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Six Sigma within Construction Context

As a Quality Initiative, Performance Indicator/Improver, Management Strategy

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Abstract

Six Sigma was developed in 1980s in manufacturing industry and became popular as a process improvement method. However, the adoption of this concept is new in construction industry and the aim of this study is to evaluate Six Sigma as a process improvement method within construction context.

This thesis includes Literature Review and three interviews. Literature Review had discussed process improvement methods used in construction industry and analyzed the basic features and principles of Six Sigma. Three interviews were conducted about the basic principles of Six Sigma and Quality Concept. Interviewers are a Project Manager, Field and Cost Engineer. The approach of the interview to Six Sigma is based on quality, performance and management aspects.

This study defends that there is no doubt about the positive effects of Six Sigma on construction projects. Particularly, Six Sigma can provide a broader quality concept, detailed performance measurement, coordinated and repeatable process/performance improvement. It has increased quality directly/indirectly and has positive effects on production efficiency. As a

management approach, Six Sigma is discussable within construction context due to differences of manufacturing and construction industry. Since construction industry includes lots of unrepeatable tasks and different process design techniques, Six Sigma does not seem applicable as a whole management approach in construction industry. Furthermore, it can be integrated to the existing management procedures of companies. Taking everything into consideration, it is obvious that Six Sigma has a lot in order to accelerate fundamental and cultural challenges construction industry needs.

Sammanfattning

Sex Sigma utvecklades inom tillverkningsindustrin under 80-talet och blev snabbt populär som en metod för processförbättring. Att föra in detta koncept i byggbranschen är nytt och syftet med denna studie är att utvärdera Sex Sigma som en metod för processförbättring inom byggindustrin.

Denna avhandling omfattar en litteraturstudie och tre intervjuer. I litteraturstudien diskuteras möjligheter att förbättra byggnadsindustrins tillverkningsmetoder och där analyseras även de grundläggande funktionerna och principerna för Sex Sigma. Totalt tre intervjuer genomfördes gällande de grundläggande principerna för Sex Sigma och dess koncept för kvalité. Intervjupersonerna är en projektledare, en projektingenjör och en kalkylator. Tillvägagångssättet för intervjuerna gällande Sex Sigma berör aspekter inom kvalitet, prestanda och ledning av projektet.

Denna studie bevisar att det inte finns något tvivel om att Sex Sigma har positiva effekter på byggprojekt. Mer specifikt kan Sex Sigma ge ett bredare koncept inom kvalité, detaljerad resultatmätning, samordning och återkommande processer/prestandaförbättringar. Den ökar kvalitén både direkt och indirekt samt har positiva effekter på effektiviteten i produktionen. Som ett ledningsverktyg är Sex Sigma omdiskuterat inom byggsammanhang på grund av skillnaderna mellan tillverknings- och byggindustrin. Eftersom uppgifterna inom byggbranschen ej återupprepas och det finns olika processtekniker för design så är Sex Sigma i sin helhet inte tillämpbar som styrmetod inom byggbranschen. Dock kan det integreras för att komplettera företagens befintliga administrativa verktyg. Med samtliga parametrar i beaktande är det uppenbart att Sex Sigma har goda förutsättningar att driva på förändringsarbetet för de fundamentala och kulturella skillnaderna inom branschen.

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Stockholm, spring of 2012

Muharrem Firat Yilmaz

Abbreviations Lists

Abbreviations	Term
DPM:	Deputy Project Manager
FE:	Field Engineer
CE:	Cost Engineer
SPICE:	Standardized Process Improvement for Construction Enterprises
TQM:	Total Quality Management
DMAIC:	Define, measure, analyze, improve, control
DFSS:	Design for Six Sigma
CTQ:	Critical to quality

List of Tables

List of Figures

Table of Contents

1. Introduction

1.1. Research Problem

Total Quality Management which is a management philosophy, focuses on continually work processes (Boddy, 2009). Particularly, Six Sigma became a useful method as a performance indicator and process improver for the companies from different industry. Increasing numbers of companies start to integrate the full implications of Six Sigma (Lloréns-Montes and Molina, 2006).

Six Sigma is a quality improvement technique based on statistics, was used firstly by Motorola in the 1980s. It helps to decrease costs, increase quality by improving process and reduce the production time (Lloréns-Montes and Molina, 2006). Six Sigma has statistical and business perspectives and its applications are improved by Six Sigma Academy (Lloréns-Montes and Molina, 2006).

However, construction work has fragmented and project-oriented work processes compared to the manufacturing industry (Han et al., 2008). So, the evaluation of Six Sigma within construction context becomes an interesting research question considering quality, performance and management aspects.

That's why, this study discusses Six Sigma as a process improvement method through some research questions and tries to understand its features and implications as a quality initiative, performance indicator/improver and management strategy.

1.2. Purpose & Objective of the Research

The purpose of this study is to analyze Six Sigma within construction context and evaluate its features through Literature Review and Interviews. This thesis aims at understanding the needs of construction industry from process improvement perspectives and matches these needs with the expected outcomes of Six Sigma.

The objective of this study is to create useful and scientific knowledge about Process Improvement and Six Sigma for construction industry.

1.3. Scope of the Study

Six Sigma can be implemented in different types of construction projects and site environment such as: transportation, water, power plant, structure, industrial and residential projects. That's why; this research will not focus on any special project types.

Furthermore, this study will attempt to cover site and office based operations of construction projects. Considering the mentality differences between project managers, site and office engineers, it is important to reflect their ideas and perspectives about process improvement.

2. Methodology

In order to reach a result of this evaluation several sub research questions will be answered theoretically and empirically.

- What kind of Process Improvement methods can be used by construction companies? (Literature Review)
- What is the basic concept of Six Sigma? (Theory, Methodologies, Metrics, Belts System, Deployment & Implementation) (Literature Review)

- What are theoretical similarities and dissimilarities between Six Sigma and Construction context (i.e. the prerequisites for implementing Six Sigma in construction)? (Analysis & Findings)

- What are the major barriers for Six Sigma applications regarding construction projects? (Analysis & Findings)

- What are the expected benefits of construction professionals from an ideal process improvement method? (Analysis & Findings)

- What kind of benefits can Six Sigma provide for construction industry? (Analysis & Findings)

- What can be done better for successful Six Sigma implementation within the construction context? (Analysis & Findings)

- How Six Sigma has been evaluated considering financial and technical aspects by construction professionals? (Analysis & Findings)

- What are the major implications of Six Sigma based on quality, performance and management aspects? (Conclusion)

This thesis is structured as follow:

Literature review attempts to discuss Process Improvement and Six Sigma considering technical and financial perspectives specializing on construction industry. Definition, methodologies, metrics, belt system, deploying and implementation of Six Sigma will be discussed in this part.

Analysis/Findings include three interviews. The aim of interviews was to understand the perception of construction professionals from a quality management procedure and process improvement.

Interviews were conducted with a Deputy Project Manager, a Lead Field and a Lead Cost Engineer. The interviewers have basic level knowledge of Six Sigma even though none of them attended Six Sigma training session. Their comments were used in order to approach Six Sigma as a business strategy, performance indicator and quality initiative & improver.

Interview part includes five main parts:

- Definition & Adoption
- Theory
- Implementation
- Resistance
- Benefits

After these five parts, analyze of interview and findings are presented in three parts:

- Six Sigma as a Quality Initiative
- Six Sigma as a Performance Indicator/Improver
- Six Sigma as a Management Strategy

Conclusion gives the answer of main implications of research by the results of Literature Review and Analysis & Findings.

Reflections/ Recommendations for further Research attempts to give useful ideas for future study about process improvement and Six Sigma. Additionally, this part includes author`s reflections about this study.

3. Six Sigma

3.1. Process Improvement in Construction

Produce something with equal or better quality with lower cost is the purpose of process improvement in construction industry. However, there are few systematic approaches which are looking to attain total quality and lead to process improvement in the construction industry (Stewart and Spencer, 2006).

Process improvement methods under Total Quality Management includes (Stewart and Spencer, 2006):

- Process Cost Model
- Standardized Process Improvement for Construction Enterprises (SPICE)
- The Balanced Scorecard
- Kaizen
- Statistical Process Control

3.1.1. Process Cost Model

Quality costs are one of the most important success factors of a quality management system. So, poor quality impact on cost and performance should be measured in order to warn company management who can realize preventive actions and beneficial activities (Aoieong et al., 2002). For that, Measurements of quality costs by Process Cost Model have been introduced by (Aoieong et al., 2002) for construction industry.

The main purpose of this model is to measure quality costs of specific processes rather than the quality costs of total project (Tang et al., 2004). Process Cost Model which uses financial theory, is a process-oriented perspective for customer satisfaction and continuous process improvement (Stewart and Spencer, 2006).

The weak point of this method is to use financial metrics which cannot monitor and measure multiple dimensions of performance properly (Stewart and Spencer, 2006).

3.1.2. Standardized Process Improvement for Construction Enterprises (SPICE)

SPICE as a process improvement framework are proposed by (Sarshar et al., 1999) in order to look beyond financial measures (Stewart and Spencer, 2006). The main focus of this method is to measure performance considering process maturity, their strengths and weaknesses (Sarshar et al., 2004).

Capability Maturity Model which was developed by Carnegie Mellon University is a process improvement tool for software industry and was reused within the construction context (Sarshar et al., 1999). SPICE was established on the principles of Capability Maturity Model and evaluates process success as a function of organization maturity (Stewart and Spencer, 2006).

3.1.3. The Balanced Scorecard

(Kaplan and Norton, 1992) introduced The Balanced Scorecard in order to link performance and measures. This method provides a balanced looking to project performance and measures different perspectives of performance (Stewart and Spencer, 2006).

The Balanced Scorecard looks business from four different perspectives (Kaplan and Norton, 1992):

- Customer perspective
- Internal perspective
- Innovation and Learning perspective
- Financial perspective

However, (Sommerville and Robertson, 2000) mentioned the existence of resistance forces to the adoption of holistic Total Quality Management approaches in the construction industry. That's why; the implementation of this method might be difficult in the construction industry.

3.1.4. Kaizen

Kaizen is another process improvement perspective which was developed by Japanese and has contributed their economic growth considerably (Stewart and Spencer, 2006).

Eliminating wastes, managing time & cost and reduction of services values are the main aim of Kaizen (Atta, 1999). However, the integration of Total Quality Management and Kaizen might be difficult since the aims and ideas of them are similar to each other (Stewart and Spencer, 2006).

3.1.5. Statistical Process Control

Statistical Process Control is used in order to follow and improve the manufacturing processes and operations and has an important role in the quality improvement processes (Woodall, 2000). The focus of this model is to analyze process defects and reduce them by root cause analysis and problem solving methods (Stewart and Spencer, 2006).

Statistical Process Control which is based on data-oriented and decision making analysis , helped the evolution of Six Sigma (Stewart and Spencer, 2006).

3.2. Definitions of Six Sigma

Six Sigma which started by Motorola, had received huge interest by professionals after General Electric and Allied Signal has achieved cultural challenges within their organizations (Pheng and Hui, 2004). After these achievements, many books and papers have been published. Some of these studies defined Six Sigma regarding their own perspectives:

- "A disciplined method of using extremely rigorous data gathering and statistical analysis to pinpoint sources of errors and ways of eliminating them" (Harry and Schroeder, 2000).
- "A strategic approach that works across all processes, products, company functions and industries" (Snee, 2000).
- "A business strategy and a systematic methodology, use of which leads to breakthrough quantum gains in product/service quality, customer satisfaction and productivity" (Antony and Banuelas, 2002).
- "A business strategy that focuses on improving customer requirements understanding, business systems, productivity, and financial performance" (Kwak and Anbari, 2006).
- "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" (Pheng and Hui, 2004).

3.3. Six Sigma Methodologies

Six Sigma has two key methods (Kwak and Anbari, 2006):

- DMAIC process (Define, measure, analyze, improve, control).
- DFSS methodology (Design for Six Sigma)

DMAIC is for existing processes which requires significant improvement due to falling below expected quality specification (Forbes and Ahmed, 2009). DFSS as a systematic methodology is for designing new products and/or process at Six Sigma quality levels (Kwak and Anbari, 2006).

DMAIC methodology and its main steps are explained by (Stamatis, 2003) and these steps are summarized below.

Define, first stages of DMAIC is for team forming, determining the responsibilities of team members, establishing team goals and review the process steps, basic steps are (Stamatis, 2003):

- Define the problem: Problem should be based on measurable data and specific
- Identify the customer: Identification of the customer includes the analyses of problem impacts and a detailed analysis of COPQ (Cost of poor quality).
- Identify CTQ characteristics: Identification of CTQ (Critical to quality) is the determination of the important issues for customers.
- Map the process: A visual representation of the existing process should be prepared in order to look beyond functional activities and core process.

- Scoping the project: Reduction of project scope is the main focus of this step. Determination of specific project issues, a problem statement and brainstorm session are the purposes of scoping the project.

Measure, second stage of DMAIC, is for having a plan for data collection, preparing a sufficient data sample and preliminary analysis of this sample. In this stage, Six Sigma team analyzes current performance through valid data in order to understand improvement opportunities and identify KPIV (Key process input variables) , basic steps are (Stamatis, 2003):

- Identify measurement and variation: Types, sources, causes and detailed impacts of variation on process should be defined by the establishment of measurement.

- Determine data type: Six Sigma team should define data types that will be collected. The main focus is to decide what kind of data and knowledge required for process improvement.

- Develop a data collection plan: Data collection plan provides data collection responsible and data displaying formats.

- Perform measurement system analysis: Graphical and baseline analysis should be performed through MSA (Measurement System Analysis) in order to be sure that data collection plan works accurately and collected data are confidential.

- Collect the data: Collected data should be proper and provide enough information to Six Sigma team in order to determine root causes of the problem.

Analyze, thirds stages of DMAIC is for finding the root causes of defects, right approach styles to data and improvement opportunities, basic steps are (Stamatis, 2003):

- Perform capability analysis: Baseline capability should be realized in order to understand performance level of the process.

- Select analysis tools: Six Sigma team should control the graphical analysis and decide which tools will be used in order to find the details of variation and performance.

- Apply graphical analysis tools: A visual performance indications should be realized through graphical analysis techniques.

- Identify sources of variation: Statistical tools are used in order to define the variations sources. The main focus in this step is to find and repair significant variations.

Improve, fourth stages of DMAIC, is for designing, implementing and validating the improvements. This stage includes FMEA (Failure Mode and Effect Analysis), a preliminary cost/benefit analysis and preparation of necessary actions, basic steps are (Stamatis, 2003):

- Generate improvement alternatives: Focus of this step is to define, generate and evaluate the possible improvements.

- Create a "should be" process map: Mapping of best improvement opportunities should be realized by Six Sigma team.

- Conduct FMEA (Failure Mode and Effect Analysis): This analysis is used in order to make the situation analysis of “before the failure”.

- Perform a cost/benefit analysis: Cost/Benefit analysis is the comparison between expected benefits and improvements costs.

- Conduct a pilot implementation: The implementation of planned improvements should be conducted on a small scale.

- Validate improvement: Sigma values before and after “Improve Stage” should be compared in order to understand the effect of process improvement.

Control, last stage of DMAIC, is for the institutionalization of process/product improvements and following performance. This is a transition phase of process from Six Sigma team to original executers under detailed control plan, basic steps are (Stamatis, 2003):

- Mistake-proofing: Remove the error possibilities is the main focus of this step. It is important to remove errors before provoking defects in the process.
- Long-term MSA (Measurement System Analysis): Data collection should be distributed over the long-term in order to measure and monitor inputs/outputs of process improvements through Measurement System Analysis.
- Appropriate and applicable charts (statistical process control): Graphical representation of process should be realized in order to control processes with lower and upper limits.
- Reaction plan: That is a detailed plan of controlling issues and necessary actions if the revised process is no longer under control.
- The new or revised SOPs (standard operating procedures): Six Sigma team should periodically revise the existing documents and procedures in order to reflect improvements results.

If the existing products/processes have inherently defective designs, DMAIC methods cannot be successful to repair them. However, DFSS can be successful on new products/process developments and meet customer expectations for performance, quality, reliability and cost (Sleeper, 2005).

Due to being relatively new, DFSS has more than one road-map in use(Sleeper, 2005). Some of them are:

- ICOV (Identify, Characterize, Optimize, and Verify) (El-Haik and YANG, 2003).
- CDOV (Concept, Design, Optimize, Verify) (Creveling et al., 2003).
- DMADV (Define, Measure, Analyze, Design, Verify) (Brue and Launsby, 2003).
- PIDOV (Plan, Identify, Design, Optimize, and Validate) (Brue and Launsby, 2003).

In the scope of this study, PIDOV is summarized through (Sleeper, 2005):

- Plan: Developing goals and metrics for Six Sigma projects considering VOC (Voice of the Customer) is the main focus of this phase. DFSS team should decide which ideas will be developed and how they will be structured.
- Identify: Identification of product concepts which can satisfy customer requirements is the main purpose. Focusing on VOC (Voice of the Customer) by the way right tools is the prerequisite of success.
- Design: New products and process should be designed by engineers based on functions and statistics. Drawings and specifications has to be developed in this step.
- Optimize: Creating a balance between quality and cost is the main issue. Statistical methods are used in this phase in order to make products and processes less sensitive to variations.
- Validate: Data should be collected from prototypes and appropriate tests should be conducted in order to validate customer requirements. The balance between quality and cost has to be controlled through Statistical Process Control tools and methods.

3.4. Metrics & Belt System

Six Sigma metrics measures defects rate without considering the complexity of the products and processes. Sigma concept as an international quality measurement technique was started by Motorola and better processes with few defects rates have higher sigma values (Pheng and Hui, 2004).

Basic Sigma Conversion Table		
Yield=Percentage of items without defects	Defects per million opportunities (DPMO)	Sigma Level
30.9	690 000	1
69.2	380 000	2
93.3	66 800	3
99.4	6 210	4
99.98	320	5
99,9997	3.4	6

Table 3-1 Basic Sigma Conversion Table (Pheng and Hui, 2004)

For instance; four sigma level mean that product satisfies requirements at 99, 4 % of the time and products numbers with defects are 6 210 (Table 3.1).

Belt System which is a hierarchy between experts, is another challenge created by Six Sigma. Six Sigma team members are: Executive Leader, Executive Champion, Deployment Champion, Project Champion, Master Black, Black and Green Belt (Chowdhury, 2001).

The definitions of belts are (Basu and Wright, 2003):

- Master Black Belts (MBBs) have high level understanding of the Six Sigma projects, and DMAIC/DFSS. They can mentor Green Belts.
- Black Belt (BB) includes on-site project and off-site classroom activities and its training takes five months.
- Green Belts (GB) who have the basic knowledge of Six Sigma and DMAIC/DFSS work with Black Belts. Training of Green Belts takes approximately seven weeks.

- External consultants are mostly experienced trainers and take roles on establishment and management of first deployment plan.

The hierarchy relations between belts are (Basu and Wright, 2003):

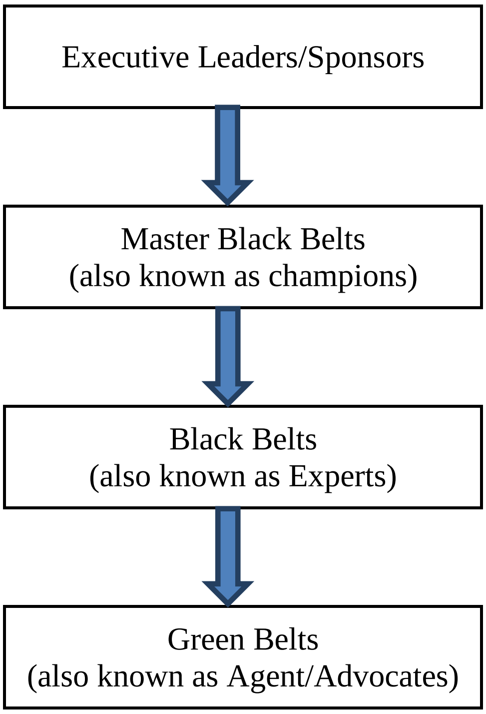

Figure3-1 The structured approach of Six Sigma & Belt Relations (Basu and Wright, 2003).

Due to belt system, team members use the same technical terms and it makes the deployment and implementation of Six Sigma much easier within the company (Antony and Banuelas, 2002).

3.5. Deploying & Implementation

(Hahn, 2005) prepared twenty key lessons learned from the deployment of Six Sigma in General Electric. These tips are the mix of published articles and his experiences, these key lessons are (Hahn, 2005):

- The time is right: Six Sigma is very popular since its concept includes the combination of competitive pressures and management recognition of Cost of Poor Quality (COPQ).

- The enthusiastic commitment of top management is essential: Mostly, quality improvement have been applied by lower or middle managers. However, Six Sigma are introduced by executive managers of the companies.

- Develop an infrastructure: Six Sigma needs a formal infrastructure which should include the definitions of key objectives & responsibilities, development of budget and measurement techniques.

- Commit top people: Implementers of Six Sigma should be imaginative and persuasive employers who are also the candidates for management positions.

- Invest in relevant hands-on training: The engagement of knowledgeable trainer to training processes is a prerequisite for the successful implementation of Six Sigma.

- Select initial projects to build credibility rapidly: Selection of right projects for the beginning of Six Sigma increases the momentum within company.

- Make it all pervasive, and involve everybody: Involvement of everybody to Six Sigma implementation makes faster the integration.

- Emphasize Design for Six Sigma (DFSS): DFSS is very vital since the process design has a fundamental role on the product quality.

- Do not forget design for reliability: Design for reliability which aims to increase long-term quality is very important

- Focus on the entire system: Even though, Six Sigma focuses on specific CTQs at the beginning, the main focus should be on the entire system and overall performance improvement.

- Emphasize customer critical to quality characteristics (CTQs): External improvements which target customer CTQs is important as well as internal improvements.

- Include commercial quality improvement: Quality improvement should be extended from transactional to commercial quality.

- Recognize all savings: Recognition of all savings is very important in order to see the real financial effects of Six Sigma.

- Customize to meet business needs: Six Sigma is applicable to all processes. However, right tools for specific process and proper planning for different kind of process are very vital.

- Consider the variability as well as the mean: Reducing variations is one of the main goals of Six Sigma in addition to improving the mean.

- Plan to get the right data: Continuous data collection and procurement system for entire system is better than data collection for specific problems.

- Beware of dogmatism: Adaptation of Six Sigma to the specific problems and business areas is mostly difficult due to the dogmatism of the project team. The main goal is to make considerable improvements within the entire system not to use some specific tools.

- Avoid non-essential bureaucracy: Avoiding unnecessary bureaucracy in Six Sigma implementation can maximize the effects of continuous process improvement.

- Keep the toolbox vital: The advantage of Six Sigma comes from the practical usage of different tools and technical concepts into a process. Some original tools can be extracted from process improvement and some not included originally can be added.

- Expect Six Sigma to become a more silent partner: Continuous and broader applications can increase the momentum of Six Sigma within the company. Also, Six Sigma should be evaluated as an ordinary part of work process.

Different researches discussed the key issues for the effective implementation of Six Sigma. (Antony and Banuelas, 2002) explained these key issues in eleven subtitles. In the scope of this study, these key issues are summarized through (Antony and Banuelas, 2002):

- Management involvement and commitment: Involvement of the managers and their supports for training are vital for Six Sigma (Halliday, 2001). The importance and motivation of Six Sigma will be less if top managers does not continually support and commit it (Pande et al., 2000).

- Cultural Change: Organizational culture and employee mentality should be improved in order to introduce Six Sigma successfully (Antony and Banuelas, 2002). The success of a specific organization in local or international markets depend on its own cultural organization (Sohal, 1998).

- Organization Infrastructure: Introduction and development of Six Sigma have to be encouraged by an efficient organizational infrastructure (Antony and Banuelas, 2002).

- Training: It is vital to provide flexible and effective training opportunities to employee (Antony and Banuelas, 2002).

- Project Management Skills: Team members must have project management skills in order to meet the deadlines and milestones (Antony and Banuelas, 2002). One of the reasons of the failure in Six Sigma projects are poor project management (Eckes, 2001).

- Project Prioritization and selection: Prioritization and selection of right projects need proper criteria that can prevent the project delay (Antony and Banuelas, 2002).

- Understanding the Six Sigma methodology, tools and techniques: Process Improvement, Leadership and Team tools are the basic contents of Six Sigma principles and training (Antony and Banuelas, 2002).

- Linking Six Sigma to Business Strategy: Six Sigma needs an adherence to the entire management system and business strategy instead using few features of it (Dale et al., 2000) .

- Linking Six Sigma to the customer: The identification of customer expectations is the start of Six Sigma projects (Harry and Schroeder, 2000).

- Linking Six Sigma to human resources: There has to be a positive link between Six Sigma and company rewards for employees in order to increase the success (Antony and Banuelas, 2002).

- Linking Six Sigma to suppliers: Many firms prefer to extend Six Sigma principles to the management of supply chain (Antony and Banuelas, 2002) and having few suppliers with high sigma performance levels is another way of quality improvement (Pande et al., 2000).

4. Analysis/Findings

4.1. Introduction to Interviews

Bechtel Corporation has deployed and implemented Six Sigma with 30million$ investment and made 200million$ savings until 2002 (Eckhouse, 2003). Six Sigma has been used as an identifier and preventer of defects in construction projects starting from design to handover phases by Bechtel Project Teams (Kwak and Anbari, 2006). That's why; interviewers were selected from Bechtel:

Deputy Project Manager (DPM) who graduated from Bosphorus University (Bachelor of Science, Civil Engineering) is Deputy Project Manager of Bechtel-ENKA General Partnership in Kosovo Motorway Project.

Field Engineer (FE) who graduated from Istanbul Technical University (Bachelor of Science, Civil Engineering) is a Lead Field Engineer of Bechtel in Australia.

Cost Engineer (CE) who graduated from Bosphorus University (Bachelor of Science, Civil Engineering) is a Lead Cost Engineer of Bechtel in Canada.

4.2. Definition of Quality

First question of interview was about the definition of Quality according to construction industry requirements (Table 4.1).

	DPM	**CE**	**FE**
Method Statement based on technical specifications	x	x	x
Laboratory Tests	x		x
Controlling of supplied material by Subcontractors	x	x	x
Financial aspects of Quality (cost of poor quality (COPQ))		x	x
Statistical production records		x	
Profit rates of the completed tasks			
Effects of bad quality on the project timing & plans		x	

Table 4.1 The concept of Quality according to Interviewers

The widest quality perception belongs to CE while DPM defined quality totally as a technical issue. DPM`s quality definition includes only method statements, laboratory tests and controlling supplied materials. This difference might be because of generation differences between them. Also, FE does not consider statistical production records, project timing & planning as a quality issue. The most interesting thing is that none of them consider the profit rates of tasks as a part of quality concept.

The comparison of quality procedures of construction industry and other industries was another question asked to interviewers. CE and FE expressed that Quality Procedures in construction industry are not well-defined and does not have project-wide approach.

They mentioned the human roles on construction industry are very important and procedures do not include human-related factors. According to them, the determiners of quality are not only procedures and technical instructions and they believed that quality procedures should be extended according to current requirements of construction industry. These answers are consistent with their quality definitions. However, DPM perceives quality as a technical issue and he believed that quality procedures are enough for construction projects.

4.3. Theory of Six Sigma

In theory part of interviews, questions were asked in order to understand the match level between the usual technical abilities of construction professionals and Six Sigma theory.

All of the interviewers mentioned that they use often their mathematical background and statistical calculation in their daily tasks. It means that the trainings of Six Sigma methods which are based on statistical theory will not be so difficult for them. Also, all of the interviewers said that statistical production records & data collection are very useful in order to understand the general cost performance of construction operations. It means that a continuous data collection and procurement system which advised by (Hahn, 2005) as a key lesson learned from Six Sigma might be very useful for construction industry.

Another question asked to interviewers was about their tasks evaluations as an entire system or as a separate process. DPM and CE evaluate the project as an entire system. For instance, CE said that he made the cost calculation regarding entire project. Oppositely, FE prefers to split up his tasks into separate process and believed that process success is the main determiner of site operations performance.

4.4. Implementation of Six Sigma

Implementation of Six Sigma requires effective project communication in order to be successful. (Hahn, 2005) and (Antony and Banuelas, 2002) showed this relation in their study. That’s why; Interviews emphasize the importance of project communication in this part.

All of the interviewers emphasized the importance of collaboration & communication between different departments and disciplines for the success of process improvement. Also, (Antony and Banuelas, 2002) evaluated project communication as a key success factor for Six Sigma implementation.

Team Members	
Project Manager	1
Project Control Department	2
Support Department (Equipment, project control, prime contract...)	4
Quality Control Department	5
The previous/next responsible department of the process	6
Construction Manager/Site Engineers	3

Table 4.2 Collaboration Prioritization during Performance Measurement

Second question was about the financial performance measurement of a process or an entire site operation. CE who is one of the main responsible of performance measurement, made a collaboration prioritization which shows the important key members during performance measurement (Table 4.2).

Interesting point is that CE considers Project Control department more important than Construction Manager/Site Engineers. CE thinks that Project Control as key responsible for data collection & distribution should have more roles than Construction departments in performance measurement.

CE does not consider Quality Control department as important as Project Control or Construction department. The reason is that quality concept in construction industry is quite different from manufacturing industry and that's one of the most important adaptability issues of Six Sigma to construction context.

Another prioritization question asked to DPM was about the low performance of site operations. If the site departments show unexpected low performance which increase the costs and reduce quality, DPM said that he will contact firstly with Construction Manager (or Department Manager), secondly Project Control (or Business Manager) and thirdly Quality Control department in order to get some explanations or reasoning (Table 4.3).

Team Members	
Project control (or Business manager)	2
Construction Manager (or Department Manager)	1
Site Engineers of the responsible department	4
Quality Control Department	3
The previous/next responsible department of the process	5

Table 4.3 Collaboration Prioritization Considering Low Performance

The last two places in Table 4.3 are Site Engineer and the previous/next responsible department of the process. Site Engineer who should be one of the applicants of Six Sigma on problematic process is at fourth place of collaboration list.

DPM prefers to contact with Construction and Business managers firstly and it shows the importance of management commitment to Six Sigma.

		Deputy Project Manager			Cost Engineer			Field Engineer		
	Tools Name	I have/had used	I know but no used	I never hear it.	I have/had used	I know but no used	I never hear it.	I have/had used	I know but no used	I never hear it.
a)	Project charter	x					x		x	
b)	Cause and effect analysis		x		x				x	
c)	Process capability analysis		x		x			x		
d)	Process maps & flow charts	x			x			x		
e)	Hypothesis tests, confidence intervals		x			x			x	
f)	Regression analysis, multivariate methods		x			x			x	
g)	DOE (Design of Experiments).	x				x				x
h)	Statistical Process Control and plans		x		x				x	
I)	FMEA (Failure Mode and Effect Analysis)		x			x			x	
j)	COPQ (Cost of poor quality).	x			x			x		
k)	CTQ (Critical to quality)		x		x			x		
l)	KPIV (Key process input variables)		x		x				x	
m)	SOPs (standard operating procedures):		x		x			x		

Table 4.4 Usage Level of Six Sigma Tools by Interviewers

Table 4.4 is a list of common Six Sigma tools is prepared for interviewers in order to understand the usage level of Six Sigma tools and the knowledge level of interviewers. Some of the tools are more related with statistical aspects of Six Sigma while some of them are more about process improvement aspects.

This table can give an idea about the similarity of common tools used in construction context and Six Sigma methodologies. According to this table, they know most of the tools from construction context. It means that there are enough common tools between Six Sigma and construction industry.

Hypothesis tests & confidence intervals, Regression analysis & multivariate methods, FMEA (Failure Mode and Effect Analysis), KPIV (Key process input variables) were never used by any of the interviewers since these tools are quite theoretical tool compared to other listed tools.

4.5. Resistance to Six Sigma

As mentioned in 4.1 Definition & Adoption of Six Sigma, human-related factors in construction industry are very vital in order to realize new concepts and innovation. That's why; interviews emphasized the importance of human-related resistance factors to Six Sigma.

When the companies want to make some new challenges considering site operations, there will be some discontent behaviors and resistances from technical members. FE mentioned that that when the cost & revenue comparison and quality does not meet against the expectations, there should be new challenges regarding site and office based duty. However, FE believed that construction industry is quite traditional for new technologies and management mentality. He expressed that major resistance to new challenge on site operations mostly come from:

- Experienced engineers
- Site team members (Site foreman, operators...)
- External technical members from support departments (QC Engineer, Equipment Foreman...)
- Project Control Department

FE believed that convincing experienced engineers and site foreman for challenges are very difficult. Also, he mentioned that support departments and project control will not be so content due to additional tasks due to new challenges.

According to CE, the major resistance to new challenges/applications which aims to increase financial and technical performance might come from:

- Experienced engineers
- Site team members (Field Engineers…)

Both of them emphasize the resistance of experienced engineers. However, both of them evaluate each other as one of the resistance sources to new applications. That’s an interesting result which can show the relation between office and field engineer. The reason of these answers can be due to their looking differences to the project. This result shows the importance of the collaboration between departments for the success of Six Sigma.

DPM thinks that the main responsible of an unsuccessful process is the Construction Department Manager. He considers Project Manager and Site Departments Managers as the main responsible of project success or failures. That’s why; it can be said that if Project Manager and Departments Managers will support the challenges/new applications such as Six Sigma, one of the major barrier will collapse.

4.6. Benefits of Six Sigma

The expected benefits of process improvement can be different regarding industry types. That's why; this part of interviews deliberates on definition of an ideal process improvement and expected benefits from it for construction industry.

CE thinks that an ideal process/performance improvement method should have different outputs based on financial, technical and quality aspects:

- Financial aspect: an ideal process improvement method should decrease the cost and increase efficiency.
- Technical aspect: an ideal process improvement method may lead to more effective researches on engineering issues.
- Quality aspect: an ideal process improvement should make final product better and satisfy the customer expectations.

CE expressed that the main purposes of process improvement should be about financial and technical aspect of project. Quality improvement was not considered as one of the main targets of ideal process improvement method by CE. However, as a result of the financial and technical improvements, quality will obviously increase. According to CE, an ideal process improvement method for construction projects should have two main targets:

- Cost Efficiency
- Effective research about engineering applications

Furthermore, CE thinks that the implementation of Six Sigma is quite new and that's why; it is not available to use it as a systematic management strategy.

DPM think that an ideal process improvement method should have three main targets:

- Reducing of product cost (process cost)
- Increasing the quality of final products
- Increasing the quantity of site production

DPM's expectations from an ideal process improvement method are quite similar to CE. However, DPM see increasing the quantity of site production as one of the main targets. He expects from an ideal process improvement method to reduce process time and make more production within the same duration. It can be said that it is one of the main aims of Six Sigma.

DPM thinks that Six Sigma can be used as a management strategy. However, there should be integration between the existing quality management initiatives, project control procedures and Six Sigma implementation. Also, he mentioned that Six Sigma is not very applicable to the unrepeatable tasks. Especially, complicated project types such as highway, water, power plant or industrial projects have lots of unrepeatable tasks even though residential projects do not have so much.

FE mentioned that an ideal process improvement method should guarantee a small improvement for final product quality. The expectation should not be too much from an ideal process improvement method. If there is a structural problem about process design, he does not believe that it can be solved with a process improvement method such as Six Sigma. It means that process design in construction project does not have any relation with Six Sigma according to FE.

FE emphasized that there is a risk of making process less efficient after the implementation of wrong process improvement tool. That's why; an ideal process improvement method must be very less risky. Additionally, he thinks that process improvement can be realized in the tasks such as:

- Precast Construction Elements
- Structural Rebar Installation
- Concrete Plants & Manufacturing
- Asphalt Plants & Manufacturing
- Equipment Utilization and Efficiency

FE emphasized the importance of Site Engineers during process improvement. He thinks that the support of site engineers is a crucial for the success of Six Sigma and implementers of Six Sigma should be mainly site engineers due to their specialized knowledge on site process.

FE thinks that although Construction Management and Six Sigma have different roots and historical background, Six Sigma can be implemented as a management strategy. Moreover, FE expressed that Six Sigma methods must be adjusted for the unrepeatable construction site operations.

Benefits types	**DPM**	**CE**	**FE**
Finance-oriented Factors (for contractor)	3	3	2
Finance-oriented Factors (for employer)	4	2	3
Common satisfaction of the Employer & Contractor based on finance & quality	1	1	1
Satisfaction of the employee of contractor	2	4	4

Table 4.5 Expected Benefits Types from an ideal Process Improvement Method

Construction Projects have different stakeholders such as owner, owner´s engineers, contractor, and subcontractors. Obviously, Six Sigma will have some benefits but the question is these benefits will be for who and how. In order to answer this question, the more dominating factors on process improvement success were asked to interviewers (Table 4.5). All of the interviewers believed that the most important success factors of process improvement is to satisfy both of the employer & contractor based on financial and quality aspects.

The most interesting point is while DPM puts the satisfaction of the employee of contractors at second place, CE and FE does not consider it as a vital factor for process improvement success. It means that DPM believed that the confirmation and support of employee are very important for considerable process improvement success.

Another interesting point is that DPM expects less financial benefits for employer from process improvement while CE expects more financial benefits for employer instead of contractor.

4.7. Six Sigma as a Quality Initiative

Interviewers' definition of quality shows that quality concept of construction industry is smaller than manufacturing industry. This difference can be seen very clearly in (Table 4.1). Construction professionals (especially site engineers) perceive the quality as a technical issue and their expectations are to fulfill the requirements of technical regulations and methods statement agreed by both of the employer & contractor.

Evidently, all of the interviewers do not consider Quality Control department as one of the key actors of process improvement. It can be said that Six Sigma as a quality initiative might be useful in order to extend quality concept to more efficient form and create a new quality framework which includes financial parameters of construction industry. According to (Harry and Schroeder, 2000), the new quality concept includes not only technical specifications but also economic value for the company & customer and highest quality can be realized when the products meets the customer requirements with lowest costs in Six Sigma approach.

Expected benefits of DPM and FE (4.6 Benefits of Six Sigma) from an ideal process improvement tool include the increase of quality directly while CE expects to increase the product quality indirectly by process improvement. All of the interviewers expect to increase the satisfaction both of the employer & contractor (Table 4.5) which can be also achieved by Six Sigma. According to (Raisinghani et al., 2005), defect reduction which is the direct purpose of Six Sigma improves quality and customer satisfaction due to higher yields. Also, (Harry and Schroeder, 2000) mentioned positive aspects of Six Sigma for Customers (Employer in construction context).

In addition to these discussions (Forbes and Ahmed, 2009) thinks that Six Sigma quality level in the construction industry is not possible to due to lack of repetition in tasks and expressed that DMAIC may be more useful rather than DFSS and its sub methodology. This study also agrees that DMAIC methodology is more applicable in the construction industry since the roots of DFSS are based on manufacturing and its main purpose is to design new products for manufacturing processes. However, there is a possibility to adapt DFSS as a process designer to construction industry. Even though FE thinks that structural process design problem cannot be solved by Six Sigma (4.6 Benefits of Six Sigma), the adoption of Six Sigma to construction context can overcome of process design problem. Furthermore, the adoption of DFSS to construction context will increase the engineering effective research on engineering applications which is also one of the expected benefits from Six Sigma by CE (4.6 Benefits of Six Sigma).

4.8. Six Sigma as a Performance Indicator/Improver

All interviewers expect the performance increase from an ideal process improvement method. DPM emphasized the importance of increasing quality & quantity for performance improvement and CE mentioned that the effective research about engineering applications should be in the scope of process improvement (4.6 Benefits of Six Sigma). Moreover, (Han et al., 2008) mentioned that Six Sigma can be used also as a performance indicator by project managers and evaluation of project performance level can be done nearly perfectly by several steps.

Obviously, performance/process improvement is almost impossible without having a solid methodology, data procurement/collection system and measurements techniques (Hahn, 2005). According to (Han et al., 2008), measurement of project performance had been done after project completion, so performance improvement might be difficult due to lack of a definite methodology. That’s why; one of the prerequisite of process improvement (Six Sigma) is to measure project performance. Evidently, all of the interviewers support the existence of continuous data collection system (4.6 Benefits of Six Sigma) for the performance measurement.

(Table 4.2) of CE and (Table 4.3) of DPM shows the importance of Project Control department regarding performance improvement and measurements. Project Control department which is mostly responsible for statistical data collections and database management, is at second place in (Table 4.3) and (Table4.2) according to CE and DPM considering performance improvement and measurement. By the integration of Six Sigma and Project Control procedures which advised by DPM, project control engineers will have more opportunities to collect and procure data and more chances for the collaboration and communication with site teams in order to monitor and measure performance.

Opposite of that, Site Engineers also will have more opportunities for collaborating with office engineers in order to make fact-based and statistical decision making. Additionally, (Han et al., 2008) thinks that in ongoing projects, fact-based performance indicator has to be used by Project managers in order to measure the project performance. In order to have coordinated and repeatable benefits from performance improvement, facts and data based guidelines and methodology should exist (Stewart and Spencer, 2006). It can be said that Six Sigma fulfills these requirements as process improvement methodology.

Another advantage of Six Sigma is to have shorter applications time. According to (Forbes and Ahmed, 2009), proper deployment of Total Quality Management or ISO 9001 can take several years which can be longer period than typical construction project duration and that's why applications of them can be limited to the construction project. Since, applications of Six Sigma has shorter cycle, it is more adaptable to construction site environment. It makes Six Sigma very practical and applicable in the limited time period. Also, it should notice that tools of Six Sigma and construction industry are quite similar and it makes the adoption of Six Sigma faster as a performance measurement approach.

4.9. Six Sigma as a Management Strategy

Mostly, social sciences made contributions to management theory (Lloréns-Montes and Molina, 2006). However, Six Sigma is based on statistic and statisticians (Kwak and Anbari, 2006) and Six Sigma are improved by companies such as Motorola, GE and IBM (Aboelmaged, 2010). So, one of the difference of Six Sigma is to be improved by companies and professionals. It makes Six Sigma very practical compared to others process improvement methods which developed in the scientific environments. However, none of the developer companies and professionals has construction industry experience. It makes Six Sigma quite questionable as a management strategy for construction industry.

The adoption of Six Sigma to the construction industry requires the integration of Six Sigma to the existing quality management strategy of the companies. There are different views about the relation of Total Quality Management and Six Sigma.

(McAdam and Lafferty, 2004) made a conceptual model as a summary of their research. (Figure 4.1) shows that the evolution of Total Quality Management (TQM) which is from mechanistic looking to a broader change philosophy.

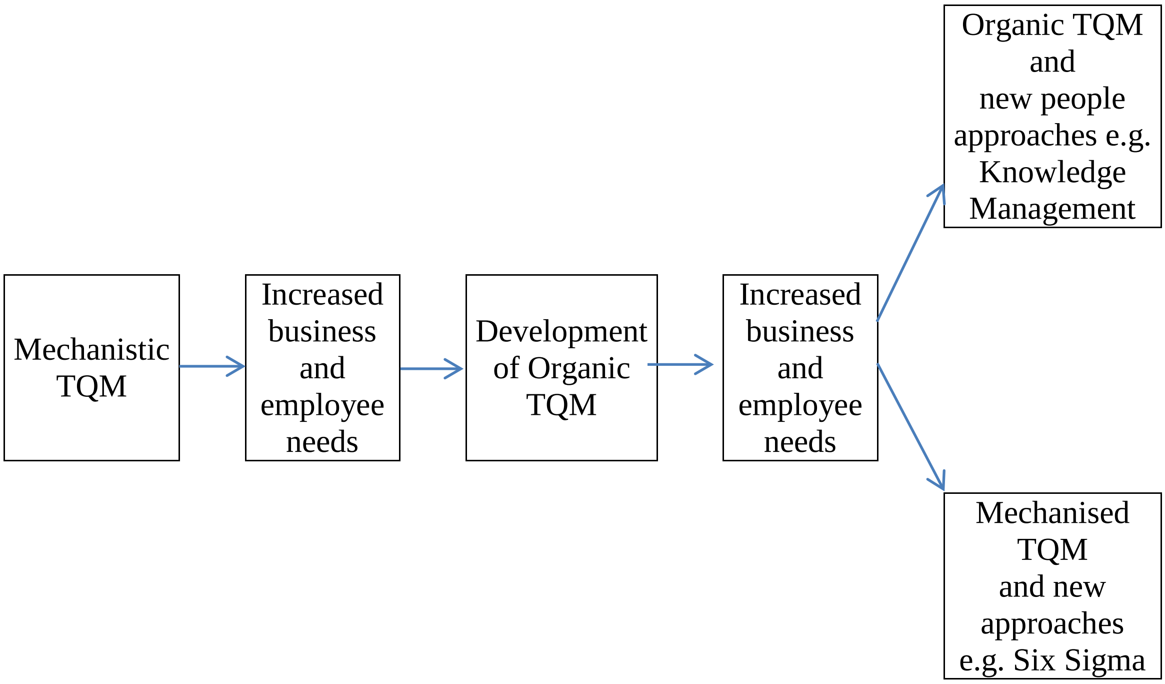

Fig. 4.1 Six sigma as a driver and subset of TQM development (McAdam and Lafferty, 2004)

TQM has two major components which are derived from Mechanistic TQM considering the increased business and employee needs (McAdam and Lafferty, 2004):

- Organic TQM
- Mechanized TQM

The concept of (McAdam and Lafferty, 2004) assumed Six Sigma as a new approaches of TQM rather than a new quality management philosophy. The findings of (McAdam and

Lafferty, 2004) and their concept are similar of the DPM´s perceptions about Six Sigma as a management strategy.

DPM evaluates Six Sigma as a “sub-management strategy” which can be applicable if it is integrated to the existing management procedures and he thinks that Six Sigma is very useful for the construction projects which include lots of repeatable tasks (4.6 Benefits of Six Sigma). CE mentioned that Six Sigma is too new within construction context and construction professionals are not ready to implement it to the whole project phases (4.6 Benefits of Six Sigma). FE emphasized the importance of project control and site engineers collaborations. Also, he thinks that the proper adoption of Six Sigma is not completed totally and it should be improved and adjusted considering characteristics of construction industry (4.6 Benefits of Six Sigma).

Considering Interviewers´ perceptions, it can be said that Six Sigma is quite discussable as a management strategy within construction context. In order to success of Six Sigma management concept, it requires to convert and improve Six Sigma methodologies and tools regarding the expectations of Construction professionals.

In addition to that, Six Sigma has advanced mathematical measurement tools and well-defined methodology which reach results quickly and successful implementation of Six Sigma create fundamental and cultural challenges within organization (Raisinghani et al., 2005) and obviously, interviews results shows that construction industry needs this fundamentally and culturally challenges.

5. Conclusion

Six Sigma can be very useful to broaden quality concept of construction industry to a more efficient form which should include financial parameters. Obviously, past researches and applications show that Six Sigma increase quality directly/indirectly considering technical and financial aspects in the construction industry even though it is not adapted properly. Process Design tools of Six Sigma have not been adapted to the construction context at least for this moment. DFSS should be adapted to the construction context properly in order to fix process design problem. Moreover, DMAIC has properly adapted and successfully implemented to the construction context as a process improvement tool. Also, DMAIC can be helpful to increase quality and quantity at the same time and it will affect technical and financial success of project considerably. Briefly, Six Sigma, as a quality initiative, aims to reduce defects and variations in processes using statistical measurements, process design and quality control analysis in order to increase (external/internal) customer satisfaction.

Six Sigma has provided an exact methodology, continuous data collection system and measurement techniques for performance/process efficiency measurement as a prerequisite. Additionally, the integration of Six Sigma approach to the existing procedures of Project Control department makes the collaboration of Site and Office department more efficient. Six Sigma methodologies make the benefits of process improvement repeatable and coordinated which are very important for the sustainable performance improvement. Moreover, the deployment and implementation of Six Sigma does not require longer period than usual project duration unlike other improvement methods. Briefly, as a performance indicator/improver, Six Sigma provides quantitative approach and process improvement tools in order to measure performance of processes and improve it.

Six Sigma was developed by professional engineers who have engineering background with the support of top executive managers. It means that philosophy of Six Sigma established in industry rather than academy and this background difference makes Six Sigma more practical and dynamic. Six Sigma has provided well-structured methodology, statistical tools and structured hierarchy as a management approach. One of the challenges of Six Sigma is to reach results quicker than other improvement methods. Even though some researchers evaluate Six Sigma as a new management approach, it can be said that adoption of Six Sigma to construction context can be realized by combination of existing quality initiatives and Six Sigma. Due to incomplete adoption of Six Sigma tools such as DFSS and high numbers of unrepeatable tasks of construction site operations, Six Sigma should be discussed more and updated based on the characteristics of construction industry. However, Six Sigma still can be applicable as a "sub-management strategy" within construction context. Briefly, as a management strategy, Six Sigma wants to increase motivation, effort, skill and knowledge within company and helps the organization to improve whole management performance by systematic methodology even though it is not properly adapted to construction context.

6. Reflections/Recommendations for Further Research

This thesis attempts to connect academic and practical process improvement knowledge considering construction industry by the way Literature Review and Interviews and it has been formed under some limitations. For instance, all of the interviewers have worked for same company and it makes findings based on just one company. Moreover; interviewers have different positions and responsibilities within company in different countries. That's why; results of interviews had been extracted from the ideas and opinions of construction professionals who have different engineering skills and international background. This research mostly has focused on quality, performance and management aspects of Six Sigma and it does not include any quantitative results which might justify the positive effects of Six Sigma especially based on cost and finance.

This study covered a large sized company and mega construction projects. For that, further researchers can evaluate Six Sigma for medium and small sized construction companies and projects. Construction process design with Six Sigma tools and the implementation of Six Sigma on unrepeatable tasks seem questionable and further studies about these issues might be useful for the adoption of Six Sigma to construction context. Subcontractor aspects of process improvement also are not discussed in this research. Considering the subcontractor roles on construction industry, it can be another interesting research question.

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