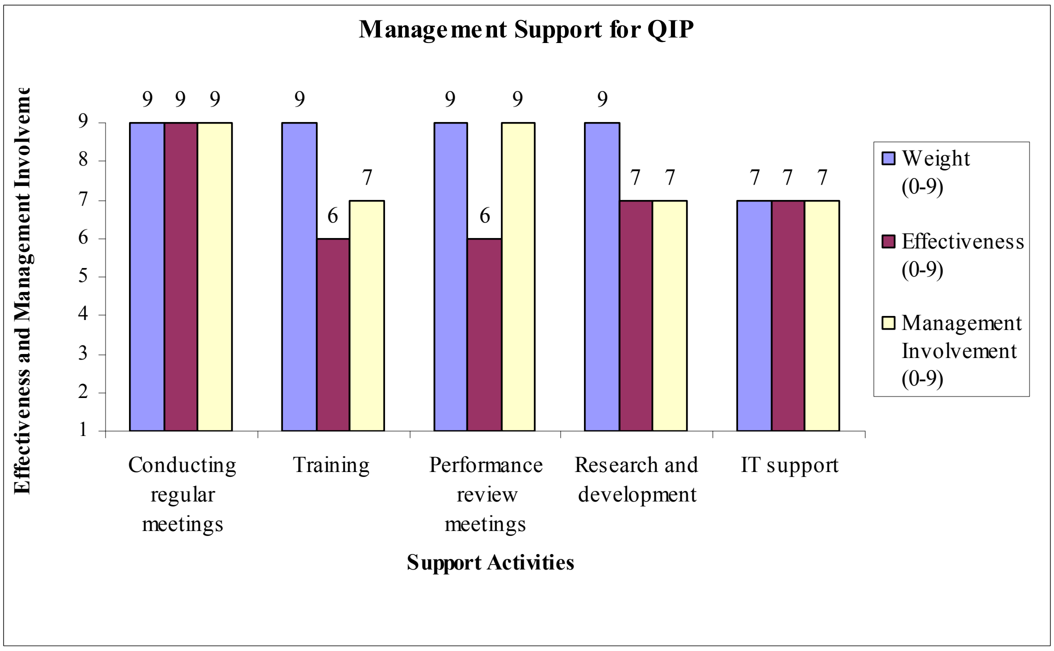


Figure 8.3- Management Support Activities for QIP

As seen in the Figure 8.3, management gave full support to QIP by conducting regular meetings, training, performance review meetings, research and development. They also supported IT for QIP at a lower importance level compared to other activities.

Although the given management support to the regular meetings, performance review meetings, training, and research and development was the same (9), the effectiveness of training and performance review meetings was the lowest (6) compared to other support activities.

Additionally, by looking at the management involvement rates of these support activities; it can be said that training, research and development, and IT had the lowest management involvement (6).

8.4.4. MEASUREMENT SYSTEMS IN THE COMPANY

The company had measurement systems to check and control variations (from planned to realized) and failures in cost, time, quality, customer satisfaction, employee complaints, material flow, supplier performance, subcontractor performance, company performance, and process flow. On the other hand, they did not have earned value, labor productivity, and wastage measurement system. The effectiveness of these indicated measurement systems are given on Table 8.10:

Table 8.10- Effectiveness of The Measurement System

Measurement System	**Effectiveness (0-9)**
Customer Satisfaction	9
Employee Complaints	9
Quality	8
Material Flow	8
Supplier performance	8
Subcontractor performance	8
Cost	7
Company performance	7
Process Flow	6
Time	5
Earned Value	
Labor Productivity	
Wastage	

As it is shown on the given Table 8.10, customer satisfaction and employee complaints measurement system worked most effectively but process flow and time measurement systems were least effectively working systems in the company.

8.4.4.1. Procedures after Measurement

After taking measures of the above given concepts, the company declared that they followed several steps with the collected results of these measurements mentioned in part 8.4.4. The tabulated form of these steps and their effectiveness are illustrated on the below Table 8.11:

Table 8.11- Applied Steps after Measurement

Steps	**Effectiveness (0-9)**
Review	7
Evaluate	7
Brainstorming	8
Analyze	7
Prepare action list	1
Application	6
Control	7
Standardize	

According to these answers, it is seen that the company reviewed and evaluated the results effectively; and then made brainstorming and analysis. After the analysis, they prepared action list to apply the situation discovered as a result of measurement. Finally they controlled the application for the effectiveness.

However they did not standardize these applied steps for the future usage in case of encountering the same situation or for developing their missing parts. The results also show that there was a big problem on the action list preparation step since the effectiveness of this step was very low (1) compared to effectiveness of others. Another less effective step was application of prepared action list which means that there was also a problem on this step.

8.4.5. RECORDS IN THE COMPANY

The company took the records of their procurement, inventory, material storage, work in progress and labor performance daily. On the other hand, equipment condition records were taken semi annually. The frequency of record taking and the steps applied after taking records are given on the following Table 8.12 and Table 8.13, respectively:

Table 8.12- Frequency of Records

Records	**Frequency**				
	Daily	Weekly	Monthly	Semi Annually	Annually
Procurement Records	**X**				
Inventories Records	**X**				
Material Storage Records	**X**				
Labor Performance Records	**X**				
Equipment Condition Records				**X**	
Work in Progress Records	**X**				

Table 8.13- Procedures with the Records

Steps	Effectiveness (0-9)
Review	7
Evaluate	6
Brainstorming	5
Analyze	6
Prepare action list	2
Application	2
Control	2
Standardize	

By looking at the effectiveness of the steps, it is clear that preparation action list, application, and control steps were not properly functioning and there was/were problem(s) on these steps. The company also did not standardize the results and experiences obtained from these records.

8.4.6. UPDATED HISTORICAL DATABASES OF THE COMPANY

The company had also updated historical databases of material unit prices, bidding experience, project performance, unit prices for work packages, subcontractor performance, activity production rates, and labor productivity rate. The effectiveness of these updated historical databases in descending order of weight is given as follows on Table 8.14:

Table 8.14- Effectiveness of Historical Databases

Item	Effectiveness (0-9)
Material unit prices	9
Bidding experience	9
Project performance	9
Unit prices for work packages	7
Subcontractor performance	7
Activity production rates	5
Labor productivity rate	5
Clients' (worked with you) strategies	

8.4.6.1. Purposes of Historical Databases

The main purpose of the historical databases for the company is to obtain new biddings. The other purposes are given in descending order of weight in the following table 8.15:

Table 8.15- Purpose of Historical Databases

Purpose	Weight (0-9)
To obtain new biddings	9
To make more accurate planning	8
To make more accurate cost estimating	8
For new investment decisions	7
To avoid risks	7
To develop new strategy	6

8.4.7. PROBLEM SOLVING TECHNIQUES OF THE COMPANY

The organization generally solved their problems related to their processes by assigning individuals to solve problems and setting up a multi disciplinary team for each problem. The effectiveness of assigning individuals (9) was slightly higher than the effectiveness of setting up a multi disciplinary team (8). The results are tabulated on the Table 8.16:

Table 8.16- The Effectiveness of Problem Solving Techniques of The Company

Action	Effectiveness (0-9)
Assign individuals to solve the problem	9
Set up a multi disciplinary team for each problem	8
A permanent project team is available	
Gathering data and making statistical analysis	

After solving their problems in their ongoing processes, the company did not standardize the solutions to apply for the future projects and other business areas.

8.4.8. FLOWCHART AND PROCESS MAPPING TOOLS IN THE COMPANY

The company used flowcharts, which showed process inputs, outputs, unit of activities, actions, and decision points, and process mapping, which includes sequence of events, information about who was doing what and with whom, and decisions that were made, in of their processes.

The respondents also agreed that since flowcharts represented the entire projects from start to finish; this opportunity allowed highly detailed observation and analysis of the workflow. They also preferred process mapping to make work in progress visible and allow controlling work in progress.

However the company did not have a proper system to apply flowcharts and process mapping tools in all processes.

8.4.9. CUSTOMER SATISFACTION MEASUREMENT

8.4.9.1. Customer Satisfaction Measurement Actions

The company measured their customer satisfaction by face to face interviews, looking at the number of complaints coming from the customers, and follow up reports. The respondents all agreed that these actions were performed effectively and there were no problems in getting customer satisfaction rate. The corresponding Table 8.17 is as follows:

Table 8.17- Customer Satisfaction Measurement Actions

Action	Effectiveness (0-9)
Questionnaire survey	
Face to face interview	9
By the number of complaints	9
Follow up reports	9

On the other hand; the company did not have a system for gathering customer expectations and did not perform any actions to collect customer expectation.

8.4.9.2. Customer Satisfaction Concepts

The company declared that they satisfied their customers on almost all concepts shown on the following Table 8.18:

Table 8.18- Customer Satisfaction Concepts

Concepts related to customer satisfaction	Satisfaction Rates (0-9)
Knowledge of customer requirements	9
Attention to customer priorities	9
Relations with customer	9
Legal issues	9
Timely completion of project	9
Adequacy of processing change orders	9
Adequacy of project quality	9
Adequacy of warranty	9
Adequacy of maintenance	9
Arbitration	8
Adequacy of project control	8
Adequacy of project planning	8
Project cost within the budget	8

In the light of the given answers related to the customer satisfaction and expectation, it is seen that although the company did not have a system to question customer expectation, satisfaction rates of the customer given for the above concepts were quite high. The respondents claimed that their company knew what their customers wanted and satisfied them in the proper sense.

8.4.10. MOTIVATION FACTORS FOR EMPLOYEES

Communication skills, equal opportunities, and involvement were selected as the frequently used motivation factors by the top management. Other motivation factors were target setting and appraisal, empowerment, and leadership in descending order of weight. Career development and recognition and reward were not used as a motivation factor. The results are tabulated on below Table 8.19:

Table 8.19- Motivation Factors used by Top Management

Motivation Factors	**Weight (0-9)**
Communication	9
Equal opportunities	8
Involvement	8
Target setting and appraisal	7
Empowerment	6
Leadership	5
Career development	0
Recognition and reward	0

8.4.10.1. Provision for Employees and Its Effects

Top management of the company sometimes rewarded all employees with salary increases and premium for their conformity to strategic target and performing their tasks safely, timely, and within the budget. However employees were not promoted as an incentive. The below Table 8.20 shows these answers:

Table 8.20- Frequency of Provision for Employees

Incentives	Always	Often	Sometimes	Rarely	No
Salary increase			**X**		
Project bonus			**X**		
Promotion					**X**

According to the respondents, the effect of these incentives was increasing performance and productivity moderately but they did not influence increasing quality and customer satisfaction as shown in Table 8.21:

Table 8.21- The Effect of Provision for The Company

Criteria	Effectiveness (0-9)
Higher performance	6
Higher productivity	5
Higher quality	0
Higher Customer satisfaction	0

8.4.10.2. Training Opportunities for Employees

Top management also provided their employees essential training opportunities such as ISO 9000, process management, labor law, environmental management system, and accounting economics to match their competencies with the company. These training sessions were provided when top management thought that it was necessary depending on the demand from employees and project requirements. The frequency and list of the given training opportunities in the company are given in the following Table 8.22 and Table 8.23:

Table 8.22- Frequency of Training Opportunities

Frequency	
Semi annually	
Annually	
When necessary	**X**

Table 8.23- List of Training Opportunities

Training List	
Process management	**X**
ISO 9000	**X**
TQM	
Six Sigma	
Lean Construction	
Graphical and statistical analysis	
Total productivity maintenance	
Labor law	**X**
Quality circles	
Quality improvement team methodology	
Environmental management system	**X**
Suggestion system	
Problem solving techniques	
Management improvement program	
Benchmarking	
Accounting economics	**X**

8.4.11. EMPLOYEE SATISFACTION MEASUREMENT

Employee satisfaction was measured by face to face interviews and the number of complaints with weight of 9 and 6, respectively. Whereas the effectiveness of face to face interview (7) is quite high, the effectiveness of measuring by the number of complaints (6) is medium as illustrated in Table 8.24 and Figure 8.4:

Table 8.24- Employee Satisfaction Measurement Actions

Action	Weight (0-9)	Effectiveness (0-9)
Not measured		
Questionnaire survey		
Face to face interview	9	7
By the number of complaints	6	6

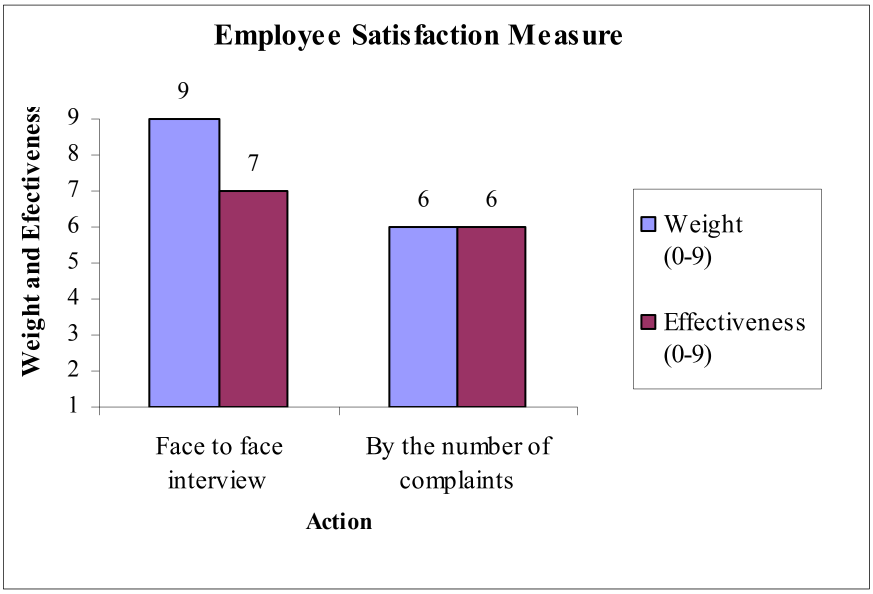


Figure 8.4- Employee Satisfaction Measurement Actions

8.4.11.1. Employee Satisfaction Concepts

According to employee satisfaction measurement results of the company, employees were satisfied mostly with legal issues and adequacy of safety precautions. The satisfaction rates for the relations and communications with employee and adequacy of labor shift planning were slightly lower than the previous ones. All the results are illustrated in the given Table 8.25:

Table 8.25- Employee Satisfaction Concepts

Concepts related to employee satisfaction	Satisfaction Rate (0-9)
Legal issues	9
Adequacy of safety precautions	9
Relations and communication with employee	8
Adequacy of labor shift planning	8
Adequacy of motivation	7
Adequacy of leadership facilities	7
Adequacy of salary	7
Adequacy of training	7
Adequacy of reward	0
Adequacy of suggestion system	0
Knowledge of employee requirements	
Adequacy of promotion	

By looking at the Table 8.25, it is seen that employee satisfaction with adequacy of reward, suggestion system, promotion, and company knowledge of employee requirements were selected as inapplicable concepts for the answer of this question by the respondents.

8.4.12. SUPPLIER RELATIONS OF THE TOP MANAGEMENT

Top management always played an active role to develop good relations with supplier by visiting domestic supplier, making meetings to determine supplier requirements and to plan improvement activities, and developing common problem solving techniques for supplier at the effectiveness rate of 8. The other supportive actions and their effectiveness rates are in the
Table 8.26:

Table 8.26- The Effectiveness of Supportive Actions for Good Supplier Relations

Supportive actions for good supplier relations	Effectiveness (0-9)
Visit to domestic supplier	8
Meetings to determine supplier requirements	8
Meetings to plan improvement activities	8
Common problem solving techniques	8
Visits to supplier abroad	7
Financial support	7
Systems/Process auditing	6
Supplier days	
Development of supplier	
Sector meetings	

8.4.13. SELF ASSESSMENT OF THE COMPANY

As it is illustrated on the Table 8.27, the self assessment was not always performed in the company. It was made by conducting workshops semiannually, and by conducting interviews when it was found necessary by the top management.

Table 8.27- The Frequency of Self Assessment Methods

Self-assessment methods	Weekly	Monthly	Semi Annually	Annually	When Necessary
Questionnaire survey					
Checklist					
Workshop			X		
Interview					X

8.4.14. CRITICAL FACTORS FOR THE COMPANY SUCCESS

The given weights of the importance and evaluation of the company success for the critical factors occurred in the defined sections related to the company success are tabulated on the following Table 8.28:

Table 8.28- The Critical Factors related to The Company Success

Sections	Critical factors related to company success	Importance (0-9)	Company Success (0-9)
ADMINISTRATIVE	Relationship between company departments	9	7
	Adequacy of office personnel	9	7
	Project cost within the budget	9	6
	Knowledge of customer needs	9	8
	Customer satisfaction	9	9
	Adequacy of supervision	9	7
	Coordination with regularity agencies	9	9
	Adequacy of planning	9	5
	Adequacy of training	9	6
	Attention to customer priorities	7	9
	Relations with other organizations	7	8

Table 8.28- The Critical Factors related to Company Success (continued)

Sections	Critical factors related to company success	Importance (0-9)	Company Success (0-9)
ENGINEERING AND PROJECT MANAGEMENT	Progress review meetings	9	7
	Adequacy of project control	9	7
	Adequacy of safety program	9	7
	Interaction with architect/engineer	9	5
	Scheduling	9	6
	Adequacy of supervision	9	9
	Shop drawing review	9	7
	Adequacy of planning	9	6
	Adequacy of subcontractor selection	9	7
	Estimating	7	6
LOGISTICAL	Adequacy of storage	9	8
	Adequacy of warehousing	9	8
	Adequacy of delivery	9	8
	Adequacy of maintenance	9	8
	Adequacy of transportation	9	8
CONSTRUCTION	Project quality	9	8
	Adequacy of job site personnel	9	6
	Material quality	9	8
	Quality of workmanship	9	8
	Timely completion of project phases	9	7
	Knowledge of the project	9	6
	Adequacy of processing change orders	9	8
	Project closeout	9	8
	Equipment quality	8	7
	Site cleanliness	8	8

When these critical factors related to the company success were examined separately, the following figures, 8.5, 8.6, 8.7, 8.8 were obtained:

In administrative section, almost all of the factors were selected as important for the company success. The achieved company success rate in customer satisfaction, attention to customer priorities, and coordination with regularity agencies was the highest. The other success rates of the company for the given factors in descending order were knowledge of customer needs (8), relations with other organizations (8), relationship between the company departments (7), adequacy of office personnel (7), adequacy of supervision (7), adequacy of training (6), project cost within the budget (6), and adequacy of planning (5).

As it is seen from the Figure 8.5, although both adequacy of planning and training had the highest important rate for the success, they had the lowest success rate according to evaluation of respondents.

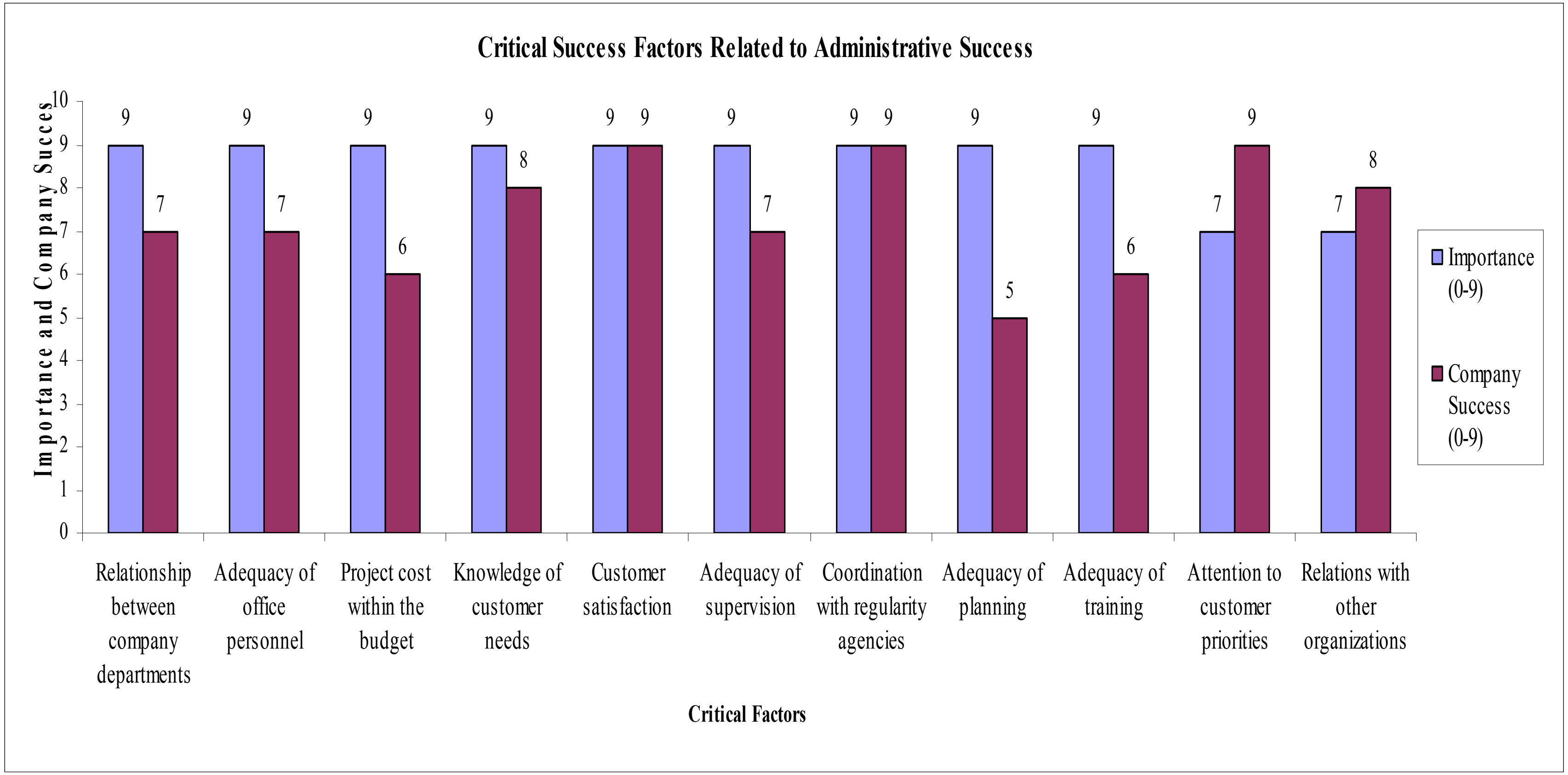


Figure 8.5- Critical Success Factors related to Administrative Success

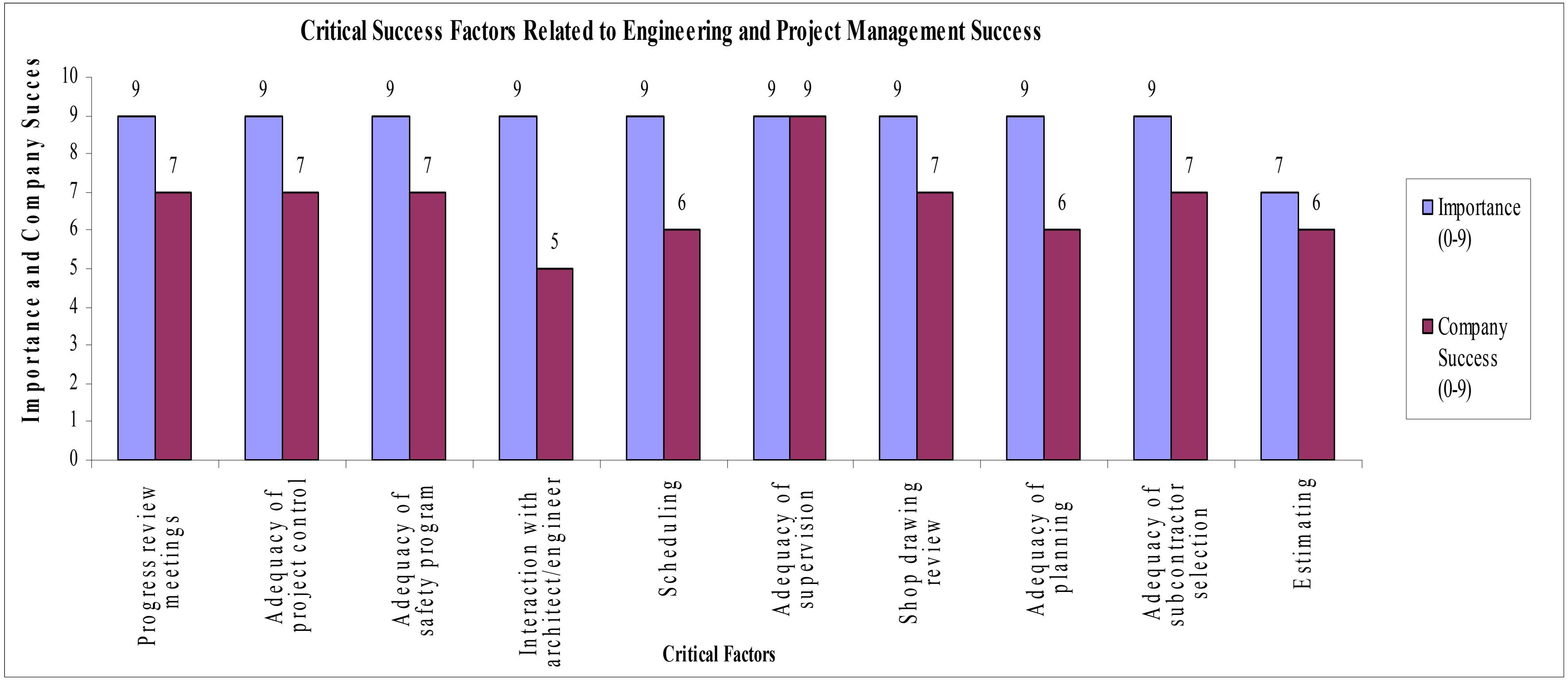


Figure 8.6- Critical Success Factors related to Engineering and Project Management Success

As it is seen from the Figure 8.6, in the engineering and project management section, all critical success factors had the highest importance rate (9) except estimating (7). The success rate of the company was highest only for the adequacy of supervision factor (9). The other success rates for the remaining factors were 7 and 6. The lowest success rate was achieved for the interaction with architect/ engineer although this factor had highest importance.

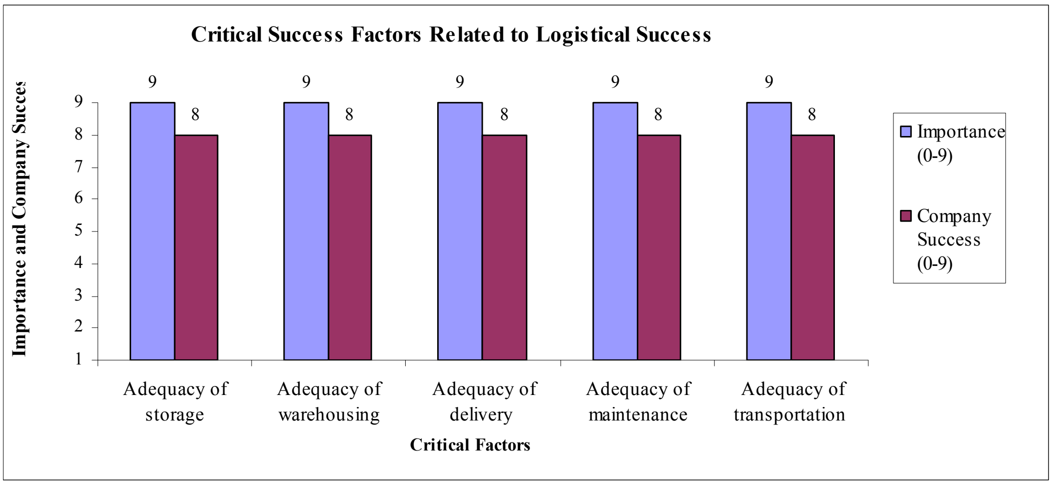


Figure 8.7- Critical Success Factors related to Logistical Success

In the logistical part, all of the factors were having the same highest importance rate (9) and success rate (8); indicating that there seemed no problem in this section. The Figure 8.7 shows these results.

In construction section, all the factors had the importance rate of 9 or 8. These results imply that all of them were important factors for the success of the company. However, the success rate was not so high (6) for the adequacy of job site personnel and knowledge of project. Other critical factors were achieved in the success rate of 8 or 7 which seemed there was not a big problem during construction in the company. All results are illustrated in the Table 8.8 as below:

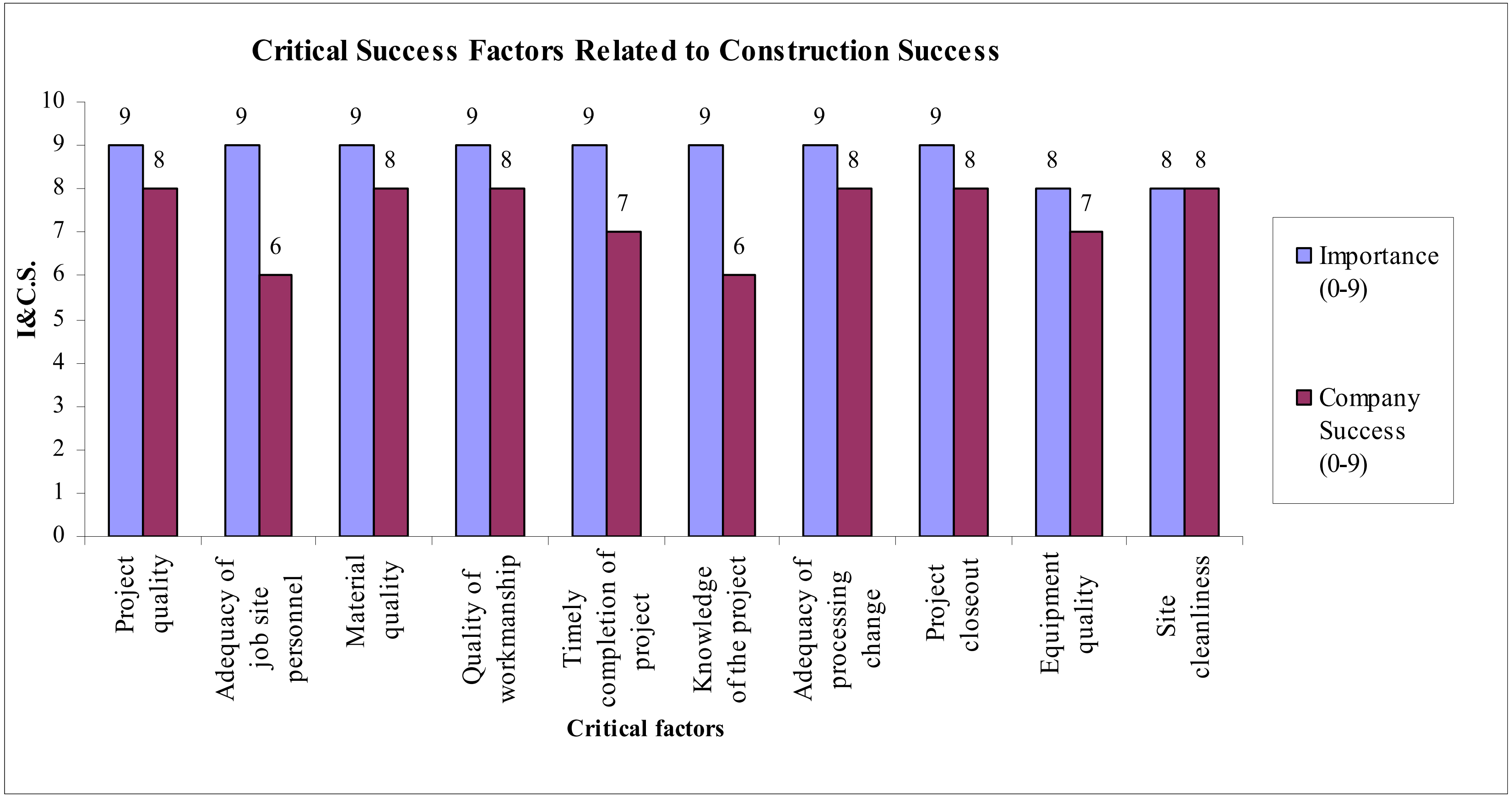


Figure 8.8- Critical Success Factors related to Construction Success

8. 4.15. LAST FIVE YEARS' ACTION LIST

The monetary weight and success rate of the action list which top management had done in the past five years that was successful in improving company performance are shown in the following Table 8.29 and Figure 8.9:

Table 8.29- Last Five Years' Action List for Success

Action List	Monetary Weight (0-9)	Success Rate (0-9)
Investment in R&D	9	8
Machinery investment	8	7
Recruiting new experienced and skilled staff	8	7
Increasing salaries	8	7
Investment in IT	7	7
Increasing motivation activities	7	7
Increasing safety precautions on site	7	6
Training	3	7
Investment in human resources		

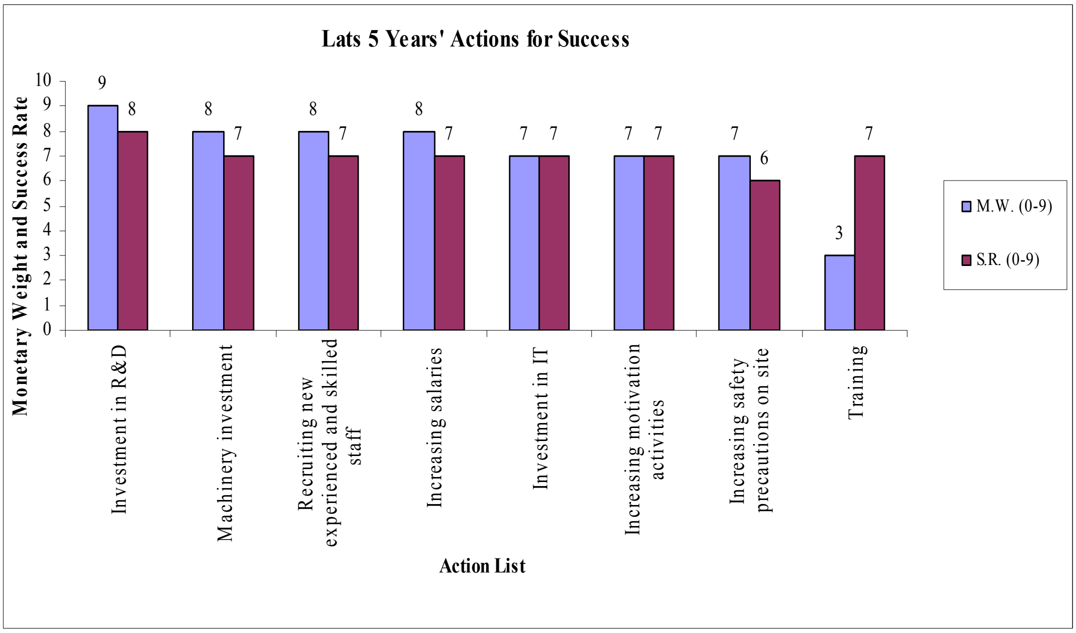


Figure 8.9- Last Five Years' Action List for Success

As it is seen in the Table 8.29 and Figure 8.9, the highest monetary value belong to investment in research and development; then machinery investment, recurring new experienced and skilled staff, and increasing salaries. Success rate in the past five years for these actions were given as 8 for the investment in research and development and as 7 for the others. Although the lowest money was spent to training, the high success rate was also given for this action. These results show that almost all the monetary actions completed in the past five years had achieved considerable success.

8.4.16. IMPROVEMENT AREAS FOR THE COPMANY

Importance weights of the given improvement areas tabulated below, evaluation of improvement potential for these areas, and improvement weight on the given areas in the past five years were obtained for this company.

The importance weights showed which of the given important areas had the highest importance for the purposed company success. On the other hand, the improvement potential rates indicated the ability of the company to cover the problems encountered in these areas. Lastly, the improvement weights gave the last five years' improvement rates in the improvement areas of the company.

By comparing these three rates given by the organization, it was aimed to detect:

- What were the most important improvement areas?
- In which of these most important improvement areas the company had the highest improvement potential?
- What were the improvement rates of these important areas in the last five years?

These improvement areas were sorted according to descending order of improvement potential in the Table 8.30:

Table 8.30- Improvement Areas for The Company

Improvement Areas	Importance Weight (0-9)	Improvement Potential (0-9)	Improvement Weight (0-9)
Increase customer satisfaction	9	9	9
Reduction of warranty claims	9	9	9
More accurate testing procedures at job sites	7	9	9
Reduction of law suit	9	9	8
Improve quality management	9	8	8
Improve cash flow	9	8	8
Good coordination with subcontractor and supplier	9	8	8
More accurate on site supervision	8	8	8
Decrease arbitration	9	8	7
Increase on site safety	9	8	7
Improve personnel management	9	7	7
More accurate planning	9	7	7
Improve productivity	9	7	7
Reduction of change orders	7	7	7
Improve design	6	8	6
Improve claim management	9	7	6
More accurate financial analysis	9	6	6
Higher profit	9	8	5
Decrease scrap and rework	9	8	5
Increase market share	5	8	5
More accurate cost estimating	9	7	5
More accurate cost control	9	7	5

According to the results in Table 8.30; the highest improvements were achieved on increasing customer satisfaction, reduction of warranty claims, and more accurate testing procedures at job sites. Whereas the degree of improvements was comparatively low on getting higher profit, decreasing scrap and rework, increasing market share, more accurate cost estimating, and more accurate cost control, the potential of the company to increase the improvement on the these areas was almost high. The following Figure 8.10 shows the results more tangible:

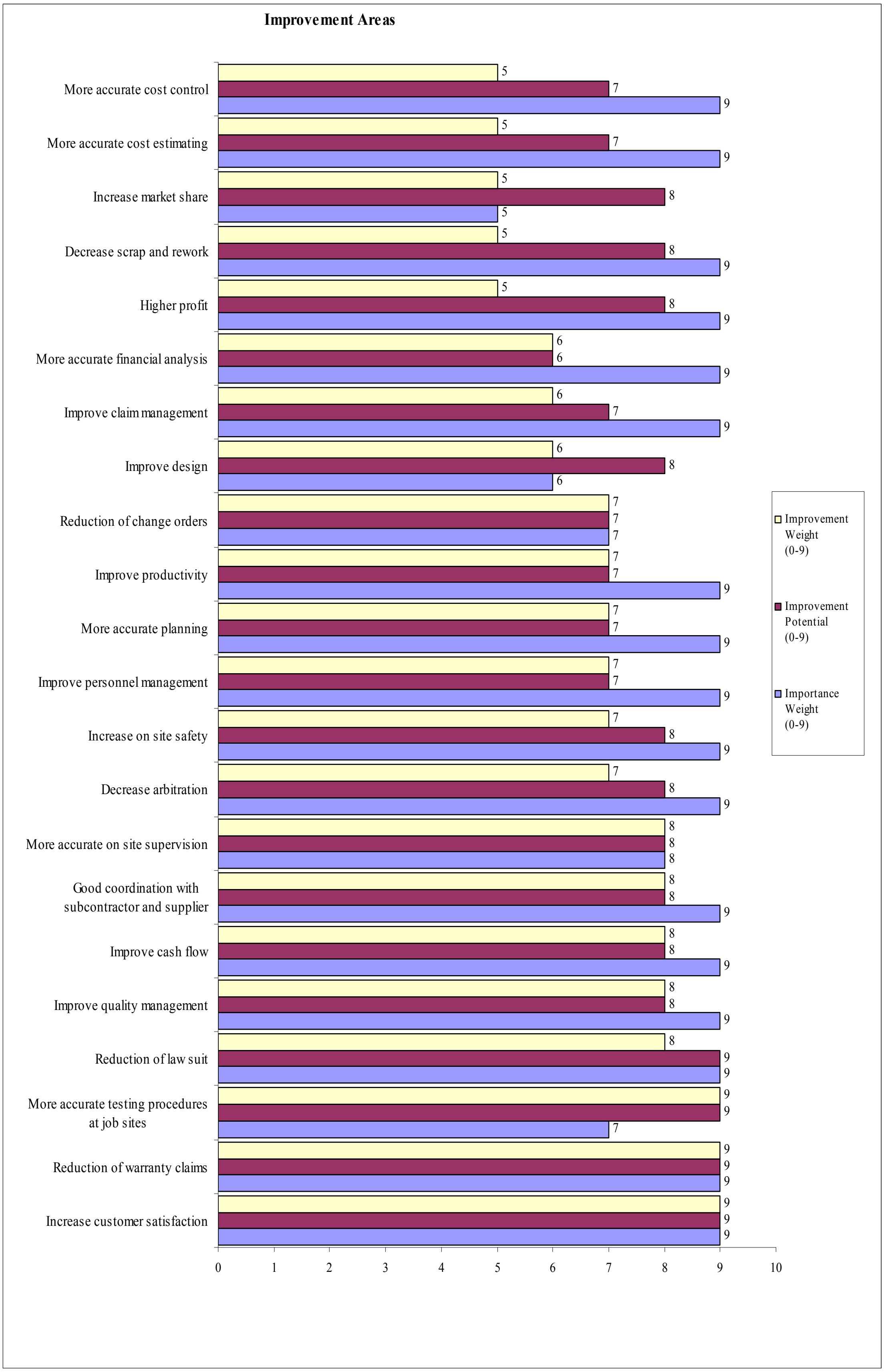


Figure 8.10- Improvement Areas for The Company

8.4.18. CONSTRUCTION COST COMPONENTS IN THE COMPANY

The following tables and graphs illustrate the occurrence rate of the prevention, appraisal, internal and external failure cost components encountered during the processes of the company.

8.4.18.1. Prevention Cost components

Field testing had the highest occurrence rate (8). Design reviews and planning and process study (7) were other prevention costs which mostly occurred during the processes, according to given Table 8.31 and Figure 8.11. Three prevention cost components having the lowest occurrence rates were training (3), education (2), and capability reviews (0). These results show that the company does not give sufficient importance to training and education as a prevention factor.

Table 8.31- Prevention Cost Components

Prevention Cost Components	**Weight (0-9)**
Field testing	8
Design reviews and Planning	7
Process study	7
Procedure writing	6
Market analysis	6
Supplier selection surveys and evaluation	5
Process improvement projects	5
Training	3
Education	2
Capability reviews	0

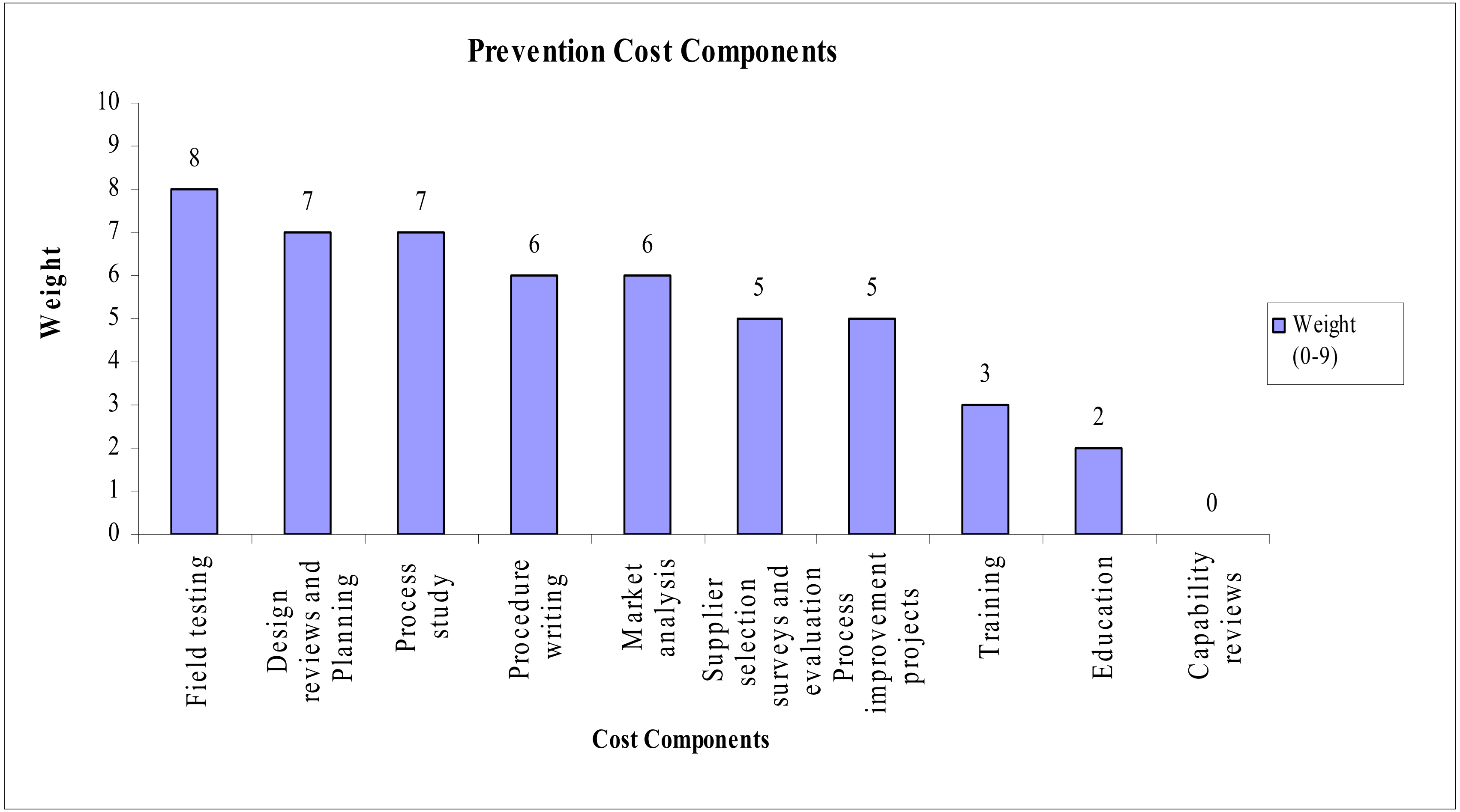


Figure 8.11- Prevention Cost Components

8.4.18.2. Appraisal Cost Components

By looking at the below Table 8.32 and Figure 8.12, it is clear that the company had almost all of the appraisal cost components at the highest occurrence weight (9-8) except personnel testing (6). It seems that the company gave the required importance to appraisal procedures.

Table 8.32- Appraisal Cost Components

Appraisal Cost Components	**Weight (0-9)**
Auditing products to determine whether they conform to requirements	9
Material reviews	9
Calibration of measuring	9
Equipment testing	9
Laboratory testing	9
Checks and grading to ensure specifications are met	8
Measuring	8
Evaluating	8
Inspections	8
Personnel testing	6

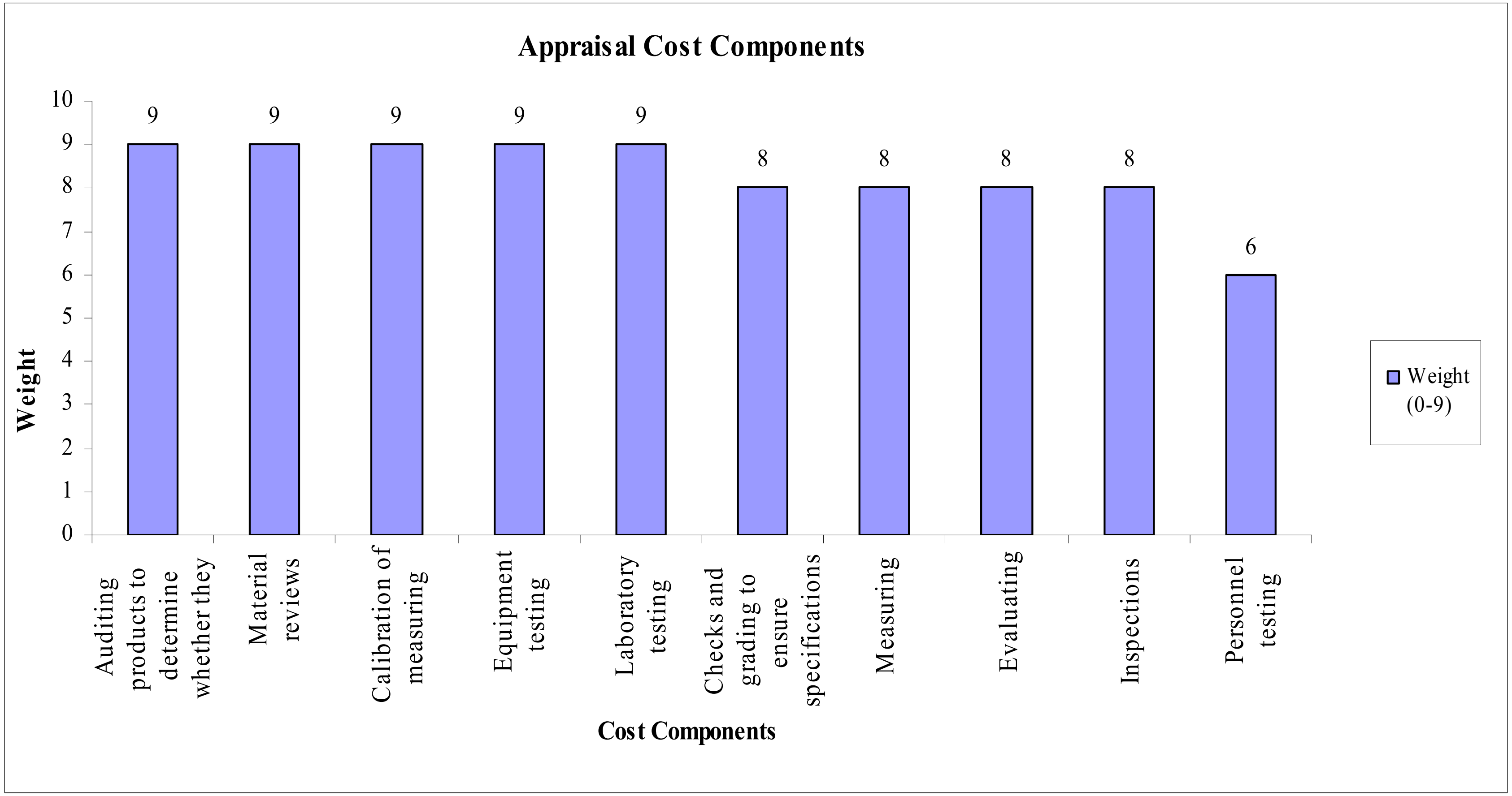


Figure 8.12- Appraisal Cost Components

8.4.18.3. Internal Failure Cost Components

Table 8.33 and Figure 8.13 show that mostly occurred internal failure cost components were overhead associated with production (8), failure reviews (8), and inaccurate planning (7). According to the given answers internal failure cost caused by engineering changes (2), compensation for delays (1), retesting (1), rework (1), and project complexity (0) had the lowest occurrence rate during the processes of the company.

Table 8.33- Internal Failure Cost Components

Internal Failure Cost Components	**Weight (0-9)**
Overhead associated with production	8
Failure reviews	8
Inaccurate planning	7
Repair cost	6
Redesign	5
Re-inspection	4
Inaccurate estimating	4
Scrap allowances	3
Engineering changes	2
Compensation for delays	1
Re-testing	1
Rework	1
Project complexity	0

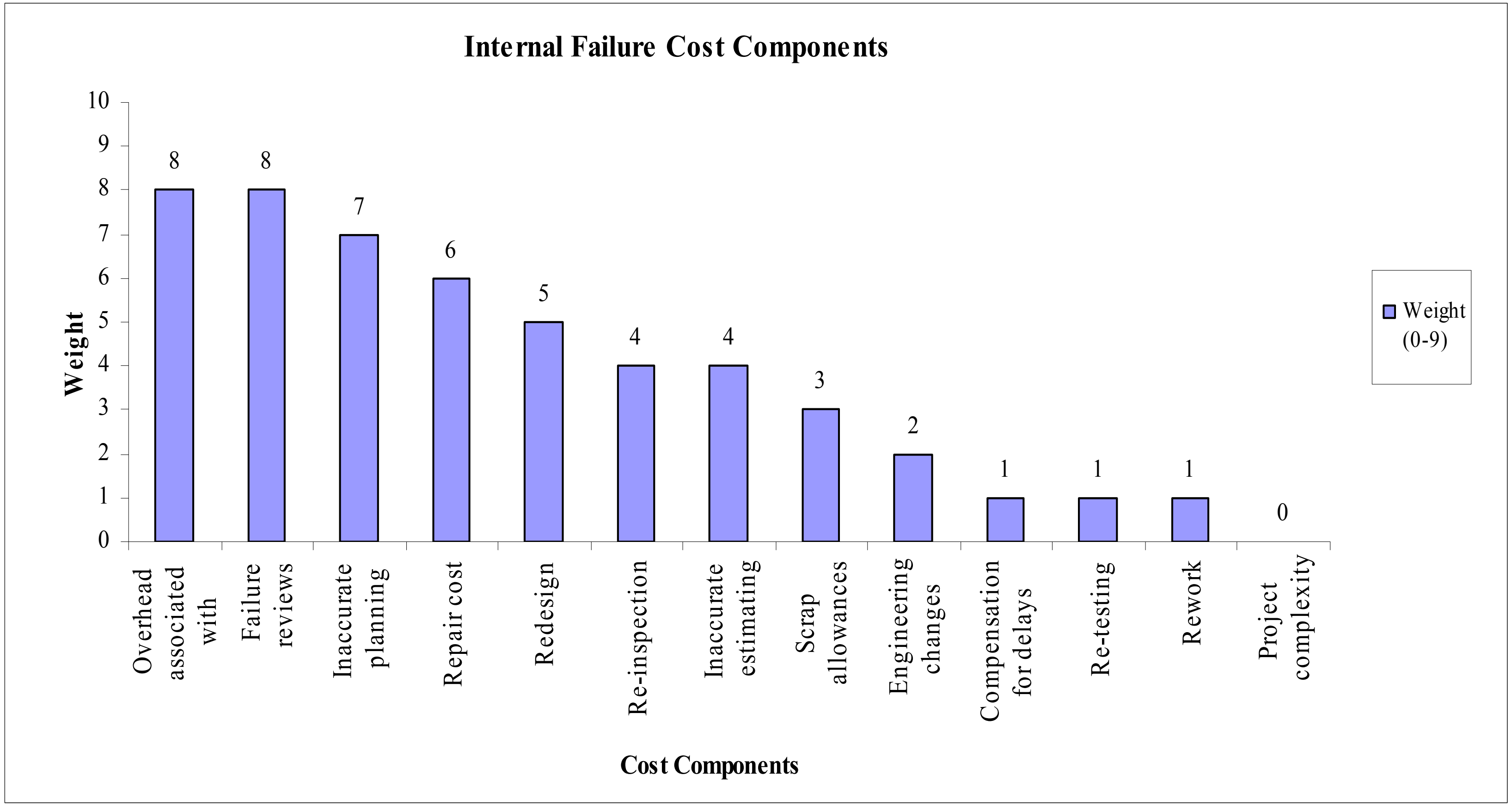


Figure 8.13- Internal Failure Cost Components

8.4.18.4. External Failure Cost Components

Excess inventory (6) and excess material handling (4) were the external cost components which had the highest occurrence rate compared to other external failure cost components. The occurrence of other external failure cost components was low. Warranty charges (1), penalties (1), product liability cost (0), and loss of future business through customer dissatisfaction (0) had the lowest occurrence rate. All results are illustrated on Table 8.34 and Figure 8.14.

Table 8.34- External Failure Cost Components

External Failure Cost Components	Weight (0-9)
Excess inventory	6
Excess material handling	4
Dealing with compensation	3
Excess travel expense	3
Handling of non-conforming products	2
Repair or replacement of non-conforming products	2
Pricing errors	2
Dealing with complaints	2
Equipment downtime	2
Warranty charges	1
Penalties	1
Product liability cost	0
Loss of future business through customer dissatisfaction	0

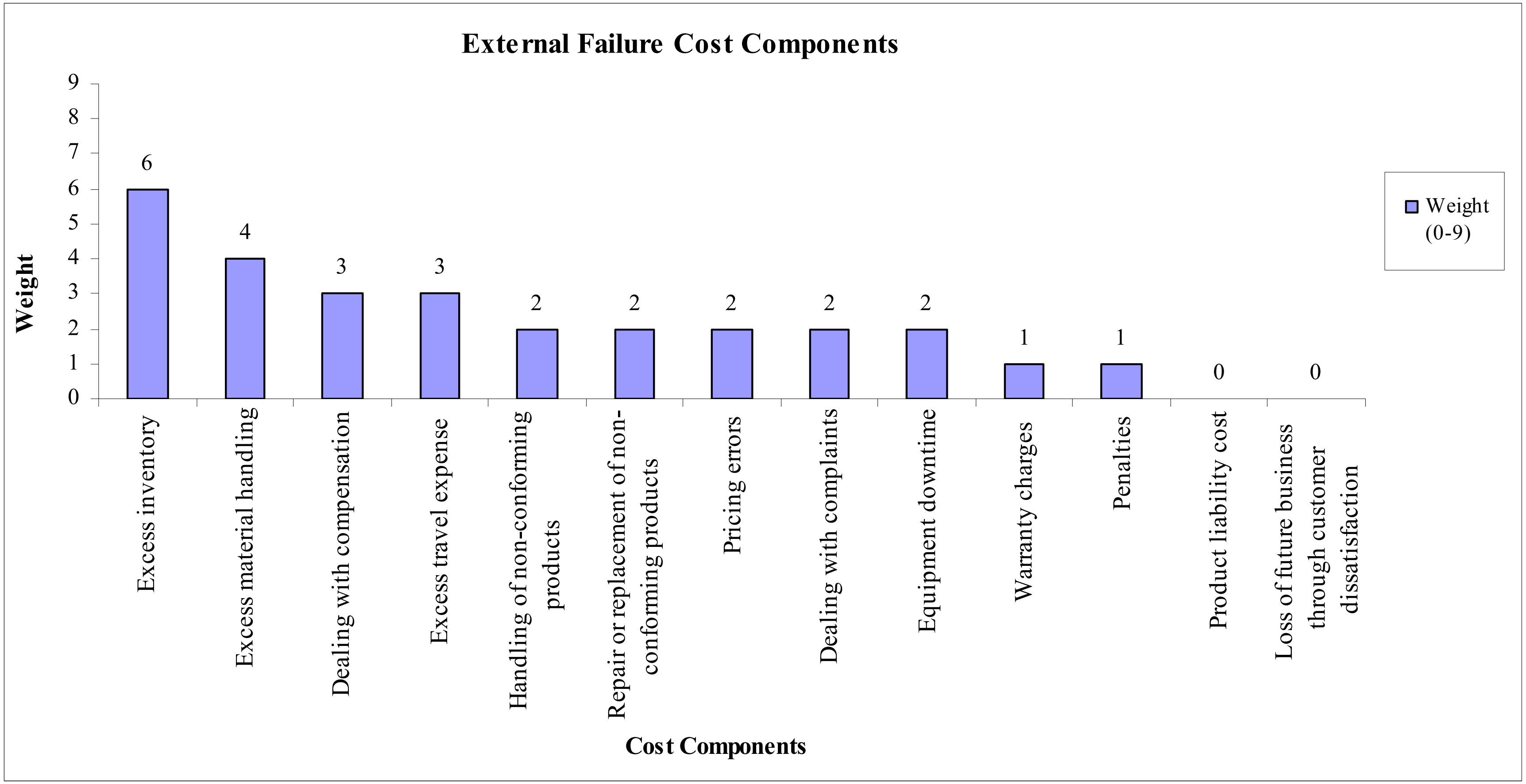


Figure 8.14- External Failure Cost Components

8.4.19. CRITICAL PROBLEMS IN THE COMPANY

The occurrence rates of the given critical problems under given general problem categories were obtained from the answers of the company respondents. These results were used to detect mostly occurred problems in the projects not in the specific processes. To discover the problems specific to processes, further data is needed to be collected by examining and measuring the corresponding processes regularly.

By means of the collected answers related to critical problem occurrence, the below tables and graphs are obtained:

8.4.19.1. Management Related Problems

Table 8.35 and Figure 8.15 show that the occurrence rates of ineffective utilization of resources (6), slow in processing and reviewing submittals, purchase orders and other paper works (5), poor communication between office and field (5), and poor provision of information to project participants (5) were the highest compared to other problems in the management related problems category. Ordering errors (2), resistance to change at management level (2), ineffective utilization of acquired knowledge and skills associated with previous projects (1), and variation in orders (1) had the least occurrence rates.

Table 8.35- Management related Problems

Management Related Problems	**Weight (0-9)**
Ineffective utilization of resources	6
Slow in processing and reviewing submittals, purchase orders and other paper works.	5
Poor communication between office and field	5
Poor prevision of information to project participants	5
Poor management who induces unnecessary changeability in construction conditions	4
Slow in making decisions and giving instructions	4
Lack of cost control and accounting	4
Limitations of management to foresee problems and develop effective countermeasures	3
Improper management methods	3
Ordering errors	2
Resistance to change at management level	2
Ineffective utilization of acquired knowledge and skills associated with previous projects	1
Variation in orders	1

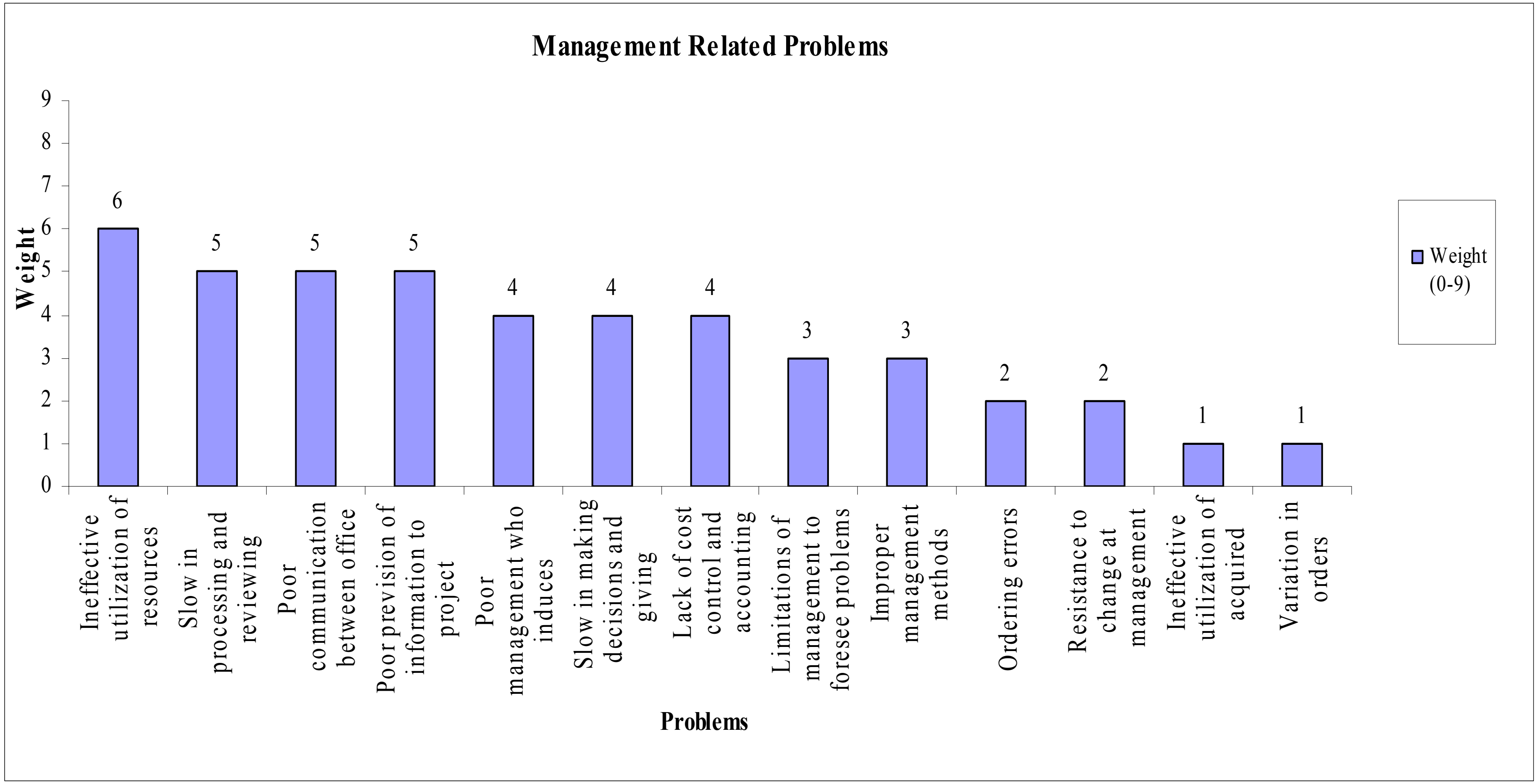


Figure 8.15- Management related Problems

8.4.19.2. Planning Related Problems

According the given results in Table 8.36 and Figure 8.16, lack of pre-task planning problem (8) was the most frequently occurred planning problem compared to other problems since they had 4 or 3 occurrence rates. So that pre task planning problem needed to be recovered in the first place, because the occurrence rate of lack of pre task planning was much higher than other problems in this category.

Table 8.36- Planning related Problems

Planning Related problems	Weight (0-9)
Lack of pre task planning	8
Lack of construction planning	4
Lack of job planning	4
Disturbances in personnel planning	3
Lack of procurement and delivery planning	3

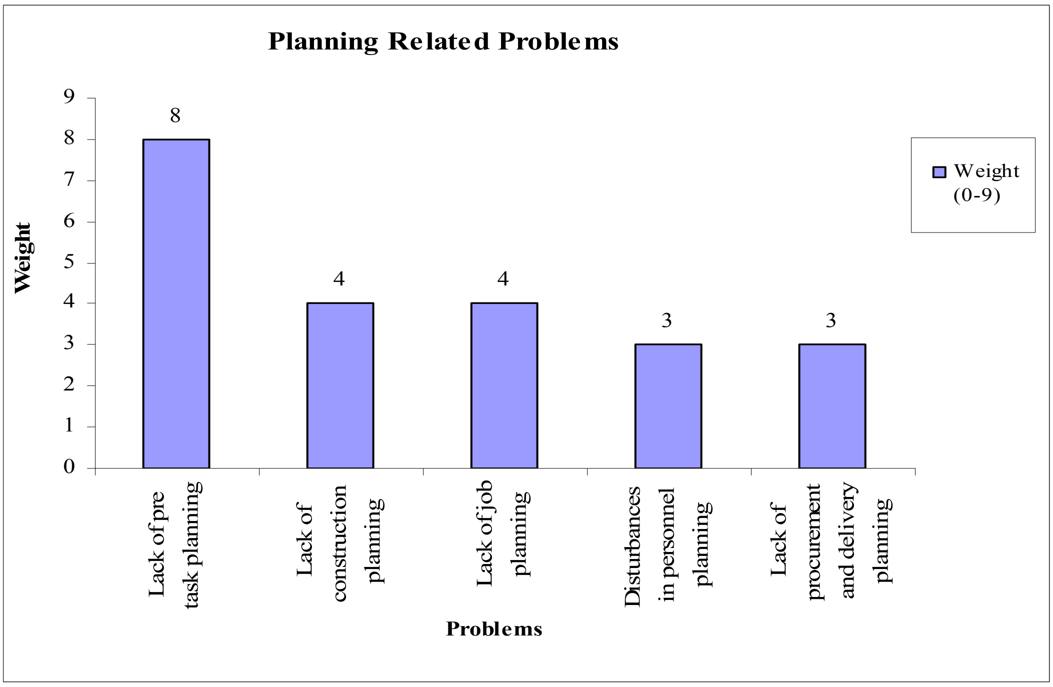


Figure 8.16- Planning related Problems

8.4.19.3. Design Related Problems

Since this is not a design company, the below problems were considered as the client or customer related problems. Frequent problems were design changes and revisions (5) and detail errors (5). Lack of coordination of design was the problem having the lowest occurrence rate, according to the given answers. All results are shown in Table 8.37 and Figure 8.17.

Table 8.37- Design related Problems

Design Related problems	Weight (0-9)
Design changes and revisions	5
Detail errors	5
Mistakes in design	3
Lack of coordination of design	0

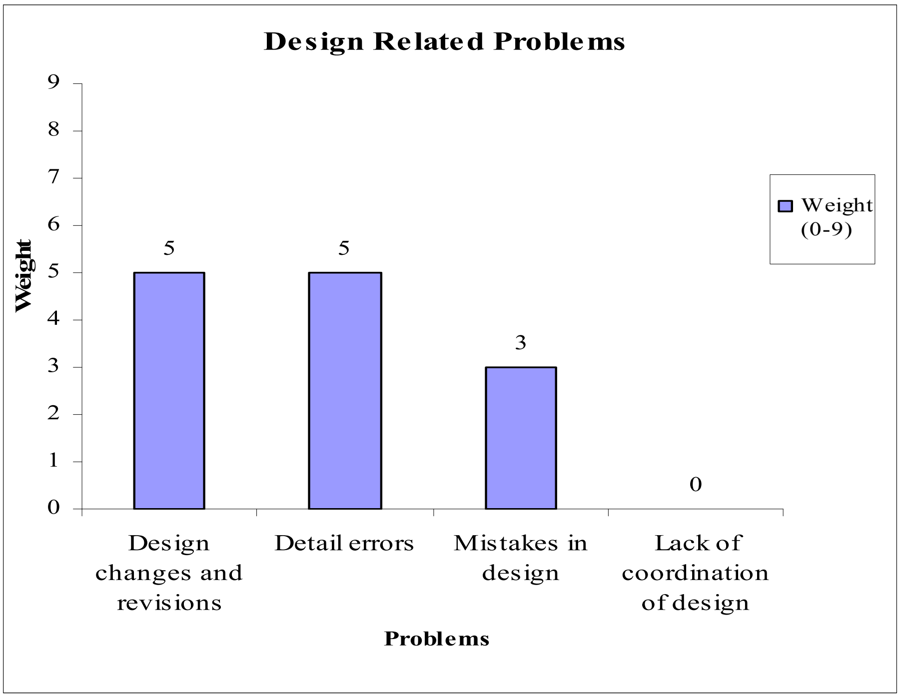


Figure 8.17- Design related Problems

8.4.19.4. Quality Related Problems

The company did not have a serious quality problem according to the answers in Table 8.38 and Figure 8.18. The respondents claimed that the quality of their work was their most important strength since they tried to produce best quality products by standing to lose time and money.

Table 8.38- Quality related Problems

Quality Related Problems	Weight (0-9)
Poor workmanship due to the lack of care and knowledge	2
Lack of supervision poor quality	2
Defective workmanship	1
Lack of quality control	1

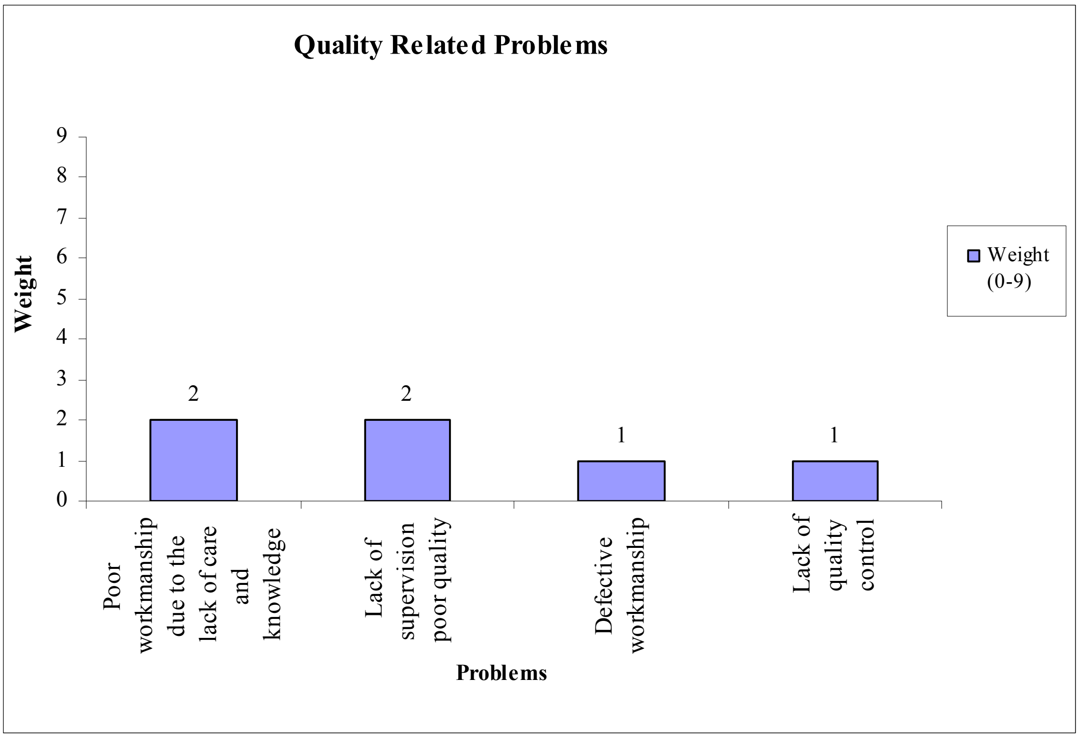


Figure 8.18- Quality related Problems

8.4.19.5. Documentation Related Problems

As shown in Table 8.39 and Figure 8.19, mostly frequent documentation related problems were unclear specifications (6), mistakes in specifications (5), slow drawing revisions and distribution (5). Poor quality site documentations (2) and inaccuracy of quality take off (2).

Table 8.39- Documentation related Problems

Documentation related problems	Weight (0-9)
Unclear specifications	6
Mistakes in specifications	5
Slow drawing revisions and distribution	5
Lack of required clarification	4
Omissions/errors in contract documentation	3
Unclear and missing site documentation	3
Unclear site drawings	3
Poor quality site documentation	2
Inaccuracy of quantity take off	2

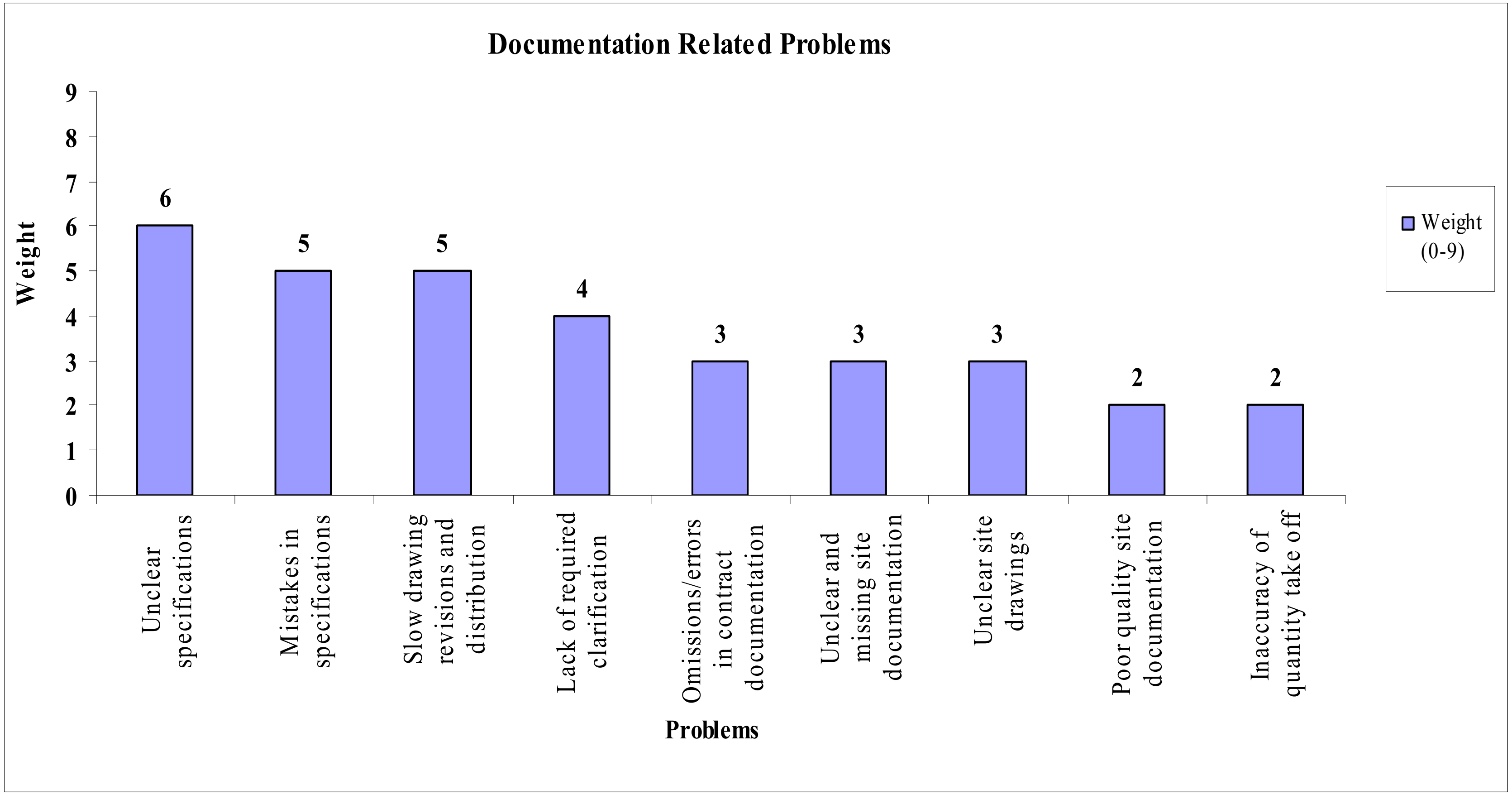


Figure 8.19- Documentation related Problems

8.4.19.6. Labor Related Problems

The frequency of labor related problems can be considered as relatively low. Most striking problem was labor errors due to the lack of attention to details. Least encountered problems were high labor turnover, labor strikes and absenteeism, and too much overtime of labor which all had the lowest occurrence rate (1).

Table 8.40- Labor related Problems

Labor related problems	**Weight (0-9)**
Labor errors due to the lack of attention to details	4
Lack of skilled and experienced labor	2
Improper crew utilization	2
Insufficient labor work separation	2
Poor labor productivity	2
Poor distribution of labor	2
Crew Interference	2
Unnecessary movement of workers	2
High labor turnover	1
Labor strikes and absenteeism	1
Too much overtime of labor	1

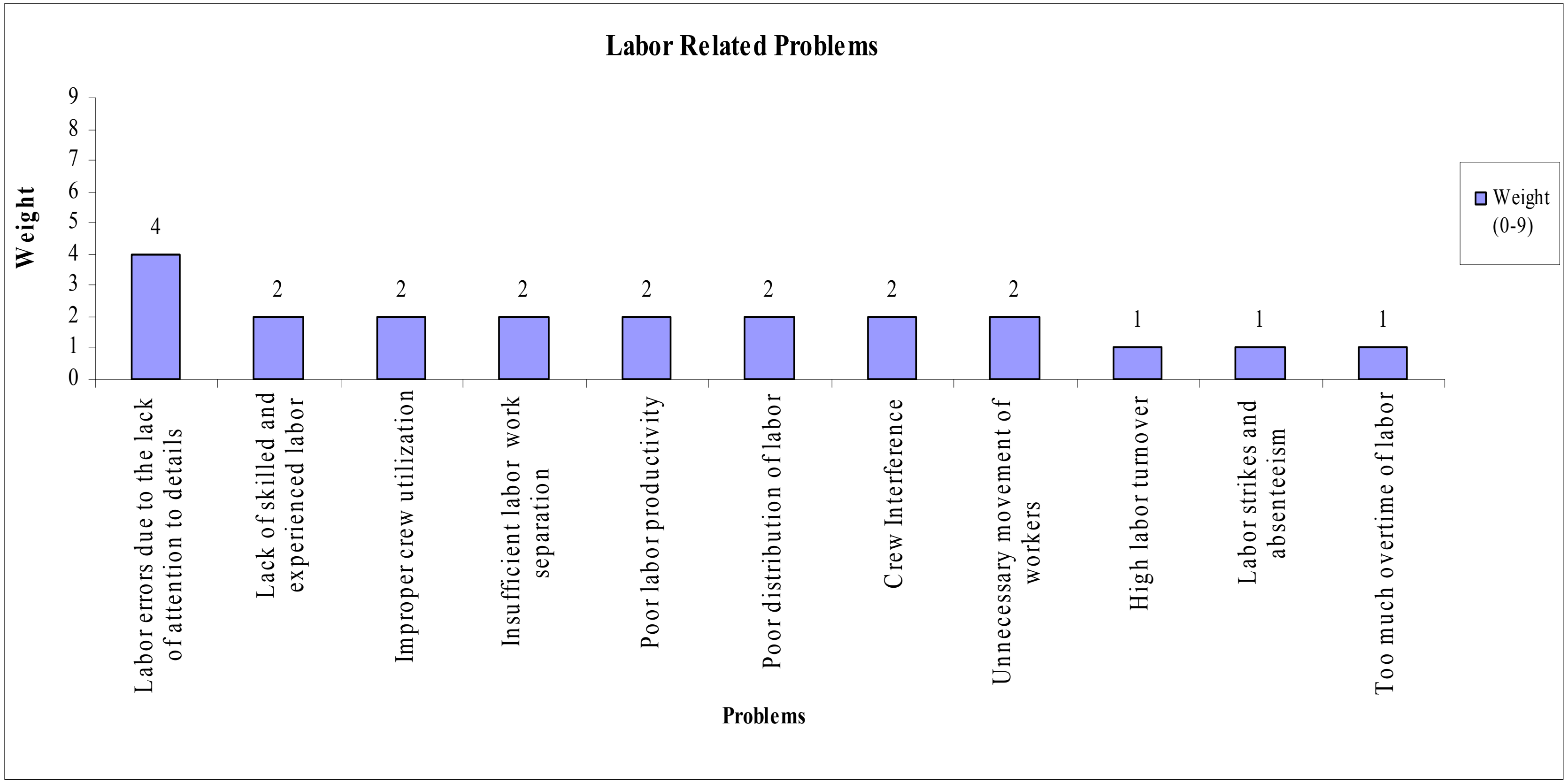


Figure 8.20- Labor related Problems

8.4.19.7. Material Related Problems

There were no serious problems related to material. However when the occurrence rates of all problems were compared, damaged material on site was the most important problem in this category.

Table 8.41- Material related Problems

Material related problems	Weight (0-9)
Damaged material on site	4
Late material fabrication and delivery	2
Loss of material on site	2
Inaccuracy of material estimate	2
Improper storage	1
Improper material handling on/off site	1
Poor material allocation	1
Improper material to specifications	1
Poor quality of material	1
Improper/misuse of material	1

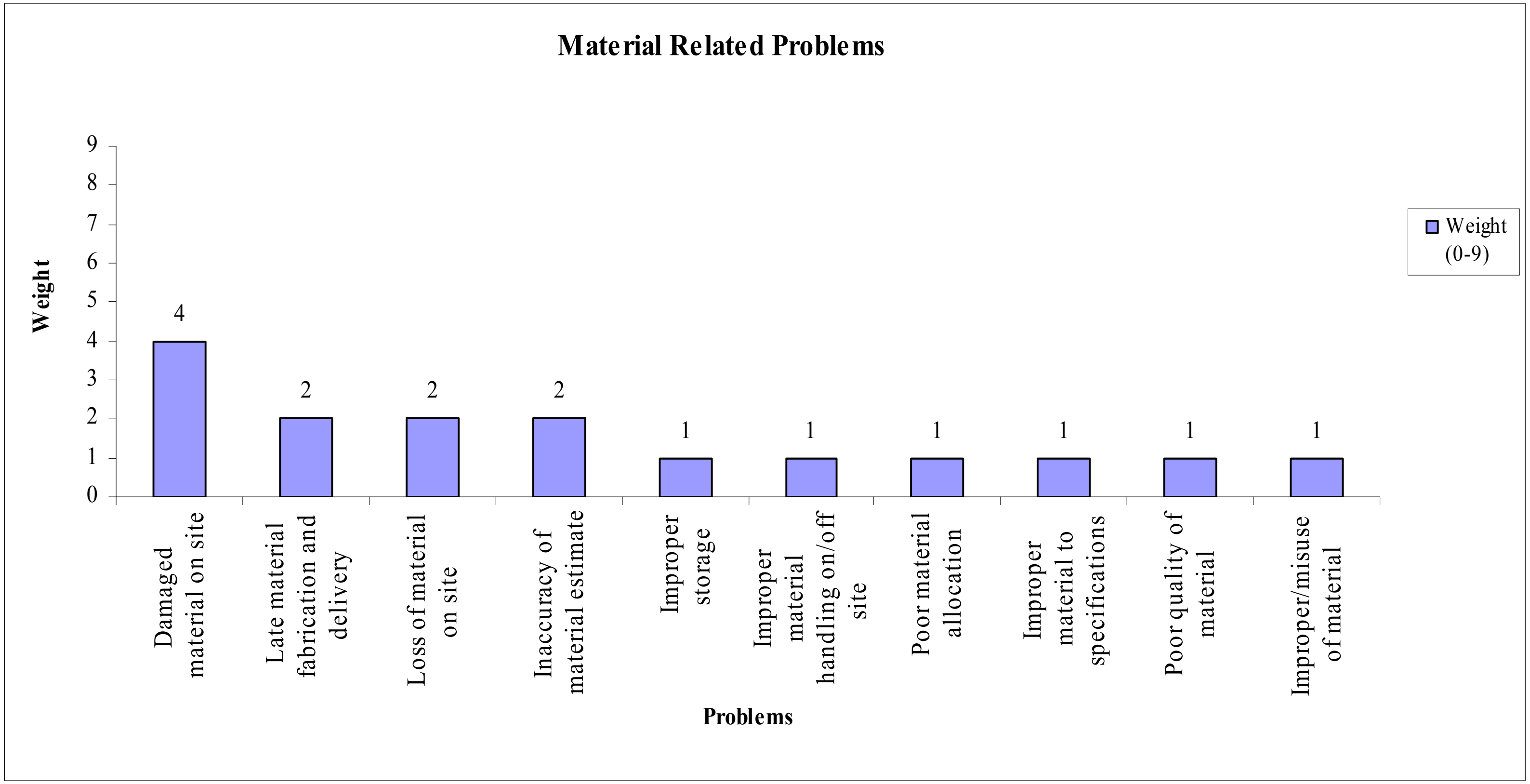


Figure 8.21- Material related Problems

8.4.19.8. Equipment Related Problems

Frequently encountered problems related to equipment were idle time for equipment (5), equipment breakdowns (4), and waiting for equipment repair (4). The other problems occurred at the lowest rates (1). Results are illustrated in Table 8.42 and Figure 8.22.

Table 8.42- Equipment related Problems

Equipment related problems	Weight (0-9)
Idle time for equipment	5
Equipment breakdowns	4
Waiting for equipment repair	4
Waiting for equipment arrival	1
Waiting for equipment installations	1
Lack of proper equipment	1

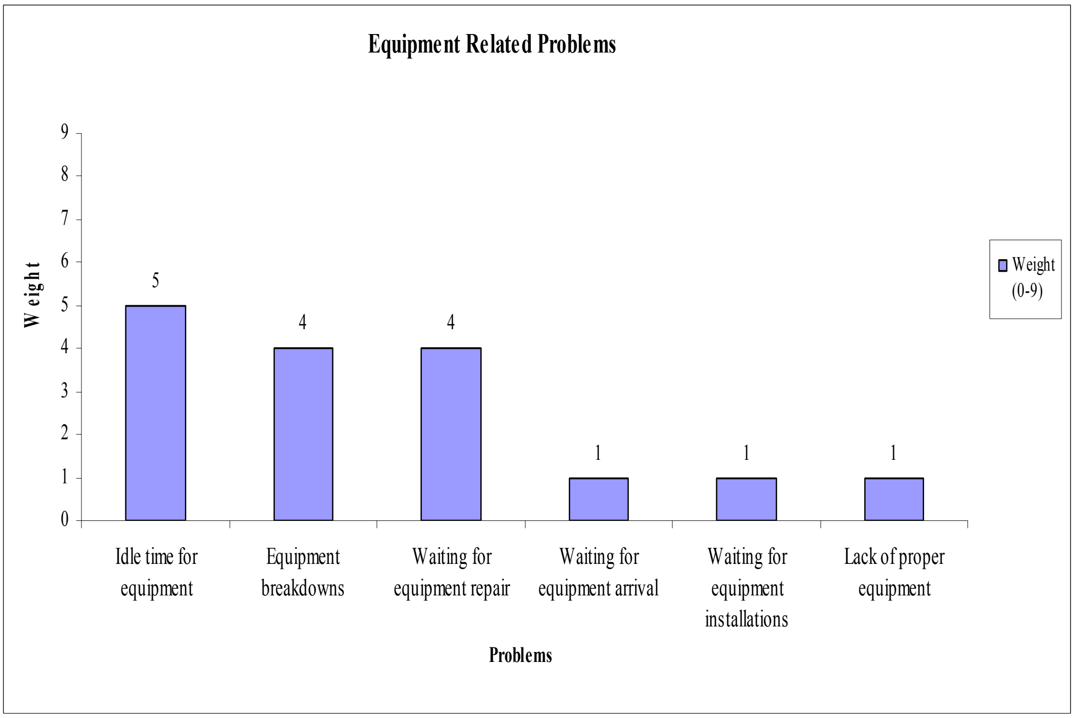


Figure 8.22- Equipment related Problems

8.4.19.9. Subcontractor Related Problems

The entire subcontractor related problems had low occurrence rates. The most important problem was slow and ineffective subcontractor (3).

Table 8.43- Subcontractor related Problems

Subcontractor related problems	Weight (0-9)
Slow/ineffective subcontractor	3
Lack of subcontractor's skill and experience	2
Subcontractor errors	2

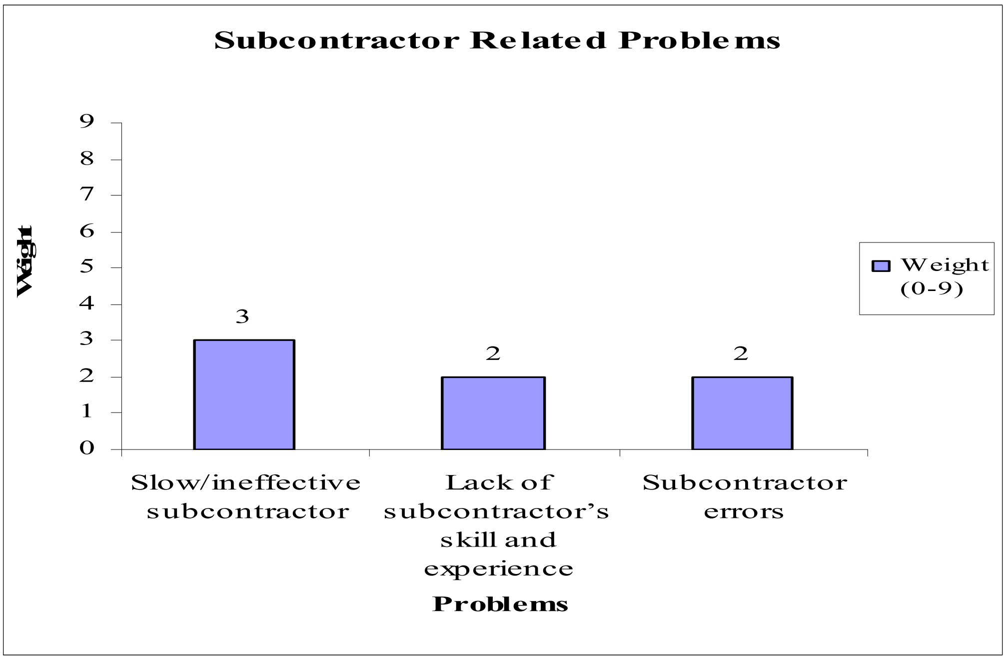


Figure 8.23- Subcontractor related Problems

8.4.19.10. Inspection Related Problems

All inspection problems had the lowest occurrence rate of 1. These results indicate that there were no problems of the company in inspection as shown in Table 8.44 and Figure 8.24.

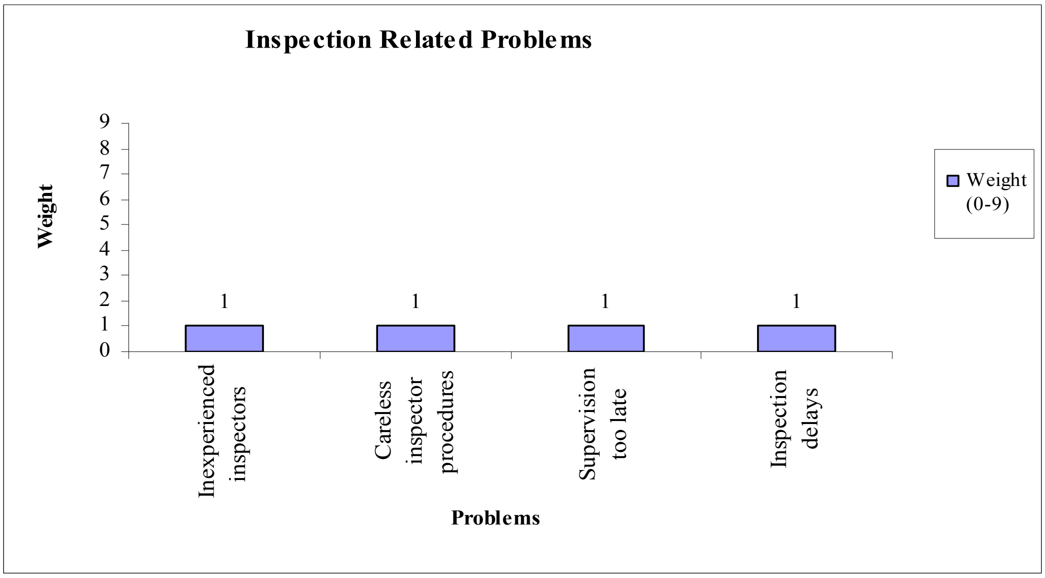


Figure 8.24- Inspection related Problems

Table 8.44- Inspection related Problems

Inspection related problems	Weight (0-9)
Inexperienced inspectors	1
Careless inspector procedures	1
Supervision too late	1
Inspection delays	1

8.4.19.11. Construction Site Related Problems

Table 8.45 and Figure 8.25 indicate that environmental effect was selected as the most important construction site problem. Respondents explained that these problems included protected area by laws, animal protection such as birds, etc. Other frequently occurred problems were delays to schedule (6), outdoor operations, uncertain ground and weather conditions (6), and unavailability of a proper feedback system (5). The remaining problems such as over manning and congested work areas, inappropriate construction methods, and poor site lay out were the problems encountered on construction site at the lowest occurrence rate (1).

Table 8.45- Construction Site related Problems

Construction site related problems	**Weight (0-9)**
Environmental effects	8
Delays to schedule	6
Outdoors operation and uncertain ground and weather conditions	6
Unavailability of a proper feedback system	5
Lack of progress	4
Poor skills of site management	2
Change orders	2
Failures in setting out	2
Unavailability of resources (labor, material, equipment, vs.) on site	2
Excessive accidents on site	2
Waiting for instructions	2
Lack of safety	2
Over manning and congested work areas	1
Inappropriate construction methods	1
Poor site layout	1

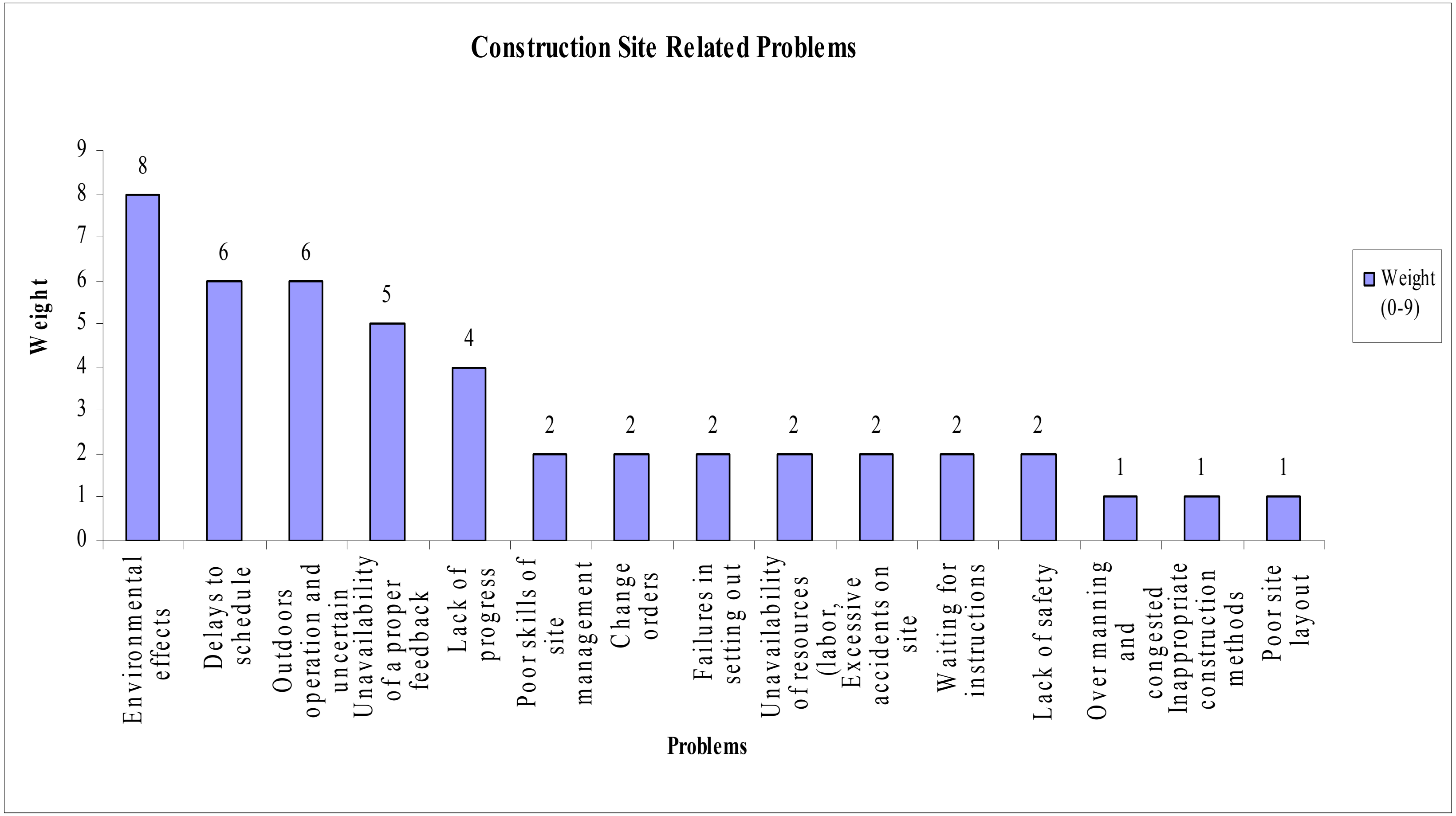


Figure 8.25- Construction Site related Problems

8.4.19.12. Project Related Problems

Although project uniqueness (size and complexity) was not considered as a problem, lack of project type experience was a relatively big problem. Results are also shown in Table 8.46 and Figure 8.26.

Table 8.46- Project related Problems

Project related problems	Weight (0-9)
Lack of project type experience	3
Project uniqueness (size and complexity)	1

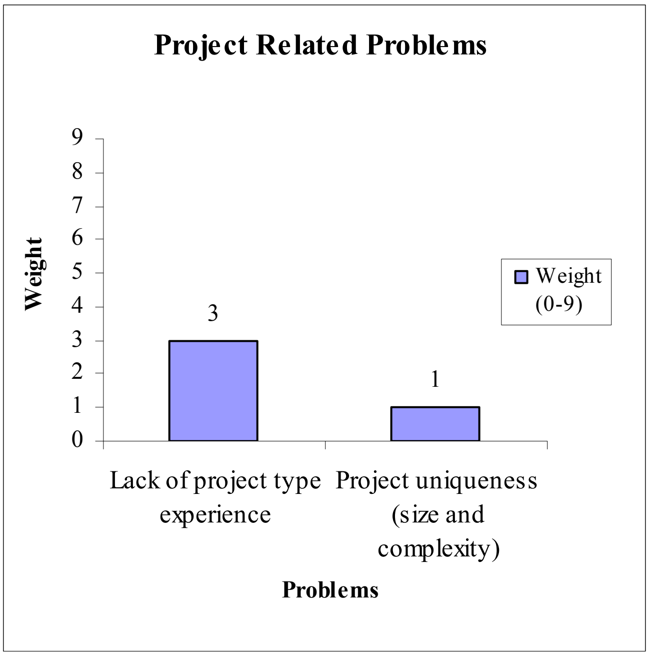


Figure 8.26- Project related Problems

8.4.20. EFFECTS OF CRITICAL PROBLEMS

The following Table 8.47 and corresponding Figures 8.27, 8.28, 8.29, 8.30 and 8.31 give the effects of given problem categories on money, quality, time, performance, productivity, and customer loss according the company experiences and projects:

Table 8.47- Effects of Critical Problem Categories

Problem Categories	Money Loss	Time Loss	Quality Loss	Performance Loss	Productivity Loss	Customer Loss
Management related problems	5	5	1	4	4	0
Planning related problems	8	8	1	5	8	0
Design related problems	6	4	1	2	5	0
Quality related problems	4	3	1	2	5	0
Project related problems	3	2	1	1	3	0
Documentation related problems	2	3	1	1	1	0
Labor related problems	3	2	1	1	5	0
Material related problems	2	3	1	4	4	0
Equipment related problems	5	6	1	3	5	0
Subcontractor related problems	4	5	1	5	5	0
Inspection related problems	2	2	1	1	2	0
Construction site related problems	5	6	1	4	4	0

8.4.20.1. Money Loss

Money loss was mostly caused by planning related problems (8) and design related problems (6) as it is shown in the below Figure 8.27. Other causes of money loss were management related problems (5), equipment related problems, and construction site related problems (5) in descending order of weight.

8.4.20.2. Time Loss

Time loss was mostly caused by planning related problems (8) and equipment related problems (6), and construction site related problems (6). Other causes of time loss were management related problems (5) and subcontractor related problems (5). All results are shown in the below Figure 8.28.

8.4.20.3. Quality Loss

The given problem categories had the least effect (1) on quality loss as illustrated in the below Figure 8.29 because the company stood to lose money and time to minimize the quality and also customer loss.

8.4.20.4. Performance Loss

Performance loss was mostly caused by planning related problems (5) and subcontractor related problems (5). Other causes of performance loss were management related problems (4), material related problems (4), and construction site related problems (4). All the results are indicated in the below Figure 8.30.

8.4.20.5. Productivity Loss

Productivity loss was mostly caused by planning related problems (8) at the highest weight as shown in the below Figure 8.31. Other causes of productivity loss were design related problems (5), quality related problems (5), labor related problems (5), equipment related problems, and subcontractor related problems (5).

As a result of all the analysis explained above related to the effect of problem categories (also by looking at all the figures related to these explanations given on the following pages); it is seen that planning related problems were the most effective cause of all losses. So that it is better to examine the reasons of planning related problems by means of detailed measurement and observations to develop effective countermeasures.

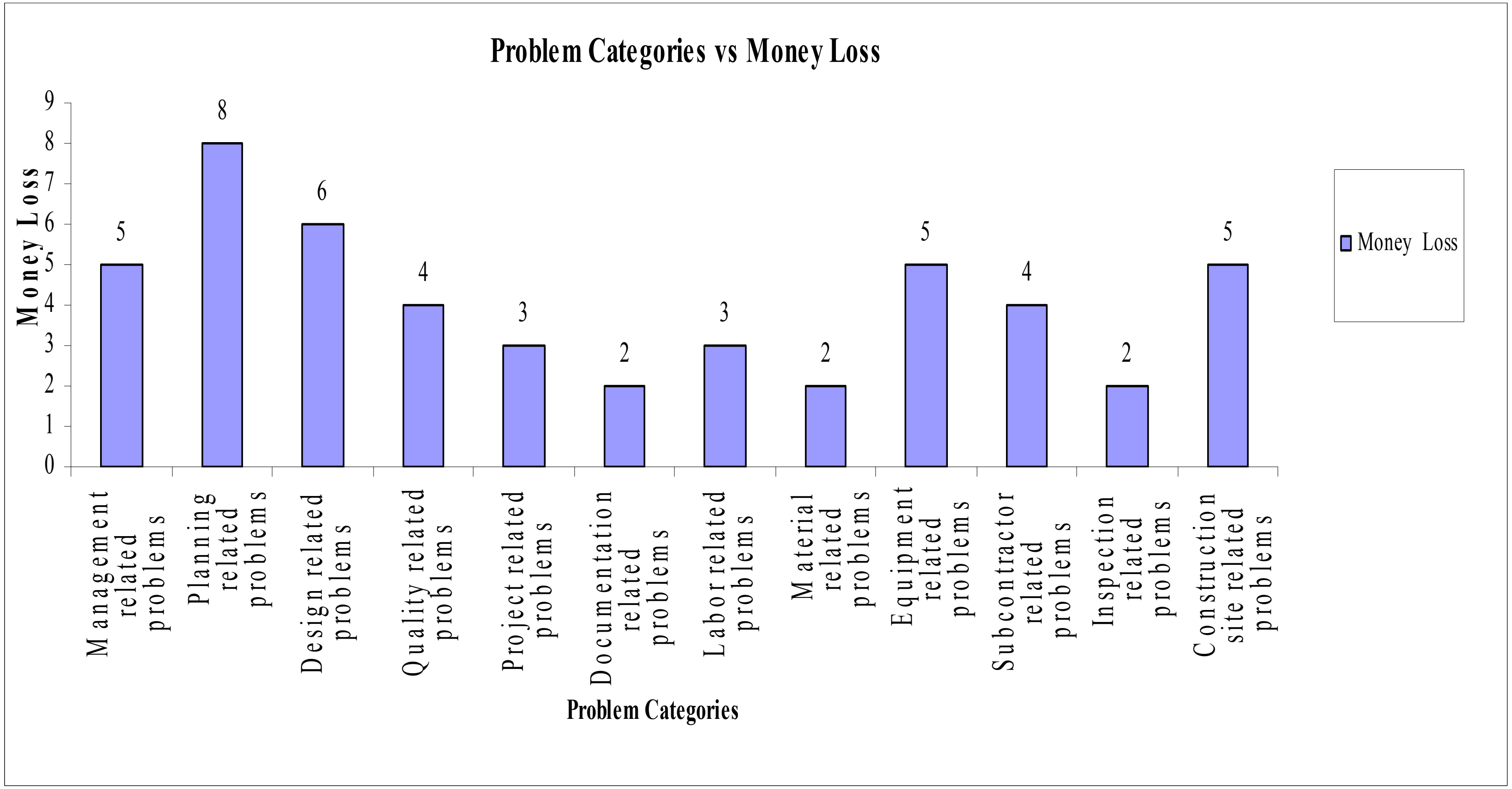


Figure 8.27- Problem Categories vs Money Loss

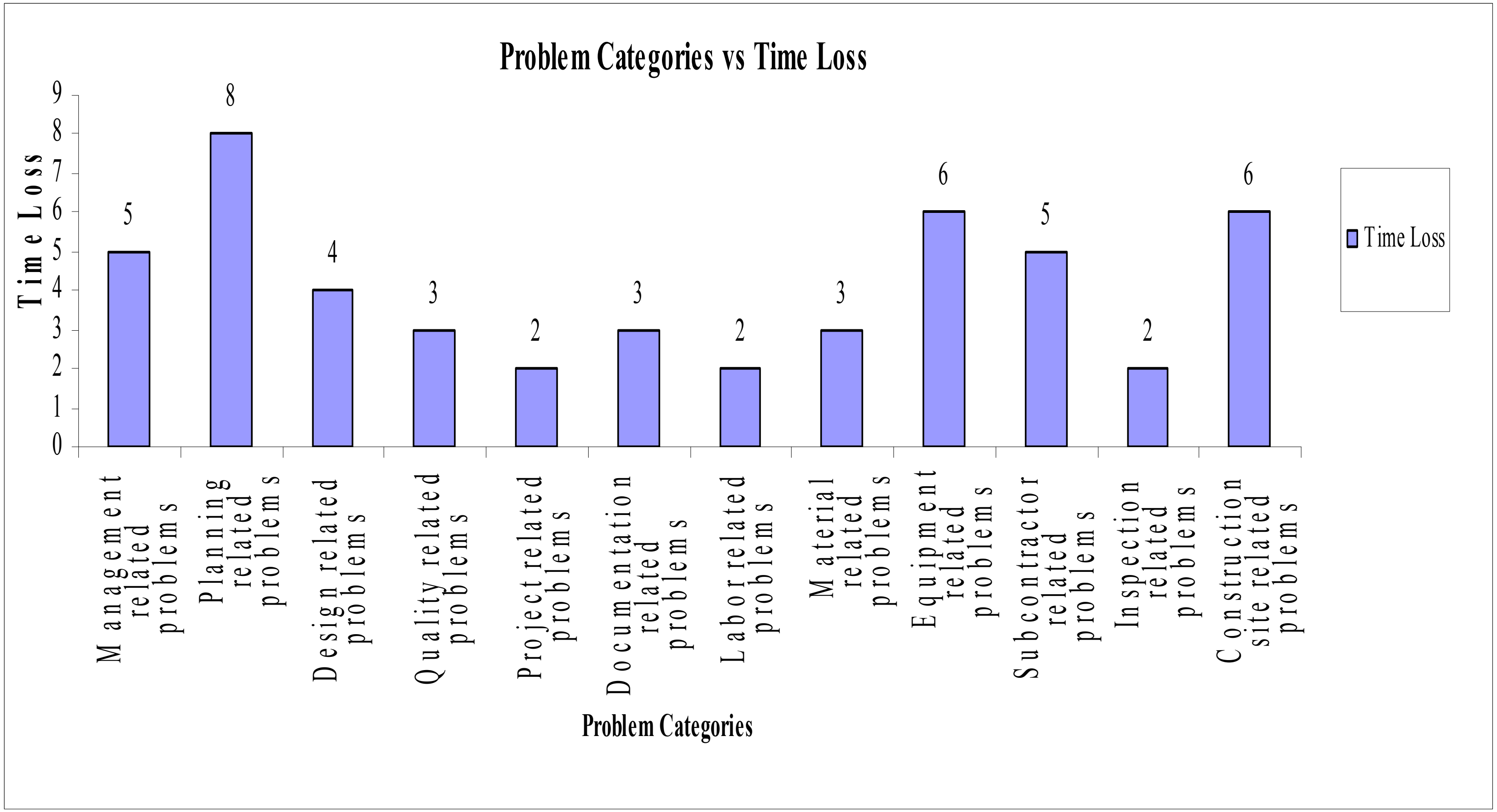


Figure 8.28- Problem Categories vs Time Loss

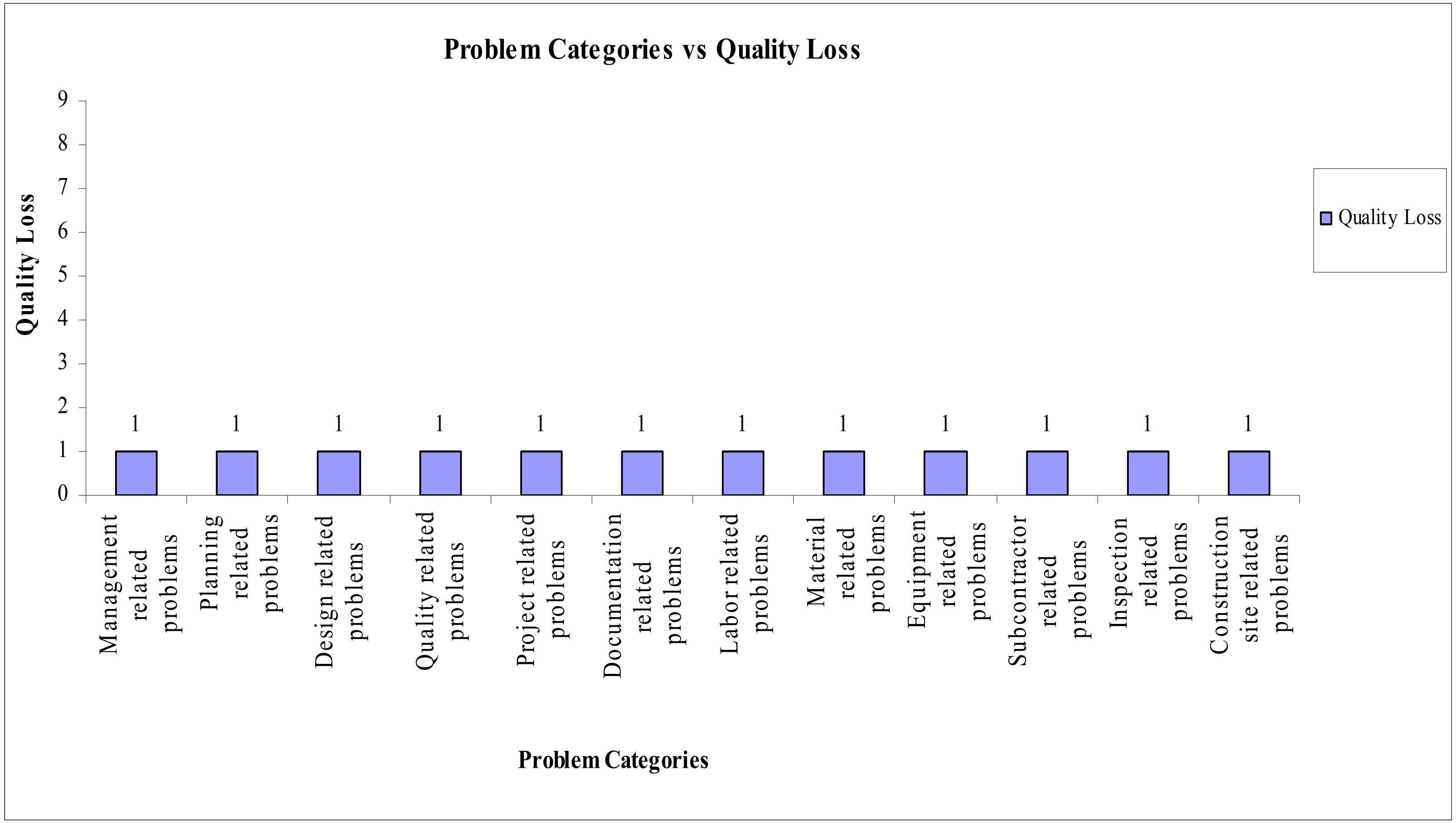


Figure 8.29- Problem Categories vs Quality Loss

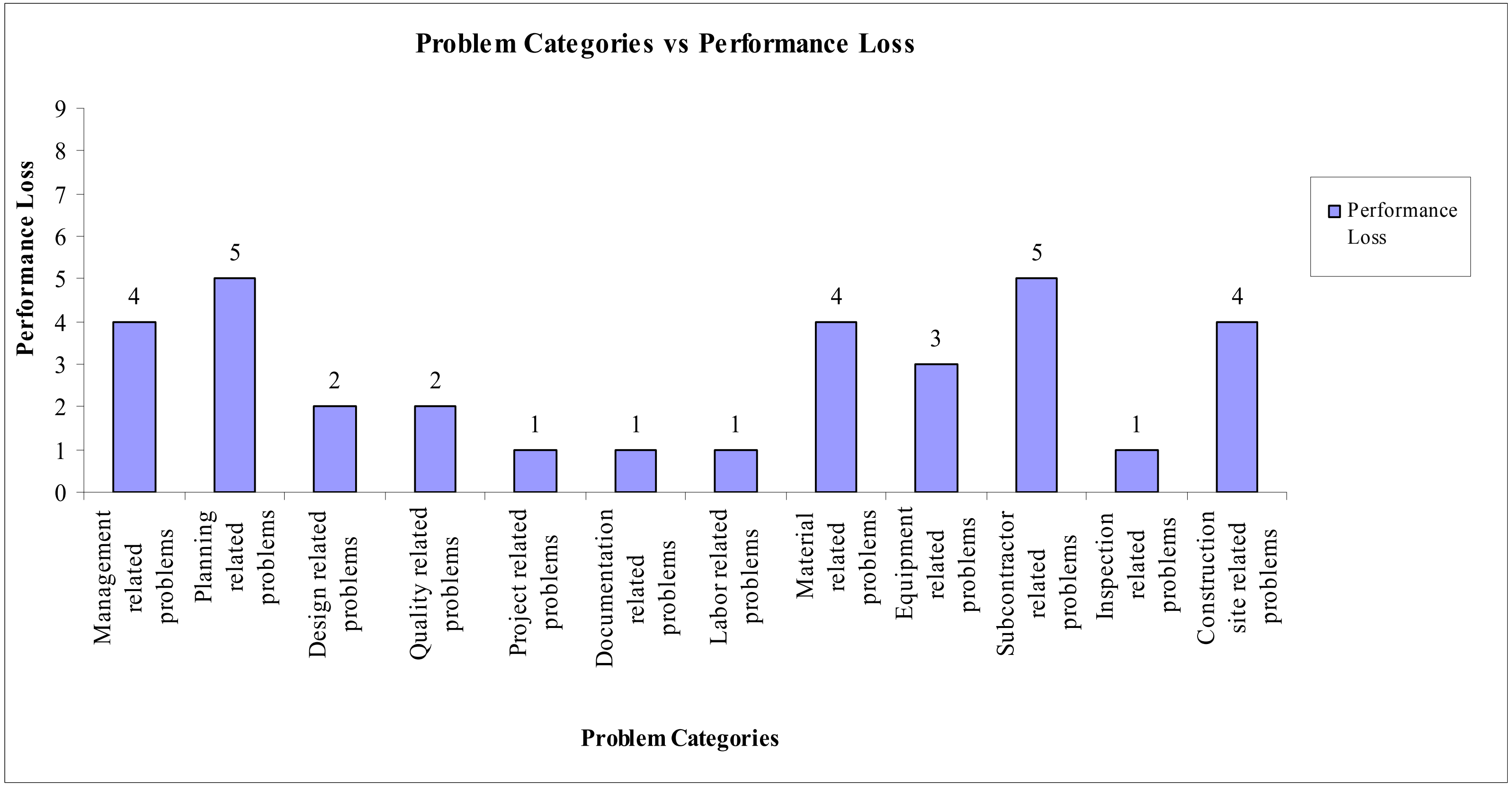


Figure 8.30- Problem Categories vs Performance Loss

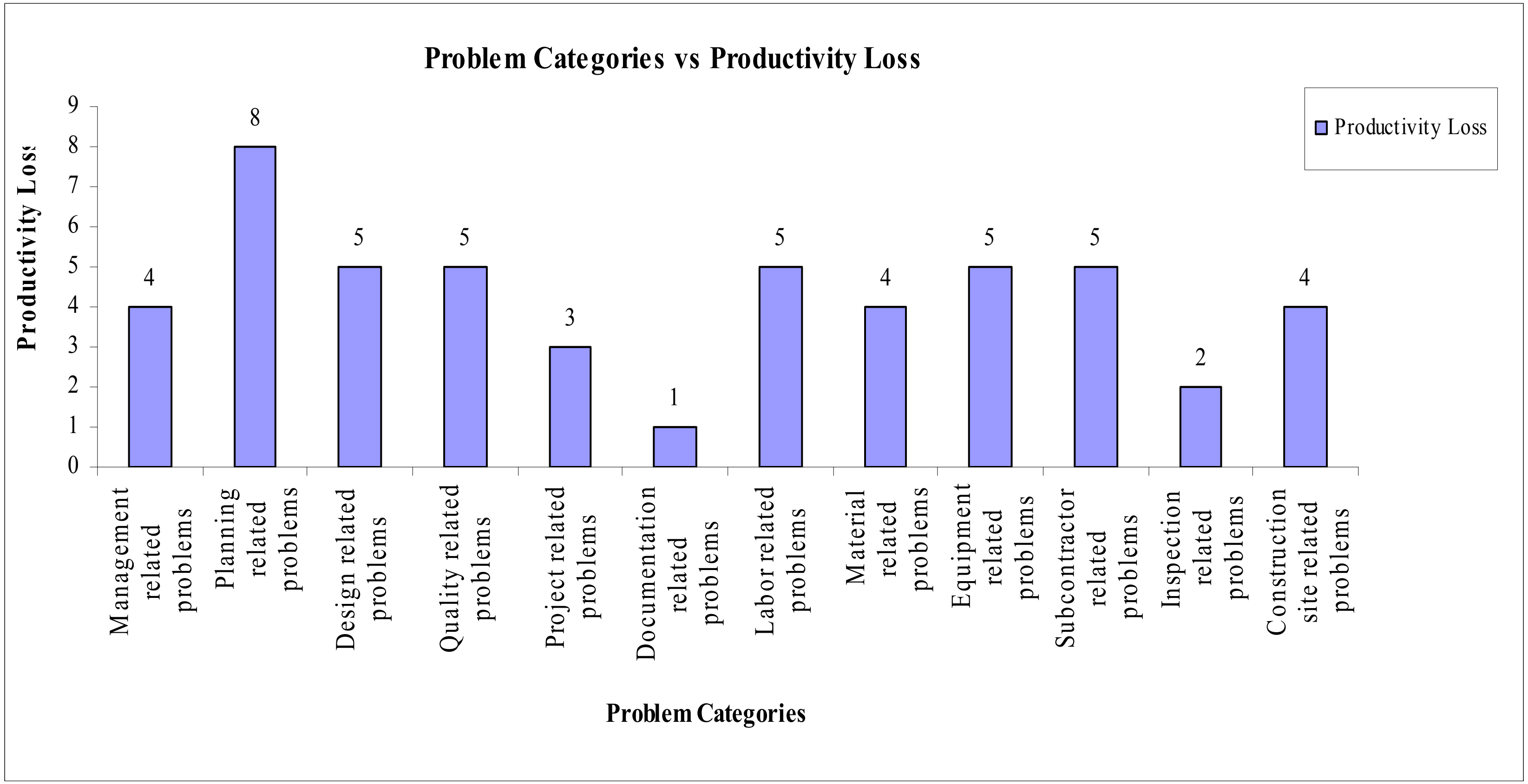


Figure 8.31- Problem Categories vs Productivity Loss

8.5. SUMMARY OF THE ANALYSIS RESULTS AND DISCUSSIONS OF THE RESPONDENTS' ADDITIONAL COMMENTS

In this section; the summary of the analysis results and respondents' additional comments related to the questions will be discussed.

8.5.1. COMPANY INFORMATION

- The company was a 20 years old private organization.
- The number of permanent staff was 308 including office and technical staff.
- The company worked on every kind of projects and also preferred the projects they did not perform before. The aim of the company was to gain new experiences and knowledge for future projects at the expense of money and time.
- It had most of the required resources needed for their projects such as labor and equipment so that it performs majority of works without subcontracting.
- About the economic infrastructure of the company according the turnovers and respondents' answers; it can be said that the company lost profit in the last years.

8.5.2. STRATEGY OF THE COMPANY

- The Company gave great importance to vision, mission statement, company objectives, and customer satisfaction. These answers showed that this company did not aim short term earnings and benefits but they aimed to develop an effective infrastructure for future success.
- Innovation, research and development (R&D) were not given high priority for the company success. These were left to the top management's decision depending on the project requirements.
- Strategy deployment could not be done effectively since the given effectiveness rates of the performed deployment actions were moderately low despite the high management involvement.
- Strategy deployment control mechanism worked effectively because the company was aware of the fact that strategy deployment was not done properly.
- Within the company objectives; processes, specific problems, quality, and customer satisfaction had the highest priority. Project cost savings was given lower priority compared to others.

8.5.3. QUALITY PERCEPTION OF THE COMPANY

- The company was aware of the fact that quality was the most important factor for the company success.
- The company considered the quality as a competitive advantage by means of eliminating defects.
- Quality goals of the company were determined according to competition in construction industry and the company strategy.
- Achieving higher quality which resulted in customer satisfaction was always more important than getting higher profit.
- Since customer satisfaction was one of the most important success factors for their company, they did not consider increasing profit by reducing quality. The company claimed that if they were not satisfied with the quality of their product, they might prefer to rework that product without considering the cost even if the customer did not notice the defect.
- Since the company accepted quality as the first target; they applied Quality Improvement Program (QIP) consciously but not as a formality.
- Although they claimed that top management generally gave high support to QIP, there seemed problem(s) on the quality supportive activities such as training, research and development, and performance review meetings compared to remaining activities, according to the given effectiveness rates of these activities.

8.5.4. MEASUREMENT SYSTEMS, RECORDS, AND HISTORICAL BACKGROUND

- The company had effective measurement systems such as cost, time, quality, material flow, customer satisfaction, employee complaints, etc. However the process flow and time measurement systems were not performed effectively compared to others.
- Measurement of earned value, labor productivity, and wastage were not taken into consideration which could be considered as deficiencies for the company performance improvements.
- The company did not have a defined system for the measurement of labor productivity. However, they had a performance award system for the employees based on the site reports. Also they based their labor productivity rates on the site reports. However they did not have a regular and written measurement system to collect the labor productivity rates.

- The company took daily reports of procurement, inventories, material storage, labor performance, and work in progress reports. On the other hand equipment condition reports were taken semi annually which was a long period compared to other report periods.

- The company had historical databases of material unit prices, bidding experience, project performance, unit prices for work packages, and subcontractor performance which are effectively in use.

- Historical databases of activity production rates and labor productivity rates had the lowest effectiveness rates which were important parts of better planning and cost estimating.

- They did not have the database related to client

- Additionally it was seen that most of these databases were not in a written and regular format which was not an effective way for the improved company success.

- Although the main purposes of these historical databases were obtaining new biddings and making more accurate planning and cost estimating, it is concluded from the given answers that these goals were not perfectly achieved since the planning and cost estimating were the major problems of the company.

- After taking measurements, reports, and records during the processes; the organization sometimes reviewed and evaluated these obtained results by brainstorming. They performed these actions with an acceptable effectiveness rates.

- In response to encountered problems during the processes by means of these results, they analyzed them to prepare action list as a solution for the application. However the effectiveness rates of these analysis, preparing action list, and application actions were much lower than the previous actions which indicated that there might have been problems in them influencing effectiveness.

- The organization also did not standardize the applied solution obtained by performing these several actions after taking measurements, reports, and records for the future usage of solution and the prevention of the same problem occurrence.

- The company claimed that they solved process related problems effectively by assigning individuals and/or a multi disciplinary team. However according to the interview results it can be concluded that they did not standardize the obtained solution which caused occurrence of the same problem each time no matter how effectively the solving techniques worked.

8.5.5. FLOWCHART AND PROCESS MAPPING

- The company used flow charts and process mapping methods in some of their processes, not all of them.
- The respondents were unanimous that flowcharts and process mapping method were essential tools for the success of the company. Additionally since they gained lots of benefit from these methods, they tried to apply these methods properly by additional items to all of the processes.
- However; they had not achieved their target completely yet. Although the company observed the benefit of using flow charts and process mapping, they did not have an established system to use flowcharts and process mapping in all processes.

8.5.6. CUSTOMER SATISFACTION

- Customer satisfaction was being measured effectively and the company was aware of the customer requirements. Therefore the company did not need to collect customer expectations.
- According to the survey results; customers of the company were satisfied with almost all of the given items from knowledge of customer requirements and attention to customer priorities to adequacy of project control, planning and cost.

8.5.7. TOP MANAGEMENT MOTIVATION FOR EMPLOYEE SATISFACTION

- The top management motivated their employees with most of the given motivation factors but they did not use career development and recognition, and reward as motivation factors which may cause deficiencies in the employee satisfaction.
- Although the management did not have an established reward system for their employee, the respondents explained that they sometimes provisioned their employees by increasing salaries and giving project bonus.
- The company thought that the given incentives did not have any effect on increasing quality and customer satisfaction. As a result, the company did not motivate employees with incentives regularly.
- There were no regular training sessions for the employees to follow the new and technological developments related to their business. Top management decided the necessity of training according the coming demand from employees, the project requirements, and terms of tender. Therefore; it is concluded that the company did not give the required

importance to employee training and training was applied only as a formality to fulfill an emergent condition.

- Employee satisfaction was not measured regularly. The employee dissatisfactions were only noticed by means of the complaints during face to face interviews.
- By looking at the employee reflection, the respondents claimed that their employees were satisfied with almost all of the given concepts from legal issues and safety to training and salary.

8.5.8. THE TOP MANAGEMENT AND SUPPLIER RELATIONS

- According to the given answers related to developing good relations with supplier, there were no problems with their suppliers

8.5.9. THE TOP MANAGEMENT AND SELF ASSESTMENT

- According to respondents; top management made self assessment by conducting workshops semi annually and by interviewing when considered necessary.
- As a result of the evaluation of the interview results, one can conclude that the self assessment system did not seem proper and applicable.

8.5.10. THE COMPANY SUCCESS ON CRITICAL SUCCESS FACTORS

- In administrative section; project cost within the budget, adequacy of training, and adequacy of planning had the lowest success rates in descending order of weight.
- In engineering and project management section, the company had the lowest success rates in adequacy of scheduling, planning, estimating, and the interaction with architect/ engineer.
- In logistical part there seems no problem which affected the company success according to given answers.
- In construction part, although all given factors were selected as important; the success rates of company in adequacy of job site personnel, knowledge of project, equipment quality, and timely completion of project were quite low.

8.5.11. LAST FIVE YEARS' INVESTMENTS AND THE COMPNAY SUCCESS

- Although respondents claimed that the company had made considerable investments on R&D, IT, machinery, new staff, and motivation factors which had moderately high success rates; the results obtained from previous sections show the insufficiency of the company related to number of staff and equipment, R&D, IT, training and motivation activities.

8.5.12. POTENTIAL IMPROVEMENT AREAS

As a result of analyzing the answers given to the questionnaire and the discussions during the interviews, following potential improvement areas and related factors were concluded:

- Almost all of the given improvement areas were selected as important for the company except more accurate testing procedures, reduction of change order, improve design, and increase market share although these had high improvement potential.
- By analyzing the improvement rates with the lowest success rates, it can be said that getting higher profit, decreasing scrap and rework, increasing market share, more accurate cost estimating and control were the most critical improvement areas.
- Proper and systematic cost control could not be made at every project; it was made at only some projects. However they had noticed the benefit of accurate cost control from the obtained success.
- They had given 12 months or life time warranty so that they had no warrant claim problems.
- They had problems related to planning of the projects which ended with high costs. These problems were due to inaccurate project plans prepared for only obtaining the bid. After the bid, these plans were shelved and the board prepared new plans made ready to be executed. As a result of this practice, the company lost money and time.
- They did not have any target to increase market. Their goal was to exist in the market by making their jobs at the best quality.
- Project designs were not prepared by the company. Designs were generally supplied by the client. However they could revise the design where necessary by using their engineering judgment to make the design more useful and buildable. After these changes and revisions they started working on the project and this procedure also caused loss of time and money to the company.
- Testing procedures on site were very accurate and they cared testing procedures more than required since they wanted to reduce defect rates caused by wrong measurement. They built

very successful laboratories for more accurate testing procedures in some projects which might have increased the project cost.

- Scrap and rework costs were always encountered during the execution of project due to their quality perception. Although the defects were not noticed by the customer or client since they were not so important, they could rework the job to correct these defects. These corrections were applied due to the importance given to quality and customer satisfaction although these caused additional cost to the company.

As a result; by analyzing the last five years' improvement rates, improvement potential of the company, and respondents comments, the most important improvement areas were cost estimating and control, planning, financial analysis, design, productivity, and scrap and rework.

8.5.13. THE COST COMPONENTS

- Training and education were two **prevention cost components** having the lowest occurrence rate. These results show that the company did not give sufficient importance to training and education as a prevention factor.

- Capability reviews as prevention were not performed by the company since it was selected as not applicable.

- According to the result of **appraisal cost components**, the company gave enough importance to appraisal procedures other than personnel testing.

- Given the interview results, it can be concluded that mostly occurred **internal failure cost components** were overhead costs associated with production, failure reviews, inaccurate planning, repair cost and redesign in descending order of weight.

- Project complexity did not appear as an internal failure factor by the company.

- External cost components with the highest occurrence rate were excess inventory and material handling on site, dealing with compensation, and excess travel expense in descending order of weight.

- All the obtained results related to cost components appears to be compatible with the answers given in previous related questions.

8.5.14. GENERAL PROBLEMS IN THE CONSTRUCTION INDUSTRY

- Frequently occurred **management related problems** were; ineffective utilization of resources, slow in processing and reviewing submittals, purchase orders and other paper works, poor communication between office and field, and poor provision of information to project participants.

- In **planning related problems**, the most critical problem, having far and away the highest occurrence rate, was lack of pre task planning. The other important problem areas needed to be improved were construction and job planning related areas.
- Respondents explained that since design was not prepared by the company, the **design related problems** were problems related to the design prepared by a design company. So the frequently occurred design problems were design changes and detail errors originated from the client or customer design.
- The company declared that it did not have any **quality related problems** since they tried to produce the best quality by standing to lose money and time.
- Unclear specification, mistakes in specification, and slow drawing revisions and distribution were the **documentation related problems** having the highest occurrence rates compared to others.
- **Documentation related problems** were frequently due to unclear specifications, causing time losses before starting the project. Slow drawing revisions and distribution also resulted in time loss due to waiting period for the client approval.
- **Labor related problems** were generally related to poor workmanship and lack of attention to details. Poor labor productivity and lack of skilled and experienced labor were other important problems related to labor.
- **Material related problem** having the highest occurrence rate was damaged material on site such as broken pipes and musty and irregularly bended iron bars on construction site. Other material related problems were due to improper material handling on/off site.
- Idle times for equipment, equipment breakdowns, and waiting for equipment repair were the frequently occurred **equipment related problems**. Inadequacy of equipment quality could be chosen as the resource of these problems.
- Although entire **subcontractor related problems** had low occurrence rate, slow and ineffective subcontractor problem was a frequent problem compared to the others.
- The company did not have any **inspection related problem**.
- In **construction site related problems**, environmental effect problem was selected as the most critical problem. Respondents explained that the company encountered lots of environmental effect problems such as protected area by laws.

- Delays to schedule, outdoor operations and uncertain ground and weather conditions, and unavailability of proper feedback system were the remaining critical construction site related problems due to their occurrence rates.

- Respondents all agreed that feedback system provided the usage of the experiences obtained from previous projects on the forthcoming projects not to make the same mistakes during the execution of that project.

- However the company did not have a proper feedback system although they were aware of the importance of that system for their success.

- Despite the low occurrence rates of all **project related problems**, lack of project type experience was slightly higher occurrence rate than project uniqueness factor.

- The reason of lack of project type experience was given as trying to select projects which they did not execute before. Although it brought additional cost to the company; they hired new staff for this unique project to finish it successfully if their own staff was insufficient to execute that project. By doing this, they aimed to collect proper experience for the future businesses as a result of their strategic decision despite the possible risks.

8.5.15. EFFECTS OF GENERAL PROBLEM CATEGORIES IN THE CONSTRUCTION INDUSTRY

In this section all the problems, causing money, time, quality, performance, productivity, and customer loss, are given in descending order of effect rates.

- **Money loss** was frequently caused by planning and design related problems. Other causes of money loss were management, equipment and construction site related problems in descending order of frequency.

- Major reasons of **time loss** were planning, equipment, and construction site related problems. Management and subcontractor related problems were also the other causes of time loss.

- **Performance loss** was the result of frequently planning and subcontractor related problems. Management, material, and construction site related problems also had effects on performance loss.

- The main cause of **productivity loss** was planning related problems. Design, quality, labor, equipment, and subcontractor related problems were other reasons of productivity loss.

- The company claimed that the given problem categories did not cause **<u>quality and customer loss</u>** because they preferred losing time and money rather than losing customer and quality.

- As a summary of all effects, **"<u>planning related problems</u>"** caused major parts of money, time, performance, and productivity loss. Equipment, construction site, and management related problems were other most critical problems in descending order of effect weight.

8.6. DISCUSSION OF RESULTS

In this part, the results of the analysis presented in the section 8.3 will be discussed and corresponding recommendations will be made on the basis of Lean Six Sigma facts and principles.

The company firstly should examine its strategic targets and its current performance carefully before starting Lean Six Sigma implementation. Then it should be aware of how much of its strategic target is achieved. If it is not on the desired level, the reasons should be defined to decide where the company should apply Lean Six Sigma first for gaining higher benefit.

Although the company has long term strategic targets which include quality, customer satisfaction, and process improvement purposes standing on the first ranks, according the analysis results it is seen that there exist deficiencies between these targets and current performance of the company. The company does not deploy its strategic targets to employees which is a fact noticed by its answers about control mechanism. Therefore; the strategy deployment mechanism of the company should be examined to detect the problem(s) for developing effective countermeasures.

The company gives the most importance to quality, QIP, and customer satisfaction which is a positive attitude for Lean Six Sigma approach but performance review meetings do not execute effectively for a proper QIP. The company should develop its current QIP with Lean Six Sigma principles to get the maximum benefit for the company success.

On the other hand, the company does not give the required support to training, research and development, and innovation which are the building structures of Lean Six Sigma. They should notice the importance of these subjects for the effective Lean Six Sigma implementation and also for the well being of the company.

Process flow and time measurement systems are not performed effectively. This situation should be fixed by detecting where the problem(s) is/are. Measuring process flows and time correctly and regularly provides the company the knowledge about the ongoing processes, value added times and activities, problems related to activities, labors, equipments, and materials.

Labor productivity, wastage, and earned value measurements are not done which is a big deficient for the company success. Labor productivity measurement provides the required knowledge for a logical job and construction planning which is one of the most important problems of the company.

The measurement of wastage in time, money, labor, and material is necessary to increase the company profit. Waste management gives the company the opportunity of knowing what is wasted, where it occurs, what is/are the reason(s) to develop proper countermeasures.

Earned value measurement is also another beneficial tool to compare the technical performance (i.e., accomplishment of planned work), schedule performance (i.e., behind/ahead of schedule), and cost performance (i.e., under/over budget) with each other for an early warning of performance problems. Since as early as possible the company noticed where the problem is, it can interfere sooner.

For a successful Lean Six Sigma implementation, the company should have effective measurement systems on the activity levels since the lower the level the more control information it has available but also the more work it get involved in.

Although the company takes daily reports for procurement, inventories, material storage, labor performance, and work in progress, the obtained results and observed problems show that these reports either are not taken accurately or they are not used effectively. For example, the equipment condition reports are taken semi annually which is a long period.

The period of taking reports should be logical and useful for getting highest gain. The company should find the problem(s) related to records by making observations and measurements. Taking regular and accurate records is a requirement for data collection which is one of the main tools of Lean Six Sigma.

Historical databases of the company do not work effectively since the company's purposed benefits are not achieved from these databases. Lean Six Sigma makes the company revise these databases regularly in a written form after collecting accurate data. Thereby, these results can be used for a better planning, cost estimating and control, construction, etc… which are the main problems of the company.

Problem solving techniques of the company also seem not to be successful since the company suffers from the problems such as planning related problems, equipment related problems, etc. discovered with the help of questionnaire and interview. Lean Six Sigma tools and methodologies provide effective problem solving techniques to the company.

Another mistake of the company is that it does not standardize the applied solutions and collected experiences although it applies some steps such as reviewing, evaluating, etc… which also seem to be problematic. For the Lean Six Sigma philosophy; all steps should be examined to find where the problem(s) is/are. Subsequently, after these steps developed and correctly applied; obtained solutions should be standardized for the usage of these solutions in the future projects.

Standardization is very important action for the Lean Six Sigma application since it leads the company to accumulate its experiences in a written format. Standardized solutions and experiences can be used in every process from planning to construction to protect against the repetition of bad results in future projects.

Although the company uses flow charts and process mapping, from the answers it is seen that these methods are not used efficiently and completely in all processes as Lean Six Sigma methodology purposed. The main purpose of flow charts and process mapping in Lean Six Sigma is making the work done visible for better measurement, analysis, detecting the problematic parts, and controlling the applications. Therefore the company should establish a proper system to use flowcharts and process mapping in all processes for the expected success from Lean Six Sigma.

The company gives higher priority to customer satisfaction and expectation so that it believes that it knows what the customer needs and also its customers are satisfied from the quality of all company services and processes. The reason is explained as that the company stands to lose money and time rather than quality, customer, and reputation.

However this way does not bring the company the expected success as it is proved by the results. It is a fact that the project completion on time and within the budget is as important as the quality of project for the reputation, customer satisfaction, and success of the company. Therefore the company should not claim that their customers were satisfied completely. Giving more than their expectations by losing money and time may not be accepted as a success because the customers do not want to spend more money for extra quality by wasting time and money. Being aware of the customer expectation and satisfaction level is also one of the main features of Lean Six Sigma.

The top management involvement and support in Lean Six Sigma implementation is the head stone. It is seen that the top management of the company is at high conception of its duties for the Lean Six Sigma which is a good start for the application of Lean Six Sigma.

However the top management does not have the required information about the employees' problems, suggestions, and satisfaction because employee satisfaction was not measured regularly and employee dissatisfactions were only noticed by means of the complaints during face to face interviews. Therefore top management should develop itself by learning what the employees need and by motivating its employees with regular rewards.

Top management should also notice that if employees are motivated regularly for their performance and productivity, the work performed by them will be at high quality, on time, and with less cost by means of decreasing rework, delays, and defects. Rewarding system is one of the recommendations of Lean Six Sigma for better performance of applied projects.

The top management also does not provide essential training opportunities for the employees to make them follow new methods and technological developments. Implementing Lean Six Sigma projects need essential training sections to apply the purposed methods for the best solutions. Therefore the top management should force their employees to follow all new developments includes methods and technology and then it should provide the employees the required training about their jobs.

The self assessment system of the company should be developed for better detecting of deficiencies, mistakes, and requirements. The top management should support self assessment system according to Lean Six Sigma principles without considering that their authority will be questioned.

As seen from the above results, there exist some implementation difficulties in the infrastructure of the company for successful implementation of the Lean Six Sigma principles. Implementing the Lean Six Sigma in all process starting from the lowest and most problematic activity level systematically may eliminate the dissonances in strategic target, strategy deployment processes, QIP, measurement, record and historical database systems, customer and employee satisfaction concepts, top management behavior and support. These Lean Six Sigma principles and tools will bring the company an excellent profit, success, customer satisfaction, and reputation.

The purpose of the questions in Part 1 and Part 2 is to reveal the current situation of the company; to find out the deficiencies in the processes where the Lean Six Sigma principles may help the company to eliminate them for better quality and performance with production time and cost reductions. Also one of the aims of these questions is to increase the awareness of the companies in what to measure, why to measure and measurement parameters.

In this study the author also questioned if a general map could be drawn to show the companies the implementation areas of the Lean Six Sigma for achieving higher profit gains. Therefore, in part 3 of the questionnaire, questions 43, 44, 46, 47, and 49 were asked to collect the following information about the processes:

Question 43: Estimated durations and estimated budget allocated for each given sub processes, and the percentages of the cases where the actual value exceeds the estimated one;

Question 44: Weights of value added time (the real time to perform that specific task), reprocess/ rework time, inspection time, move time, wait time, and idle time components in the estimated process durations;

Question 46: The occurrence weight of prevention, appraisal, internal and external failure costs during the given process;

Question 47: The weight of the additional expense in percentage compared to actual budget of the processes and the contribution of prevention, appraisal, and internal and external cost components to these additional expenses;

Question 49: The occurrence weight of the given problem categories which were the variability source in the processes and the effect of these problems to money, time, quality, performance, productivity, and customer loss.

However, these questions were not be answered by the companies. The reasons might be explained as follows:

- The current structure of the companies is not suitable to measure their processes on the basis of the asked parameters so that they are in difficulty about answering these questions.
- They are not aware of the importance of measuring these asked parameters in their processes.
- The executed construction projects are so variable that to answer these specific questions related to processes by making generalizing are really difficult.
- There is no data available on these concepts since they do not measure the asked concepts.

Therefore, by considering the above reasons, it is suggested that companies should start measuring these given parameters in a selected specific project by means of detailed observations and data collections.

Although the companies could not answer these questions, they should be asked to give an opinion to these companies about:

- The necessity of measuring these parameters,
- What they should measure in their processes,
- How and why they should measure their processes, and
- What benefits will be gained from these measurements.

Consequently, the results of these questions can be used for the following purposes:

Question 43: The money and time flows of the processes can be drawn, and then the percentage of cases exceeding the estimates can be indicated on this drawing. This will allow the determination of where the duration and budget exceed the contingency limits to obtain a general idea about where the big part of money and time is going, for the following stages of the measurement.

Question 44: The value stream of processes can be drawn to calculate process cycle efficiency of the individual processes. Process cycle efficiency is the indicator of how effectively the process is executed so that the processes which are needed to be improved can be identified to decrease performance, productivity, time and money loss. The extensive information about the process cycle efficiency is given in the chapter 5 (Six Sigma Chapter).

Question 46: The percentages of money spent for the prevention, appraisal, internal and external cost components in each process can be determined. The percentage of spent money in each process for these components will give the required information to detect the frequency of the causes of specific money loss in the processes.

Question 47: The additional expenses spent for the each sub-process compared to actual budget and the contribution of cost component to these additional expenses will give a general idea about the amount of the money spent for these given cost components. The data obtained by both question 46 and 47 will provide the required knowledge to determine the amount of money loss and additional expense for these given cost components. Money loss and additional expense are not separate but different concepts because whereas money loss means the money spent without any gain, additional expense covers both money loss and money spent to increase quality and competitive advantage.

Question 49: The occurrence weight of the critical problems in the given sub-processes and their expected effect weights in terms of money, time, quality, productivity, performance, and customer loss may give the opportunity to detect the most critical problem(s) in each process and its/their effect(s) to the company. The process flow chart can be drawn which shows mostly occurring problem in each process and the related effect of it; so that the problems and effects can be seen visually to develop countermeasures and to improve flow.

As a result, the above data can be used to draw a general map of measured construction processes; illustrating % of budget and time extensions, % of additional expenses, % of cost components, % of time components (such as value added time, non value added time, etc.), frequency of most critical problems, their effects in terms of money, time, quality, performance, productivity, and customer loss. This map can be used as guidance for the selection of potential Lean Six Sigma projects which can be applied with the most benefit and less cost to achieve the highest company improvement.

The results of the questionnaire is beneficial guide to think about the deficiencies in the infrastructure of the company according to Lean Six Sigma principles, the general potential improvement areas, problems and costs encountered in construction industry. The most relevant one(s), in terms of monetary effect and the company success, can be selected by only detailed observations and data collection of the company with a proper and trained team.

8.7. A GENERAL FRAMEWORK FOR LEAN SIX SIGMA APPLICATION FOR CONSTRUCTION COMPANIES

By using analysis results obtained in part 8.4 in parallel with Lean Six Sigma principles and tools, five road maps, (Figures 8.33, 8.34, 8.35, 8.36 and 8.37) forming the main parts of the framework, are prepared.

First road map is related to the required measurements and preparations as an infrastructure for the Lean Six Sigma application.

Remaining four figures show the required steps to implement Lean Six Sigma as a guide. These figures are drawn based on the Six Sigma DMAIC approach because of the following reasons obtained from literature:

- It is thought in Lean Six Sigma methodology as a roadmap for problem solving and process improvement.
- The DMAIC approach is suited for investigating and improving existing processes and it can help in identifying and eliminating the root causes behind the problems in the processes.
- All 'sigmaists' know the framework used to achieve Lean Six Sigma goals as DMAIC (Define, Measure, Analyze, Improve, Control).
- It is commonly believed that the real power of Lean Six Sigma lies in the integration of various tools, techniques, and methodologies within the DMAIC model.

The detailed information related to DMAIC approach of Lean Six Sigma is given in section 5.8.1.

The order of road map figures in the developed "General Framework for Lean Six Sigma Application for Construction Companies" is illustrated on the following figure (Figure 8.32).

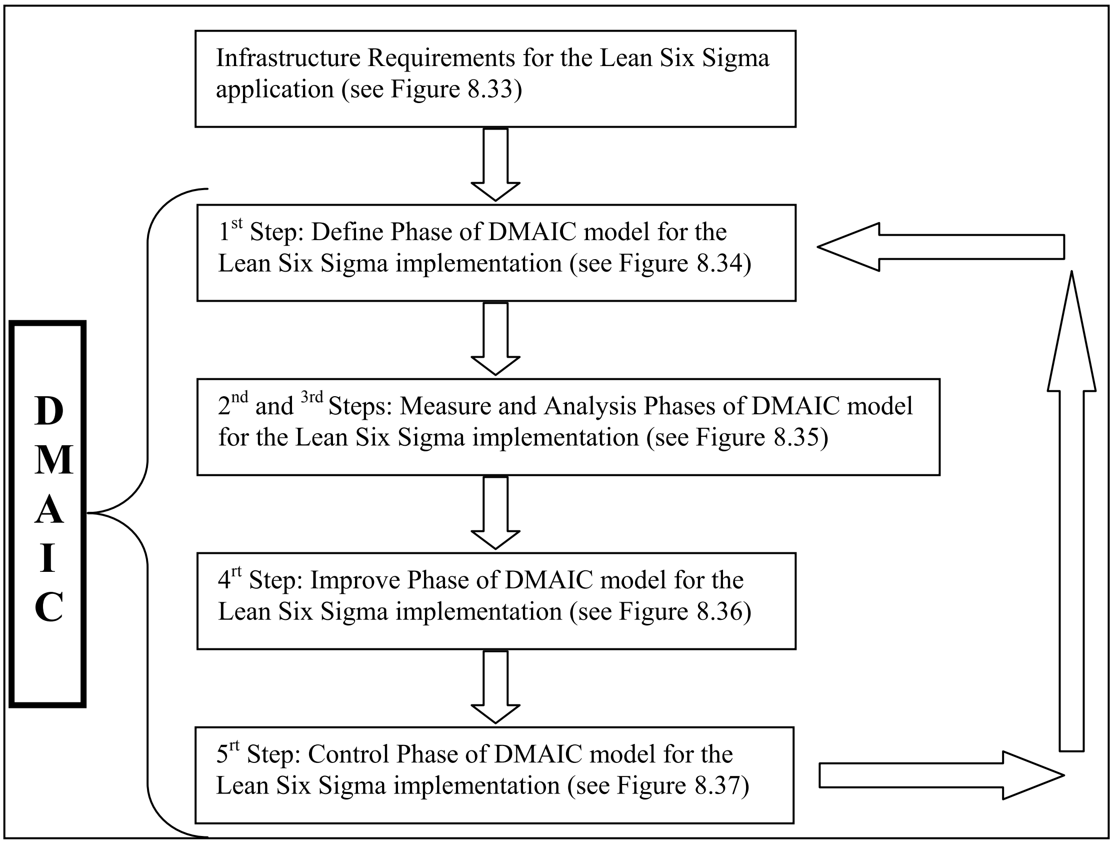


Figure 8.32- The order of road map figures in the developed "General Framework for Lean Six Sigma Application for Construction Companies"

The successive arrows in the Figure 8.32 indicate that after fifth step is completed, this road map can be applied to another selected project by starting from the first step. The previous steps can also be repeated if the obtained results are not applicable in the successive step.

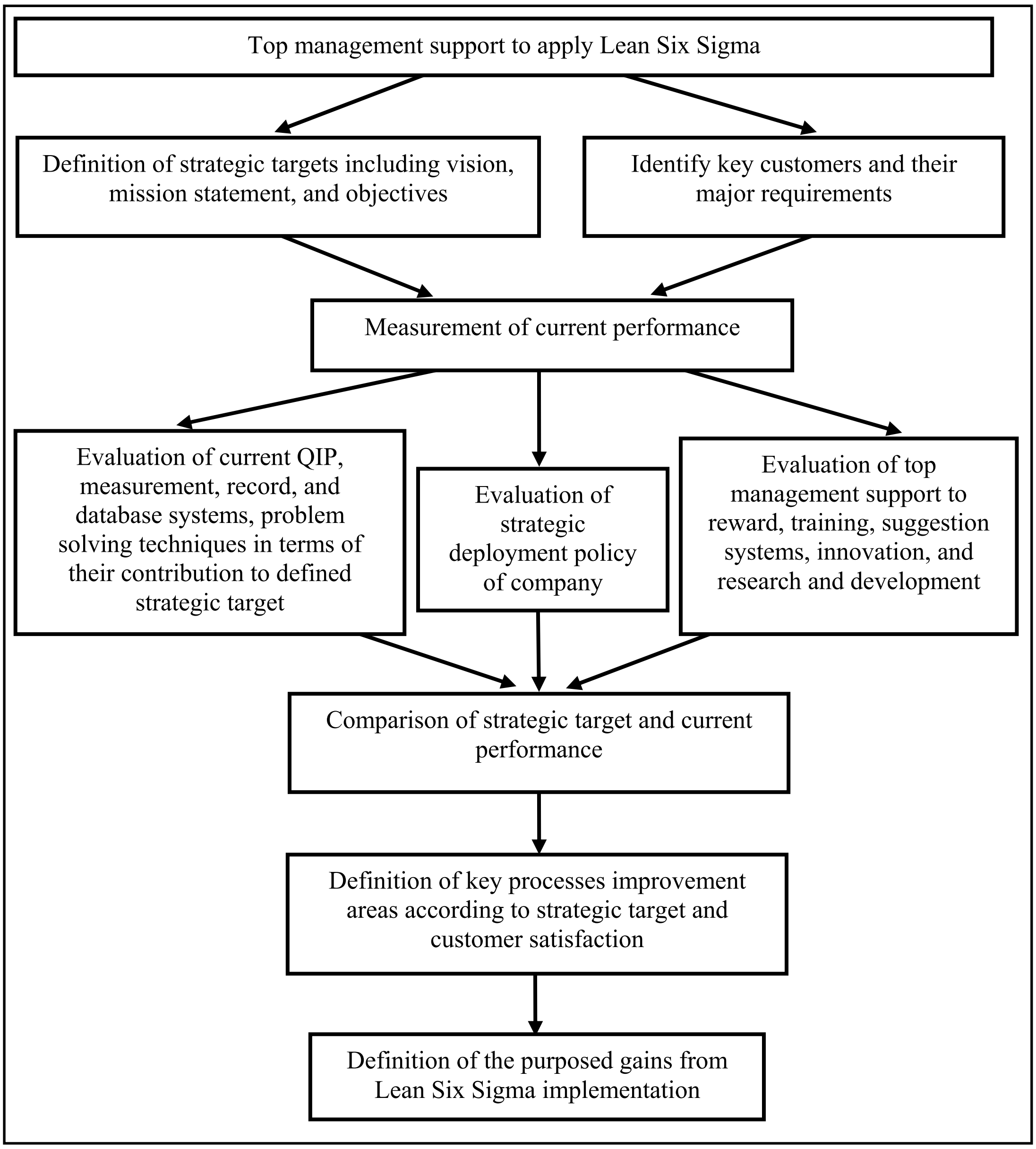


Figure 8.33 - Infrastructure Requirements for the Lean Six Sigma Application

After the preparatory infrastructure requirements, the company may establish a suitable infrastructure to start Lean Six Sigma implementation. The following figures illustrate **a general guide to implement a Lean Six Sigma project** by using DMAIC methodology including all steps from “forming an appropriate team” to “controlling” stage.

Figure 8.34 illustrates the first step of the purposed implementation framework which is the Define phase of DMAIC model.

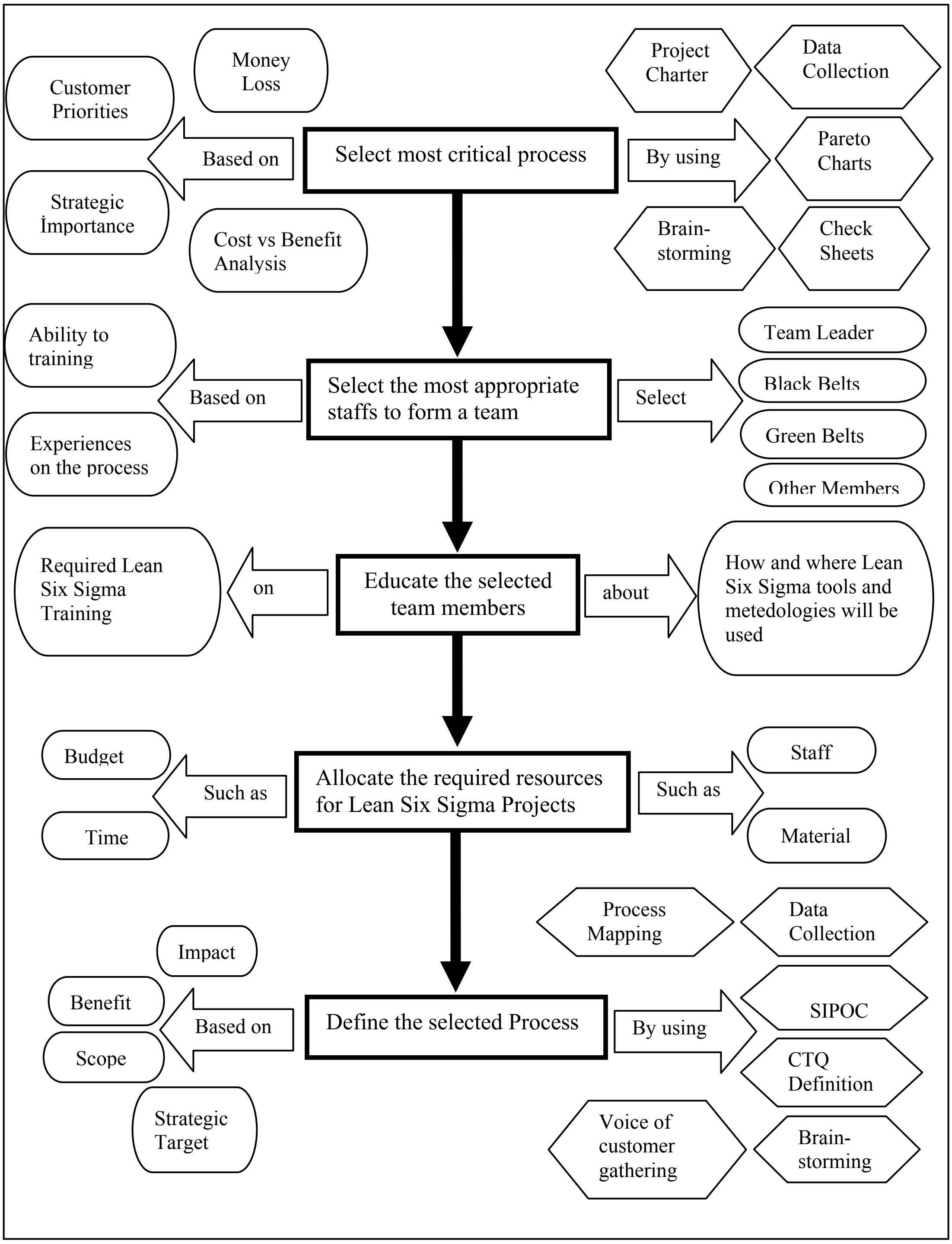


Figure 8.34 - Define Phase of DMAIC model for the Lean Six Sigma Implementation

The following map (Figure 8.35) gives the details of the Measure and Analysis phases of DMAIC methodology.

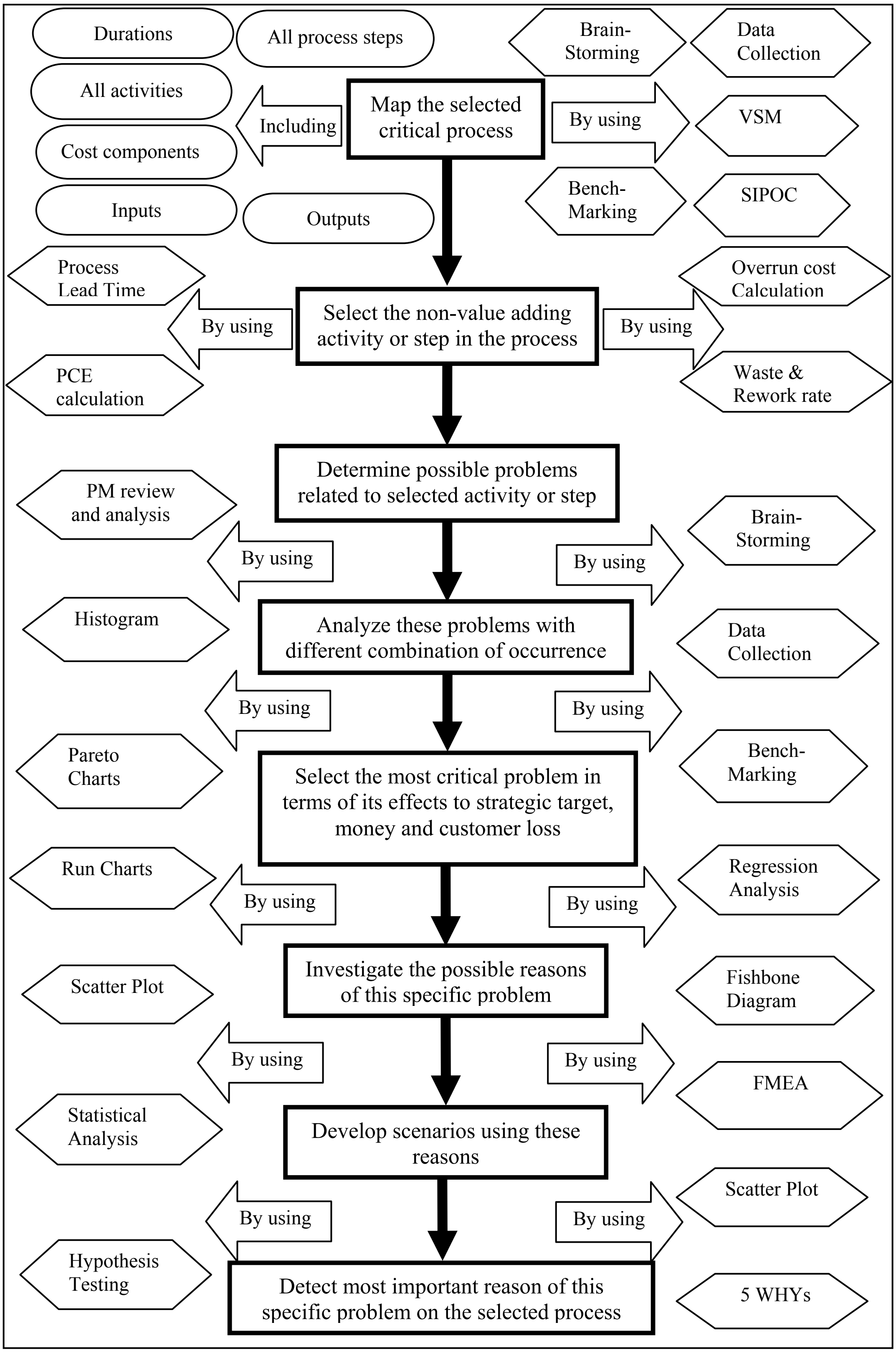


Figure 8.35 - Measure and Analysis Phases of DMAIC model for the Lean Six Sigma Implementation

The following map (Figure 8.36) shows the Improve phase of DMAIC model which is the fourth step of the proposed framework.

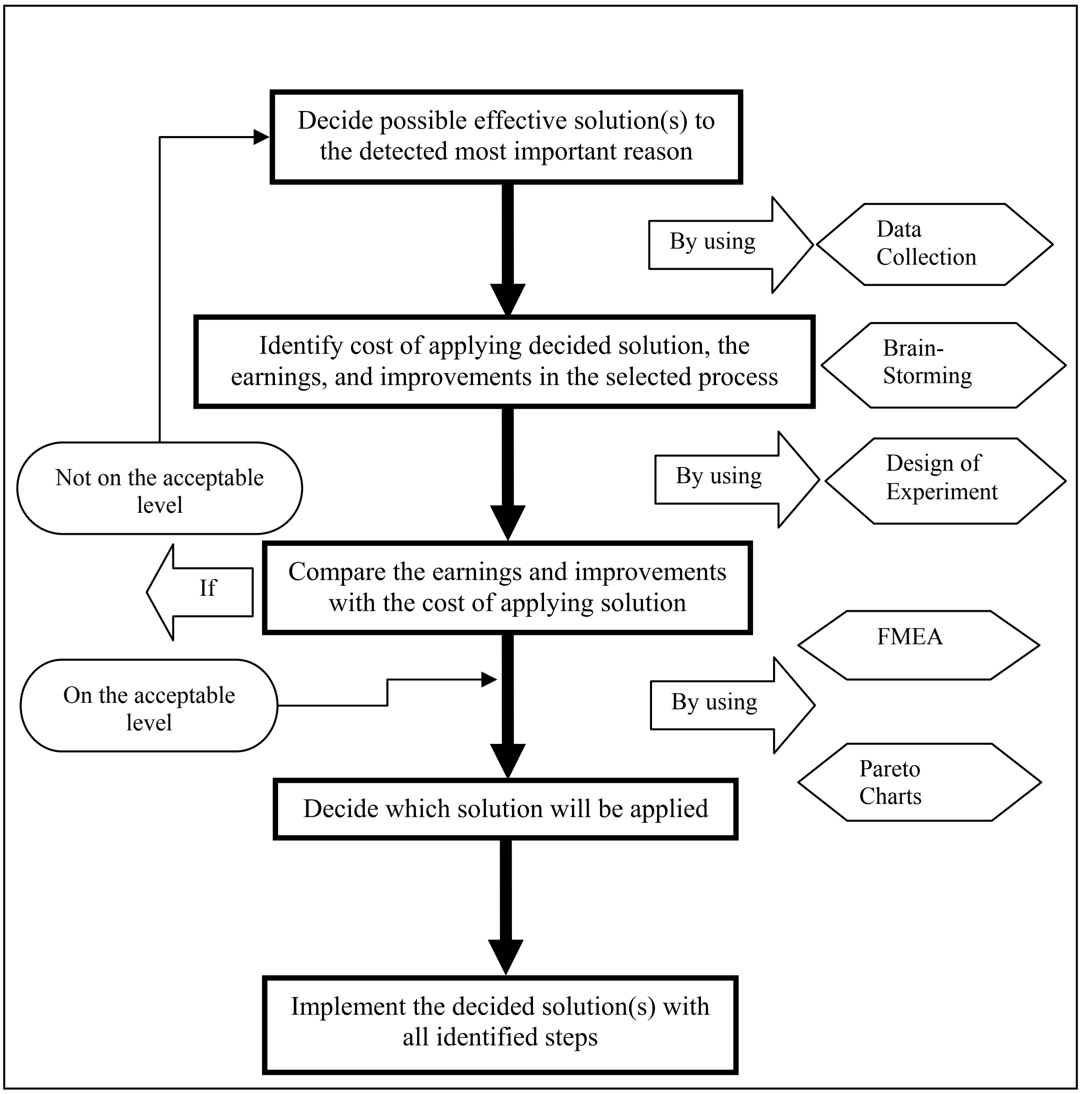


Figure 8.36 - Improve Phase of DMAIC model for the Lean Six Sigma Implementation

Finally, the map below (Figure 8.37) demonstrates the Control step of DMAIC methodology which is the last step of the purposed framework to implement a Lean Six Sigma Project.

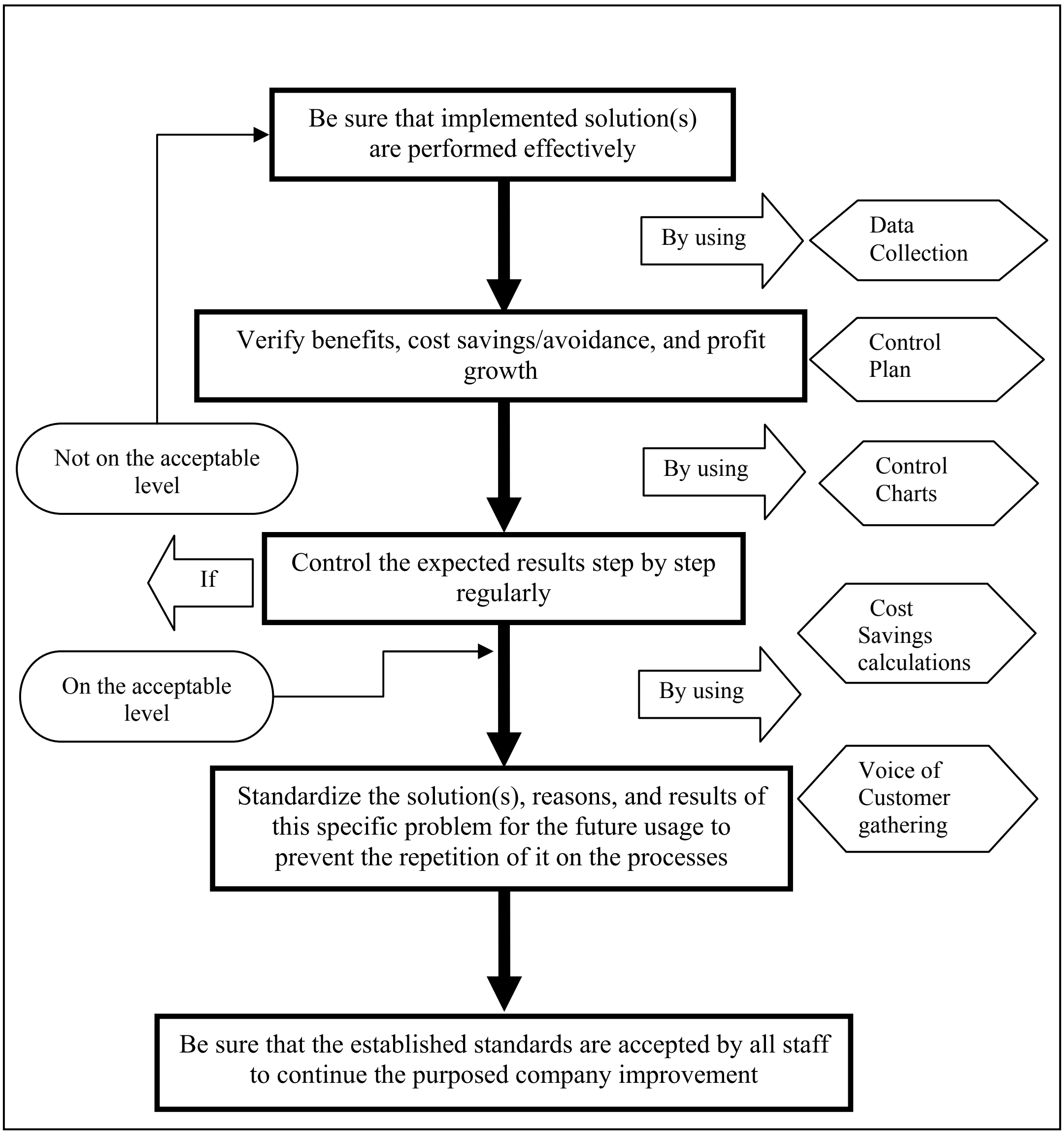


Figure 8.37 - Improve Phase of DMAIC model for the Lean Six Sigma Implementation

The boxes framed with continuous black lines followed by arrowheads present the main route to be followed; on the other hand the elliptical symbols give complementary information related to the main route. The hexagonal symbols indicate the required tools to be used during the execution of the corresponding main road.

As it is shown in the above figures (Figure 8.33, 8.34, 8.35, 8.36, and 8.37); each step includes detailed data collection, measurement, analysis, and control steps Further detailing of these steps are changeable according the specific content and purpose of projects and also company structure. The intensity of all steps on these figures can be changed according to the company budget, available resources, number of staff, project size and nature, complexity of problems, and general company structure.

Leading of a master black belt Lean Six Sigma expert may be necessary at the start, for professional and sentient implementation of Lean Six Sigma methodology. After taking the required training and knowledge, the company can apply these steps by itself.

Organizations may benefit from Lean Six Sigma implementation in following ways:

- Increase productivity and performance of employees;
- Increase process cycle efficiency and removal of waste;
- Reduce money loss due to rework, scrap, employees' mistakes, etc…;
- Decrease cost intensity of process due to improvement in inputs, outputs, and operations;
- Increase competitive advantages and market share;
- Generation of drastic improvements in profit, productivity, quality, performance, and customer satisfaction.

CHAPTER 9

CONCLUSION

9.1. GENERAL SUMMARY

In this study, construction industry was examined for determination of the potential Lean Six Sigma implementation level and expected benefits from its use.

The author conducted interviews with three companies in order to find out their readiness for such a management by innovation. One of the companies was selected for further study due to their organizational structure, innovative strategy and interest in this study.

Data collected through several workshops and interviews were analyzed and examined (see section 8.5), considering the limitations explained in section 8.3. Given the results obtained and Lean Six Sigma principles a roadmap was determined for the pilot company in part 8.6.

Additionally; by taking up this pilot study and Lean Six Sigma principles as references, five roadmaps are generated as a guidance to implement Lean Six Sigma methodology for companies indicating the general steps before and during the implementation. These roadmaps are presented in section 8.7 (see Figure 8.32, 8.33, 8.34, 8.35, 8.36 and 8.37).

9.2. CONCLUSION AND RECOMMENDATIONS

The construction industry has a profound impact on our daily lives and it is a key indicator and driver of economic activity and wealth creation.

Despite the fact that the construction sector is an immensely important industry in terms of economic and social impact, much research has pointed out a gap in terms of labor productivity, quality, performance and responsiveness to customer needs when compared with other large industries.

All the corresponding researches and literature also declare that these large industries have reached far better levels of organizational maturity, enabling them to consistently deliver high quality and low cost products, services and to focus on growing customer expectations, by adopting new technologies and management principles such as TQM, Lean and Six Sigma necessitated by increasing global competition.

However, the construction industry has used its structural differences as an excuse for not adopting these new technologies and management techniques (Ferng and Price, 2005) and it unfortunately has tended to lag behind other industries in the adaptation of new technologies and management techniques for the performance, quality and quality improvement and also better customer focus.

Lean Construction, Six Sigma, and Lean Six Sigma are the most popular ones of these new technologies and management techniques. The detailed information about these methodologies, the differences and synergies between them are presented in Chapters 3, 4, 5, 6, respectively.

As a result of obtained knowledge and information from the literature; it is concluded that Lean Six Sigma is the most comprehensive method combining the appropriate tools and methods of Lean Construction and Six Sigma methodologies. Therefore Lean Six Sigma principles, tools and methods are taken as a reference for the given recommendations and presented guidance roadmaps.

A principle of these methodologies is that performance should be measured numerically, and that the deficiencies should be determined between the current situation and desired performance goals.

The purpose of Part 1 and Part 2 of the questionnaire is to evaluate the current situation of the company in terms of achieved strategic target, problems they encounter during their processes and to show that how Lean Six Sigma principles may serve the company.

This study also aimed to give guidance to the construction companies by exploring the possible applications of Lean Six Sigma principles for maximizing their profit levels. Part 3 of the questionnaire was prepared in order to serve this purpose (questions 43, 44, 46, 47, and 49) pointing out the detailed observations, measurements, and data collection required from the company, also indicating the potential gains for the company in doing this. The questions were aimed to answer the following questions:

- Where is the company success lowest?
- What are the potential improvements?
- What are the internal and external failure cost components?
- What are the most damaging problems in terms of money, time, quality, performance, productivity, and customer loss?

The obtained results can be summarized as follows:

- The company has the lowest success rates on adequacy of project cost control, planning, estimation.
- Potential improvement areas are again more accurate cost estimating and controlling, and planning, and additionally financial analysis, productivity improvement, and decreasing scrap and rework.

- The most important internal failure cost components are overhead cost, failure reviews, again inaccurate planning and repair and rework cost.
- The most important external cost components are excess inventory and material handling, on site and dealing with compensation.
- Shortcomings related to planning, such as the almost complete absence of pre task planning, seem to be the main reasons to cost, time and performance problems. Other critical problems are;
    - Equipment problems; such as idle times for equipment, waiting for equipment breakdowns and repair,
    - Construction site problems; such as environmental effects, delays to schedule, outdoor operations and uncertain ground and weather conditions, and unavailability of proper feedback system, and lastly
    - Management related problems such as, ineffective utilization of resources, slow in processing and reviewing submittals, purchase orders and other paper works, poor communication between office and field, and poor provision of information to project participants.

These above results can be used as a guidance to decide what the main improvement areas are and which problem is the most suitable for Lean Six Sigma application. The author has tried to comment almost all of the results in the light of given answers and obtained knowledge about Lean Six Sigma from literature.

The survey results presented in Chapter 8 show that the infrastructure of a construction company represents a problem for implementation of such an innovative methodology.

The following general recommendation, in addition to given roadmap figures, can be given to this selected pilot company interested in Lean Six Sigma application, to accelerate this implementation:

- The company firstly should start to apply mentioned Lean Six Sigma principles to develop and prepare its current infrastructure for the Lean Six Sigma project implementation by following the given recommendation on the basis of Lean Six Sigma principles and the analysis results (see section 8.5 and 8.6).
- A result of analyses described in sections 8.5 and 8.6 is the selection of critical activities causing most monetary loss.
- To choose the most important activity, company should make further data collection, brainstorming, observations, measurements, and analysis with the selected site and office staff.
- The company should then decide which of the observed problems on which specific process and activity should be attended to. The chosen activity should be mapped including all activity steps, labors, equipment and material usage, including duration of each step. Thereby value-adding steps and their durations, material, equipment and labor usage efficiency can be detected.

- After detecting the non value added durations, steps, labor, material and equipment usage; further Lean Six Sigma statistical analysis should be performed for different combination of causes to decide most effective solution.
- Companies new to Six Sigma or Lean should consult a Lean Six Sigma expert assistance to make a robust start for the implementation and learn the details of Lean Six Sigma tools and methodologies.

As a result; in the light of this study and corresponding case study analysis result, the author purposed to show construction companies;

- What Lean Six Sigma is,
- What the measurement parameters of Lean Six Sigma are,
- How they can measure these parameters,
- What their deficiencies are in their current infrastructure by seeing with Lean Six Sigma methodology eyes,
- How they can repair these deficiencies and incorrect actions by means of Lean Six Sigma principles,
- What they will gain with this Lean Six Sigma application.

The proposed roadmaps presented in section 8.6 and applied questionnaire/interview questions will also be helpful to construction companies to investigate their own deficiencies in their structure and performance and to guide how they can start this improvement.

For future studies, the prepared questionnaire can be modified by considering further limitations and complications.

The construction industry needs to make radical changes to the processes through which it delivers its projects and these processes should be explicit and transparent to the industry and its clients to facilitate a quick and smooth progression (Egan Report, 1998). With construction managers increasing interest in performance and profitability, there is increased focus on the analysis of process variation and elimination through root cause analysis and problem solving.

One of the options is to follow the recent developments and technologies such as Lean Construction, Six Sigma, and Lean Six Sigma and apply the ones appropriate for the particular company.

The construction companies should continuously review and improve themselves in the light of the given guides on the basis of the analysis made and Lean Six Sigma principles. Use of the Lean Six Sigma methodology identifies overall process capabilities and areas that need improvement. Provided that Lean Six Sigma concepts, principles, methodologies, and tools are explained to the construction companies, one can expect that they can benefit from the methodology.

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APPENDIX

INTERVIEW QUESTIONS

INTRODUCTION

The purpose of this interview is to collect the required data for determination of the quality, productivity, performance gaps that need to be closed and the critical problems in construction industry, its effects, and financial implications, and cost intensity of construction main processes and sub-processes. The objectives of the study are:

- Determining the conformance level of the construction industry infrastructure (from i.e. economic, i.e. strategic, i.e. cultural, i.e. organizational aspects) for the Lean Six Sigma implementation;
- Prioritizing key improvement areas/processes where Lean Six Sigma projects can have the greatest monetary impact;
- Forming an optimum framework for improvement;
- Identifying and mapping actionable process variables for improvement that could be candidates for Lean Six Sigma projects in construction;
- Looking at the system level value stream to determine the unique or shared elements of Six-Sigma and Lean Construction appropriate for construction industry.

INSTRUCTIONS FOR QUESTIONS

PART ONE determines general information about your company, such as name, age, expert areas, employees, turnover, experience of respondent and quality system accreditation.

PART TWO are questions related to company and top management strategies, quality programs, measurement systems, records, use of tool as well as company perceptions of quality, cost, performance and areas of improvement, customer and employee satisfaction, critical factors for company success, and investments in recent years and their success rate.

PART THREE is composed of questions about the construction process life cycle to collect information related to time and budget extensions, additional expenses, non value adding time, variability and other critical problems in processes, their effects, quality cost components (prevention, appraisal, and failure costs) and their contribution to additional expense.

The multiple choice questions can be answered with more than one option, and the respondent is encouraged to add his/her ideas to the given blanks in the tables. For the questions which is required to be answered in 0-9 scale:

"0" means "Not Applicable"

"1" means "very low"

"9" means "very high"

Your company will remain anonymous in the processing and dissertation of results.

Thank you for your time and attention.

PART 1

1. Company name:

2. For how many years is your firm in the construction sector?

1-5 years	6-10 years	11-20 years	Over 20 years

3. Number of technical and administrative personnel working in your firm:

Less than 50	Between 50-500	Between 500-1000	Over 1000

4. Approximate numbers of your permanent or temporary staff?

Temporary	
Permanent	

5. What kind of organization is your firm? Type of organization:

Private	Partnership	Joint venture	Government ownership

6. What kinds of clients does your firm have? Types of clients:

Companies	Developers	Government	Individuals

7. What are the annual domestic and overseas turnovers (2006) of your firm?

Domestic annual turnover	
Overseas annual turnover	

8. Do you have any system (tendering strategy) to control the increase or decrease in your turnover?

	YES
	NO

If your answer is YES, then read the following question.

9. What is the percentage of increase/decrease in your domestic and overseas turnover over the last 3 years?

	Domestic Turnover		Overseas Turnover	
	Increase	Decrease	Increase	Decrease
Last year				
2 years ago				
3 years ago				

10. What is the quality system of the company?

	ISO 9001 accredited
	In the process of obtaining the ISO 9000 accreditation
	With an in-house quality system
	TQM
	None

11. What types of projects does your company undertake? (you can select more than one)

Infrastructure	Industrial	Building	Housing	Rehabilitation	Highway	Public works

12. What percentage of your work is self-performed in contrast to sub-contracting?

0-10%	10-25%	25-50%	50-75%	75-100%

13. What is the experience level of the respondent in his/her profession?

1-5 years	6-10 years	11-20 years	Over 20 years

14. Which of the following categories describes your positions?

Field workforce	Field superintendent	Field manager	Project manager	Executive (CEO, President, VP, etc)

PART 2

15. What does your company's overall strategy include; please indicate the weight of the given components in 0-9 scale?

Strategy Components	**Weight (0-9)**
Vision	
Mission statement	
Company objectives and principles	
Innovation	
Research and development	
Profit	
Customer satisfaction	

16. How is your strategy implemented in your organization to have an effect on your employees; what is the effectiveness of this action; and how often does top management involve in these actions?

Action	**Indicate with a mark**	**Effectiveness (0-9)**	**Management Involvement (0-9)**
No formal implementation			
In house training			
Site coordination meetings			
Involvement in Annual Board Meetings			
Involvement in Executive Committee Meetings			
Vertical integration meetings			
Strategy deployment by setting individual targets			

17. a) Do all employees act in accordance with your strategy?

YES; but some of them	YES, all of them	NO

b) How do you control it; what is the effectiveness of this action; and how often does top management involve in these actions?

Control Action	Indicate with a mark	Effectiveness (0-9)	Management Involvement (0-9)
No control			
Control meetings			
Progress meetings			
Process audits			
Performance evaluation			

18. If your company has a set of objectives and principles, at which weight (0-9) do these objectives focus on the given concepts?

Concepts	Weight (0-9)
Project cost savings	
Process	
Specific problems	
Quality	
Customer satisfaction	
New investments	
Vertical integration	

19. Please rank "quality, safety, duration, cost, and scope" in ascending order of importance for the success of your company. (1-low / 5- high)

Quality	Safety	Duration	Cost	Scope

20. Please give the weight of the following concepts to define your organization's perception of quality?

Quality Definition concepts	Weight (0-9)
Elimination of defects	
A competitive advantage	
A tool to increase profit	
A formality	
Customer satisfaction	

21. Do you set your quality goals to the level of:

	Be the Leading company in your sector
	To a level set internally
	The competition in general
	To increase profit range

22. a) Does your company have a Quality Improvement Program (QIP)?

	YES
	NO

b) What are the major objectives of your QIP; please indicate the importance weight of this objective?

Objective	**Importance Weight (0-9)**
Compliance with statutory	
Fulfill a formality	
Fulfill a strategic decision	
Customer satisfaction	
Become a preferred bidder for	
Increase profit range by cost reduction	
Increase performance	
Increase quality	
Decrease arbitration	

23. a) How does the top management support your QIP?

Support of top management	No Support	Low Support	Medium support	High Support

b) If your answer is different than "no support", what is the weight and effectiveness of the given support activity and how often does top management involve in this support activity?

Weight (0-9)	**Support Activity**	**Effectiveness (0-9)**	**Management Involvement (0-9)**
	Conducting regular meetings		
	Training		
	Performance review meetings		
	Research and development		
	IT support		

c) After QIP success, does your company reward the employees?

YES; always	YES, but sometimes	NO

24. a) Does your company have <u>a measurement system</u> to check and control the variations (from planned to realized) and failures in the following concepts; how effectively does this measurement system work?

Measurement System	**Indicate with a mark**	**Effectiveness (0-9)**
Cost		
Time		
Quality		
Earned Value		
Material Flow		
Process Flow		
Labor Productivity		
Company performance		
Customer Satisfaction		
Employee Complaints		
Supplier performance		
Subcontractor performance		
Wastage		

b) After taking measures of the given concepts which of the given steps do you follow and what is the effectiveness of this action? (If you have different steps please indicate)

Indicate with a mark	**Steps**	**Effectiveness (0-9)**
	No action	
	Review	
	Evaluate	
	Brainstorming	
	Analyze	
	Prepare action list	
	Application	
	Control	
	Standardize	

25. a) How frequently do you take records of your procurements, inventories, material storage, labor performance, equipment condition, work in progress?

Records	**Frequency**					
	Daily	Weekly	Monthly	Semi Annually	Annually	
Procurement Records						
Inventories Records						
Material Storage Records						
Labor Performance Records						
Equipment Condition Records						
Work in Progress Records						

b) After taking records of the given concepts, which of the given steps do you follow and what is the effectiveness of this action? (If you have different steps please indicate)

Indicate with a mark	**Steps**	**Effectiveness (0-9)**
	No action	
	Review	
	Evaluate	
	Brainstorming	
	Analyze	
	Prepare action list	
	Application	
	Control	
	Standardize	

26. a) Do you have an updated historical background of the following items and what is its effectiveness?

Indicate with a mark	**Item**	**Effectiveness (0-9)**
	Material unit prices	
	Unit prices for work packages	
	Activity production rates	
	Labor productivity rate	
	Clients' (worked with you) strategies	
	Bidding experience	
	Project performance	
	Subcontractor performance	

b) For which purpose do you use this database, please indicate the weight of purpose?

Purpose	**Weight (0-9)**
For new investment decisions	
To develop new strategy	
To obtain new biddings	
To avoid risks	
To make more accurate planning	
To make more accurate cost estimating	

27. **a)** How does your organization generally solve the problems in your processes and what is the effectiveness of this action? (You can choose more than one and also add new solutions you used)

Indicate with a mark	Action	Effectiveness (0-9)
	Assign individuals to solve the problem	
	Set up a multi disciplinary team for each problem	
	A permanent project team is available	
	Gathering data and making statistical analysis	

b) After solving problems in your ongoing processes, do you standardize these solutions to apply for future projects and other business areas?

	YES
	NO

c) If your answer is "YES", which of the given steps do you follow to standardize these solutions?

Indicate with a mark	Steps	Effectiveness (0-9)
	Review	
	Evaluate	
	Brainstorming	
	Analyze	
	Prepare action list	
	Application	
	Control	
	Standardize	

28. **A flowchart** is a graphical representation of a process, representing the entire process from start to finish.

a) Do you use process flowchart in your business?

YES	NO

b) If you use flowcharts, what does it show? (Indicate with a mark)

Process inputs	Process outputs	Units of activities	Actions	Decision points

c) Since it represents the entire process from start to finish, what does this opportunity allow?

Highly detailed observation	Analysis of workflow	Optimization of workflow

29. **Process mapping** is a well-known technique for creating a common vision and shared experience and information for improving business results. Process maps are good for streamlining work activities and telling new people, as well as internal and external customers, "what we do around here."

a) Do you use process mapping in your business?

YES	NO

b) Which of the following items does your process map include?

Indicate with a mark	Process map item
	Sequence of events
	Waiting times
	Delays
	Information about who is doing what and with whom
	Information about who is doing what and when
	Information about who is doing what and for how long
	Decisions that are made
	Change orders

c) Why do you prefer process mapping? (You can choose more than more option)

	Make work in progress visible
	Create a common vision
	Contribute sharing experience and information
	Allow controlling work in progress
	Decrease confusion about work done

30. How do you measure customer satisfaction?

Weight (0-9)	Action	Effectiveness (0-9)
	Not measured	
	Questionnaire survey	
	Face to face interview	
	By the number of complaints	
	Follow up reports	

31. At what percentage does your customer satisfy with the following concepts?

Concepts related to customer satisfaction	Satisfaction rate (0-9)
Knowledge of customer requirements	
Attention to customer priorities	
Relations with customer	
Arbitration	
Legal issues	
Adequacy of project control	
Adequacy of project planning	
Timely completion of project	
Project cost within the budget	
Adequacy of processing change orders	
Adequacy of project quality	
Adequacy of warranty	
Adequacy of maintenance	

32. a) Do you have a system for gathering customer expectations?

	YES
	NO

b) If your answer is “YES”, what is the weight and effectiveness of the given actions to gather customer expectations?

Weight (0-9)	Action	Effectiveness (0-9)
	Questionnaire survey	
	Regular meetings	
	Interviews	

33. At what weight (0-9) does top management use the given motivation factors to motivate the employees?

Leadership	
Communication	
Target setting and appraisal	
Career development	
Empowerment	
Equal opportunities	
Involvement	
Recognition and reward	

34. a) Does your top management provision all employees the following incentives for their conformity to strategic target and performing their tasks safely, timely, and with high quality?

Incentives	YES; always	YES, often	YES, sometimes	YES, rarely	NO
Salary increase					
Project bonus					
Promotion					

b) What is the effect of this provision for the success of your company?

Criteria	**Effect (0-9)**
No key effect	
Higher performance	
Higher productivity	
Higher quality	
Higher Customer satisfaction	

35. a) How often does the top management provide the employees essential training opportunities to match their competencies with the company?

NO training	Monthly	Semi annually	Annually

b) Training given to employees includes:

Training List	**Indicate with a mark**
Process management	
ISO 9000	
TQM	
Six Sigma	
Lean Construction	
Graphical and statistical analysis	
Total productivity maintenance	
Labor law	
Quality circles	
Quality improvement team methodology	
Environmental management system	
Suggestion system	
Problem solving techniques	
Management improvement program	
Benchmarking	
Accounting economics	

36. How do you measure employee satisfaction?

Weight (0-9)	**Action**	**Effectiveness (0-9)**
	Not measured	
	Questionnaire survey	
	Face to face interview	
	By the number of complaints	

37. At what percentage does your employee satisfy with the following concepts?

Concepts related to employee satisfaction	**Satisfaction rate (0-9)**
Knowledge of employee requirements	
Adequacy of motivation	
Relations and communication with employee	
Adequacy of leadership facilities	
Legal issues	
Adequacy of salary	
Adequacy of training	
Adequacy of promotion	
Adequacy of reward	
Adequacy of labor shift planning	
Adequacy of suggestion system	
Adequacy of safety precautions	

38. **a)** Does management play an active role to develop good relations with supplier?

YES; always	YES, but sometimes	NO

b) If your answer is "YES", which of the following supportive actions does your management undertake to develop good relations with supplier and what is the effectiveness of this action?

Supportive actions for good supplier relations	**Indicate with a mark**	**Effectiveness (0-9)**
Visits to supplier abroad		
Visit to domestic supplier		
Supplier days		
Systems/Process auditing		
Development of supplier		
Financial support		
Sector meetings		
Open door meetings		
Meetings to determine supplier requirements		
Meetings to plan improvement activities		
Common problem solving techniques		

39. **a)** Does your company make self-assessment?

YES, but not always	YES; always	NO

b) If your answer is "YES", how often does your company use the following methods for self assessment?

Self-assessment methods	**Weekly**	**Monthly**	**Semi annually**	**Annually**
Questionnaire survey				
Checklist				
Workshop				
Interview				

40. The critical factors occur in each section related to company success are shown in the following table. Firstly, please give a weight to the given critical factors in each section according to the importance level for company success; and then evaluate the success of your company according to these critical factors.

Sections	Critical factors related to company success	Importance (0-9)	Company Success (0-9)
Administrative	Relationship between company departments		
	Adequacy of office personnel		
	Project cost within the budget		
	Knowledge of customer needs		
	Attention to customer priorities		
	Customer satisfaction		
	Adequacy of supervision		
	Coordination with regularity agencies		
	Relations with other organizations		
	Adequacy of planning		
	Adequacy of training		
Engineering and Project Management	Progress review meetings		
	Adequacy of project control		
	Adequacy of safety program		
	Estimating		
	Interaction with architect/engineer		
	Scheduling		
	Adequacy of supervision		
	Shop drawing review		
	Adequacy of planning		
	Adequacy of subcontractor selection		
Logistical	Adequacy of storage		
	Adequacy of warehousing		
	Adequacy of delivery		
	Adequacy of maintenance		
	Adequacy of transportation		
Construction	Project quality		
	Adequacy of job site personnel		
	Material quality		
	Quality of workmanship		
	Equipment quality		
	Timely completion of project phases		
	Knowledge of the project		
	Site cleanliness		
	Adequacy of processing change orders		
	Project closeout		

41. What has top management done in the past five years that was successful in improving company performance, please indicate the monetary weight of this action; and what is the success rate of this action in improving company performance?

Action List	Monetary Weight (0-9)	Success Rate (0-9)
Training		
Machinery investment		
Investment in IT		
Investment in human resources		
Investment in R&D		
Recruiting new experienced and skilled staff		
Increasing salaries		
Increasing motivation activities		
Increasing safety precautions on site		

42. 1st column: Please indicate the importance weight (0-9) of the improvement areas in your business.

2nd column: Please evaluate the improvement areas for the improvement potential in your business.

3rd columns: Please indicate the weight of improvement on the improvement areas in the past five years.

Improvement Areas	Importance Weight (0-9)	Improvement Potential (0-9)	Improvement Weight (0-9)
Decrease arbitration			
Improve quality management			
Improve claim management			
Increase customer satisfaction			
Improve personnel management			
Improve cash flow			
More accurate cost estimating			
More accurate financial analysis			
More accurate cost control			
More accurate planning			
Good coordination with subcontractor and supplier			
Reduction of warranty claims			
Reduction of change orders			
More accurate on site supervision			
Increase market share			
Improve design			
Improve productivity			
Reduction of law suit			
Higher profit			
More accurate testing procedures at job sites			
Decrease scrap and rework			
Increase on site safety			

PART 3

43. A general construction life cycle is given below. Please give the estimated durations and the percentages of budget allocated for each stage and indicate the percentages of cases where the actual durations and budget exceed the estimated values.

Main process	Sub process	Estimated Duration	% of cases where the actual durations exceed the estimates	% of estimated budget	% of cases where the actual budget exceed the estimated value
Feasibility	Project description				
	Feasibility studies				
	Strategy design and approvals				
	Financial facts				
Planning And Design	Basic design				
	Cost and schedule				
	Contract terms and conditions				
	Detail planning/design				
	Working drawings				
	User manuals and operational catalog preparation				
Implementation	Manufacturing/production				
	Delivery				
	Construction				
	Erection/installation				
	Testing				
Handover And Commissioning	Final testing				
	Certification				
	Maintenance				

44. Please indicate the weight (0-9) of value added time (the real time needed to perform that specific task), reprocess/rework time, inspection time, move time, wait time, and idle time components of the estimated process durations.

Main Process	Sub Process	Estimated Duration	Value added time	Reprocess Or Rework time	Inspection Time	Move Time	Wait Time	Idle Time
			(0-9)	(0-9)	(0-9)	(0-9)	(0-9)	(0-9)
Feasibility	Project description							
	Feasibility studies							
	Strategy design and approvals							
	Financial facts							
Planning And Design	Basic design							
	Cost and schedule							
	Contract terms and conditions							
	Detail planning/Design							
	Working drawings							
	User manuals and operational catalog preparation							
Implementation	Manufacturing/Production							
	Delivery							
	Construction							
	Erection/Installation							
	Testing							
Handover And Commissioning	Final testing							
	Certification							
	Maintenance							

45. In the following tables, the prevention, appraisal, internal failure and external failure cost components are given. Please give a weight (0-9) for the occurrence rate of the given cost components during your processes.

Prevention Cost Components	**Weight (0-9)**
Design reviews and Planning	
Process study	
Education	
Training	
Supplier selection surveys and evaluation	
Capability reviews	
Process improvement projects	
Field testing	
Procedure writing	
Market analysis	

Appraisal Cost Components	**Weight (0-9)**
Checks and grading to ensure specifications are met	
Measuring	
Evaluating	
Auditing products to determine whether they conform to requirements	
Inspections	
Material reviews	
Calibration of measuring	
Equipment testing	
Laboratory testing	
Personnel testing	

Internal Failure Cost Components	**Weight (0-9)**
Scrap allowances	
Overhead associated with production	
Compensation for delays	
Failure reviews	
Redesign	
Re-inspection	
Repair cost	
Re-testing	
Rework	
Engineering changes	
Project complexity	
Inaccurate planning	
Inaccurate estimating	

External Failure Cost Components	**Weight (0-9)**
Handling of non-conforming products	
Repair or replacement of non-conforming products	
Pricing errors	
Warranty charges	
Product liability cost	
Dealing with complaints	
Dealing with compensation	
Loss of future business through customer dissatisfaction	
Equipment downtime	
Excess inventory	
Excess travel expense	
Excess material handling	
Penalties	

46. Please indicate the occurrence weight of the Prevention, Appraisal, Internal and External Failure Costs in 0-9 scale during your processes according to your experiences and projects?

Main Processes	**Sub-processes**	**Occurrence Weight of below costs (0-9)**			
		Prevention Cost	Appraisal Cost	Internal Failure Cost	External Failure Cost
Feasibility	Project description				
	Feasibility studies				
	Strategy design and approvals				
	Financial facts				
Planning And Design	Basic design				
	Cost and schedule				
	Contract terms and conditions				
	Detail planning/Design				
	Working drawings				
	User manual and operation catalog preparation				
Implementation	Manufacturing/ Production				
	Delivery				
	Construction				
	Erection/ Installation				
	Testing				
Handover And Commissioning	Final testing				
	Certification				
	Maintenance				

47. Firstly, please fill the following table by giving the weight of additional expense (A.E.) in percentage compared to actual budget (A.B.) of the processes and then give a weight for the contribution of Prevention, Appraisal, Internal Failure, and External Failure Costs to the Additional Expense in 0-9 scale; according to your own experiences and projects?

Main Processes	**Sub-processes**	Weight of A.E. on A.B. (%)	**Contribution of below costs to additional expense (0-9)**			
			Prevention Cost	Appraisal Cost	Internal Failure Cost	External Failure cost
Feasibility	Project description					
	Feasibility studies					
	Strategy design and approvals					
	Financial facts					
Planning And Design	Basic design					
	Cost and schedule					
	Contract terms and conditions					
	Detail planning/Design					
	Working drawings					
	User manual and operation catalog preparation					
Implementation	Manufacturing/Production					
	Delivery					
	Construction					
	Erection/Installation					
	Testing					
Handover And Commissioning	Final testing					
	Certification					
	Maintenance					

48. On the following tables, in addition to the general problem categories seen in the construction industry, critical problems under each category are given. Please give a weight (0-9) to each problem for the occurrence rate in the given category.

Management related problems	**Weight (0-9)**
Limitations of management to foresee problems and develop effective countermeasures	
Ineffective utilization of resources	
Ineffective utilization of acquired knowledge and skills associated with previous projects	
Poor management who induces unnecessary changeability in construction conditions	
Slow in making decisions and giving instructions	
Slow in processing and reviewing submittals, purchase orders and other paper works.	
Poor communication between office and field	
Improper management methods	
Ordering errors	
Variation in orders	
Poor prevision of information to project participants	
Resistance to change at management level	
Lack of cost control and accounting	

Planning related problems	**Weight (0-9)**
Lack of construction planning	
Disturbances in personnel planning	
Lack of procurement and delivery planning	
Lack of pre task planning	
Lack of job planning	

Design related problems	**Weight (0-9)**
Mistakes in design	
Lack of coordination of design	
Design changes and revisions	
Detail errors	

Quality related problems	**Weight (0-9)**
Poor workmanship due to the lack of care and knowledge	
Defective workmanship	
Lack of supervision poor quality	
Lack of quality control	

Documentation related problems	**Weight (0-9)**
Mistakes in specifications	
Unclear specifications	
Omissions/errors in contract documentation	
Unclear and missing site documentation	
Unclear site drawings	
Slow drawing revisions and distribution	
Lack of required clarification	
Poor quality site documentation	
Inaccuracy of quantity take off	

Inspection related problems	**Weight (0-9)**
Inexperienced inspectors	
Careless inspector procedures	
Supervision too late	
Inspection delays	

Labor related problems	Weight (0-9)
Lack of skilled and experienced labor	
Improper crew utilization	
Insufficient labor work separation	
High labor turnover	
Labor strikes and absenteeism	
Poor labor productivity	
Labor errors due to the lack of attention to details	
Poor distribution of labor	
Too much overtime of labor	
Crew Interference	
Unnecessary movement of workers	

Material related problems	Weight (0-9)
Improper storage	
Improper material handling on/off site	
Poor material allocation	
Late material fabrication and delivery	
Damaged material on site	
Loss of material on site	
Improper material to specifications	
Poor quality of material	
Improper/misuse of material	
Inaccuracy of material estimate	

Equipment related problems	Weight (0-9)
Equipment breakdowns	
Waiting for equipment arrival	
Waiting for equipment installations	
Waiting for equipment repair	
Lack of proper equipment	
Idle time for equipment	

Subcontractor related problems	Weight (0-9)
Slow/ineffective subcontractor	
Lack of subcontractor's skill and experience	
Subcontractor errors	

Construction site related problems	Weight (0-9)
Poor skills of site management	
Change orders	
Failures in setting out	
Delays to schedule	
Unavailability of resources (labor, material, equipment, vs.) on site	
Outdoors operation and uncertain ground and weather conditions	
Environmental effects	
Excessive accidents on site	
Waiting for instructions	
Over manning and congested work areas	
Lack of progress	
Lack of safety	
Inappropriate construction methods	
Unavailability of a proper feedback system	
Poor site layout	

Project related problems	Weight (0-9)
Project uniqueness (size and complexity)	
Lack of project type experience	

49. On the following tables, problem categories, which are general sources of variability (from planned to actual), seen in the construction industry, and possible effect of these critical problems are given.

a) Firstly, please give **a weight (0-9)** for **the frequency** according to the occurrence rate of given variability source on the given processes.

Main Process	**Sub Process**	**Problem Categories**											
		Management Prrb	Planning Prb	Design Prb.	Quality Prb	Project Prb	Documentation Prb	Labor Prb	Material Prb	Equipment Prb	Subcontracto Prb	Inspection Prb	Construction Site prb
Feasibility	Project description												
	Feasibility studies												
	Strategy design and approvals												
	Financial facts												
Planning And Design	Basic design												
	Cost and schedule												
	Contract terms and conditions												
	Detail planning/design												
	Working drawings												
	User manual and operation catalog preparation												
Implementation	Manufacturing/ Production												
	Delivery												
	Construction												
	Erection/ Installation												
	Testing												
Handover And Commissioning	Final testing												
	Certification												
	Maintenance												

b) Then give a weight (0-9) for the given effect of these critical problems according to your own experiences and projects.

Problem Categories	**Effect Weight (0-9)**						
	Money Loss	**Time Loss**	**Quality Loss**	**Performance Loss**	**Productivity Loss**	**Customer Loss**	
Management related problems							
Planning related problems							
Design related problems							
Quality related problems							
Project related problems							
Documentation related problems							
Labor related problems							
Material related problems							
Equipment related problems							
Subcontractor related problems							
Inspection related problems							
Construction site related problems							