Master Thesis

Six Sigma Implementation within the Building Construction Industry. A Case Study of the Research Building Construction.

Master's Degree in Building Constructions at the University Polytechnic of Valencia

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Abstract

This Master of Science thesis is based on a research project on the implementation of Six Sigma within the Research Building Construction Industry. The case studies presented have been researched in Germany. Six Sigma consists in improving the projects mainly in terms of quality and also in terms of time management. According to the Six Sigma system, the goal is to detect the errors in those fields. This can consequently improve and optimise the projects, which have been already implemented with Six Sigma. Moreover, this system can also reduce the errors, and that means less work accidents and less extra money waste, by means of focusing on quality and time management. This system has already been implemented in different fields such as service, hospitality, finance, retail, automotive, media, manufacturing and in its first implementation in the year 1987, in the information technology industry by the company "Motorola". It is to be considered though that early delivery is not always profitable, owing to the possibility of a quality reduction in the final product of the project. For this reason, an equivalence must exist between time and quality. On the other hand, in the construction industry, every building is like a prototype for the automotive or information technology industry, and that means that improving time and quality in the Research Building Construction Industry can be quite difficult. However, this is not entirely the case, because the research of the Six Sigma implementation in that field demonstrates that Six Sigma is able to optimise and improve those common and specific projects in time and quality.

Keywords: Six Sigma, quality management, time management, scheduling.

Contents

1 Master thesis

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3 Introduction to the General Topic

Six Sigma is a system which primarily can improve the quality and consequently the time management of projects. The Six Sigma system has already been implemented in different industry sectors, and fortunately it has brought about benefits. It has improved the time, quality and cost management in the projects, according to the *Six Sigma Body of Knowledge*[1], which consists in the process called DMAIC (Define, Measure, Analyse, Improve and Control) (Pyzdek & Keller, 2003). However, Six Sigma focuses on detecting the errors in the projects, with which it then can create a database to improve the process of the projects.

Problem Statement and Justification on the Research Project

Nowadays every industry sector needs more specific controls. Six Sigma is able to take control of the projects. Furthermore, it is also able to improve their quality and use of time. The building construction industry is currently in development, and with the Six Sigma implementation in this industry sector, it will be able to improve the quality and time management of its projects.

Hypothesis and Objectives of the Study

Research building construction projects are estimated to specific costs, determined quality and expected delivery times for the final products. However, while projects are carrying on their processes, many times the project-errors are not considered and not taken into account. This is the case despite the fact that Six Sigma is able to benefit the projects, and, consequently, is able to improve them in terms of quality and time management.

Firstly, the main objective of this Master of Science thesis is to implement Six Sigma within the Research Building Construction Industry. Another objective of this Master thesis is to study the combination between quality and speed in those projects. For this reason, it is important to research the systematic process and then to obtain a proper result and incorporate benefits into the process for the future product in the Research Building Construction Industry. Six Sigma means entails researching the errors in the "project-assembly". Thus the goal of this project is to research those errors in order to improve the quality and the delivery time in Research Building Construction in Germany. According to the *Six Sigma Body of Knowledge*, and using the Six Sigma tools like DMAIC, the following points are shown to summarise that project:

- 1. Analysing the management course within the building construction company
- 2. Identifying systematic processes within the construction management course
- 3. Creating a management system according to the DMAIC process of Six Sigma
- 4. Studying the variables of delay due to error within the building construction company
- 5. Improving the projects in terms of quality and time management
- 6. Proving that the Six Sigma system is relevant within the building construction industry

[1] American Society for Quality

Research Method

The research method here consists basically in dealing with the feedback of the stakeholders and clients, who are the financial promoters of the projects[2], but before that, it is going to be defined the experiment within the documents and information to improve the quality and time management. Furthermore, this thesis is going to create a database with the information and documentation of the stakeholders and clients of the projects. Moreover, the database is going to collect mainly the causes of and specific information about the errors in the projects. Thus this research method is able to pursue the successful implementation and improvement of the projects of the Research Building Construction Industry. The method is focused mainly on researching the implementation of Six Sigma in that industry field. Despite this fact, the research here presented is going to test and create a system according to the *Six Sigma Body of Knowledge* because there are different projects that at the same time have common points to research, and which make this research project possible. The most popular tool in Six Sigma is DMAIC. It stands for "Define, Measure, Analyse, Improve and Control". The projects considered in this thesis are research-building constructions, and all of them can connect with each other due to the Six Sigma implementation. Additionally, this implementation is able to create synergies among all members in the same project. Hence, it is also able to use the Japanese method "Kaizen" for the clients to improve their projects. The research method is also based on the use of the quality and schedule plans made by the stakeholders and by the clients of the projects. Moreover, the research presented here is going to use the feedback received from them. The research method of this Master of Science is based on a number of research building construction projects. Six Sigma-implementation is going to be tested in the following three specific projects:

1st Research Building Construction Project.

Project Name: "Neubau Forschungs- und Laborgebäude Nr. 01".
User: Humboldt University in Berlin. School of Biology
Project Duration: 09/2010 - 10/2015
Estimated Cost ("KG 200 -700"): 33.8 million Euros (gross)

2nd Research Building Construction Project.

Project Name: "Neubau Forschungs- und Laborgebäude Nr. 02".
User: "Max-Delbrück-Centrum für molekulare Medizin (MDC)"
Project Duration: 10/2012 - 10/2017
Estimated Cost ("KG 200 -700"): 39.8 million Euros (gross)

3rd Research Building Construction Project.

Project Name: "Neubau Forschungs- und Laborgebäude Nr. 03".
User: "Helmholtz-Zentrum Berlin für Materialen und Energie GmbH"
Project Duration: 12/2012 - 05/2017
Estimated Cost ("KG 200 -700"): 32.7 million Euros (gross)

[2] For that research it is going to be used the concept of clients in the Six Sigma term

Data Collection, Analysis and Evaluation of Data

As empirical research, this Master of Science thesis consists basically in designing the Six Sigma system and implementing this method in the Research Building Construction Industry. The goals are the implementation and improvement of quality and time management in that field. Due to the research method, this thesis is going to create a database with the information and documentation of the stakeholders and clients of the projects. Subsequent to the establishment of the database and the Six Sigma implementation, it is going to analyse this information according to the *Six Sigma Body of Knowledge*. Thus, it is going to work toward improving quality and time management. The data collection is going to be important for the development of the Research Building Construction Projects. Furthermore, it is going to be able to be implemented in every research building construction project and to benefit and improve the quality and time management of them. The feedback that is received from the stakeholders and clients in the process of the project is important. Thus, this research of the Six Sigma implementation in the Research Building Construction Industry will be able to be implemented in the global sector of the Construction Industry.

Expected Results and Output of the Study

The expected results of the Master of Science thesis include the improvement of quality and time management within the research of building construction projects. Furthermore, within the expected results is the possible implementation of other construction projects, and consequently the possibility of improving them in quality and time management (Kochendörfer, 2010). In consequence, the projects previously cited are going to provide the experiment samples of the research project. The output is going to be the information and documentation of the Six Sigma implementation, as well as the research study of the specific projects of research building construction projects.

Training in Six Sigma

The first step undertaken was the "Six Sigma White Belt Certificate", which provided knowledge and a background on the topic. This first step has been followed by taking courses in Six Sigma Body of Knowledge for Yellow Belts, and finally obtaining the "Lean/Design For Six Sigma Green Belt Certification".

Use of Computer Programmes

This Master Thesis is going to use mainly the statistical programme *MiniTab*, *LATEX* for the academic writing and *Microsoft Office Word and Excel* for schemes and tables.

4 State of Art

State of Art of Six Sigma

Different papers have been written that address the meaning and the philosophy of Six Sigma. In 1987 the company Motorola launched the program called Quality Program for Six Sigma, and much has been written about Six Sigma according to the Motorola methodology, tools and applications. The first point is that Six Sigma was created in the manufacturing sector.

Therefore, it is the manufacturing sector that has been cited in all publications, followed next by the service, financial and hospital sectors. The construction sector is barely mentioned. Moreover, most publications have been oriented toward the issues of tools and techniques. The next most common issues in the approach phases (DMAIC). There were few references that deal with implementation, especially within the building construction sector.

The previous papers are going to be used directly for the implementation of the Six Sigma system within the building construction industry. Therefore, the next section concerns the state of art of Six Sigma implementation within the building construction industry for later analysis in a particular construction case of the research building construction.

State of Art of Six Sigma Implementation Within The Building Construction Industry

Different papers that address problems of the Six Sigma implementation within the building construction industry have been used here. The following are several examples of applications within the implementation of the Six Sigma methodology at specific companies:

Despite the fact that companies in different sectors have achieved profits through the implementation of Six Sigma, an extended model of Six Sigma has been developed to incorporate some of Six Sigma factors into the implementing by a company. (Shanmugaraja, M., Nataraj, M. & Gunasekaran, N., 2012)

According to the factors based on the different objectives of Six Sigma implementation, enabling factors have been studied, identified and prioritised that are based on the Body of Knowledge by way of evaluating and prioritising those Six Sigma factors. (Kiatcharoenpol, Ruekkasaem, Prajogo, D. & Laosirihongthong, T., 2011)

To sum it up, customer requirements are constantly increasing in the construction industry . Therefore, DMAIC model of Six Sigma has been applied for conducting an analysis of the construction process, in order to find new essential factors that will improve the building construction sector. For that reason, influences have been researched in the construction process, in construction quality resistance and in proposals for corrections within the building construction industry. (Tchidi, He & Li, 2012)

5 Six Sigma Survey at the Building Construction Company

Before implementing Six Sigma in the building construction company, how the new quality system fits the organisation should be known. Thus, the following question must be answered:

"Is the building construction company ready for the implementation of the Six Sigma methodology?"

According to the article and the questionnaire of the FH Köln "Passt Six Sigma zu uns? Is Six Sigma adaptable to us?" is going to develop a survey for the building construction company. This survey has been already implemented among different sectors and companies. This survey was successfully implemented within different companies and, as well, within the building construction companies sector in Germany (Schmieder & Aksel, 2006). This survey is based on the cited article and it shows the following 20 items distributed in three parts:

- Part 1. Company Situation and Business Structures
- Part 2. Previous QM-Concepts or QM-Systems
- Part 3. Application and Acceptance of Metrics

The survey at the building construction company is going to use a range of scores between 0 points, for any value according to Six Sigma implementation and 15 points, as the maximum score of a full value according to Six Sigma implementation. This means that if the building construction company has some values for being ready or even has enough values for Six Sigma implementation, the company will achieve some amount of points until the maximum score of 15 points. However, if the building construction company does not yet have a sense of knowledge of the values of Six Sigma implementation, the surveyed company can achieve limited points.

The minimum score that any building construction company has to achieve in order to implement the Six Sigma system within the organisation is: 175 points.

Part 1. Company Situation and Business Structures

1. Existence of series or individual manufacturing or constantly repetitive operations and transactions in the building construction company

It would be better for the Six Sigma implementation to produce only one batch. However, within the building construction industry there are repetitive as well as individual operations.

2. Customers or suppliers, that deploy Six Sigma

For the moment, there is no application or low knowledge of the Six Sigma by the customers or suppliers.

3. Where is the interest in Six Sigma at the building construction company mainly based?

Changes and improvement is firmly institutionalized in the company management.

4. Designating at least three to five motivated employees for new project work (partially)

There is the possibility at the building construction company of using at least three motivated employees and 50% of their working hours.

5. The building construction company is ready to invest for the project in the special training of the employees

It is customary to invest ten working days and 5.000 Euros per person for the training of Green Belt, i.e. the head of the smaller Six Sigma projects. In this way, the building construction company invests time and money into the training.

6. Current "utilisation" of the organisation with initiatives and concepts

Currently there are capacities free to be utilised by the organisation with initiatives and concepts.

7. Considerations from the Six Sigma organisational level

The consideration of the Six Sigma system comes from the middle and upper management.

8. Expectations in the introduction and in the implementation phase with the constant commitment of the upper management

The ongoing commitment of the top management can be expected, in addition to there being the introduction and the implementation phase.

9. Existence of structured approaches for improvement in the building construction company

This means the approaches that are already structured within the building construction industry such as organisational development and process modelling. Thus, the employees of the operational level in the building construction company can empower and improve those structured approaches. Furthermore, they can approach them independent of problems.

10. Running structured training or education programmes in the building construction company

There are often structured training or education programmes in the company.

11. Carrying out building construction projects at the company

There are currently building construction projects and they are being carried out.

Part 2. Previous QM-concepts or QM-systems

12. Owning already a certified QM-system

There is no certified system, such as ISO 9001, ISO/TS16949, QS 9000 or VDA 6.1. However, a system of quality management exists in the company.

13. What (additional) QM-concepts does the building construction company deploy?

In addition, the building construction company has knowledge about TQM and Kaizen.

14. Problem areas covered with the current concepts

The problem areas in the building construction company are covered, from the easy to moderate topics, by the current concepts.

15. How long has the building construction company been engaged with KVP/Kaizen?

KVP stands for "Kontinuierlicher Verbesserungsprozess" in German. The building construction company has been engaged with KVP/Kaizen for about three years.

16. Which KVP / Kaizen methods have been installed at the company?

The company has installed the methods of waste analysis and process standards.

Part 3. Application and Acceptance of Metrics

17. Distributing or using metrics at the building construction company

This refers to the width of the indicator system. More generally, Six Sigma is quite strong on data, numbers and facts.

18. Application of indicators on the level of the organisation

This means the depth and thoroughness of the indicator system. The company is going to use the dissemination and application of indicators in almost all areas. The application of indicators occurs at the level of middle management (Rahman, 2008).

19. Operational indicators refer to the end result / product of the processes or intermediate results

The company engages not only the operational metrics on the end result and product of processes but also on intermediate results.

20. Finding acceptance of the indicators in the organisation and among the employees

There is going to be a strong acceptance of the indicators in the company and among employees. This is the preliminary estimate before the implementation.

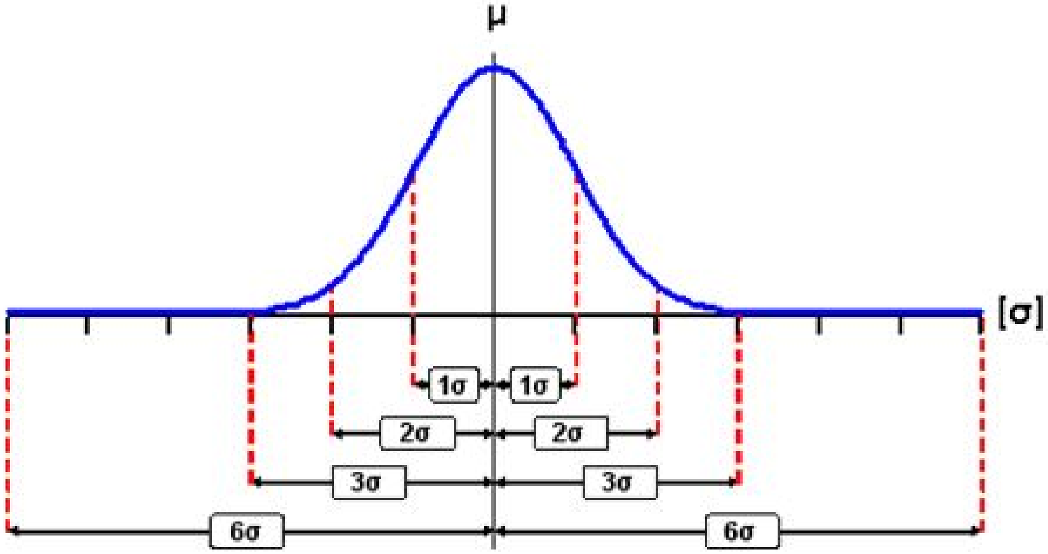

Figure 1: The Gaussian distribution of the Six Sigma Levels, “Six Sigma Deutschland GmbH”

Conclusion of the Six Sigma Survey at the Building Construction Company

The company provides a sufficient basis for the successful introduction and implementation of Six Sigma (Schmieder & Aksel, 2006). The following table represents the result of the Six Sigma survey at the building construction company.

Part	Item	Points	Part	Item	Points
1^{st}	1	10	1^{st}	11	15
1^{st}	2	3	2^{nd}	12	5
1^{st}	3	15	2^{nd}	13	8
1^{st}	4	15	2^{nd}	14	10
1^{st}	5	10	2^{nd}	15	8
1^{st}	6	15	2^{nd}	16	6
1^{st}	7	15	3^{rd}	17	10
1^{st}	8	15	3^{rd}	18	10
1^{st}	9	5	3^{rd}	19	10
1^{st}	10	10	3^{rd}	20	10

Table 1: Results of the Six Sigma Questionnaire

The building construction company achieves 205 points in total. Thus, the conditions in the building construction company for a successful introduction and implementation of Six Sigma are good (Schmieder & Aksel, 2006).

6 Meanings of Six Sigma

Six Sigma refers firstly to the identification of the process. It can be implemented within the building construction industry. It can also answer the following question: Who wants the project and why? The scope of the building construction project can be the improvement as SMART Objective because the building construction products need improvement. Six Sigma is also concerned with the benchmark of key product or process characteristics in relation to other world-class companies. Furthermore, key team members and resources for the building construction projects should be specific, natural, achievable, realistic and improved in terms of time. One important point is using critical milestones and stakeholder reviews, as well as budget allocation (Pyzdek & Keller, 2003).

The Define Phase of the Six Sigma includes the concrete definition of all important aspects in respect to the building construction project. This phase examines the organisation, planning and controlling of building construction projects and provides practical knowledge on managing construction project scope, schedule and resources (Kumar, Nowicki, Ramirez-Marquez & Verma, 2008). Thus, topics include project life cycle, work breakdown structure, network diagrams, scheduling techniques and resource allocation decisions. Concepts are applied through a team project which will teach students how to plan and execute building construction projects successfully (Kovach, 2007). The following are Six Sigma topics that can be implemented within the building construction industry:

- Exact definition of the building construction project
- Forming the team at the building construction company
- Customer requirement analysis
- Defining the process of the building construction projects
- Overview of DMAIC

Six Sigma Project Contract in the Building Construction Company

This section relates to the implementation of the Six Sigma project contract within the building construction industry. The Six Sigma project contract is an advance that clarifies and documents all relevant elements of the project in the project contract. The building construction project agreement is a document in which all the essential points of a Six Sigma project will be held at the project start. The document should be signed by all parties. The following is an example of a Six Sigma building construction project agreement, with references mapped to each field (based on Six Sigma Deutschland GmbH):

6σ	Projektvertrag		Projektmanagement GmbH
Projekttitel:	**Laborprojekt „Neubau Laborgebäude"**		
Projekt-Nr:	LP 001	Datum:	28.05.2013
Standort:	Wilmersdorfer Str. Berlin	GF / BB:	T. R.
Lph-Nr:	Lph 5	PL / BB:	M. H.
Abteilung:	Terminmanagement	Stlv. PL / GB:	I. O.
Projektbeginn:	01.07.2013	Controller:	P. K.
Projektende:	31.02.2014	MA /YB:	W. M.

Problemstellung:

Die Anzahl der Fehler an der Leistungsphase 5 (Ausführungsplanung) hat in den letzten 8 Wochen ansehnlich zugenommen. Den Wochenberichten des Projektleiters zufolge, ist die Anzahl der Fehler bezogen auf vorherige Zeiträume, um ca. 120% gestiegen. Die Kosten an dieser Lph. 5 sind dadurch um 67.490 € gestiegen.

Produkt/Service:	Ausführungsplanung
Spezifikationen:	Tragwerksplanung dürfen keine 15% Fehler erfahren
Fehler/Defekt:	Verspätung in der Lph 5
Maßeinheit:	DPMO bzw. FPMM
Prozess-Start:	Annahme der Ausführungsplanung mit Stand: 25.01.2013
Prozess-Ende:	Übergabe der Ausführungsplanung an der Lp. 6, die Vorbereitung der Vergabe

Projektziel/e:

Die Anzahl der Fehler auf weniger als 7.500 DPMO senken. Damit die aktuellen Mehrkosten von 67.490 € beseitigen und weitere 40.000 € durch andere Verbesserungsmaßnahmen einsparen.

Prozessleistung	momentane:	32.286 DPMO (nach den Ausführungsplanung Stand: 25.05.13)
	angestrebte:	DPMO<7.500

Mitglieder Projektteam

Name	Funktion/Abteilung	Datum, Unterschrift
T. R.	Geschäftsführer / BB:	
M. H.	Projektleiter / BB:	
I. O.	Stlv. Projektleiter / GB:	
P. K.	Controller:	
W. M.	Mitarbeiter /YB:	

Figure 2: Sample of Six Sigma Project Contract

The individual points of the **Six Sigma project contract** are explained below:

Project title: it should consist of keywords for the building construction project theme (preferably without using terms such as "improvement" or "reduction"). This can be provided potentially with alphanumeric notes (e.g. AB-001).

People involved:the people involved in the building construction project, such as Black or Green Belt, process owner, champion, master controller or BB should be indicated.

Project framework: formal disclosures to business unit, location and department of the building construction project should be given (Stewart, R. A. & Spencer, C. A.,2006).

Disclosure time: this sets the dates for the start of the building construction project and the expected end of the building construction project. The creation of a detailed timetable with milestones should be remembered from this theme before.

Problem setting: this should consist of 1 to 3 sentences and convey the extent of the problem in the building construction project (see also the formulation of the problem).

Project Size Unit and Error: this gives the exact name and specifications of the treated "unit" (product or the service). It also describes the other errors in the present process. Therefore, this unit is measured with that measure.

Process boundaries: the beginning and the end of a process should be shown (possibly based on already existent Process Maps within the building construction industry)

Project Objective (s): this specifies the unit of measure of the error, together with the champion line up and the controller. (Nota Bene: Goals must be specific, measurable, achievable, relevant to the building construction company and scheduled.)

Process performance: this is to be specified in the error rate FPMM or by another measure if there is any known current information. This waits for accurate information in the Measure Phase.

Project team: this information on individuals in the building construction project team (name and position in service).

Formulation of the Problem Setting

Six Sigma is a highly-charged, data and evidence-based approach. Therefore, part of every building construction project formulates a concrete problem-setting (Zu, Fredendall & Douglas, 2008).

This should include the following information:

- A - error (defect / problem)
- B - Process (with product or service of the building construction industry as output)
- C - length of time (referred to by the problem or in which it was observed)

Figure 3: Project Progression

- D - data base (previously evaluated data on which to base this statement)
- E - Error consequences (cost of poor quality and / or other effects) in the formulation.

The following "template" can be used within the building construction industry:
A is the error before (over the cycle C) B process. This statement is obtained via the data D. This condition leads to the cost E.

Example (see Six Sigma Project Contract):
The number of errors at the output stage 5 (implementation planning) has increased successfully in the last 8 weeks. According to the weekly reports of the project manager, the number of errors is related to previous periods, increased by approximately 120 per cent. The cost of these fifth phase is thus increased by 67,490 Euros.

Building construction project goals are then derived from the problem setting. Often the extent of the problem is difficult to estimate only at the beginning. Therefore, problem and building construction project goals need to be refined or revised during the project (See Figure "Project Progression")

Graphical Presentation of the Project

SIPOC

Within the building construction industry, the SIPOC is the process with the participating suppliers and customers. The inputs and outputs are shown gross. A SIPOC is a process mapping "higher order" like manufacturing and service processes within the building construction industry (Pyzdek & Keller, 2003). The SIPOC acronym stands for the following:

Suppliers - Inputs - Process - Outputs - Customers

The following are the contents:

- Building construction process boundaries (start and end)
- Building construction process outputs (product and / or service)
- Building construction customer (recipient of legal issues)
- Requirements for the building construction process outputs (CTQ, CTC & CTD)
- Building construction process inputs (material, data, etc.)
- Suppliers of building construction process inputs
- Requirements for building construction process inputs

Use a SIPOC The SIPOC form is helpful ...

- to identify suppliers of building construction process inputs
- to identify the customers of the building construction process outputs
- for the verification of the requirements for the building construction process inputs and building construction process outputs
- for identification and equalisation of competing building construction customer needs
- for the determination of any building construction project team and information resources
- to select the right data sources and matching mass numbers for the building construction industry
- to the overall framework and the interfaces of the building construction process mapping
- to create a unified understanding of the building construction process of the building construction project team

SUPPLIERS	INPUTS	PROCESS	OUTPUTS	CUSTOMERS
	Requirements		Requirements	
SUPPLIERS	INPUTS	Lph. 5 Implementation planning. Building planning	OUTPUTS	CUSTOMERS
SUPPLIERS	INPUTS	Lph. 5 Implementation planning. Structural engineering	OUTPUTS	CUSTOMERS
SUPPLIERS	INPUTS	Lph. 5 Implementation planning. Technical building equipment	OUTPUTS	CUSTOMERS
SUPPLIERS	INPUTS	Lph. 5 Implementation planning. Laboratory planning	OUTPUTS	CUSTOMERS

Table 2: Building a SIPOC

Building a SIPOC
The SIPOC form is split according to the individual letters into five main sections. A series of tables or checklists have been created for the following table "building a SIPOC", which will be used in the fifth phase "Control".

Create a SIPOC
For the creation of a SIPOC the step sequence has been proven in the following information (Pyzdek & Keller, 2003):

Suppppliers: suppliers of building construction process inputs
Step 7. Who is the supplier of the relevant building construction process inputs?

Inputs: needed for the building construction process inputs
Step 6. Which inputs do we need for the building construction process?
Step 8. What are the requirements of the building construction process for the respective input?

Process: Building construction process description
Step 1. What building construction process occurs for those tasks?
Step 2A. When does the building construction process start?
Step 2B. When does the building construction process end?
Step 2C. What are the most important building construction process steps?

Outputs: expenditure obtained by the building construction process
Step 3. What are the expenses of the building construction process?
Step 5. Which requirements have reasons respective the outputs?

Customer: the receiver of the building construction process output
Step 4. Who are the recipients of the outputs?

A SIPOC should be created together in the building construction project group to obtain the knowledge and Konsene the participants (Lin & Guannan, 2012). The following points are important for a "correct" SIPOC:

- Resolving the steps 1 to 8 in sequence

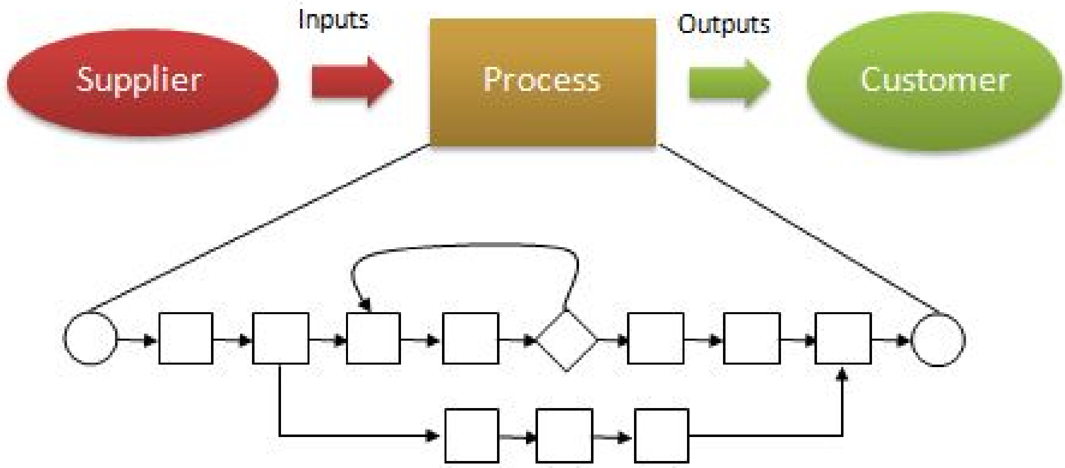

Figure 4: Building Construction Process Representation

- Determining the building construction requirements from the customer perspective
- Building construction requirements should be quantifiable (How to evaluate the performance by way of our customer)
- Clarifying building construction process start and end with customers
- Individual building construction process steps need not be identified (see figure "Building Construction Process Representation"). A detailed description is given in the section Analyse - Process Representation

Customer Requirement Analysis

We specify the interests and requirements of the customers through the customer requirement analysis within the building construction industry (Kwak & Anbari, 2006). Therefore, this section is able to achieve the following:

- Customer building construction requirements structured to simplify the gathering of information
- Use a planning board to analyse the information on the following points:

  Important building construction requirements

  Performance compared to the competition

  Building construction improvements (goals)

  Impact of building construction process improvements on the purchase decision of the customer

Pareto Chart

The Pareto principle is going to be implemented for this research within the building construction industry. The Pareto principle is also commonly named the 80-20 rule, the principle of factor sparsity and the law of the vital few. It means that, for many events, also within the building construction industry, around 80% of the effects come from 20% of the causes. This principle was first introduced in the early 1900s by the Italian economist Vilfredo Pareto and has been applied as a "rule of thumb" in various areas. Later on, the economist Pareto noticed similar patterns in wealth and income. Since that happened, the Pareto principle has been applied to aspects of business management and elsewhere (Baumert & Kete, 2002). Thus, it is currently possible to notice similar patterns within the building construction industry. Moreover, it can be said that: "Only 20 percent of a building construction companys products will result in 80 percent of its profits".

The idea as a rule of thumb has application in many places, but it is commonly misused. For example, it is a misuse to state that a solution to a building construction problem "fits the 80-20 rule" just because it fits 80% of the cases; it must also be implied that this building construction solution requires only 20% of the building construction resources needed to solve all cases. Additionally, it is a misuse of the 80-20 rule to interpret building construction data with a small number of categories or observations.

The term 80-20 is only shorthand for the general principle at work. In individual building construction cases, the distribution could just as well be, say, 80-10 or 80-30. There is no need for the two numbers to add up to the number 100, as they are measures of different things, e.g., "number of building construction customers" versus "amount spent". However, each building construction case in which they do not add up to 100%, is equivalent to one in which they do (Taleb, 2007). [3].

Pareto Main Tool of the Define Phase

A Pareto diagram is a vertical bar graph showing problems, or opportunities. In the Define phase, the Pareto diagram is used to quantify the opportunities inherent in each of the tiny elements. However, the data have been recorded for orders received according to the Building Construction Process Representation (see figure in the previous chapter). In concept, the Pareto diagram also helps to focus on potential improvement efforts within the building construction industry (Pyzdek & Keller, 2003). The following is an example of the application of the Pareto principle:

- 80% of the defects of a building construction process come from 20% of the causes.
- 80% of profits come from 20% of building construction customers.

The distribution of the Pareto principle is claimed to appear in several different aspects relevant to entrepreneurs and business managers[4]. For example:

- 80% of a building construction organisation's profits come from 20% of its customers
- 80% of a building construction organisation's complaints come from 20% of its customers

[3]The Black Swan, pp. 229-252, 274-285 Mathematical note

[4]Living Life the 80-20 Way by Richard Koch, 2004

- 80% of a building construction organisation's profits come from 20% of the time its employees spend
- 80% of a building construction organisation's profits come from 20% of its products
- 80% of a building construction organisation's profits are made by 20% of its employees.

The Pareto principle refers to the fact that a small percentage of building construction processes cause a large percentage of the problems. It can be noted that, as often happens, the final percentage of the Pareto charts are slightly different from 100%. This is due to round-off error and is not a cause of concern.

Case Study of the Pareto Charts within the Building Construction Industry

There are three different level of Pareto Charts in that Six Sigma building construction project. There is one for each of the following levels:

- 1. Departments
- 2. Work activities
- 3. Human resources

Pareto Chart of Category (Level 1). Departments: The different departments of the company are going to be used for the implementation of the Pareto tool within the building construction company. The following results of the figure "Pareto Chart of Category (Level 1)" refer to the Pareto rule 80-20.

Pareto Chart of Category (Level 2). Work Activities: The work activities/tasks of the Department No. 4 have been chosen for the second level of Pareto Chart.

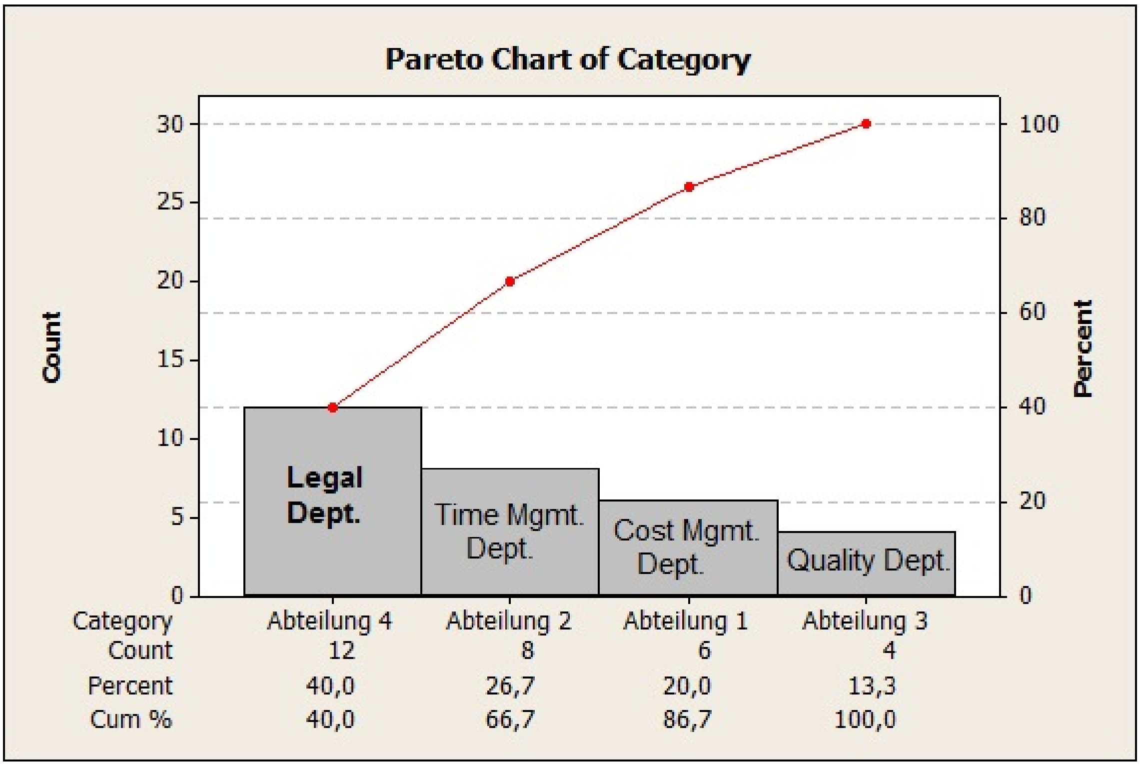

Figure 5: Pareto Chart of Category (Level 1)

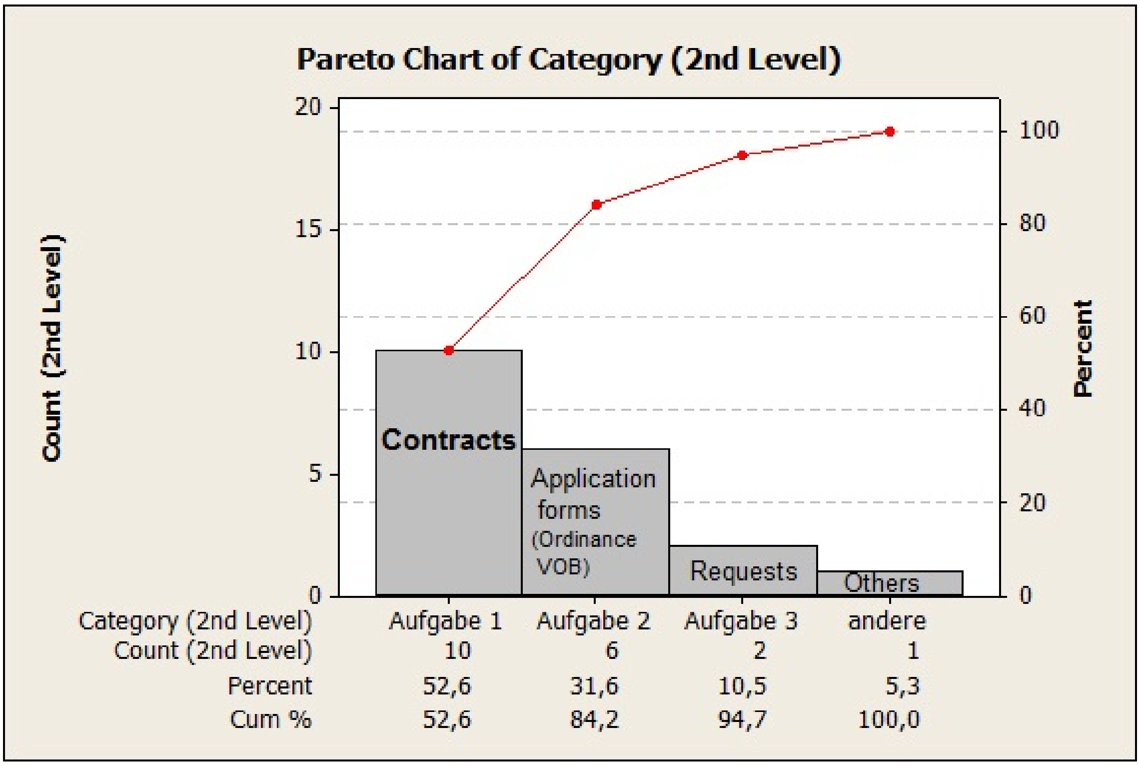

Figure 6: Pareto Chart of Category (Level 2)

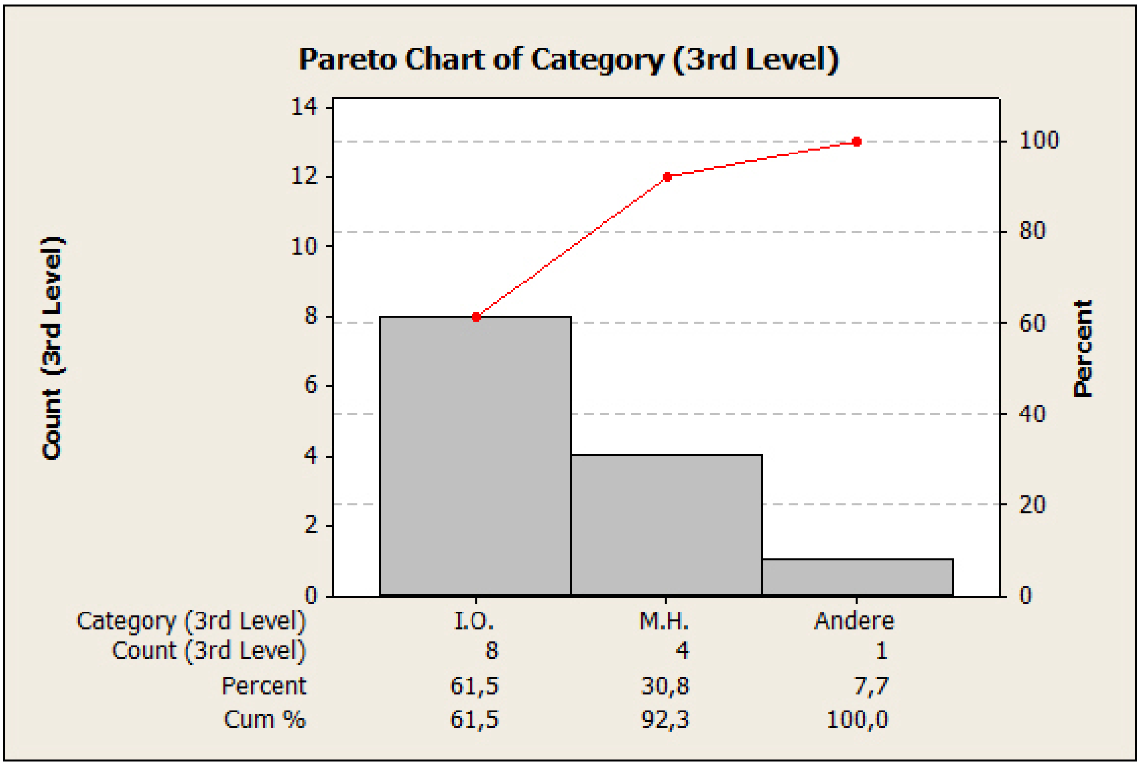

Figure 7: Pareto Chart of Category (Level 3)

Pareto Chart of Category (Level 3). Human Resources: The Pareto chart is going to be implemented in this section among two employees of the building construction company. The results are shown in the figure below.

Six Sigma Measure Phase

The objectives of the Measure Phase of the Six Sigma within the field of the building construction industry will be included in this section. The creation of a qualitatively and quantitatively adequate data base for the measurement of the "status quo" and for later Six Sigma analysis are the main tasks in the Measure phase. It is important is that the initial graphical and statistical methods are presented. In the course of the measurement system analysis, the relevant metrics are determined and the associated measurement systems are verified. Thus, a data collection of the building construction industry is calculated regarding the process capability metrics (the status quo) (Aboelmaged, 2010). However, the following question can be answered : "How do you measure the impact?" Therefore, it is important to keep the process DMAIC of the Six Sigma. The following is a validation of the Six Sigma measurement system and a review of the job description within the building construction industry:

- Ensure Six Sigma measurement system reliability
- Prepare data collection plan of the case study within the building construction industry
- Collecting data is reliable for the Building Industry
- Building construction process effectiveness and efficiency
- Building construction problem-specific derivation of the relevant measured quantities
- Targeted implementation of a Six Sigma measurement system within the building construction industry
- Introduction to the building engineering software support
- Determination of the reference process performance (sigma value) in the form of a characteristic value for location and scatter

The objectives of the Six Sigma Measure Phase include:

- 1. Process definition: to ensure the specific building construction process under investigation is clearly defined.
- 2. Metric definition: to define a reliable means of measuring the building construction process, relative to the building engineering project deliverables.
- 3. Establish the process baseline: to quantify the current operating results as a means of verifying previously-defined building construction company needs, and to properly substantiate improvement results.
- 4. Evaluate measurement system: to validate the reliability of data for drawing meaningful conclusions within the building construction industry.

For DFSS applications, where DMAIC is used, the objectives of the Six Sigma measure stage will be limited to defining the key metrics and development of a measurement system and plan for obtaining measurements once the new design becomes operational. Evidence can be shown for asserting that Six Sigma quality begins with measurement. Only when Six Sigma quality is quantified, can meaningful discussion about improvement begin. Measurement is conceptually quite simple: measurement is the assignment of numbers to observed phenomena according to certain rules. Six Sigma measurement is a requirement of any science, including also building construction management science. (Pyzdek & Keller, 2003)

Building Construction Process Definition

A building construction process can consist of repeatable tasks, carried out in a specific order. If building construction processes cannot be defined as a series of repeatable tasks, then there may be multiple building construction processes in effect, even an infinite number of processes, or simply the lack of a well-defined process. It is not uncommon to discover that situation when interviewing building construction process personnel. Operational building construction workers may customize a process to address situations seen in practice, which may not get communicated to all the relevant stakeholders. Moreover, building construction customers will experience significant variation depending on the shift or even the specific personnel processing their order. Occasionally, this results in an improved product or service within the building construction industry, and sometimes not. In any event, since the aim here is that of seeking to understand the actual building construction process in the measure phase, the input of the building construction process personnel is necessary. Then in the improve phase, a desired building construction process will be documented after receiving of input from all stakeholders (Pyzdek & Keller, 2003).

There are several useful Six Sigma tools available for defining the process.

- Flowcharts are particularly useful for highlighting building construction process complexities.
- Building construction process maps provide an additional level of detail to indicate functional responsibilities for each building construction process step.
- SIPOC is a Six Sigma tool for identifying the building construction process inputs, outputs and stakeholders. SIPOC was previously discussed in other Chapter.

Generally, these Six Sigma tools will be used in conjunction with one another.

Cause & Effect / Fishbone Diagrams

This section is going to use the Measure Phase the Cause & Effect Diagram (also called a Fishbone Diagram or Ishikawa Diagram). This diagram was created by Kaoru Ishikawa and is used to identify, organise and display the potential causes of a specific effect/event in a graphical way similar to a fishbone within the building construction industry.

The Cause & Effect Diagram illustrates the relationship between one specified building construction event (output) and its categorised potential building construction causes (inputs) in a visual and systematic way.

The major categories of the potential causes within the projects of the building construction industry are going to be checked in the next step.

P4ME

P4ME stands for the following: (P) People; 4x(M) Methods, Machines, Materials & Measurements and (E) Environment.

People: people who are involved in the process of the building industry.
Methods: how the building construction process is completed (e.g. procedures, policies, regulations, laws);
Machines: equipment or Six Sigma tools needed to perform the process of the building industry
Materials: building materials or information needed to do the construction works
Measurements: data collected from the building construction process for inspection or evaluation
Environment: surroundings of the building construction process (e.g. location, time, culture)

The first step in creating the Fishbone Diagram is identifying and defining the effect/event being analysed. Clearly state the operational definition of the effect/event of interest. The event can be a positive outcome desired or a negative problem targeted for solving. Then the effect/event can be entered in the end box of the Fishbone Diagram and a spine pointed to it can be drawn.

Figure 8: Fishbone Digram. Step 1

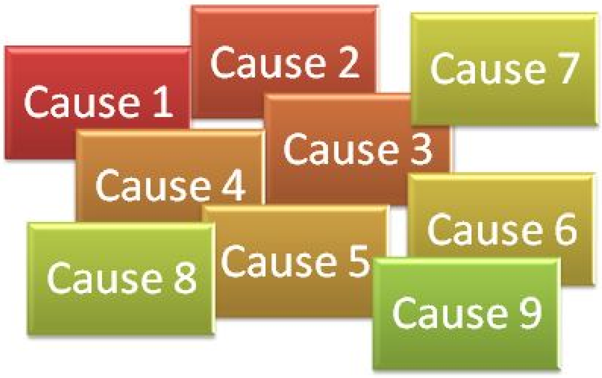

Figure 9: Brainstorm of causes

A case of the Six Sigma implementation within the building industry is the study of the delay in delivery of the implementation planning (Phase 5/Leistungphase 5 in Germany). The effect/event being analysed in this case study is the delay in delivery of the implementation planning in the building industry.

This case study involves a project management company that is interested in finding the root causes of the delay in delivery of the implementation planning. The Cause & Effect Diagram is used to identify, organise and analyse the potential root causes within the building construction industry.

The next step is a brainstorm of the potential causes/factors of the effect/event occurring in the delay in delivery of the implementation planning. Any factors with a potential impact of the effect/event should be identified and included in this step. Thus, all the identified potential building construction causes must be put aside for later use.

The next step (step 3) is to identify the main categories of building construction causes and group the potential causes accordingly. Besides P4ME (i.e. people, methods, machines, materials, measurements and enviroment), potential building construction causes can also be grouped into other customised categories. Below each major category, sub-categories can be defined and classified to help visualise the potential building construction causes. Therfore, each cause category has to be entered in a box and the box connected to the spine. Link each potential building construction cause to its corresponding cause category (Chakravorty, 2009).

Step 4 is to analyse the Cause & Effect Diagram. The Cause & Effect Diagram includes all the possible factors within the building construction industry. Moreover, the Pareto Chart can be used to filter causes that the project team needs to focus on identifying causes with high impact that the team can also take action upon.Furthermore, how to measure causes and effects quantitatively has to be measured and prepared for further statistical analysis.

Figure 10: Causes/factors in the building industry

After completing the Cause & Effect Diagram, the building construction company conducts further research on each potential root cause. Therefore, it is discovered that the building construction company needs to collect and analyse the data next to check whether root causes identified in C&E Diagram are statistically the causes of the delay in delivery within the implementation planning.

The benefits to using the Cause & Effect Diagram are the following:

- It helps to identify and sort the potential building construction causes of an effect occurring quickly.
- It provides a systematic way to brainstorm on potential building construction causes effectively and efficiently.
- It identifies areas requiring data collection for further quantitative analysis.

The limitations of the Cause & Effect Diagram are the following:

- The Cause & Effect Diagram only provides qualitative analysis of correlation between each building construction cause and the effect.
- The Cause & Effect Diagram can only focus on one effect/event at a time.
- Further statistical analysis is required to quantify the relationship between various factors and the effect and identify the root building construction causes.

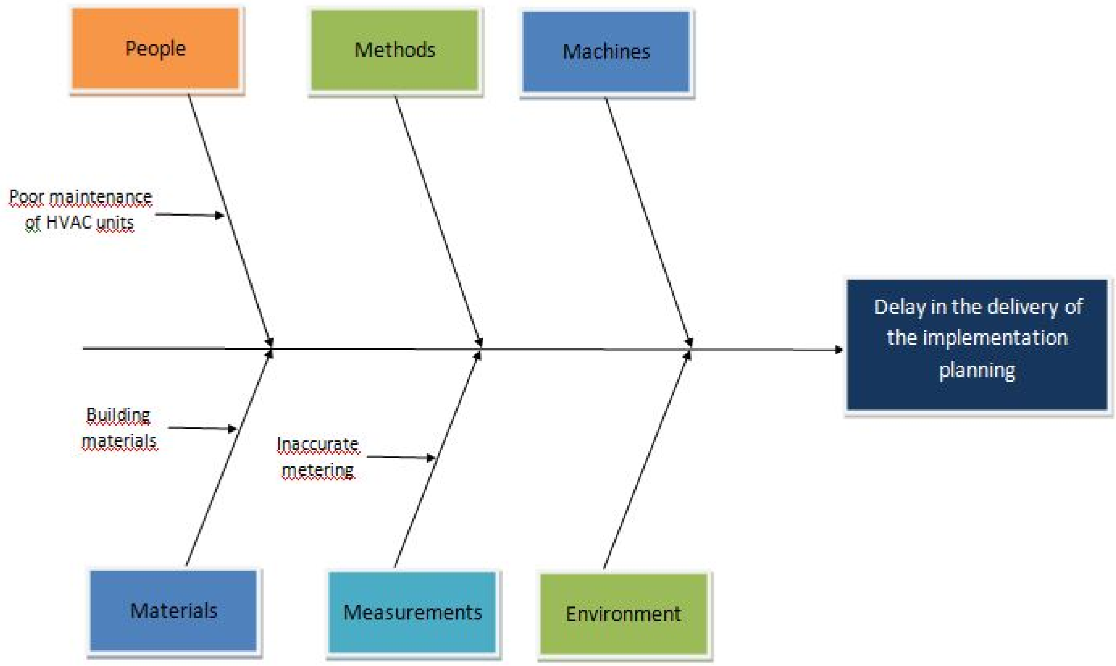

Figure 11: Cause & Effect Diagram within the Building Construction Industry

Building Construction Process Mapping

In this section the Building Construction Process Map is going to be used. It is a graphical representation of a process flow of the building construction industry. It also visualises how the building construction business process is accomplished step by step. Therefore, the process map describes how the construction materials or information sequentially flows from one construction business entity to the next. Moreover, it illustrates who is responsible for what in between the building construction process boundaries. It also depicts the input and output of each individual building construction process step. As previously seen in the Measure phase, the project team should map the current state of the building construction process instead of the ideal state (Han, Chae, Im & Ryu, 2008)

This case study is going to use the following four symbols, which are the most commonly used symbols in a process map.

Step 1: Define boundaries of the building construction process that need to be mapped.
Thus, a Process Map can depict the flow of an entire building construction process or a segment of it. Thus, it is necessary to identify and define the beginning and ending points of the building construction process before starting to plot. It should use an operational definition.

Step 2: Define and sort the building construction process steps with the flow.
Consult with building construction process owners and subject matter experts or observe the building construction process in action to understand how the process is actually performed. Record the building construction process steps and sort them according to the order of their occurrence.

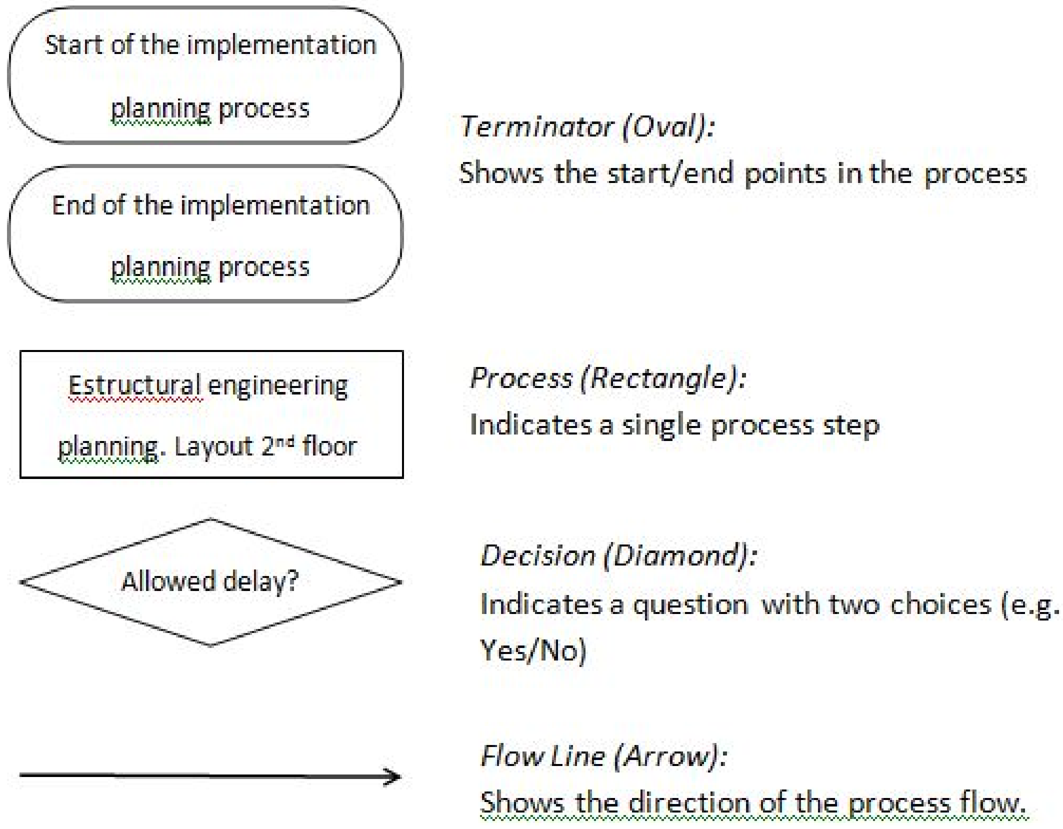

Figure 12: Building Construction Process Map Basic Symbols

Step 3: Fill the step information into the appropriate building construction process symbols and plot the diagram.
In the team meeting of building construction process mapping, place the sticky notes with different colours on a white board to be able to adjust the under-construction process map flexibly. The flow lines are plotted directly on the white board. For the decision step, it is necessary to rotate the sticky note 45. When the building construction map is completed on the white board, the building construction map should start being recorded.

Step 4: Identify and record the inputs within the building construction industry.
To illustrate the responsibility of different organisations involved in the building construction process, the Lane Process Map can be used.

7 Case Study

The normal distribution within the building construction industry is going to be used for this research. This distribution is a probability distribution of a continuous aleatory variable whose values (which in this case are values of delay) spread symmetrically around the mean.

The normal distribution for this research, as usual, can be completely described by using the mean (μ) and variance $\left(\sigma^2\right)$. This research is going to test whether the variable X (value of delays) is normally distributed (Harry & Stewart, 1988).

Furthermore, 20 similar products are going to be examined in the field of the building construction industry ($N = 20$) . This can be denoted as follows:

$$X \sim N\left(\mu, \sigma^2\right) \tag{1}$$

Location of Normal Distribution

In the case in which the variable is normally distributed, the mean, the median and the mode have the same value (Trivedi, 1982).

The probability density curve of normal distribution is symmetric around a centre value which is the mean, the median and the mode at the same time. (See the figure below of the Probability Density and Shape of Normal Distribution).

Spread of Normal Distribution

The spread of variation of the normally distributed data can be described using the variance $\left(\sigma^2\right)$ or the standard deviation (σ) (Joglekar, 2003).

Thus for this Six Sigma implementation, the smaller the variance or the standard deviation, the less variability in the data set of the tested product or service within the building construction industry.

68-95-99.7 Rule

The 68-95-99.7 rule or the empirical rule in statistics states that for a normal distribution (Harmon, 2011),

- About 68% of the data fall within one standard deviation of the mean.
- About 95% of the data fall within two standard deviation of the mean.
- About 99.7% of the data fall within three standard deviation of the mean.

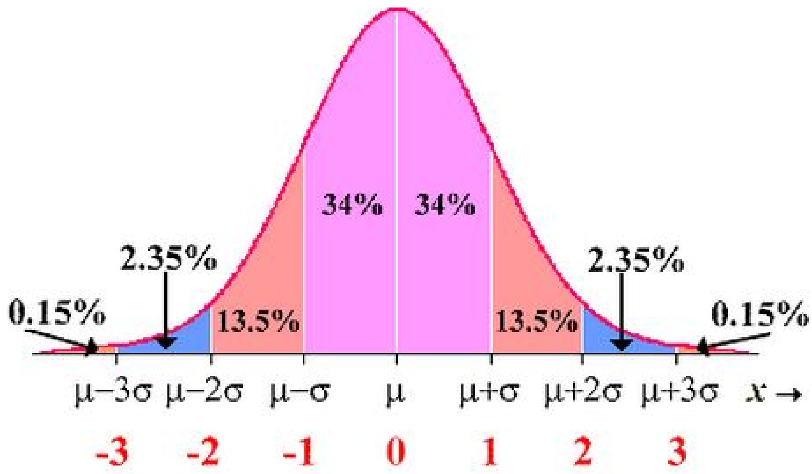

Figure 13: 68-95-99.7 Rule, oswego.edu

This means that the following test of 20 products is going to be distributed according to the table below:

Rule (%)	Standard deviation	Number of products
68%	$\pm\sigma$	13,6
95%	$\pm 2\sigma$	19
99.7%	$\pm 3\sigma$	19,94

Table 3: 68-95-99.7 Rule

Normality

In Six Sigma not all the distribution that has a "bell" shape is a normal distribution. To check whether a group of data, which is going to be explained in the next point, is normally distributed, it is necessary to run a normality test. There are different normality tests available for information (Harmon, 2011).

Normality Testing

To check whether the population of the interest, as it is explained as well in the following point, is normally distributed, it is submitted to a normality test (Harmon, 2011).

- Null Hypothesis (H_0): The data of the 20 tested products, which are selected for that case study, are normally distributed.
- Alternative Hypothesis (H_a): The data of the 20 tested products, which are selected for that case study, are not normally distributed.

Case Study of the Normal Distribution within the Building Construction Industry

This research is interested in knowing whether the delay of the deliveries (products) is normally distributed. Specifically 20 deliveries of a similar document are researched within the building construction industry, which relate to the contract of the construction works.

- Null Hipothesis (H_0): The delay of the 20 products, which are implemented in that case study, are normally distributed.
- Alternative Hypotesis (H_a): The delay of the 20 products, which are implemented in that case study, are not normally distributed.

The following products have been measured and tested throughout the term of two entire months. This demonstrates that in the building construction industry there are systematic processes for the implementation of Six Sigma tools, and consequently, that those products and services can be improved, which are within the field of building construction and implemented as in the manufacturing industry.

Delivery Product	Delay (Days)	Delivery Product	Delay (Days)
Product 01	2	Product 11	2
Product 02	3	Product 12	4
Product 03	1	Product 13	2
Product 04	4	Product 14	1
Product 05	2	Product 15	0
Product 06	3	Product 16	5
Product 07	6	Product 17	0
Product 08	3	Product 18	2
Product 09	4	Product 19	3
Product 10	0	Product 20	1

Table 4: Delay of the Deliveries (Products)

Normal Distribution of the Delay of the deliveries/ products

A normality test is going to be run with this data and information for the research of Normal Distribution within the Building Construction Industry (see figure "Probability Plot of Delay" on the next page).

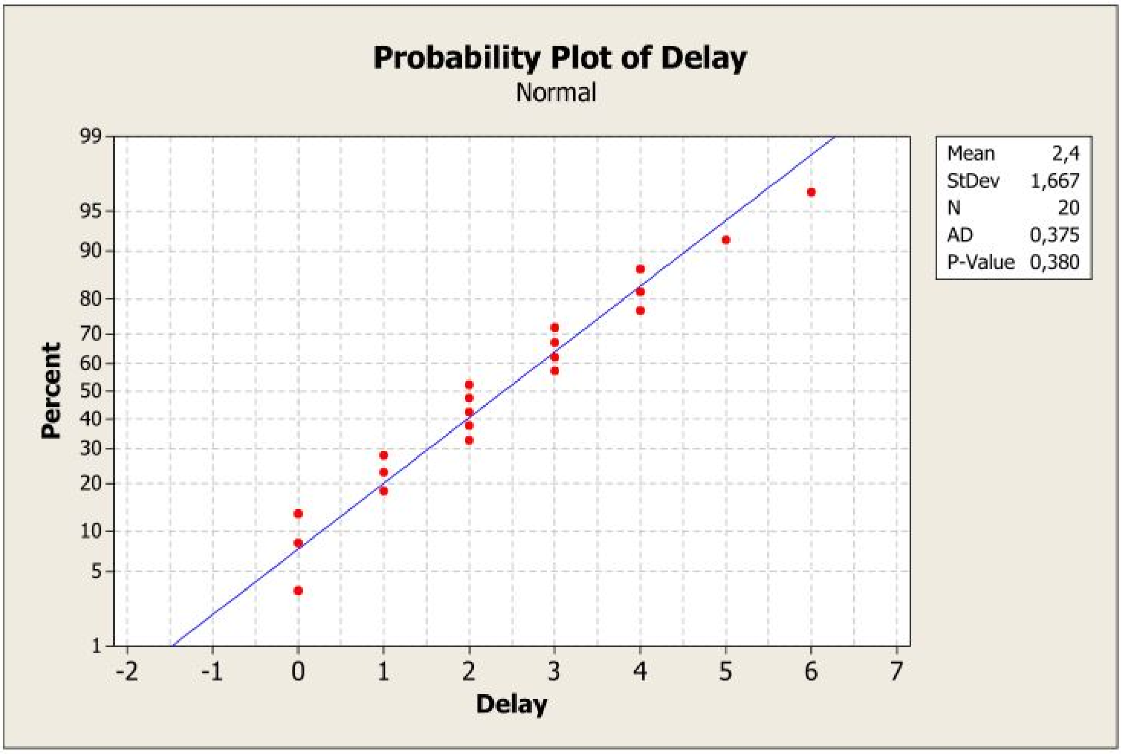

Figure 14: Probability Plot of Delay

Z Distribution within the Building Construction Industry

Z distribution is the simplest normal distribution with the mean equal to zero and the variance equal to one (Joglekar, 2003). However, within the building construction industry any normal distribution can be transferred to z distribution in that case study by applying

$$Z = \frac{X - \mu}{\sigma} \tag{2}$$

where

$$X \sim N\left(\mu, \sigma^2\right) \sigma \neq 0 \tag{3}$$

Therefore, for a delay, e.g., of 3 days (products 02, 06, 08 and 19) there is a Z distribution of:

$$Z = \frac{3 - 2.4}{1.667} = 0.36 \tag{4}$$

As a complement the Z distribution is calculated in the following table of the building construction industry for all the tested products.

X Value (Days)	Product No.	Number of products	Z Distribution
0	10, 15, 17	3	-1.44
1	03, 14, 20	3	-0.84
2	01, 05, 11, 13, 18	5	-0.24
3	02, 06, 08, 19	4	0.36
4	03, 14, 20	3	0.96
5	16	1	1.56
6	06	1	2.16

Table 5: Z Distribution of the products

Shape of Normal Distribution for the Test of Delay

The probability density funstion can be seen in the following figure "Probability Density and Shape of Normal Distribution" for the test of delay implemented in this case study as a curve of normal distribution, which is "bell" shaped. However, for this research within the building construction industry, to the shape (see the figure below) will be determined according to the probability density function of normal distribution (Trivedi, 1982).

$$f\left(X\right)=\frac{1}{\sqrt{2\pi\sigma^2}}e^{-\frac{(X-\mu)^2}{2\sigma^2}} \tag{5}$$

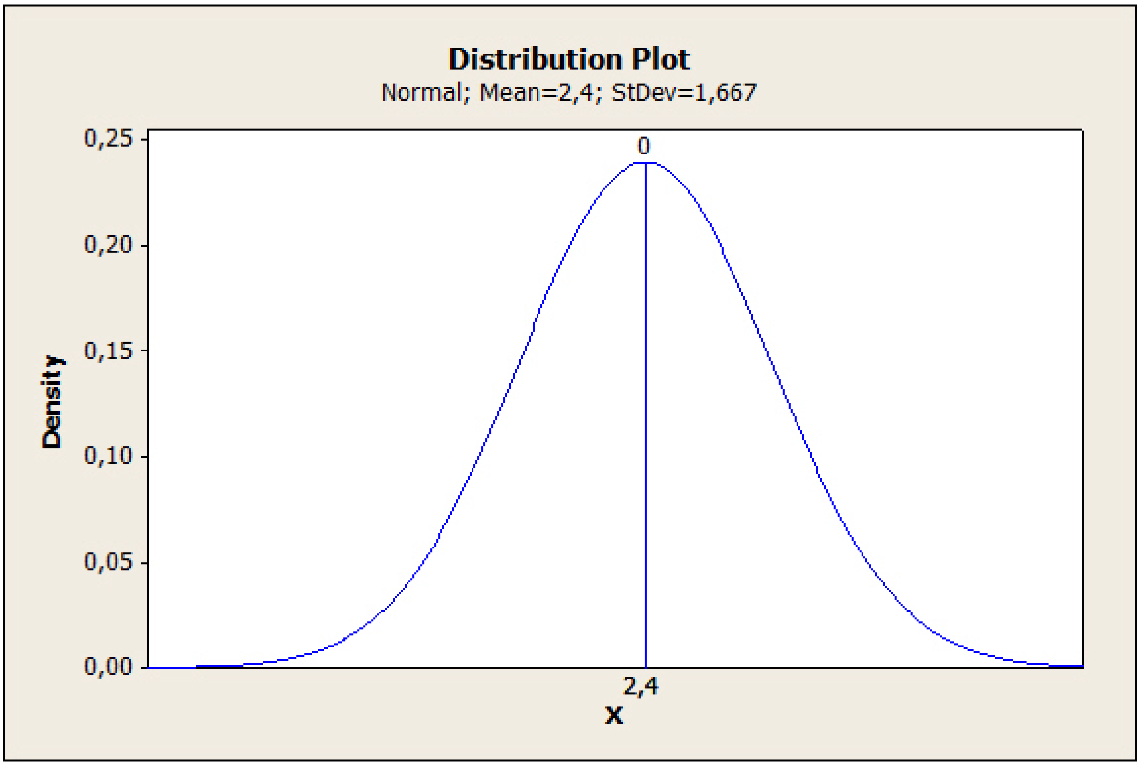

Figure 15: Probability Density and Shape of Normal Distribution

Conclusions of the Normal Distribution & Normality

- For this test there is a mean of 2.4 days of delay for each product within the building construction industry.
- The statistical standard deviation for that test is 1.667σ.
- The p-value of the normality is 0.38 (see the figure above) greater than alpha level (0.05). Thus, it isnot possible to reject the null hypothesis (H_0) of the delay of the 20 products and claim that the data, which are tested within the building construction industry, are normally distributed.

Graphical Analysis of the Six Sigma

In statistics of the Six Sigma system, graphical analysis is a method to visualise the quantitative tested data. Graphical analysis is used to discover the structure and pattern in the delay data, explaining and presenting the Six Sigma statistical conclusions. A complete Six Sigma statistical analysis includes both quantitative analysis and graphical analysis (Pyzdek & Keller, 2003).

There are various Six Sigma graphical analysis tools available for implementation in this research. Here are four of the most commonly used Six Sigma tools:

- Graphical Analysis 1. Box Plot
- Graphical Analysis 2. Histogram
- Graphical Analysis 3. Scatter Plot
- Graphical Analysis 4. Run Chart

Graphical Analysis 1. Box Plot of Delay

In this work the value X of delay is going to be tested. Accordingly, a box plot is a graphical method for summarising a data set by visualising the minimum value, 25^{th} percentile, median, 75^{th} percentile, the maximum value and potential outliers.

A percentile is the value below which a certain percentage of data fall. For example, if 75% of the observations have values lower than 685 in a data set, then 685 is the 75^{th} percentile of the data (Pyzdek & Keller, 2003).

$$InterquartileRange = 75^{th} Percentile - 25^{th} Percentile \tag{6}$$

Therefore, the box plot is useful for the following work:

- Comparing quickly the distributions of the test
- Viewing the central tendency of the data

  The central tendency is the statistics that summarise an entire data set with a single value, including the mean, trimmed mean, median, and mode, all of which are different ways of Six Sigma thinking of the centre of a data set. Graphs such as histograms, box plots, and dotplots are useful in visualising data's central tendency and can assist in deciding which central tendency statistic is most appropriate with a given data set. Knowing the central tendency is an important first step in understanding your data (Pyzdek & Keller, 2003).

- Highlighting the variability of the data for the box plot of delay

  This deals with the extent to which a data set or distribution is scattered around its mean.

- Determining whether a sample distribution is symmetric or skewed
- Checking for outliers

  For unusually large or small observations: Outliers can have a disproportionate influence on statistical results, such as the mean, which can result in inaccurate interpretations. For example, a data set includes the values 1,2,3 and 34. The mean value, 10, which is higher than the majority of the data (1,2,3), is influenced greatly by the extreme data point, 34. In this case, the delay data values appear higher than they really are due to the mean value. You should investigate outliers because they can provide useful information about your data or process.

For each group, vertical boxes has been plotted representing approximately 50% of the observations, with lines (called "whiskers") extending from the box that roughly represent the upper and lower 25% of the distribution, and asterisks beyond the whiskers representing outliers (Pyzdek & Keller, 2003).

Investigators compared the hardness of four different blends of paint. Samples of each blend were applied to a small piece of metal, then cured, and measured for hardness.

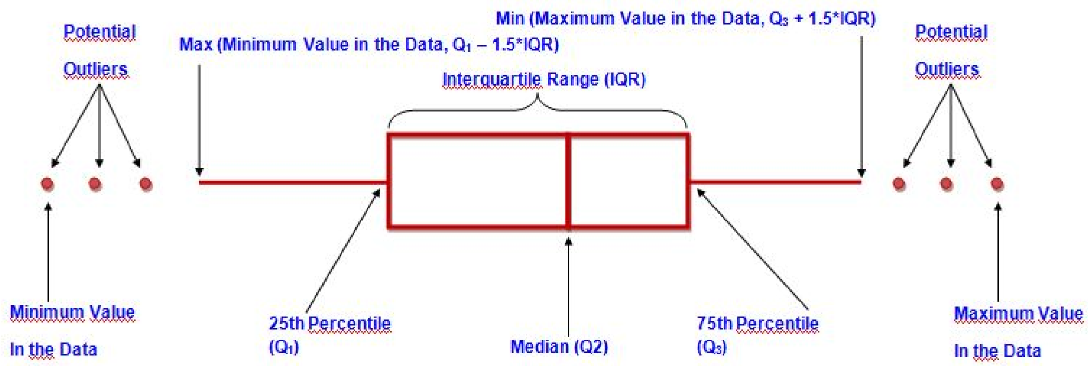

Figure 16: Interquartile Range (IQR) of the Box Plot

Here are the results of the test within the building construction industry of the box plot of delay:

Q_1 Median (Q_2)	1 2
Q_3	3.75
IQRange	2.75
Whiskers to:	0.6
N	20

Table 6: Information of the Box Plot of Delay

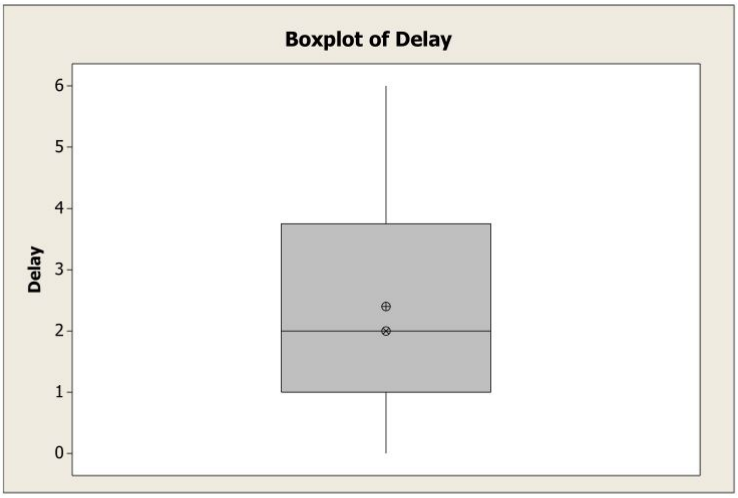

Figure 17: Box Plot of Delay

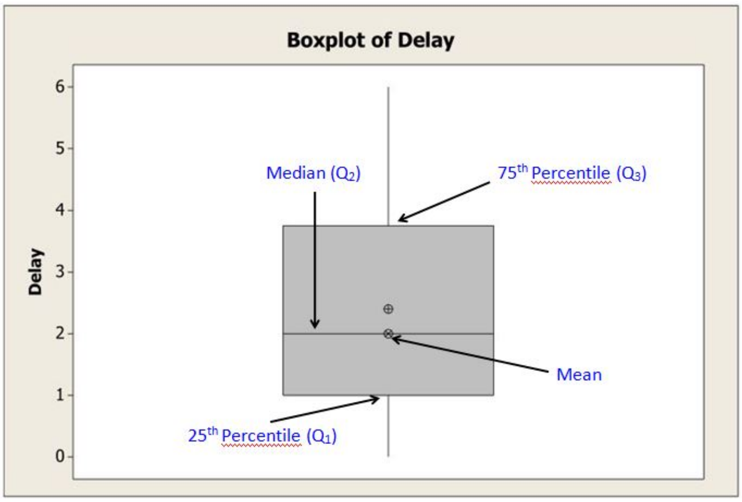

Figure 18: Box Plot of Delay

Graphical Analysis 2. Histogram

The second graphical tool, which is going to be used in this work, is a histogram of the values of delay. That Six Sigma graphical tool is useful for showing the distribution of the tested data. The X axis in this histogram, which presents the values of the products delay in days, shows the achievable values of the variable of the product delay. The axis for the frequency of the value of delays is the Y axis. In that histogram, the seven contiguous rectangles are built up over the intervals with each proportion equal to the frequency density of the interval. The total area of all the seven rectangles in that histogram is the number of data (N=20).

This histogram of delay values (see figure below "Summary for Delay") can also be normalised, so that the X axis (value of delay) still presents the achievable values of the variable but the Y axis is the percentage of observations which fall into each interval on the X axis.

The total area of all the seven rectangles in that normalised histogram is 1. Moreover, with this histogram as Six Sigma graphical tool, there is a better understanding of the shape, location and spread of the data (Pyzdek & Keller, 2003).

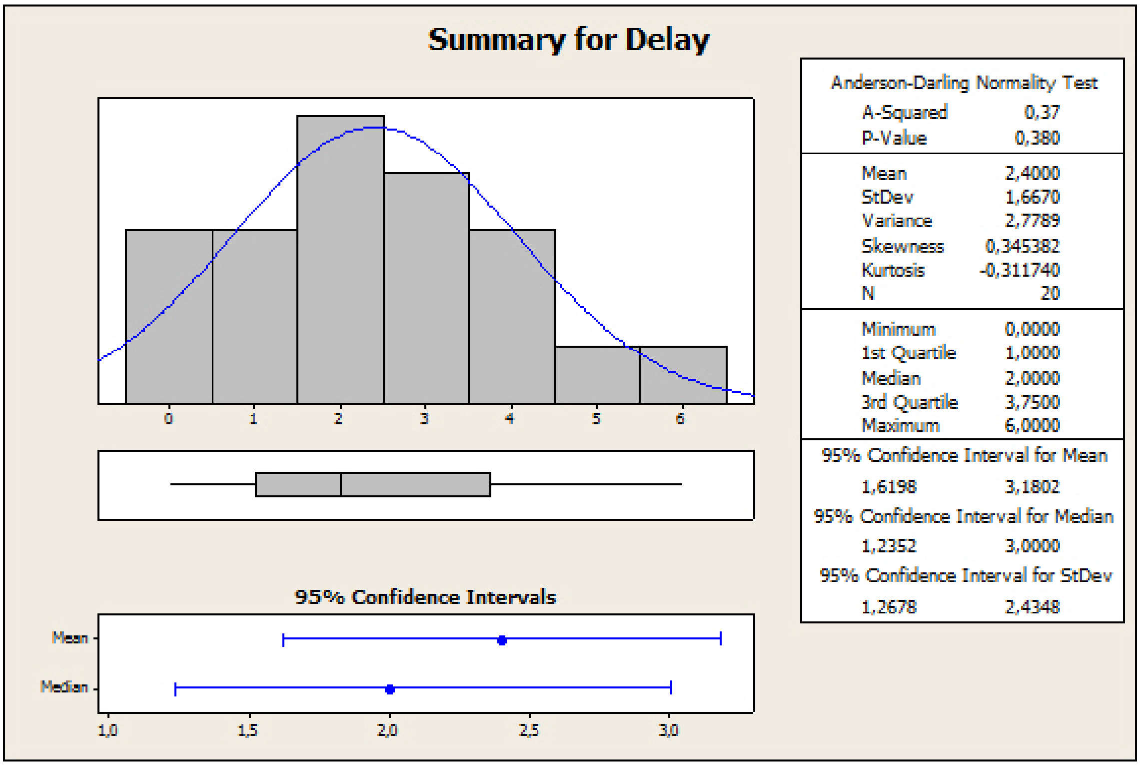

Figure 19: Summary for Delay

This graphical summary (see figure above) provides several graphs that summarise the data of products delay, as well as a statistical summary, all conveniently and clearly presented in the same window.

Data Description

During the execution process of the products within the building construction industry, the data about the delay over the course of two months have been collected. The delay values indicate the number of days per product with or without delay. Moreover, the observation task started in the project for those two months and there is observation throughout two months.

Histogram of Data With Normal Curve

This Six Sigma graphical tool, the histogram, can also be useful for the delay data to cover and assess the normality of the tested data with a normal curve. A normal distribution is symmetric and bell-shaped, as indicated by the curve in the following figure. (Note that this curve is truncated where it extends beyond the borders of the graph). It is often difficult to evaluate normality with small samples. However, in this case study there is a clear curve truncated and it can be used to evaluate the normality of the tested data (Pyzdek & Keller, 2003).

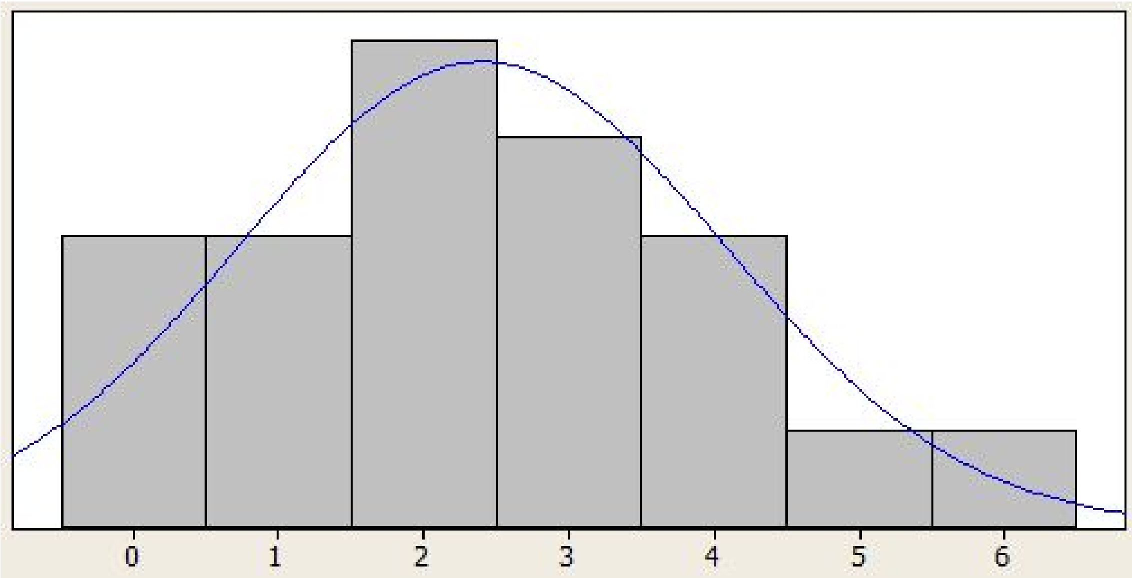

Figure 20: Histogram for Delay Data

As an example, an hypothetical delay is now going to be taken into account for the data of two more products (product No. 21 and 22). Their hypothetical information is given in the next table.

Delivery Product	Delay (Days)
Product 21	12
Product 22	9

Table 7: Hypothetical Delay of the Products

With this information a new histogram graph is going to be created. However, it would be quite difficult in this new case to evaluate the normality of the tested data due to the two new possible outliers, as shown in the figure below.

Conclusions of the Histogram of Data With Normal Curve

The delay data follow the normal curve in this case study within the building construction industry. This is primarily due to the absence of any outlier at the far right or far left of the graph. Without this possible outlier, the data look much more normal, as illustrated

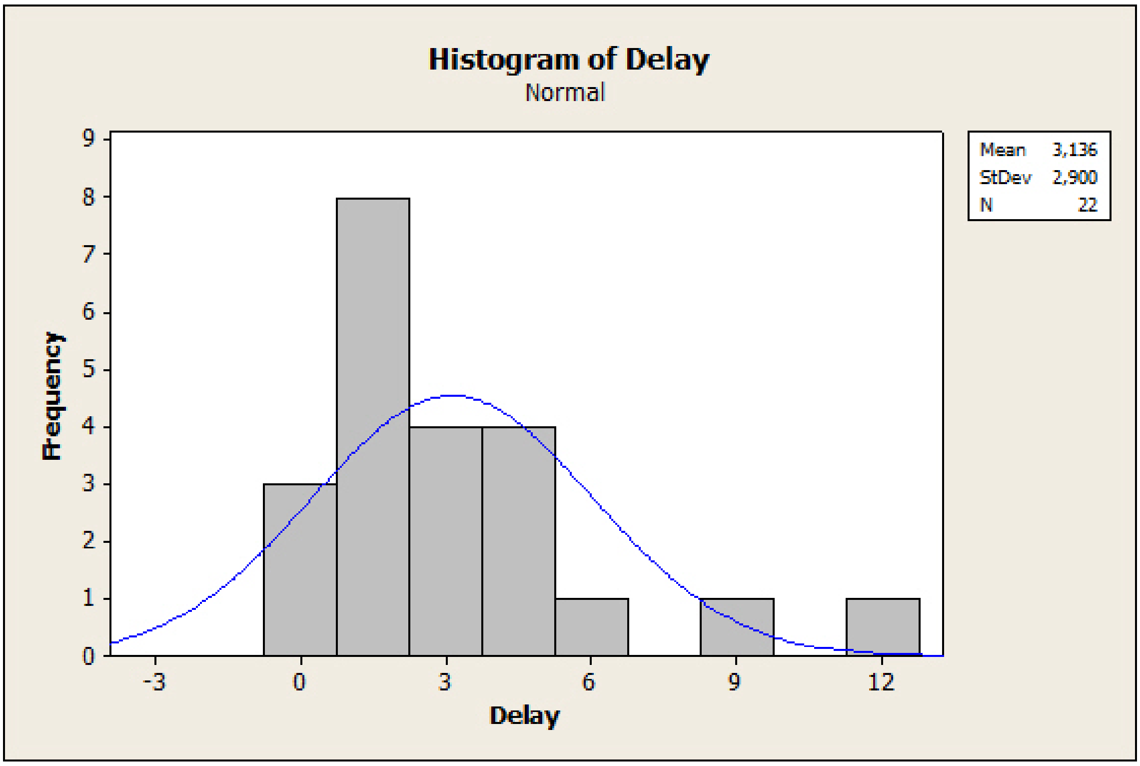

Figure 21: Sample Histogram for Delay Data with Outliers

in the figure "Histogram for Delay Data".

Box Plot of the Summary for Delay

This box plot used in the summary for delay can summarise information about the shape, dispersion, and centre of the tested data. It can also discover the outliers, as can be seen in the figure "Hypothetical Box Plot with Outliers".

Here are some explanations about the box plot.

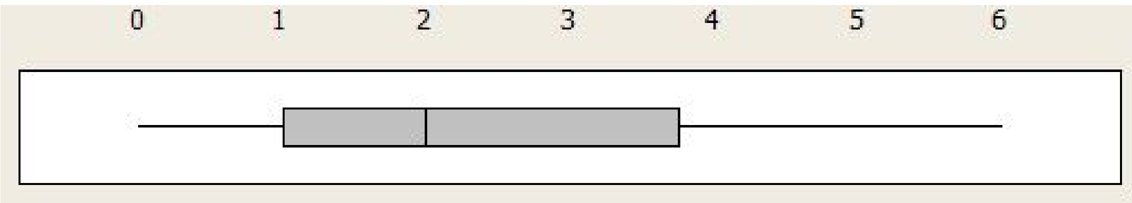

Figure 22: Box Plot of the Summary for Delay

Firstly, the left position of the box represents the first quartile (Q_1), while the right position represents the third quartile (Q_3). Thus, this box portion of the plot represents the interquartile range (IQR), or the middle 50% of the observation.

Secondly, the stripe drawn through the box represents the median of the data (Q_2). The stripes extending from the box are called "whiskers". They extend outward to denote the lowest and highest values of delay in the data set (excluding outliers). Extreme values of that box plot, called outliers, have a representation by dots.

Lastly, a value of delay is considered an outlier if it is outside of the box of delay data (that means it is greater than Q_3 or less than Q_1) by more than 1.5 times the IQR (see the figure below "Hypothetical Box Plot with Outliers"). However, in this case study there is no evidence of outliers in the data set (Pyzdek & Keller, 2003).

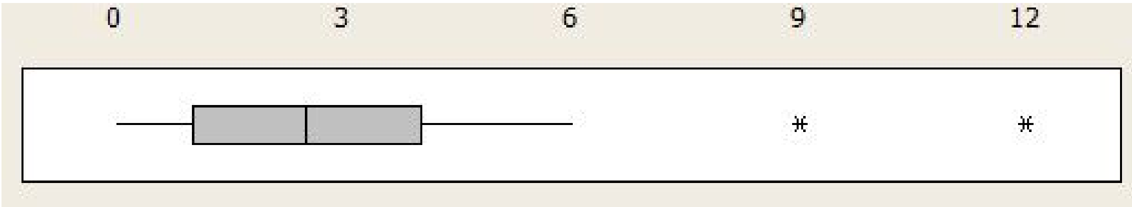

Figure 23: Hypothetical Box Plot with Outliers

The box plot of the delay data used within the building construction industry can be useful for evaluating the symmetry of the tested data in two cases.

- The delay data are partially symmetric in the box plot of the summary for delay. However, the hypothetical delay data are pretty symmetric. Thus, the median line is nearly in the middle of the IQR box and the whiskers are similar in length (see figure above "Hypothetical Box Plot with Outliers")

- The delay data are not clearly skewed. Therefore, the median may fall in the middle of the IQR box, and the right whisker is visibly longer than the left whisker (Pyzdek & Keller, 2003).

Conclusions of the Box Plot of the Summary for Delay

In the box plot of the delay data, which is used within the building construction industry, the median is visibly centred in the IQR box, and the whisker on the right is longer than the left whisker. This shows that without any outlier, which is represented in the box plot of the summary for delay with an asterisk for the products No. 21 and 22 in the figure "Hypothetical Box Plot with Outliers", the delay data are slightly symmetric. Therefore, there is good evidence that the outlier may not be from the same population. Just as if they were in the tested data, they may not be as the rest of the sample data.

Here is the **table of statistics** according to the summary for delay data.

Anderson-Darling normality test (A-squared and p-value)

For this case study the Anderson-Darling normality test is going to be used. It can determine whether the delay data follow a normal distribution. As shown in the previous chapter, the case study follows a normal distribution. It can be said that the A^2 statistic provided by this test does not give enough information by itself, but it is necessary to determine the p-value. In the following table, the p-value ranges from 0 to 1, and it can indicate how possible it is for the delay data used within the building construction industry to follow a normal distribution.

Firstly, it is necessary to decide how low the p-value must be for the case study to conclude that the tested data are not normal. A value of 0.1 is commonly chosen, but the alpha level (0.05) has been chosen for the case study within the building construction industry. This value exactly coincides with the half value. Then, in view of the fact that the p-value is not lower than the criterion, it must be concluded that the delay data follow a normal distribution. Overall, there is enough evidence to conclude that the data follow a normal distribution (Pyzdek & Keller, 2003).

Anderson-Darling Normality Test	Value
A-Squared	0.37
P-Value	0.38

Table 8: A-Squared & P-Value

Conclusions of A-Squared & P-Value

The A-Squared value for the delay data (0.37) is almost the same as the associated p-value (0.38). Assuming that the alpha level (0.05) has been chosen as the level of significance, it must be concluded that the data follow a normal distribution, because 0.38 is not lower than 0.05.

Standard Deviation & Variance

The values of the standard deviation and the variance measure dispersion for those delay data show how far the observation in this case study deviate from the mean (2.4 days). The standard deviation ($\sigma = 1.667$) of this case study within the building construction industry is equivalent to an average distance, which is also independent of direction) from the mean (2.4 days). The variance $\left(\sigma^2 = 2.7789\right)$ is uniquely the standard deviation ($\sigma = 1.667$) squared.

Like the mean (2.4 days), the standard deviation ($\sigma = 1.667$), and as well the variance, is quite sensitive to the extreme values.

Anderson-Darling Normality Test	Value
Standard Deviation (σ)	1.667
Variance (σ^2)	2.7789

Table 9: Standard Deviation & Variance

Conclusions of Standard Deviation & Variance

The standard deviation (σ) for the delay data is 1.667. It means that on average, the values of the delay data set tend to differ from the mean (2.4 days) by ± 1.667.

Skewness

For this case study in the building construction industry has been used the concept of *skewness*, which refers to a lack of the symmetry in the delay data. A distribution is skewed if one part of the delay data extends farther than the other part. The skewness statistic is provided with the shown graphical summary for delay:

- A skewness value in this case study close to 0 indicates that there are symmetric delay data.
- A negative skewness value means a left slant.
- A positive skewness value means a right slant.

Kurtosis

The concept of *Kurtosis* has also been used. This refers to how tidily peaked a distribution is. A value of kurtosis statistic is provided with the graphical summary of delay:

- A kurtosis value in this case study close to 0 indicates that there are normally peaked delay data.
- A negative kurtosis value means a distribution that is flatter than normal.
- A positive kurtosis value means a distribution with a sharper than normal peak.

Anderson-Darling Normality Test	Value
Skewness	0.345382
Kurtosis	-0.311740

Table 10: Skewness & Kurtosis

Conclusions of Skewness & Kurtosis

In the case study within the building construction industry, the skewness value for the delay data is 0.345382 indicating that the distribution is close to the 0 value. This therefore indicates that the symmetric delay data and the positive value imply a slightly right slant. This is due to the fact that there is no outlier shown at the far right of the histogram for delay data.

The kurtosis value for the delay data is -0.311740 indicating that the distribution is tidily peaked as a normal distribution. Thus, the histogram illustrates that the peak of the delay data rises well above like the normal curve (blue).

Graphical Analysis 3. Scatter Plot

The third graphical analysis that is going to be used in the case study within the building construction industry is a scatter plot. It is a diagram to present the relationship between the two variables, which are the variable of delay and the following variable of errors per product of the data set. The first variable is the delay value. The second value, which is going to be used in the case study, is the number of errors per delivered product. A Six Sigma scatter plot consists of a set of data (values of delay and errors per product) points. A single observation in that Six Sigma graph is presented by a data point on the scatter plot with its variable of errors (horizontal position) equal to the value of one variable and its variable of delay (vertical position) equal to the value of the other variable (Pyzdek & Keller, 2003).

A scatter plot as a Six Sigma graphical analysis helps to understand the following:

- Whether the two variables (variable of delay & error) are related to each other
- The strength of their relationship between the variables of delay & error
- The shape of their relationship in the Six Sigma graphical analysis
- The presence of outliers when they are far away from the symmetric data set

According to the case study implemented within the building construction industry, here is the following tested information for the error of each product. The scatter plot is going to show the symbols at the data values of the two continuous variables (delay & error) at their coordinates (x for delay variable and y for error variable). As seen in the figure "Scatterplot of Delay vs Errors", this Six Sigma graphical analysis contains, as is typical, the following elements:

- The x-axis represents the value of the delay, which is a continuous variable. As is customary, this variable of delay is the predictor (independent) variable.
- The y-axis represents the value of the error, which is a continuous variable too. As is customary, this variable of error is the response (dependent) variable.
- Symbols are plotted at the (x for delays, y for errors) coordinates of the tested data.

Delivery Product	Delay (Days)	Number of Errors	Delivery Product	Delay (Days)	Number of Errors
Product 01	2	0	Product 11	2	1
Product 02	3	1	Product 12	4	1
Product 03	1	3	Product 13	2	2
Product 04	4	1	Product 14	1	3
Product 05	2	0	Product 15	0	4
Product 06	3	1	Product 16	5	1
Product 07	6	1	Product 17	0	3
Product 08	3	0	Product 18	2	0
Product 09	4	1	Product 19	3	1
Product 10	0	2	Product 20	1	2

Table 11: Errors of the Deliveries per Product

The scatter plot is used to assess the direction, strength, and linearity of the relationship between the two variables of delay & error:

- The data values of delay & error tending to rise together indicate a positive correlation.
- If one data value (delay or error) rises as the other decreases, a negative correlation is indicated in the scatter plot.
- A stronger relationship between the two variables can produce a tighter clustering of data points.
- In the case of outliers, they will fall farther away from the main group of dots.

Thus, it can visually be determined if the relationship between the values of delay and error is linear or curved. Scatter plots should be used instead of time series plots when the time-dependent data are not chronologically ordered, or if the data collection intervals are irregular.
Here is the information about the regression of the scatter plot:

Regression fit	Value
Errors	2.364 - 0.4015
Delay R-Sq	34.3%

Table 12: Regression Fit of the Scatter Plot

Conclusions of the Scatter Plot

This scatter plot for the delay and error data does not show a strong relationship, but a good relationship, which is linear and negative, between the two variables of delay & error. Thus, the delay variable may be a good predictor of errors per product.

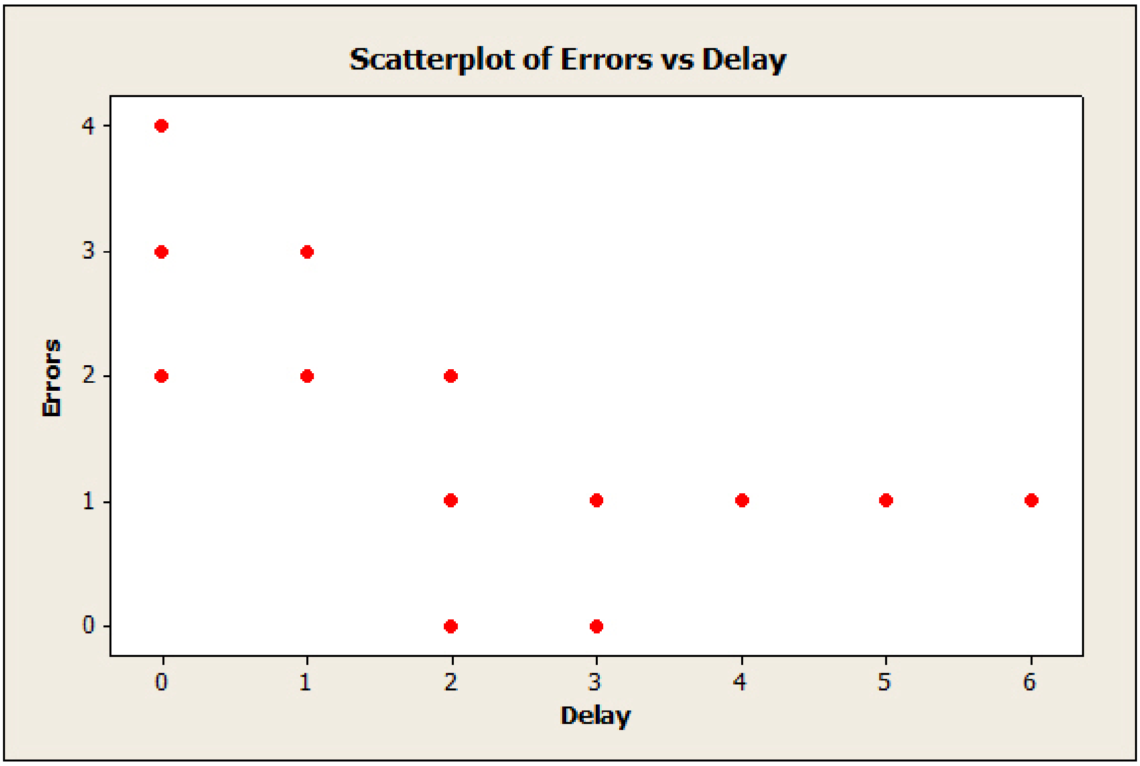

Figure 24: Scatterplot of Delay vs Errors

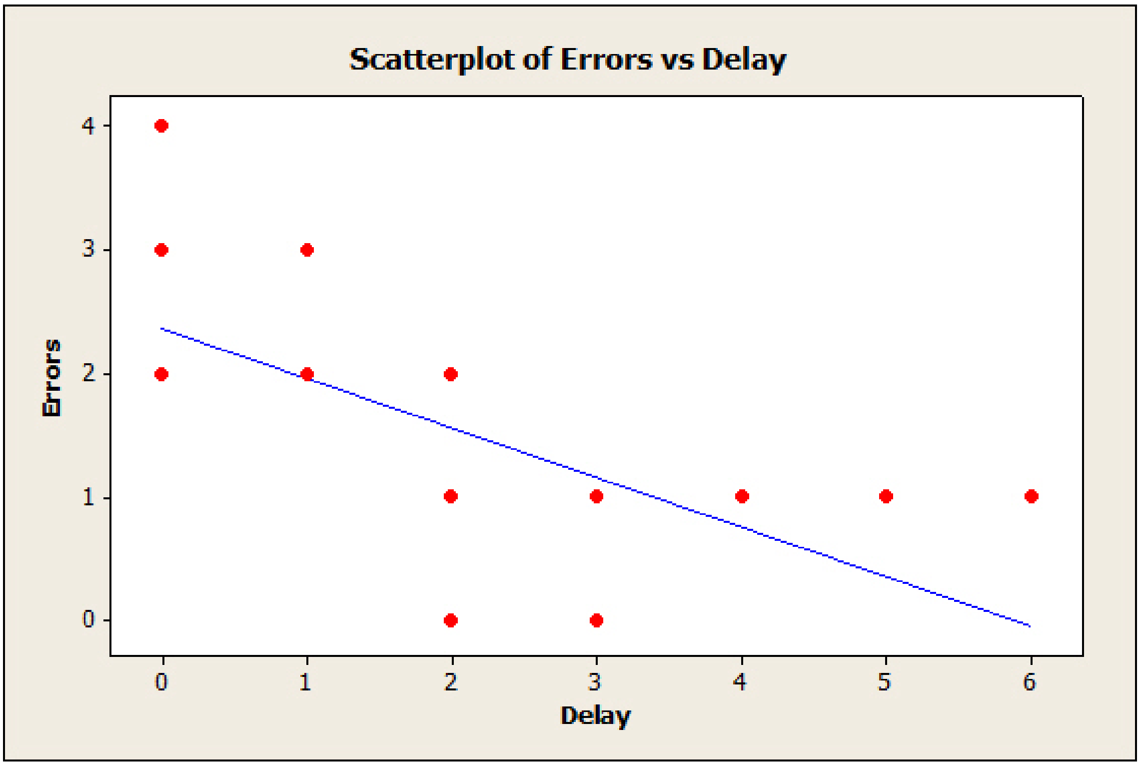

Figure 25: Scatter Plot of Delay vs Errors with Regression

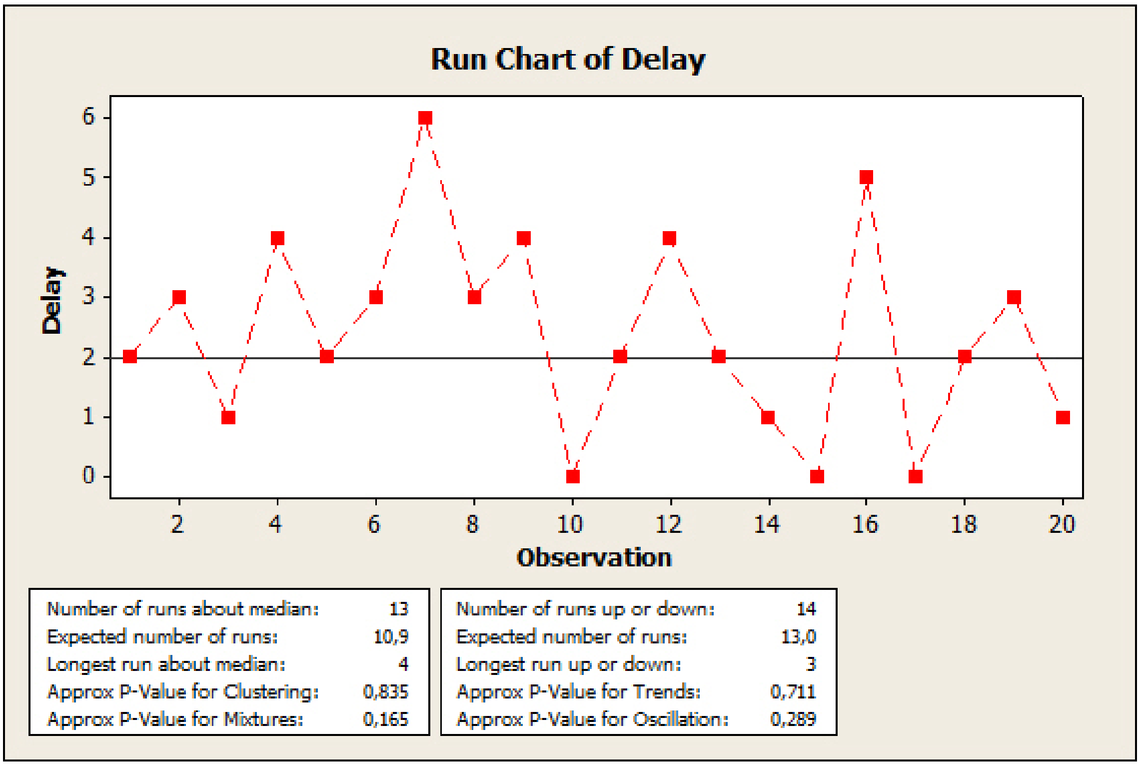

Figure 26: Run Chart of Delay

Graphical Analysis 4. Run Chart

The fourth Six Sigma graphical analysis that is going to be used in this case study within the building construction industry is the run chart. This graph is a chart to present the data of delay & error in time order. It captures the process performance over the time when the data has been set.

The X axis of the run chart for delay and error indicates the time and the Y axis of the run chart indicates the observed values.

Those run charts look similar to control charts except that the run chart does not have control limits plotted. Therefore, it is easier to produce run charts for that case study than a control chart.

This Six Sigma graphical analysis is used to identify the anomalies in the delay and error data and discover the pattern of data changing over time (Pyzdek & Keller, 2003).

Conclusions of the Run Chart of Delay

The time series in this run chart of delay appear stable. There are no extreme outliers, trending or seasonal patterns.

In this chart of delay, the p-value for clustering (0.835) and mixtures (0.165) is greater than the α-level of 0.05. Therefore, it can be concluded that the data does not indicate

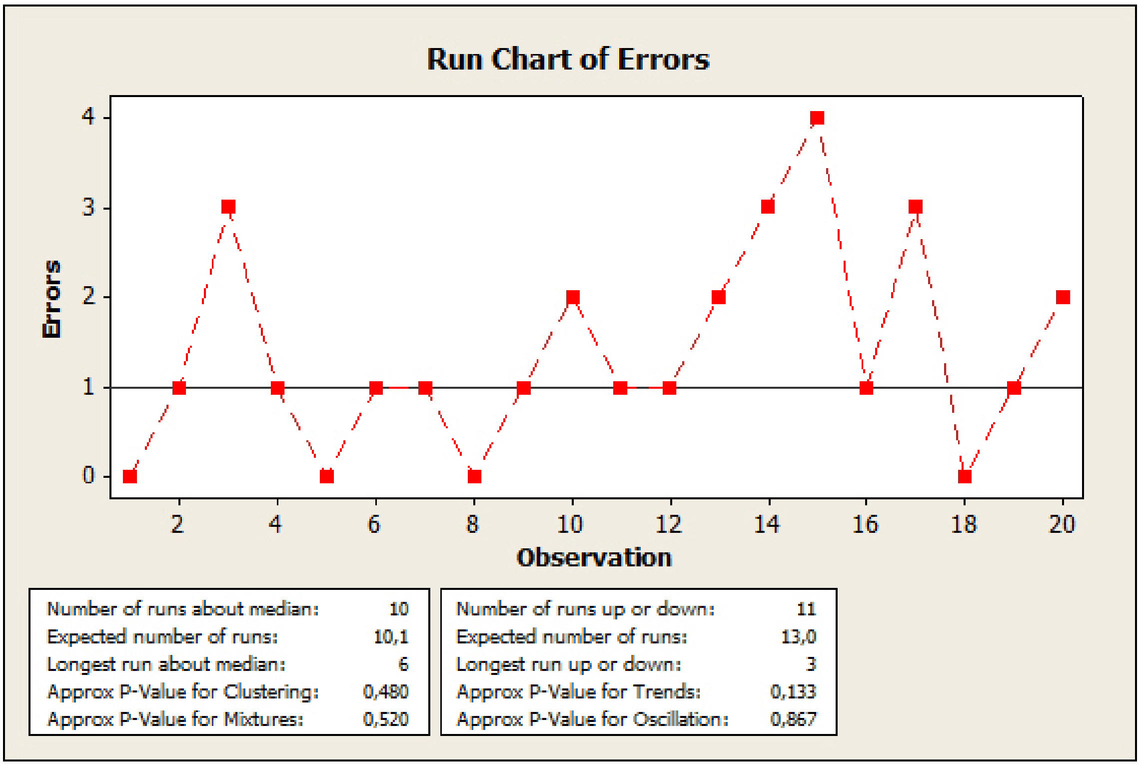

Figure 27: Run Chart of Errors

mixtures or clusters.

Moreover, the p-value for trends (0.711) and oscillation (0.289) is greater than the α-level of 0.05. Thus, it can be concluded that the data does not indicate a trend or oscillation.

Conclusions of the Run Chart of Errors

The time series in this run chart of errors appear stable too. Thus, there are no extreme outliers, trending or seasonal patterns.

In this chart of errors, the p-value for clustering (0.48) and mixtures (0.52) is greater than the α-level of 0.05. Therefore, it can be concluded that the data does not indicate mixtures or clusters.

Moreover, the p-value for trends (0.133) and oscillation (0.867) is greater than the α-level of 0.05. Thus, it can be concluded that the data does not indicate a trend or oscillation.

8 Conclusions and Future Lines of Research

Conclusion

This research study has shown that Six Sigma can be implemented within the building construction industry, especially within the construction project management.

The building construction industry is undergoing in a new form of development toward the Kaizen philosophy, the continuous improvement.

It has been shown that the building construction industry has a systematic system.

Several threads have been located in the construction project management. All threads are improved within the building construction industry.

It has also been shown that Six Sigma can improve time and quality management within the building construction industry.

Limitations Within the Research Building Construction Industry

Six Sigma is a systematic, data-driven quality management concept with the aim of implementing a viable zero-defect strategy. A practical zero-defect strategy means that with a million characteristic values no more than 3.4 errors are tolerated. Therefore, there are 3.4 DPMO (defects per million opportunities). The term Six Sigma originates from statistics. The sigma level is the error component of a process based on the Gaussian distribution. Six Sigma is a process and interface optimization and includes continuous improvement. Moreover, the goal of Six Sigma is to meet customer needs. The so-called CTQ (critical to quality characteristics) (Pyzdek & Keller, 2003).

Six Sigma can be applied in every area of the business where there are processes. Therefore, implementing Six Sigma in the Research Building Construction Industry is also to be tried. The results of a Six Sigma program can be achieved only within the framework of Six Sigma projects, with the inclusion of their management and execution Black Belts and Green Belts. There is intensive use of statistical tools within a structured approach (DMAIC) for analysing and improving processes. The main purpose is to reduce variation and errors.

In summary, it is difficult to implement a process quality management in the building construction industry because every project is like a new prototype in another industry.

Future Lines of Research

When the results will be ready in the study of the time and quality management of this Master of Science, it will be possible for this research to be carried on with the implementation of the Lean Sig Sigma (Lean Construction + Six Sigma) within the area of cost management issues. Furthermore, as relates to this future management application, the research of the Six Sigma implementation in the Research Building Construction Industry will be able to be implemented in the global sector of the Construction Industry for the purposes of quality and time management.

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