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Exploring the Suitability of Six Sigma in Major Swedish Construction Companies

Master's Thesis in the Master's Programme Design and Construction Project Management

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ABSTRACT

In the Swedish construction industry there is a lack of systematic quality development. In contrast, the manufacturing industry has continuously been working with quality development with the help of different methodologies. One such methodology is Six Sigma where a team is trained to use DMAIC and different graphical and statistical tools in quality improvement projects to reduce the DPMO. This report examines if major Swedish construction companies could benefit from the use of Six Sigma and studies what would be required in order to implement the methodology. Also, some of the tools within Six Sigma are examined and their suitability to construction is discussed. The study was conducted partly by researching literature and partly by interviewing people who work with quality in different ways, mainly in construction but also with a Six Sigma expert at Volvo Cars. The results of the study indicate that the way in which construction companies report their variations is insufficient and that there is a lack of measurement databases which hinders the use of Six Sigma. Also, the results point towards a low competition on the Swedish construction market leading to low pressure on the construction companies to develop their quality. The study shows a few examples of beneficial Six Sigma implementation in construction and by Bechtel Corporation. Finally, the results indicate that Volvo Cars has gotten further ahead than the construction industry when it comes to quality awareness and controlling their processes because of factors such as higher pressure from outside stakeholders and harder market competition. In conclusion, the construction industry should include quality awareness in their company cultures and at least start to move from zero defects in the end product to zero defects in the project process which would result in the same thing but with less expenses for the company. The next step should be to use soft-parameter based tools and to start measuring and documenting defects and variations systematically to enable systematic quality development. Also, it should be possible to standardise to a much higher degree than today in order to further decrease variation. If the aforementioned actions were taken it would surely be possible to use Six Sigma to further optimise the processes within construction and continuously develop the quality.

Key words: Six Sigma, Six Sigma in Construction, Six Sigma implementation, Six Sigma tools, Quality Development, Construction Processes, Construction Organisations, Organisational Culture, Swedish construction industry.

Undersökning av Förutsättningarna för Sex Sigma i Ledande Svenska Byggbolag

Examensarbete inom masterprogrammet Design and Construction Project Management

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SAMMANFATTNING

I den svenska byggbranschen finns det brister i det systematiska kvalitetsutvecklingsarbetet i jämförelse med tillverkningsindustrin som kontinuerligt har jobbat med kvalitetsutveckling med hjälp utav olika metodiker. En sådan metodik är Sex Sigma där en grupp utbildade i DMAIC, samt olika grafiska och statistiska verktyg, arbetar i olika kvalitetsutvecklingsprojekt i syfte att reducera sitt DPMO-tal. I denna rapport undersöks om Skanska och Veidekke kan tjäna på att använda sig utav Sex Sigma och vad som krävs för att implementera metodiken. Vidare så är några av de verktyg som är kopplade till Sex Sigma undersökta och deras användbarhet inom byggbranschen diskuterad. Studien är delvis gjord genom litteraturstudier och delvis genom intervjuer med folk som på olika sätt jobbar med kvalitet främst inom byggbranschen men även med en Sex Sigma expert från Volvo Cars. Resultatet från studien indikerar på att det sätt som byggbolagen rapporterar avvikelser är otillräckligt och att det saknas databaser vilket försvårar implementeringen av Sex Sigma. Vidare så pekar studien på att det råder bristande konkurrens inom den svenska byggbranschen vilket medför att byggbolagen inte pressas att utveckla kvaliteten. Studien visar också på några exempel på lönsamma implementeringar av Sex Sigma i byggbranschen, till exempel hos Bechtel Corporation. Slutligen så indikerar studien att Volvo Cars ligger före byggbranschen när det kommer till kvalitetstänk och processkontroll vilket är orsakat av större press från olika intressenter och en hårdare konkurrens. Slutsatsen är att byggbranschen måste inkludera kvalitetstänk i företagskulturen i större utsträckning och skifta tänk från noll fel i slutprodukten till noll fel i byggprocesserna vilket skulle ge samma resultat men med lägre utgifter för företaget. Nästa steg är att använda sig utav verktyg baserade på mjuka parametrar och börja mäta fel och avvikelser systematiskt för att möjliggöra en systematisk kvalitetsutveckling. Vidare så är det möjligt att standardisera mer än idag i syfte att ytterligare minska antalet avvikelser. Om ovan nämnda åtgärder vidtas skulle det vara möjligt att använda Sex Sigma för att ytterligare optimera byggprocesserna och få en kontinuerlig utveckling av kvaliteten.

Nyckelord: Sex Sigma, Sex Sigma i Byggbranschen, Sex Sigma implementering, Sex Sigma verktyg, Kvalitetsutveckling, Byggprocesser, Byggnadsorganisation, Organisationskultur, Svensk byggindustri

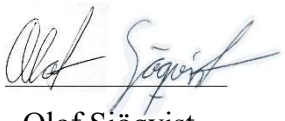
Contents

Preface

In this study, interviews related to Six Sigma, Quality and methodology implementation were conducted with people from Akademiska Hus, NCC, Skanska, Veidekke and Volvo Cars. The study was carried out at the Department of Civil and Environmental Engineering, Division of Construction Management, Chalmers University of Technology, Sweden.

This study was conducted by Olof Sjöqvist and Michael Vrbanc with Professor Christian Koch as supervisor. The Interviews were carried out at the respective company or at Chalmers University of Technology. We would like to thank Christian Koch for his supervision and support. We would also like to thank Johan Alte, Peter Fredriksson, Maria Guttman, Hans Hofflander and Janni Tjell for their participations in the interviews and their contributions to our work.

Göteborg January 2016



Olof Sjöqvist

Michael Vrbanc

1 Introduction

A common opinion about the Swedish construction industry is that there is room for improvement of quality in all parts of the construction process. Also, while construction companies often have follow up meetings and tend to mention quality as an important part of their work, there seems to be a general lack of systematic quality and process development. In contrast, manufacturing companies have been collecting and analysing data and shown great improvements in the quality of their products and processes. (Koch & Jonsson, 2015)

The word quality can have different meanings depending on the context. In this thesis quality is thought of in the contexts of Six Sigma and construction and is thus defined as *how well a product or process output meets the agreed upon specifics, according to the output receiver, (e.g. the customer or company department), and any unwanted variation from the specifics is regarded as a decrease in quality.* Therefore, it is important that the output producer, (e.g. a construction company or a team within a company), is aware of and understands the requirements of the receiver.

Within the manufacturing industry, Six Sigma is used as a means of quality improvement. Furthermore, Six Sigma is a methodology, based on a number of tools, which has repeatedly been proven to improve the quality of processes and products by decreasing the number of defects and unwanted variations. (Magnusson, et al., 2003)

However, Six Sigma is not commonly used in the construction industry and it seems to be mostly used in the prefabrication sector which is somewhat similar to manufacturing and less project based than other areas of construction (Tchidi, et al., 2012; Tutesigensi & Pleim, 2008; Kashiwagi, et al., 2004). Also, there is no indication that any major company in the Swedish construction industry is using the methodology at all.

1.1 Purpose

The purpose of this thesis is to examine if quality within the Swedish construction industry could benefit from the use of Six Sigma methodology and what would be required from the major construction companies in order to successfully implement Six Sigma.

1.2 Delimitations

The focus of the report will be on Six Sigma used for quality improvement of existing products and processes within construction. Also, the focus will be on major construction companies in the Swedish construction industry.

1.3 Research Questions

The following research questions have been stated in order to clarify the aim of the thesis and as an aid to reach the purpose mentioned above.

- What is Six Sigma and how does it relate to quality?
  - Which organisational requirements need to be fulfilled to successfully implement Six Sigma and other similar methods?
  - How do major actors in the construction industry work with quality and quality development today?

- Is there a demand for quality improvement and could Six Sigma fill that demand in the construction industry?

2 Thesis method

As mentioned in Chapter 1, Six Sigma is not an established methodology within the Swedish construction industry and the research done on the subject can be considered insufficient. Therefore, it is necessary to look at both previous research and the industry itself in order to examine if the use of Six Sigma could be beneficial in the Swedish construction industry. Also, Dubois and Gadde (2002) argue that researchers who go back and forward between literature and the empirical world in their studies get a deeper understanding of both sides. Furthermore, the two researchers believe that the goal of all studies is to confront theories with the real world and suggest that this should be done throughout the study. Therefore, the methodology of this thesis consists of two major parts, literature and empirical studies, which are conducted in parallel in order to examine if Six Sigma could be applicable in the Swedish construction industry. The execution of the two thesis methodology parts is described in the following subchapters.

2.1 Literature study

According to Webster and Watson (2002), a literature review is crucial for any research project since it shows which areas have already been researched and at the same time which areas should be studied deeper. Furthermore, the studies can give the researcher a deeper understanding in the area of research and a chance to determine which variables are relevant for their own particular research and how they are connected to one and other (Dubois & Gadde, 2002).

The literature study in this report contains three main parts: Construction Organisations, Six Sigma and Six Sigma in construction. First, the study follows a concept-centric approach, focusing on a concept to link relevant literature together (Webster & Richard, 2002). Second, an author-centric approach is used, (finding other articles which the authors have written), in order to get a deeper understanding of the subject and to examine if the theories are consistent. Third, the books used in courses within the Design and Construction Project Management Master's programme are looked over and used to the extent which they are relevant, in order to build upon previous knowledge.

The main databases and search engines used were Scopus, Summon, ARCOM and Google Scholar. Some of the search phrases used were "Six Sigma", "Six Sigma + Construction", "Construction organisation", "Construction management", "Project management", "Organisational culture", "Implementation + Construction"

The most relevant articles were found when searching for articles which have "Six Sigma" and Construction in their abstracts, titles and key-words. This search gave 107 hits on Scopus out of which 40 were skimmed through and 9 were used in this thesis. The same phrase gave 113 hits on Summon out of which 17 were skimmed through and 6 were used, (some articles which were available at both Scopus and Summon have here only been counted once). Similar search phrases, backtracking in relevant articles and researcher searches did not result in more than a few additional relevant articles. Thus, the conclusion was drawn that insufficient relevant research has been done on the subject of Six Sigma in the construction industry and no examples were found on Six Sigma in the Swedish construction industry.

2.2 Empirical study

The empirical study was conducted in order to get deeper knowledge about how construction companies work with quality improvement and about how companies in other industries work with Six Sigma, adding to the knowledge attained from the literature study.

Dubois and Gadde (2002) believe that a researcher should not underestimate the value of specific cases and they argue that because theories and the empirical world are constantly changing, a deeper look into a specific case might be more valuable than shallower studies with several cases. Similarly, only a few specific companies have been chosen for this thesis and the results are seen as an indication of how the chosen major actors work with quality or implementation in construction or Six Sigma in manufacturing, rather than a mean value for the respective industry.

Background material for the empirical study is collected from company homepages, news articles, annual reports and similar documents, for both construction and manufacturing companies. Also, five interviews were conducted with one person representing a construction client company, one person working with Six Sigma in manufacturing, one person working with methodology implementation in construction and two people working with quality in construction companies.

The construction companies chosen are Veidekke and Skanska because they are major actors in Swedish construction who seem to value their quality work according to the background material mentioned above. The interviewees at Veidekke and Skanska were found by looking for people who work with quality in the respective companies and one person was found with the assistance of Professor Christian Koch. The questions asked in the respective interviews were aimed at exploring how the companies view, develop and work with quality, systematisation and other things connected to Six Sigma. In addition, a third construction company, NCC, was chosen because of their work with implementing a major work method in the company. The interviewed person in NCC was chosen because of her work with the aforementioned implementation. The questions were aimed to give an understanding of how the implementation was conducted in order to see what could be expected from the implementation of a similar type of methodology, such as Six Sigma, within construction.

The manufacturing company chosen was Volvo Car Corporation, (Volvo Cars), because it has worked with Six Sigma for over 15 years and is the leading car manufacturer in Sweden. Volvo Cars' interview person was chosen because she has worked with Six Sigma on different levels since Volvo Cars started using the methodology and she is an expert on the subject. The aim of the interview was to get a deeper understanding of how Six Sigma was implemented at Volvo Cars and how it has been beneficial to the company. Also, questions similar to those in the Veidekke and Skanska interviews were asked so that their views on quality can be compared.

The construction client chosen is Akademiska Hus because it seems to be one of the most quality aware of the major construction clients in Sweden when comparing their website information and available documents to those of other major clients. Also, when people in construction companies were asked if any clients were particularly quality aware, Akademiska Hus was the most frequent answer. The aim of the interview was to get a quality-aware client's view on construction companies' work with quality and its development. Furthermore, questions about if Akademiska Hus feels that it can check and control quality during projects and push the construction company into

increasing its quality, were asked to get the client's view of their own market power and the market competition.

2.3 Method discussion

It has been difficult to find information about Six Sigma in the Swedish construction industry because of the limited amount of research done on the subject. Furthermore, many of the articles that were found have an Asian perspective and include conditions which differ from those in Sweden. Information about Six Sigma in general was easier to find and the main sources for Six Sigma information used in this report were: "Look Forward Beyond Lean and Six Sigma: A self-Perpetuating Enterprise Improvement Method" by Robert Dirgo, "Six Sigma Demystified" by Paul Keller and "Six Sigma handbook" by Thomas Pyzdek and Paul Keller. These books are seen as a more or less complete explanation of the methodology and were considered sufficient background for the theoretical description of Six Sigma in this report. However, the somewhat American approach in the books was toned down and balanced out with the rest of the literature and with the interviews. Perhaps a Swedish source on Six Sigma could have added some insight but the sources used were considered sufficient for this thesis.

The authors' of this thesis are pleased with the answers attained from the interviews and are happy that the interviewees shared both their own and their companies' perspectives. More interviews might have resulted in more information but since Six Sigma is not used in Swedish construction such information might have been of topic and unnecessary. Also, due to the amount of information gained form the conducted interviews, the difficulty in finding the right people to interview and how much time it took both to find interviewees and to process the interviews afterwards, the number of interviews conducted was considered sufficient. An alternative to the interviews which was considered initially was to make surveys instead of the interviews or as a complement to them in order to get a broader perspective. However, such surveys were not included in this thesis due to lack of time and because a lot more people would have to answer them in order to get a trustworthy result. Furthermore, it would have been more difficult to analyse the results from surveys because people can interpret questions and terms, such as quality, differently compared to interviews where it is easier to understand the shades of what people say and where both parties can ask if something is unclear. An interview with someone at Bechtel, which is perhaps the most famous example of a construction company working with Six Sigma, could have contributed with interesting insight into working with Six Sigma in construction. The main reasons for which such an interview was not conducted was that it was difficult to find the right person to interview because of the company's size and that Bechtel is not operating in the Swedish construction market.

3 Construction Organisations

In this thesis, organisations are seen as people, tools, knowledge, objects and symbols, with a specific purpose, liked together and within an organised framework (Clegg, et al., 2011). However, even though the frameworks are organised, Fryer (2004) argues that organisations are in most cases not designed but constantly grow and continuously develop over time. There are several different organisational structures within construction, depending on factors such as their purpose and size. The bigger the company is the less likely it is to succeed without formal roles and responsibilities because more people leads to more tasks performed making it increasingly difficult to spot if tasks are being repeated, carried out improperly or entirely skipped (Fryer, 2004).

According to Gluch (2009), most of the organisations within the construction industry are project based matrix organisations which have both a permanent hierarchical structure based on functions, geographical location and customer needs and temporary project structures which change between each project. The main purpose in a construction project is to build, which is a complex task consisting of a several varying subtasks. One of the biggest challenges within a construction project is to coordinate activities, materials and workforce during a limited time at a specific location with varying conditions (Gluch, 2009) (Landin, 2000). Furthermore, there are a lot of different actors involved such as agencies and technical specialists. Also, because of the project structure, the organisations are dynamic collectives with individuals who enter and leave the project at different stages in the project process (Stinchcombe, 1985).

Construction projects are characterised by high autonomy with a decentralised decision-making structure. Therefore, it is a challenge for project based organisations to coordinate the permanent organisational structures with the temporary project structures and the activities which are connected to the project. Another challenge is that the construction processes and role structures have a strong connection to the organisational culture, how to build, which actors should be involved and their roles in the project (Kadefors, 1995). The execution of complex construction projects is based on the experience of skilled professionals (Dubois & Gadde, 2002). Every project is its own entity with its own team of individuals who are working towards a common goal, namely the successful execution and completion of the project. Therefore, project individuals tend to stick more with the praxis and norms within specific projects rather than those from the companies where they are employed. This can lead to problems with organisational learning, change management, management praxis and implementation of innovations and new technologies. Also, implementations which change the praxis of the project can lead to additional problems. (Gluch, 2009) (Bresnen, et al., 2005)

Variations and contingencies are common in the project based nature of the construction industry which forces construction organisations to be flexible and adaptable to new conditions (Fryer, 2004). In addition, Sears et al. (2008) argue that schedules and planning might have to be altered when new challenges are discovered. Therefore, it is important to have managers who can properly assign responsibilities and divide the organisation into smaller sections or groups without separating them from the organisational framework (Fryer, 2004). Also, the managers should be able to communicate with the organisational members so that information is properly distributed to and understood by all the involved people and at the correct time (Sears, et al., 2008).

According to Clegg et al. (2011), culture is the objects and behaviours which people use, apply and identify themselves by according to their norms in certain contexts and situations. Furthermore, Clegg et al. (2011) state that people are often incognisant of their culture so the easiest way to recognise it is to have someone act against it. Similarly, Schein (1997) believes that culture consists of three levels of depth, (which he calls artefacts, values and basic assumptions), where basic assumptions are the core of the culture even though they are obscure to the people who have them.

Organisational culture is the culture shared by members of an organisation. Clegg et al. (2011), agrees with Schein (1997) that the most important part of organisational culture is the basic assumptions and argues that they are ground for subconscious decisions which shape the whole organisation, including the values and artefacts. Furthermore, Clegg et al. (2011) argue that an organisation can benefit from a strong culture and that managers have sought to shape organisational cultures so that they make organisational members more committed and compliant. Similarly, Schein (1997) argues that organisational culture and subcultures of groups within the organisation can provide stability, significance and structure for the group members. However, Clegg et al. also states that strong cultures are not always good cultures and a strong bad culture, e.g. belief that the oldest person is always right or that one way of doing things is the best way because it has worked before, can have a negative impact on an organisation.

Geographical culture is often strong and can play a big role in how organisations operate and shape their organisation (Clegg, et al., 2011). For example, Swedish companies often work with a flat organisational structure since it is deeply rooted in Swedish culture that everyone should have their say whilst Chinese organisations tend to follow a hierarchical structure because the hierarchical mentality is more rooted within Chinese culture (Nisbett, 2003).

According to Maylor (2010) implementations of new methodologies in project based organisations need to be measured in order to see if they are successful and to what degree. If the implementations are measured, the people within the organisation can make objective decisions upon wider application, development or desertion of the implemented methodology. Also, Maylor (2010) believes that acceptance of changes by people on ground level in the organisation is key for successful implementation.

Mid to low level managers within construction organisations often have the freedom to choose if they want to implement a new methodology or not (Clegg, et al., 2011). Therefore, top-down implementations in such organisations can be stalled if low level managers do not agree with the choices of top management. In addition, Clegg et al. (2011) argue that managers in organisations with non-hierarchical cultures, which is the standard in Sweden, are expected to keep track of their own performances. Granebring and Révay (2005) argue that top-down implementation can obstruct the organisational freedom and both Rossing et al. (2005) and Rudolph et al. (2008) present examples of failed top-down implementations within project based organisations in their reports. Rossing et al. (2005) believe that varying motives and disagreement between top management, low level management and regular employees is a probable cause for such failures.

3.1 The Swedish construction industry

The construction industry is a big business sector in Sweden which had over 312000 employees in the year 2012 and a revenue of over 500 billion the same year (Sveriges Byggindustrier, 2013). This indicates that around seven percent of the total number of employees in Sweden work in the construction industry. The same is true for many other countries such as the United States where the construction industry is the largest monetary production activity with a revenue of 1.2 trillion dollars in 2006 (Sears, et al., 2008).

The Swedish construction industry contains over 93000 companies, not counting consultant companies such as Sweco and facility management companies such as Wallenstam. Almost half of the companies counted have less than 50 employees (Sveriges Byggindustrier, 2013). Also, the Swedish construction industry has three companies, Skanska, NCC and PEAB, which are bigger than the rest and have a dominant position on the market (Sveriges Byggindustrier, 2015). Veidekke, which was interviewed in this thesis, comes in on number six in Sweden and has rapidly been growing rapidly in the last few years with an increase in revenue at 54% between the years of 2013 and 2014 (Sveriges Byggindustrier, 2015).

The participants in a construction project can normally be divided into three main groups, (clients, designers and builders), independent of the delivery form. Thus, there is one stakeholder group responsible for finance and initiation of the project, one group of stakeholders who are responsible for the drawings and a third group of stakeholders who are responsible for the construction. (WSP Management, 2009)

The most common delivery forms in the Swedish construction industry are design-bid-build and design-build together with some special variations of the two forms. A growing delivery form is partnering which is a structured type of collaboration where all the actors are involved early on in the project. Partnering is normally based on either a design-bid-build or design-build contract. The number of actors within a project depends on the delivery form. For example, a design-build project with one of the major companies will involve less other companies than a design-bid-build project which usually involves a greater number of companies (WSP Management, 2009).

3.1.1 The government's assessment

In 2002 the Swedish government gave Statskontoret, (an agency within the Swedish financial department), the mission to make a current situation assessment, based on interviews and external studies, of the Swedish construction industry (Statskontoret, 2009). Statskontoret stated that the Swedish construction industry has a slow development and names several areas with improvement potential. In 2008 a follow-up assessment was conducted, again based on interviews and external studies, where Statskontoret stated that they could see improvements in some areas but that they were mostly local improvements and did not impact the industry on a larger scale.

Statskontoret (2009) found that the number of construction errors had increased rather than decreased during the time period in which the agency carried out its assessment. Also, the agency claims that nothing points to better quality being a reason for the increased prices in construction during the same period. The main reasons for the construction errors were found to be lack of proper communication and poor leadership. According to Statskontoret, both during rough and booming market situations there has been little outside pressure on the construction organisations to increase the construction quality and decrease the amount of construction errors. Furthermore,

Statskontoret (2009) claims that another reason for the slow quality development is that the construction companies do not educate their employees enough.

Statskontoret (2009) argues that the client, not the end user, is responsible for confirmation of the quality of construction projects and to pressure the construction companies towards quality improvement. However, the agency believes that the relatively small number of contractors in Sweden and the complex collaboration between them often makes it difficult for the clients to make this kind of demands and to forward them down the complex project chains. In addition, the agency argues that the client often lacks in the necessary understanding of construction projects to make the proper quality demands.

4 Six Sigma

The Six Sigma methodology was developed and copyrighted by Motorola in the 1980s (Tchidi, et al., 2012). The name Six Sigma comes from the field of statistics where the letter sigma is used to signify the standard deviation within a set of data. In Six Sigma methodology, to operate at a specific sigma level means to have no more than a corresponding number of defects per million opportunities (DPMO) or, as shown in figure 4.1, to operate with no more than a corresponding percentage of defects, (or variations). To operate at level six sigma means to have no more than 0.00034% defects or 3.4 DPMO (Keller, 2011). In contrast, to operate at sigma level five would mean a maximum of 233 DPMO. To illustrate this, Dirgo (2005) gives the example of 180 train crashes and 31536 aborted aircraft take-offs per year if operating just below five sigma, as opposed to less than one train crash and 107 aborted take-offs if operating at six sigma. Pheng and Hui (2004) argue that Six Sigma pushes the user to aim for perfection while recognising that there will be occasional defects. Similarly, Samman and Graham (2007) argue that the Six Sigma perfection, being 3.4 DPMO, makes people more open to the implementation of Six Sigma than they would have been to a 0 defects methodology.

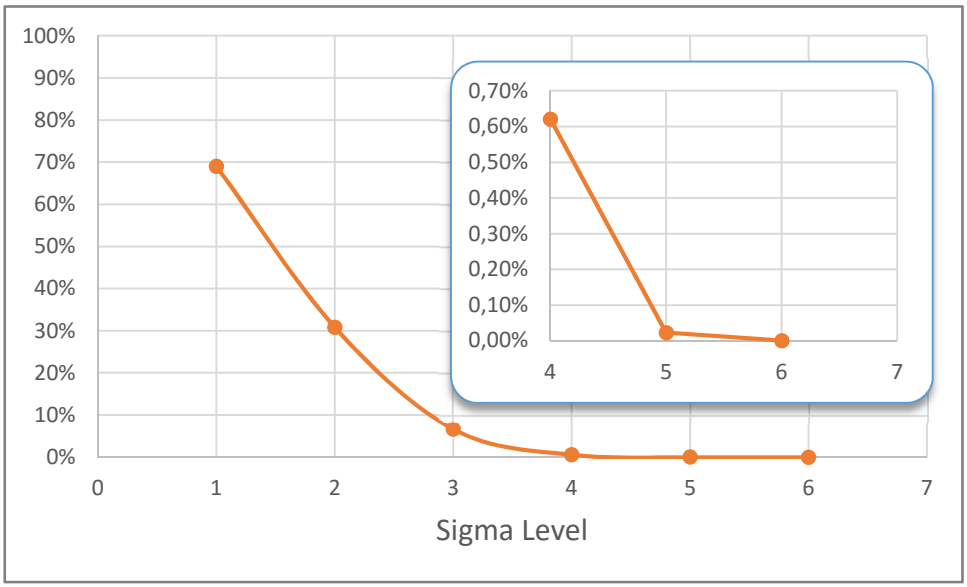


Figure 4.1 The percentage of accepted defects and variations per sigma level (Dirgo, 2005).

In literature, Six Sigma is often mentioned as a methodology with several tools used to increase quality of processes. Therefore, in this thesis Six Sigma is seen as a structured guideline methodology and a toolbox for quality improvement projects, (Six Sigma projects), which includes education of Six Sigma team members and several tools fit for different areas of use. To give an example, a carpenter should know that using a hammer to get a screw in might work better than a saw but a properly sized screwdriver is probably the most efficient choice. Similarly, the deeper a user of Six Sigma studies its tools, the better the user will become at choosing and using the appropriate ones. It is important to keep in mind that Six Sigma is not designed to fix all the problems by itself but rather to make them and their causes visible so that the user can properly tackle the problems and see that the wanted results are obtained. An examination of how people are educated so that they can properly work with Six Sigma is presented in Chapter 4.3. (Dirgo, 2005) (Keller, 2011)

4.1 Six Sigma Structure

Six Sigma projects are conducted in a structured five phase approach which makes it easier for the people working with it, the Six Sigma team, to select the appropriate tools at the right time. The five phases are Define, Measure, Analyse, Improve and Control or DMAIC for short. DMAIC can be seen as the backbone of Six Sigma projects and it is important for a Six Sigma user to keep track of which phase the project is in and to know when to move on to the next phase. Dirgo (2005) argues that finalising each DMAIC phase before starting on the next one is key in order for the project to be successful. The following paragraphs briefly describe each phase and some of the tools which can be used during the corresponding phase. However, the tools are not necessarily used in only one of the phases. Also, many of the tools are graphical and can be used to give the team a simplified outline of complex situations but more than one tool might be needed to paint a complete picture.

The main goals of the Define phase are to set the magnitude of the project and to select which problems should be attempted to solve. Within this phase the Six Sigma team decides on the projects' scope, goals, problem statement, milestones, stakeholders, schedule, resources, budget and expected project output. Also, the team members chosen are given their respective responsibilities and are properly informed of the problem statement and milestones so that they are clear in what they should aim for. Furthermore, it is important to keep the receivers of the output in mind and to make sure that their requirements are clearly defined and agreed upon since the quality of the output is in the eye of the receiver. In addition, the team usually starts to pick out which tools it will use during the coming phases of the Six Sigma project but the selection is finalised in the Measure phase. (Gupta, 2006)

The main objectives of the Measure phase are to select the proper Six Sigma tools for the project and to gather the necessary data. Also, it is important to clearly define the current state so that the potential quality improvements are not overlooked, so that the potentials are understood by the project participants and so that the implemented improvements at the end of the project can be verified. Dirgo (2005) argues that many different tools can be used during this process but one that should not be excluded without consideration is Process mapping, see Chapter 4.2.3. Process mapping can make the team members aware of process details they would otherwise overlook and give them a clearer view of what needs to be focused on. Furthermore, the data collected should not be accepted as fact without considering factors which are missing or unobservable in the gathered data nor without critically assessing the way in which the data has been gathered so that the variability within the gathered data is known. (Dirgo, 2005) (Keller, 2011)

During the Analysis phase, the main objective is to examine the data gathered in the Measure phase in order to find the cause of the problems in the problem statement. Also, the current state presented in the Measure phase is used to properly prioritise the problems in order of quality impact by using tools such as the Pareto chart which is briefly described in Chapter 4.2.2. As in the Measure phase, the results of the analysis should not be accepted as fact without comparing the results from different analytic tools and critically evaluating the tools used to ensure that the output is reliable. Also, using the right tools during this phase is crucial for drawing the correct conclusions from the data gathered. (Dirgo, 2005) (Gupta, 2006)

In the Improve phase, the Six Sigma team uses the results from the analysis together with the problem statement to optimally, in terms of quality and profit, solve the stated problems. Prioritisation, evaluation and implementation are the key factors of success in this phase. (Dirgo, 2005) (Gupta, 2006) (Pyzdek & Keller, 2014)

The Control phase is used to ensure that the improvements implemented in the previous phase are preserved but also to ensure that their benefits are continuous. In addition, the Six Sigma team should develop a control plan for future control of the improvements. Also, a learning process should be implemented wherein the team reflects upon what they have learned throughout the Six Sigma project in order to make future projects go smoother, e.g. by knowing which tools to use under which circumstances. (Dirgo, 2005) (Pyzdek & Keller, 2014)

4.2 Examples of Six Sigma tools

As mentioned in Chapter 4.1, the Six Sigma methodology includes a number of different tools for different situations and phases in DMAIC. The following subchapters shortly describe a few of the tools are which are frequently used in Six Sigma in order to give the reader some further insight into how the methodology works and to explore if the tools might be applicable in construction.

4.2.1 Cause-and-Effect diagram

Cause-and-Effect diagrams, (also known as fishbone diagrams due to their appearances or Ishakawa diagrams in honour of the Japanese engineer who created the model), are graphic brainstorming tools, see Figure 4.2. The diagrams give the users an organised way of listing the potential causes for a given effect, which makes it easier to separate possible problems and target specific areas to improve. The causes are listed as smaller lines that branch off the main effect creating a diagram which looks similar to the bony remains of a dead fish. The model is commonly used within the Analysis and Improve phases of DMAIC. When using the model, it is important to remember that the listed causes are just potential causes because no actually measured data is used. Other tools, based on actual data, might be needed to see if the potential causes are for real. However, even if tools based on actual data are used, the cause- and-effect diagram can be used as a supporting tool to make sure that no potential causes are overlooked (Keller, 2011).

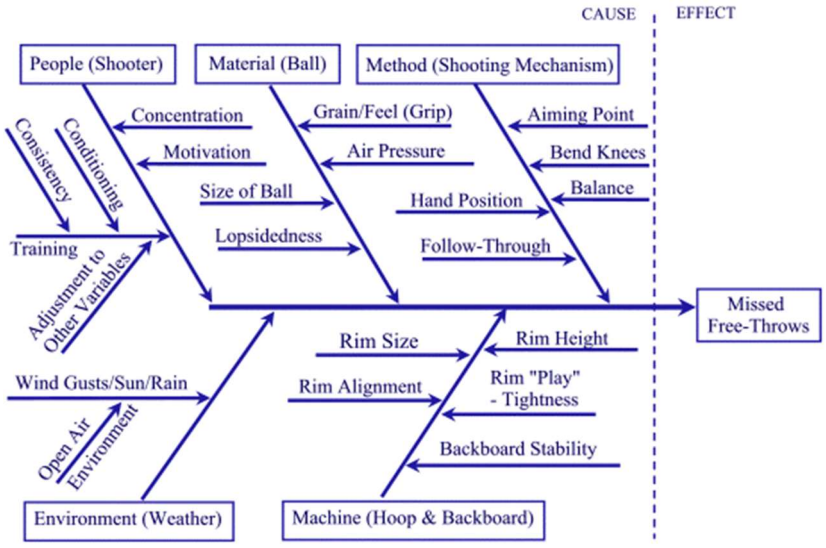


Figure 4.2 Cause-and-Effect diagram (MoreSteam.com, 2015).

4.2.2 Pareto chart

The Pareto chart is a common tool within the Define and Analyse phases of DMAIC. The purpose of the chart is to give an overview of the most vital variations and defects so that the Six Sigma team knows which ones to focus on in order to make the biggest impact. The Pareto chart is a vertical bar graph where each vertical bar represents an exclusive category of interest. These categories are sorted in a decreasing order from left to right based on their contribution which should be measured in terms of quantity or costs. The data used must be stackable which means that things such as percent yields or error rates are excluded. Counts or costs should be presented on the left axis and the right should present the percentages connected to a cumulative line which adds the percentages from each bar. If the start of the line is steep, as in figure 4.3, it shows that the first categories have a big impact on the total percentage. A straighter line shows that the contribution from each category is more similar and makes it more difficult to choose which problems to tackle first. In order to keep the line from getting too straight, the team using a Pareto chart should avoid dividing the problems into too many categories and instead use a few major ones (Keller, 2011).

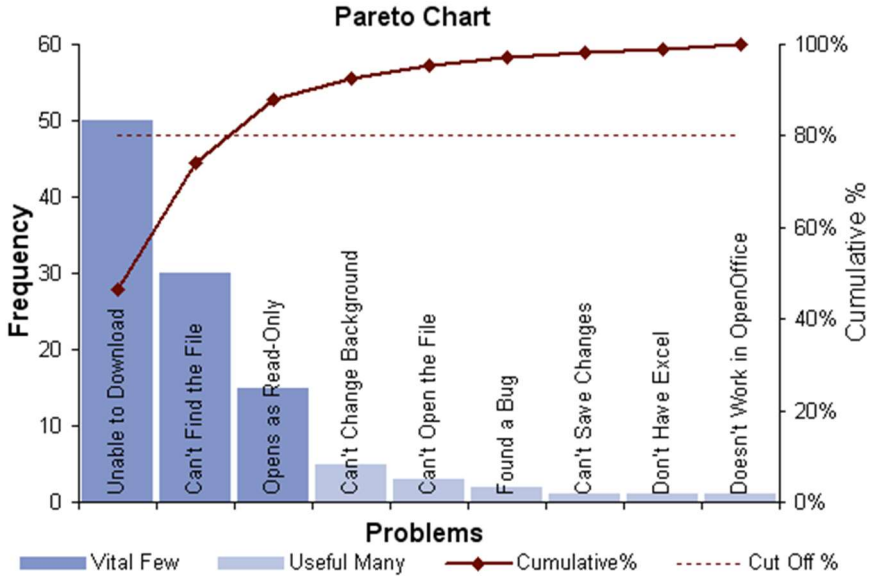


Figure 4.3 Pareto chart (Minnesota Department of Health, 2015).

4.2.3 Process mapping

Process mapping is detailed graphical visualisation of a process, often similar to or interchangeable with process flowcharts, material flow analyses and value stream mappings. A process map is used to graphically describe a process in order to give the user an overview of the steps within the process. This forces the user to look at all the process steps and makes it easier to study their specifics. Some process maps also show which department does what, making any duplicated process steps easy to spot. According to Magnuson et al. (2003), even people with Six Sigma training often skip the use of process mapping to describe the current state and to make sure that all the members of the Six Sigma team have the same understanding of it. Therefore, the team may overlook some of the process steps and miss opportunities for quality improvement

and cost reduction. A simple example of a process map can be seen in figure 4.4 where the process of borrowing a book at a library is mapped out.

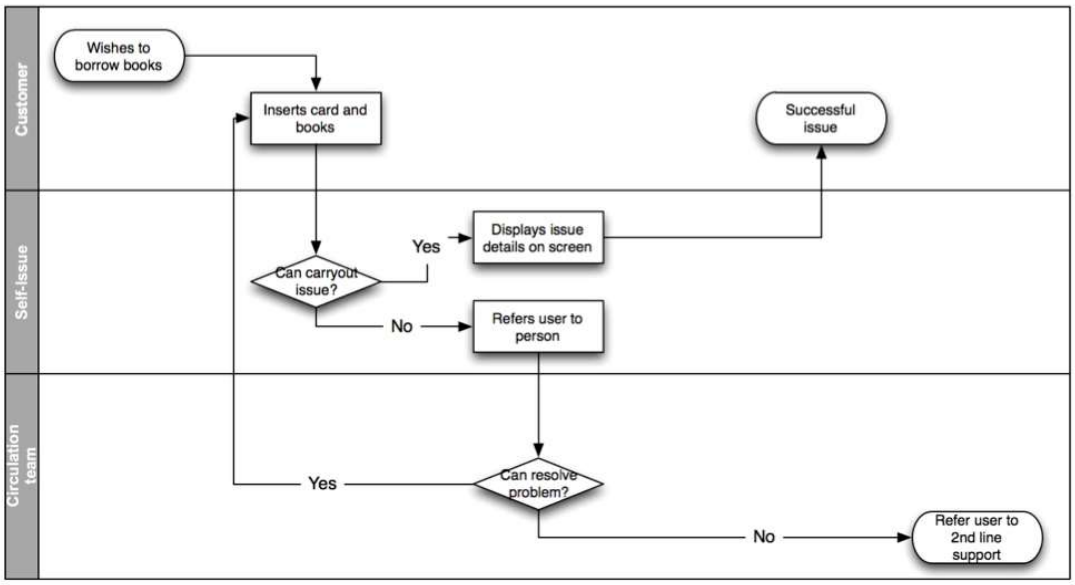


Figure 4.4 Process map (Library Systems Support and Guidance, 2015).

4.2.4 Scatter diagram

Scatter diagrams or scatter plots are simple XY-plot tools which help the users to explore the correlation of one variable with another, usually in the Analyse phase of DMAIC. The two axes are used to measure two respective variables, an independent one on the X-axis and a dependent one on the Y-axis. Each measurement value is marked by one dot which makes it possible to see if there is a pattern in the data. The correlations work in such a way that a change in one of the variables results in a change in the other. This can point out cause and effect relationships but the user should be aware of outside variables which could affect the result. The closer the cluster of dots are to being in a line, the stronger the correlation between the two variables. (Keller, 2011).

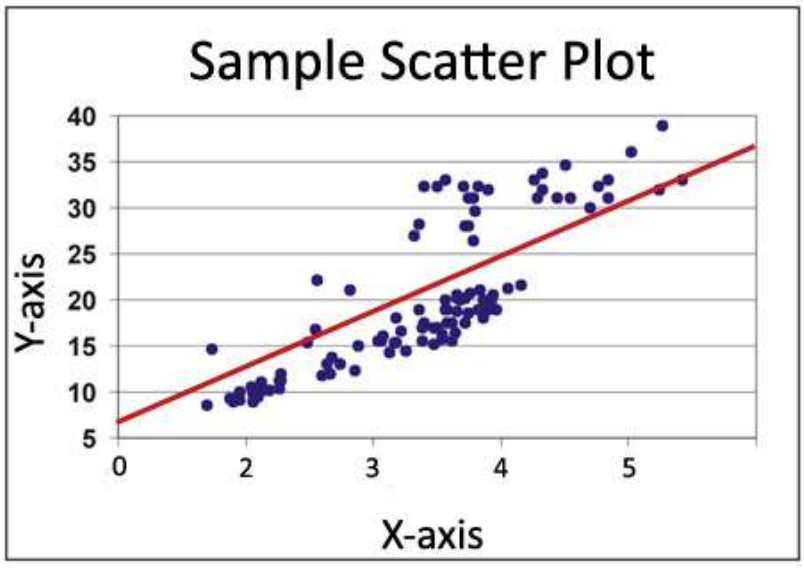


Figure 4.5 Scatter diagram (Austin Community Collage district, 2015)

4.2.5 Spaghetti Diagram

A Spaghetti diagram is most commonly used in the Analyse stage of DMAIC. The purpose of the diagram is to graphically illustrate how material and employees are moving between different stations. The background of the diagram is based on a floor plan, layout or some similar type of simplified map on which the movements can be drawn. Every movement is represented by one line which makes it possible to make the movement more efficient by for example rearranging different stations (Keller, 2011).

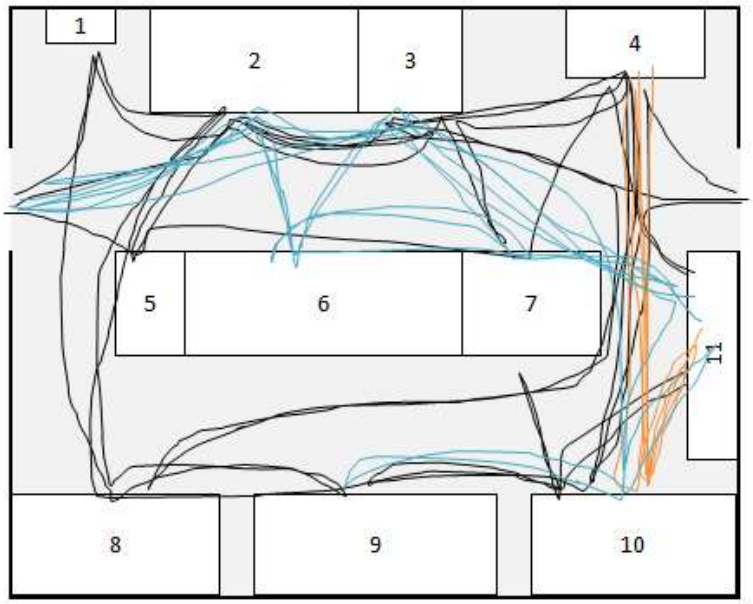


Figure 4.6 Spaghetti diagram (Nicholas, 2015)

4.3 Employees within Six Sigma organisations

To implement Six Sigma in an efficient way it is helpful to have an executive overview training to help the senior executives and managers understand what a Six Sigma programme requires and how to plan a strategy accordingly. The next step is to make a first project selection followed by training of an initial wave of Champions, Black Belts and Green Belts. This training should be based on a just in time basis to secure that the employees can be directly involved in pending Six Sigma projects (Keller, 2011) (Pyzdek & Keller, 2014).

Another important factor for success is a positive attitude. Bad attitude normally reflects a distrust in the management's motives or capabilities as a result of former real or imagined failures (Keller, 2011) (Pyzdek & Keller, 2014). It is also important to have a continued top management enthusiasm and support because it is they who should drive the Six Sigma programme forward. Also, top management are in charge of linking the programme to business strategy, customer requirements, workforce participation and suppliers. Furthermore, it is necessary to have a data driven decision making process based on an objective measurement criteria to monitor processes and outcomes (Huq, et al., 2010).

The most valuable resource in a Six Sigma based organisation is as in many other organisations its employees. It is the employees who make the critical link between the customers' satisfaction and securing that the organisation is aligned with dynamic costumers needs. To meet these needs it is important to have a highly skilled staff. The Six Sigma methodology has a well-defined education model with four different levels, Champions, Black Belts, Master Black Belts and Green Belts, and the following paragraphs briefly describe their roles and training (Pyzdek & Keller, 2014).

Champions are employees with middle- to upper level of manager positions. They are responsible for both the Six Sigma programme itself and to ensure that necessary organisational supporting systems are in place. Champions need to be dedicated and have extraordinary communication skills. Also, they need to display energy and passion so they can excite and mobilize others. The financial understanding must also be good so that they not only deliver technical solutions but also bottom line results. The first people selected for Champion education should be individuals who are excited about the benefits of Six Sigma and are well respected and known across the organisation in order to build credibility for the programme and make further deployment easier. A typical training programme for Champions is around two to three days with a combination of theory and practice. The outcome of the training should be an understanding of their roles as managers in Six Sigma projects, clarification of their responsibilities and an estimation of which amount of sponsorship that the initial Six Sigma programme will need. Another outcome should be selected Green and Black Belt candidates and a plan for a project which will be included in the programme (Keller, 2011) (Pyzdek & Keller, 2014).

Black Belts are in American literature generally described as full time change agents who have been removed from their work as operationally responsible for the organisation to be available for the Six Sigma deployment. A candidate for the Black Belt status should be respected by the other employees and should have technical skills. Also, Black Belts should be hands on oriented and preferably well known for their ability to get things done. As with Champions, Black Belts should be good in communication in different forms, oral and writhing, in different contexts including public or private and to be able to understand and forward instructions from leaders and sponsors. In addition, they should be able to work effectively in small groups as both leaders and participants including one to one settings. A Black Belt who does not have the aforementioned skills risks being ineffective and having employees who are unhappy and frustrated. It is not necessary for the Black Belts to be statistician but, due to the fact that they are expected to master a wide range of tools in a pretty short period, it is preferable that they have mathematical knowledge on at least a college level in combination with knowledge in the basic tools of quantitative analysis. Also, a Black Belt should have experience with spreadsheets, database management, presentation software, word processors at least one operating system. During the training, candidates should get knowledge in statistical and simulation software. Any cutbacks in such training risks making the Black Belt training programme pointless (Keller, 2011) (Pyzdek & Keller, 2014).

Master Black Belt is the highest knowledge level within the Six Sigma methodology. It is the Master Black Belts who provide the technical leadership of a Six Sigma programme. This means that they need to have vast knowledge about the Six Sigma methodology but they also need to have excellent skills in mathematical theory which forms the basis of the statistical methods and tools used. Normally the Master Black Belts have an advanced technical degree and long-time Six Sigma experience. Due to

their roles as Six Sigma programme leaders, they also need excellent skills in project management, coaching, teaching and managing the programme itself at an enterprise level. Their role is also to help Black Belts apply methods correctly in unusual situations and secure that Black and Green Belts get the right training to minimise the spread of error. The recruitment of Master Black Belts is normally based on the ranking of Black Belts and the interest which they show in Six Sigma leadership. Thereafter the leadership selects candidates depending of the enterprise needs and its Six Sigma programme's level of maturity. (Keller, 2011) (Pyzdek & Keller, 2014)

Green Belt is the lowest official education level within the Six Sigma methodology. Some companies use even lower education levels such as "White Belts" but they are company specific and will not be described here. A Green Belt is an employee who has been trained in the basic Six Sigma tools and techniques, especially the DAMIC model. Green Belts remain at their normal work stations as for example process supervisors, operators, technicians and other employees who want to contribute to a project team. Usually, all employees in a company which uses Six Sigma get a Green Belt education sooner or later. There requirements for Green Belts are not as high as the higher levels because they do not work as deeply with the methodology and can often get support from the higher levels (Keller, 2011) (Pyzdek & Keller, 2014).

4.4 Six Sigma implementation

As mention in chapter 3, it is important to keep both geographical culture differences and cultural differences on an organisational level in mind when implementing new methodologies. Also, there is no single best way for organisational change which is important to remember during implementing of Six Sigma (Trompenaars & Hampden-Turner, 1997). Therefore, the implementation should be adapted depending on where it takes place and by whom, which is especially important for multinational companies where the geographical culture differences could force them to adapt both the Six Sigma theory and practice. (Nonthaleerak & Hendry, 2006).

After conducting a literature review, Schön (2006) claims that the following aspects are the most important for a successful Six Sigma implementation

- Support and commitment of senior management
- Six Sigma training
- Human resources
- Organisational infrastructure
- Communication with employees
- Prioritisation and selection of appropriate projects
- Understanding Six Sigma methodology, tools and techniques
- Adequate investment resources
- A uniform language and terminology
- A strategy to implement Six Sigma
- Linking Six Sigma to business strategy and priorities
- A focus on results
- Follow-up and communication of success stories
- Developing a distinctive path to Six Sigma

The culture in Sweden is characterised by that the interest of the organisations is secondary to the fulfilment of individuals whiten them (Trompenaars & Hampden-

Turner, 1997). This means that the organisation works as a platform for the self-expression and self–fulfilment. This self-fulfilment culture, as it is called by Trompenaars and Hampden-Turner (1997), is more or less unstructured and unhierarchical. A participative culture like this requires a flexible and indvidualistic approach to the Six Sigma implementation (Gowen, 2002). The potential of Six Sigma implementation is connected to increased personal creativty by decresing the time they spend on avoidable problems (Crom, 2000).

Schön (2007) argues that a top-down implementation is a quick and structured way of implementation with a clear message from the senior management that they will support it. However, she claims that there is a risk that such an implementation will proceed too quickly where insufficient attention is paid to the distinctive needs of individual units and departments. A bottom up approach, such as the one at Ericsson which is described below, commonly results in a slower spreading between departments and is often depended on a few key persons. Schön (2007) states that a combination of top-down implementation and committed leaders at all levels who take care of the individual needs for different units, departments and individuals is the most effective way to implement Six Sigma. Furthermore, the researcher argues that the initiative to implement Six Sigma must come from the executive management to assure that the most senior person in organisation is totally committed to the implementation which is a key factor for success. (Schön, 2006). In contrast, Arthur (2014) claims that half of the top-down implementations of Six Sigma fail and he believes recommendations of such implementation often lack the necessary scientific proof. Therefore, Arthur argues for a Six Sigma project-focused approach starting on a low level. He suggests that the evidence points towards companies having more success when they have started with one project at a time which is adapted to the existing business and where the Six Sigma team is at first only educated in the tools which they will need for the specific project. However, Arthur also believes that not enough studies have been made on why methodology implementations fail or succeed to be able to draw a concrete conclusion on whether a top-down or a bottom up approach would be most likely to succeed (Arthur, 2014).

4.4.1 Examples of Six Sigma implementation in Sweden

The first example is from the implementation at Ericsson, a multinational Swedish telecommunication company. The example sets of 1996 when four employees were offered the opportunity to attend a Six Sigma Black Belt training programme at ABB in Switzerland. This implementation can be seen as a bottom-up implementation because it was not initiated by the top management and the results of the implementation worked as advertising for its future use in the company. The programme has been done on a voluntary basis where the initiators have put no effort to convince doubtful mangers on the value of Six Sigma but focused on enthusiastic managers and hoped that the good results would make others follow in due time. Furthermore, to make the programme trustworthy it was important that all projects were real projects even during the training programme and that they were not simplified. A result of the voluntary participation was a slow spread within the company. In contrast to the American approach of Six Sigma, at Ericsson the methodology was used as a natural part of the employee's normal work processes where they can use it in their daily work. A problem with this approach is that there is no specific budget for the Six Sigma programme which results in a need to find sponsors for every Six Sigma project and to frequently send employees to training. This also means that it can be difficult to find money for the bigger projects that would contribute to bigger returns in the end.

The model of integrating Six Sigma within the normal work also resulted in problems with analysing how much it would save because of the difficulties in connecting the savings to Six Sigma. Furthermore, a risk was recognised in that if some of the key Six Sigma people would leave the company it could lead to problems with the whole programme and its spreading because of the individualistic Six Sigma knowledge and experience. (Schön, 2006)

The second example is from SKF, a multinational company within the ball bearing industry. Six Sigma was first implemented locally at the aviation division of SKF in the United States during year 1998 and in year 2002 at the car division. The work with a companywide implementation programme, or group launch, begun in 2004. SKF used their experience from other improvement programmes, such as their TQM-programme, to plan the implementation of Six Sigma. The implementation was characterised by careful planning where a lot of different people with different knowledges where involved in order to make the implementation successful. A year after the group launch was initiated, the management had enough understanding of what they wanted to get out from it. Also, the projects which were chosen where in line with the strategic goals of SKF and the company's business plan. The expected outcome of the Six Sigma projects was to save three times as much as the actual cost of each Six Sigma project. SKF also put attention to so called soft savings which do not appear on the bottom line. The foundation of the Six Sigma programme at SKF is made in an American approach with a hierarchical structure and managers who demand results and follow ups. However, a difference is that more attention is put on information and training than controlling. To solve the problem with culture issues, the various units around the world are free to set up their own implementation plan as long it is in line with the common goals. Furthermore, this implementation is a clear example of the top-down model with a very dedicated and supportive executive management. (Schön, 2006)

5 Six Sigma in a construction context

Paslawski (2013) argues that the project based, flexible and flat organisation culture which is common in construction organisations is in direct opposite from the hierarchical data analysation environment created with the implementation of Six Sigma. Therefore, Paslawski believes that the flat organisation culture in combination with and the lack of process stability are difficult obstacles to overcome when implementing Six Sigma in construction organisations. In contrast, Stewart and Spencer (2006) argue that the structure of Six Sigma does make room for flexibility and that one of the biggest advantages of Six Sigma is that it does not give the Six Sigma team all the solutions but rather helps to clarify the problems and opportunities and lets the team decide how to proceed. In addition, Tutesigensi and Pleim (2008) argue that the some of the causes on which organisations blame the exclusion of Six Sigma are false or misunderstood and without proper investigation. Also, the two researchers argue that when asked, many construction organisations mention using quality systems, such as ISO 9001 and self-checking systems, instead of Six Sigma but fail to recognise that the same type of systems are used even more commonly in manufacturing organisations and there without using them as an excuse to exclude Six Sigma. Similarly, Feng and Price (2005) believe that there is less separating construction and manufacturing, in the context of Six Sigma, than many are led to believe. Six Sigma is by no means limited to manufacturing and it has already been implemented in project based industries such as health care, finance and service oriented industries (Samman & Graham, 2007). Also, Tchidi et al. (2012) conducted a case study where a construction company switched from traditional on site construction to Six Sigma based prefabrication and found that the company saved 26% on construction time and lowered their material waste with almost 85%.

According to Feng and Price (2005), the traditional price based environment in the construction industry has led to adversarial relationships between different actors in construction projects. Similarly, Kashiwagi et al. (2004), believe that the best price culture in the construction industry has stood in the way of quality development and the implementation of Six Sigma. Also, the lowest bid principle has led to some questionable project bids where contractors have been accused of the intent to find contract loopholes and profit on claims, resulting in distrust and secrecy. Therefore, many companies have moved towards new ways of work, such as partnering, with more or less transparent and long-lasting business relationships aimed at small but steady profits, often pointing out trust and communication as two of the main factors of success. Moreover, Tutesigensi and Pleim (2008) believe that the long-term relationships can aid construction organisations in standardising the collection of data which is needed for the quantitative line of approach within Six Sigma projects.

Tutesigensi and Pleim (2008) mention insufficient quality requirements from the construction clients as one of the main explanations for the lack of quality and exclusion of quality improvement methods such as Six Sigma in the construction industry. In contrast, Tchidi et al. (2012) argue that the clients see quality as the main factor when they choose their contractors. However, Tchidi et al. agree on the potential benefit of Six Sigma since they believe that the aim of the methodology is to increase the perceived quality by the client. Similarly, Samman and Graham (2007) argue that when improving construction processes, the wants and needs of the client have to be kept in mind. In order for construction companies to see the need for quality improvement and implement Six Sigma on a large scale in construction, Kashiwagi et al. believe that

there needs to be a switch in the clients focus from best price to best value. Feng and Price (2005) argue that construction organisations have started to choose best value over best cost and take more notice of construction quality.

Samman and Graham (2007) and Paslawski (2013) have recognised big gaps in the quality of construction processes and believe that the profits of successful Six Sigma implementation in the construction industry could be huge. In addition, Tchidi et al. (2012) argue that construction projects are often negatively affected by insufficient technology and poor management. Moreover, Peng and Hui (2004) argue that Six Sigma cannot be properly implemented in construction without commitment and support by management. Likewise, Samman and Graham (2007) mention management support as one of four key factors for successful Six Sigma implementation in any organisation.

To truly improve the quality within construction, Tchidi et al. (2012) argue that the complete construction projects, from planning phase to delivery, have to be improved. In their report, the researchers recognise Six Sigma as a fit for such an improvement since the methodology can be used at both the highest organisational levels as a quality mind-set and at the lowest levels as a quality measurement and improvement system. Furthermore, Kashiwagi et al. (2004) and Stewart and Spencer (2006) believe that Six Sigma projects can lower construction process times, reduce costs, and ensure that quality expectations are met. In addition, Six Sigma can help construction organisations to make a smaller impact on the environment by decreasing waste and energy use during projects and the researchers urge construction companies to see the importance of this methodology (Tchidi, et al., 2012).

Six Sigma has repeatedly been proven to be profitable for large organisations and can be expected to be just as profitable for small and medium sized enterprises (SMEs) if designed with consideration of the organisation sizes and contexts (Tutesigensi & Pleim, 2008). However, Tutesigensi and Pleim (2008) sent out a survey about Six Sigma to 700 SMEs in the United Kingdom's construction industry but only 30 companies answered the survey and none of them indicated that they work with the methodology. The two researchers argue that the construction industry depends greatly on its SMEs and they believe that an improvement in the SMEs' quality would improve the quality in the rest of the construction industry as well.

Han et al. (2008) believe that the defect rate in the construction industry is in many ways caused by unreliable workflow due to process variability and claim that the Lean principles aim to address the effects of such variability. The researchers argue that the principles of Lean thinking cannot reduce or eliminate the variability by removing its roots and thus believe that Lean should be combined with Six Sigma to get the best of both worlds. Han et al. (2008) also argue that Lean production cannot clearly show how to measure the level of defects in an ongoing process nor which underlying mechanisms contribute to the variations. Also, the researchers argue that it is impossible to set up quantitative goals of how to improve the workflow by removing the critical causes of defects in the process variability with the Lean methodology. However, the researches claim that such things are possible with Six Sigma. Therefore, Han et al. (2008) believe that Six Sigma is a necessary to find the causes of problems where Lean cannot.

Tchidi et al. (2012) present an example of Six Sigma used in Chinese construction prefabrication where tools such as Pareto, see Chapter 4.2.2, and cause-and-effect

diagrams, see Chapter 4.2.1, were used. The Six Sigma tools were used to improve the construction of three types of beams and the Six Sigma level was increased from less than 2.5 sigma to about 5 sigma. Similarly, Lee and Su present a case from Taiwan where Six Sigma tools, including Process mapping which is briefly described in Chapter 4.2.3, are used to improve the quality of lightweight walls so that they can withstand earthquakes without cracking. In both the aforementioned reports it is claimed that Six Sigma and its tools can be used within construction to minimise the waste and defects in standardised processes.

The quality inspections within construction projects often focus on materials rather than workflows. Therefore, the introduction of Six Sigma methodology within the construction industry could begin with a relatively simple and repetitive construction activity, preferably similar to manufacturing. It is also recommended that the selected activities are of a kind where the productivity is immediately reflected by the process variation factors such as workers' proficiency. Industrial or plant construction and equipment installations are examples of such activities. Further on it should be possible to move forward with the Six Sigma methodology to other kinds of construction projects which are more complicated and less repetitive. (Han, et al., 2008)

According to Han et al. (2008) the construction industry is, compared to the manufacturing industry, lacking a systematic methodology to assess defect rates and the possibility to evaluate performance improvements as the defects are removed in the production process. Therefore, the researchers argue that construction companies do not have complete objectives for performance improvement at the site. Han et al. (2008) believe that the Six Sigma methodology can contribute with a more stable work quality by controlling factors like safety, quality and cost.

Atkin et al. (2003) argue that core values, techniques and tools are the three main steps when improving construction processes. Arguably, Six Sigma fits into those three steps. First, the methodology has clear core values such as high quality, doing right the first time and decreasing variation. Second, DMAIC and its phases are the main techniques of Six Sigma. Third, tools such as the ones mentioned in Chapter 4.2 are a big part of the methodology.

5.1 Bechtel Corporation

An example of a major construction company which uses Six Sigma is Bechtel Corporation. Bechtel is a global engineering, construction and project management company which has completed more than 25000 projects in 160 countries since 1898. The company has about 58000 employees all around the world and was in 2013 the fourth largest private owned company in the United States. (Forbes, 2013). (Bechtel Corporation, 2015a)

Bechtel has worked with Six Sigma since 2000 and was the among the first construction companies to do so. Also, the company claims to have broken even on their investment in less than three years. Bechtel uses Six Sigma to deliver project budgets and schedules with a higher certainty than before and to minimise the project risks. The company has trained more than 4700 staff as Champions, Black Belts, Green Belts and Yellow Belts. Also, the Company has managed to get more than two billion dollars in total installed cost savings to their customer projects. (Bechtel Corporation, 2015c)

An example of a project where Bechtel has used Six Sigma is in the construction of the 377 MW Ivanpah Solar Facility which is the world's largest concentrating solar facility. This project included installations and the assembly of 173500 software controlled

heliostats or mirrors which means 42 million components. The megaproject also included 22 million rivets, 2000 km of cable, 7500 tons of steel and 36000 cubic yards of concrete which suggests that the project was both large and complex. During the project, Bechtel used Six Sigma to develop new processes that helped them to reach performance goals and have a successful project execution by analysing design, procurement and construction challenges. For example, redesign of construction equipment led to optimised logistics to secure that materials came in and out without any hiccups or major delays (Gillespie, et al., 2013).

Another example of Bechtel's use of Six Sigma is a tunnel project in London where the company transformed the Victorian tunnel so that it could have traffic with electric trains. A major challenge in the project was the Connaught Tunnel which had a limited height that needed to be increased due to the installation of overhead power lines. In order to increase the tunnel height, the only solution was to lower the bottom. A problem was that this needed to be done within 30 weeks and an earlier test-lowering had taken 44.5 days compared to the scheduled 21 days. Another problem was to remove any risk of tunnel collapse during the construction. London's congestions, rivers, all sorts of tunnels in the surrounding area and the limited space where all factors which increased the project difficulty. However, by using Six Sigma the company found solutions to decrease the replacement time and minimise schedule, budget and quality risks. In the end the project was completed five weeks before schedule (Bechtel Corporation, 2015b).

6 Results from interviews

This chapter is intended to give the reader an insight into how some Swedish companies relevant to the aim of this thesis and individuals within those companies perceive quality and Six Sigma. The chapter includes five subchapters where the perspectives on quality and Six Sigma were obtained from interviews.

6.1 Quality manager at Veidekke

The following information was attained from an interview conducted on Friday the Thirteenth of November, 2015, with Johan Alte who works with quality management and sustainability at Veidekke Entreprenad AB in Sweden.

At Veidekke, quality is generally seen as delivering what the customer wants. In addition, Alte sees quality as an umbrella covering everything between Veidekke and their co-workers, clients and suppliers. For example, Veidekke has to give the necessary information to their suppliers so that they can make correct deliveries with the right material and at the right time. According to Alte, the whole Veidekke operation is ISO-9001 certified and he argues that Veidekke is working with improving the quality in all three contexts of Veidekke and its co-workers, clients and suppliers.

Alte argues that the Swedish legislations regarding self-monitoring, (In Swedish: egenkontroll), have been counterproductive. Actors within the construction industry have appointed a control-person who is responsible for the self-monitoring and has to produce a control-plan, in accordance with Swedish construction laws, (In Swedish: plan- och bygglagen). Before being delivered to the building committee, the control-plan has to include the signature of the control-person, the date of when the self-monitoring was conducted and if the organisation has delivered the main parts of what it is supposed to in simple yes or no questions. Therefore, Alte argues that a signature that everything is ok is practically all the building committee looks for from the construction companies. There is no information included on neither who was working with particular parts of the project nor what the causes for any emerged problems were. Thus, there is no database from which data can be gathered for analysis. The self-monitoring is conducted because it is asked for by the building committee, not because the company sees value in it. Therefore, less effort spent on the self-monitoring means less effort needed from the local managers.

According to Alte, a self-monitoring system such as the one in construction would not be acceptable in the automobile industry and he believes that the car companies have much more control of who did what. For example, if a person working in manufacturing repeatedly makes the same mistakes, that person can be re-educated in the areas where problems have been observed. Furthermore, a car company does not conduct quality work in order to satisfy a control-person but to satisfy its end customers, to increase its quality and to avoid mistakes which cost money to correct. Alte mentions that an inspector checks the house before the customer moves in and he believes that if car companies would also answer to such inspectors instead of the end customer, their quality development would suffer as well. In addition, the more the inspector misses in the inspection the less the construction company needs to correct, which has had a negative impact on the construction industry. To work with Six Sigma in construction, Alte believes that the people involved need to change their thinking, to take more responsibility for their own contributions and to be more aware of why such a methodology should be used. Alte also mentions that there are a lot of customers, companies and even TV-shows who test drive cars which puts reassure on the car

companies and their quality but there are few who test apartments. Therefore, the pressure to constantly develop quality and performance which the car companies get from such tests is not present in construction. However, Alte mentions that the analytical company "Prognoscentret" has conducted some semi-public apartment tests where the companies can see how their own apartments were ranked. Alte argues that even the presence of only one analysis has put pressure on construction companies and that that top management at Veidekke has put out goals that the company should always be in the top half.

Alte states that Veidekkes' subcontractors also work with self-monitoring when they present their results to Veidekke. For successful implementation of a major quality improvement method the quality thinking needs to be a part of the whole chain and the actors need to realise their own gains from such an implementation. Furthermore, Alte believes that the main contractors might need to pay up for problems caused by its subcontractors because the smaller companies might not survive otherwise.

According to Alte, efficiency is often deprioritised in the construction industry and he believes that too much thinking evolves around working to deliver what has been ordered as opposed to thinking about development and making profit. In addition, Alte argues that today people in Swedish construction organisations in general spend about 25 percent of their time on collecting, redoing, waiting and searching for things because of errors made earlier in the projects. Alte believes that if people were thinking more about efficiency and if the self-monitoring was used to decrease errors so that the next phase could start without delay, then the self-monitoring system would be used for the benefit of the company. Even if only a small percentage of the errors were reduction it would still be noticeable on the bottom line.

In order to see the benefits of Six Sigma there has to be a way to measure and compare data in a way that makes sense. Variations and contingencies in projects make it difficult to find equal ground for the data so that it can be properly analysed. To illustrate this, Alte makes the example of one project during the summer when the sun is shining and it is easy to get workers because of the current market boom and another project in winter with snow, rain and completely different people to work with. He believes that there should be a way to compare the two projects or to compare more similar projects with one and other but argues that today Swedish construction companies have no proper way of doing so in a quality improvement context. For example, there is no data on problems gathered in databases where such data could be analysed to find the causes of common problems.

It is perhaps impossible to standardise as much in construction as has been done in manufacturing because manufacturing companies, as opposed to construction companies, often produce the same products over and over and under the same conditions. Therefore, in manufacturing it is possible to implement a change at the start of production and to analyse the effects of the change within weeks as opposed to making changes in the planning phase in construction and to analyse it four or five years later when the construction is complete. However, Alte does see potential for standardisation of construction processes and mentions Veidekke MAX and prefabrication as steps in that direction but he also sees a challenge in making people understand why standardisation could be beneficial. In addition, Alte argues that people in construction are generally neither educated nor interested enough in construction

quality and its effects. Therefore, Alte believes that further education is necessary to increase understanding and change the way of thinking in the industry.

According to Alte, understanding and finding how to divide projects into comparable and measurable parts is difficult in today's construction environment because the processes are not controlled enough. Some sort of standardised processes, e.g. detailed instructions on how windows are installed, would be needed to get similar processes to measure and compare. Furthermore, Alte argues that nobody wants to waste time on unnecessary data collection and that there is sort of a catch-22 because data is needed to show why it has been gathered and there is no motivation to start gathering data if nobody can show why it should be gathered. Therefore, he believes that it could be beneficial if somebody took a chance and tried to find a way to get people to gather the first set of data so that it can then be used to perhaps improve quality and thereby show its benefits and act as a motivation for future data collection.

When asked if a market crisis could force construction companies into implementing new ideas such as Six Sigma, Alte answered that it would be unlikely because of the low market competition but he believes that a market boom which opens up for foreign companies to operate permanently in Sweden would be more likely to force construction companies to take such measures. However, he also adds that the customer would need to stop looking only at procurement prices and be more interested in the quality. Also, Alte argues that today individuals within client companies and not the company itself are the one who take the initiative to check the quality during the projects and he believes that most individuals choose not to.

According to Alte, project start-up meetings are often functioning better than project end meetings. When the local managers have new projects they want to focus on the new journey and put as little energy as possible in the old one. Alte believes that people do appreciate the end meetings but that their output has the potential to be more beneficial than it is today. Also, it is difficult to connect the past experience with the present conditions, because of the differences between each project, and especially to get the experience down in writing so that the next person working under similar conditions can learn from it. In addition, if one person is working with the roof and explains what errors have occurred there then another person who is working with the foundation at the time is not likely to be interested in learning from the roof errors. Therefore, Alte wonders if there could be more specialised roles in construction and he says that maybe it is not optimal that the local managers participate in the whole project from start to finish. However, Alte argues that many see the construction industry as a creative world and believes that some would be hesitant or even resistant to more specialisation and standardisation. Somewhat jokingly he adds that it seems like the more structured people choose manufacturing while the more creative ones choose construction.

Alte believes that there are big differences in the quality awareness of local managers and he mentions that some projects have over 1000 remarks on the final inspection while others have zero. In addition, Alte argues that it can be 30-40% more expensive to handle problems after the client has moved in and that a zero defects when the client enters has long been a measure of quality in the business. Alte mentions that partial inspections, client inspections and main inspections were conducted in the projects where zero defects at delivery was reached and that all problems were solved right after being observed. Therefore, additional early inspections would be beneficial and Alte believes that there are systems and methodologies such as Six Sigma used in manufacturing which could be helpful during the inspections in construction.

Furthermore, Alte sees potential in a methodology which shows what the most common defects are. In addition, he has a vision to be able to tell his customers which problems Veidekke are focusing on because of their previous reoccurrence and to be able to tell customers how much it would cost to have additional inspections and problem controls. However, Alte believes that any such systems which are used in manufacturing would need to be restructured so that they fit in with the business and education on the how and why would be necessary. Also, Alte mentions that, except for with satisfied customer indexes, (Swedish: Nöjd Kund Index or NKI), Excel is still the main computer program used for graphical illustration and he believes that an upgrade in such programs is overdue.

Six Sigma focuses on highlighting problems, finding solutions and controlling the results. Alte points out the similarity between these three focus areas and three areas already present in construction namely risk management, work preparation and self-monitoring. In addition, Alte argues that even though notes are kept on tolerated values, electronic moisture measurements, safety controls and so on and he argues that the next step should be to increase the electronic measuring and to save the data in digital databases. Also, Alte mentions that there are risk analyses on quality, environment, work environment, customers and economy. However, Alte believes that a restructure of the Six Sigma methodology would be necessary before its implementation so that it can be used together with the systems already in use and he argues that changing the terminology so that it better fits the construction industry would make people more open to Six Sigma. Furthermore, he believes that it would be possible to connect the risks, risk handling and risk control and again points out the similarity to the three aforementioned focus areas of Six Sigma.

6.2 Development manager at Skanska

The following information was attained from an interview on Friday the Fourth of December, 2015, with Peter Fredriksson. Fredriksson works as a Development Manager in a group called Operational Efficiency which works with development of the production as a corporate staff function at Skanska Sverige AB in Sweden.

At Skanska, the most important measurement number from a quality perspective is customer satisfaction, which is also the base of discussions around quality in a management context. However, in reality the discussions tend to end up in pure technical product quality. Fredriksson asserts that people sometimes move to fast from the discussion about satisfied customers to technical product quality and he believes that the reason behind this could be that there it is still room and need for improvement of the technical product quality. Fredriksson estimates that roughly 95 percent of quality talk in construction focuses on how to pass final inspections and other purely technical matters which Fredriksson states are also important issues.

The biggest quality challenges which Skanska have are within the area of building construction. According to Fredriksson, the production of asphalt and concrete is more related to the manufacturing industry and the quality is easier to maintain, which has resulted in less need to talk about quality in a problem-oriented way. Within the infrastructure side Skanska has come further with the quality work than within building construction. Fredriksson thinks that the clients on the infrastructure side in general have a more detailed control structure and more clear requirements which contributes to a better quality. Also, he argues that the tender and execution time is longer within

infrastructure projects which further aids the quality. On the building construction side, projects worth several hundred million Swedish Crowns can quite suddenly go to tendering, with only two weeks to make a tender. In two weeks it is difficult to calculate the value of a non-standardised house and at same time deliver a good price, which in the end leads to stress within the project. It may also lead to problems with delayed or unfinished construction documents where simple disruptions can bring big problems.

Today, there is a lot of discussions within all sectors about what the customers want and how Skanska can help them understand, define and develop their needs by using Skanska's competences. Also, the trend with more and more partnering within the procurements has further aided Skanska in helping their customers to define what they want. This leads to a situation where the quality comes in earlier in the value chain for Skanska compared to a design bid build contract with for example the Swedish transport administration (Trafikverket) where the construction documents are completed before the procurement and Skanska only have to build. Good preparations are important in order to get a successful project and Fredriksson believes that partnering can contribute to that.

According to Fredriksson, Skanska works with quality improvement in a structured way within building construction and infrastructure. Skanska has hundreds of factories producing asphalt and concrete where they work a lot with monitoring the quality with different recipes to get the correct mixes. There is also a lot of quality measuring at the local plants which is sent upwards in the organisation for analysis in a structured way. Fredriksson argues that the internal competitions are mainly about money but he also believes that quality and safety in general are about who can deliver the best results. Skanska does measure and follow up on quality and if someone does something good it is highlighted but they do not point out for example the best or worst three of the week. Also, Fredriksson points out the connection between being environmentally friendly and saving money due to lower energy costs.

On the building construction side, the customer satisfaction is measured by different surveys with standardised questions. The answers are compiled, compared and analysed to get a view of the situation and, if necessary, followed up to understand why someone has answered in a specific way. These surveys are sent out to both commercial and private customers who buy for example an apartment. In the beginning of every project, the customers are able to state what is particularly important for them so that Skanska can pay extra attention to those specifics. Fredriksson feels that this is something which Skanska is doing well and he argues that they have many satisfied customers especially within the commercial and public sectors. Even the private customers' satisfaction is increasing, he adds. If the satisfied customer index would decrease for any part of the company or its products, Skanska has the ability to analyse why and implement the necessary improvements. At construction projects with commercial customers which stretch over a longer time period, surveys are held periodically every six months, once directly after delivery and once more after a couple of years depending on warranty conditions and how long the business relation lasts. The private customers will get a satisfied customer survey two to three months after they get access to their apartment or house. After two years it is time for the guarantee inspection which is followed up by another survey a couple of months later.

Survey data is collected after each construction and sent up department for department up to corporation level. The data is presented in different forms, primarily within the specific project organisation. For example, if a local manager is building 50 apartments and is responsible for economy, satisfied customers, suppliers and the employees, the

manager will certainly care more about and put more focus on that project than other ones. If a district manager has ten different projects, totally worth around 300 million Swedish Crowns, the manager is still connected enough to talk about satisfied customers even if there are local managers who answer to the district manager. When survey data from the projects are sent upwards in the report system, they are reviewed but little attention is payed to them unless something seems to be wrong.

The knowledge sharing at Skanska is primarily done through face to face meetings. In addition, Skanska has tried to build different knowledge and IT-systems but it has not worked successfully enough. According to Fredriksson, the face-to-face knowledge sharing works well in Gothenburg where the employees know each other and can easily go and see one and other. For example, if the project organisation of north Gothenburg gets an order to build five houses of a specific kind, they will be able to consult the project organisation of south Gothenburg if they have had a similar project and withdraw from that experience bank. However, Fredriksson believes that it is unlikely that a team in Malmö would go to Umeå to get such expert advice, especially if they have already got some advice from a trip to Lund. By skipping the trip to Umeå, the team will save some money but probably also miss out on some smart ideas. This is partly compensated by Skype meetings but unfortunately Skanska does not have any systematic model for how this type of information should be distributed across the country between the different projects. However, Skanska does have programmes for how employees should make site visits in a structured way. Furthermore, Skanska has something they call project support teams which have the task to travel around between the projects to support and act as a sounding board, often to younger employees. The people in such teams often have great experience of construction and have constructed many houses during their time as employees within the company. In conclusion, Fredriksson states that Skanska is working with knowledge sharing in different ways but also that there is room for improvement. This is a difficult and important question for the whole construction industry since there is a connection between improved knowledge sharing and improved quality.

According to Fredriksson, Skanska does not have a good model to measure production rate but they try to standardise where it makes sense and make an impact in the business. Within house production, which is Skanska's most standardised product, in Design and Build projects the production rate is partly measured by how long different square meters of construction take to build. However, the problem is that each house has its specific conditions and variables. Therefore, even if Skanska's big production would create some kind of basis for comparison, it would still be difficult to interpret. Furthermore, Fredriksson who has also worked at Volvo Car Corporation asserts that the same could be argued in the automobile industry. Volvo Cars' manufacturing facility in Gent produces more cars per hour than the one at Torslanda where, according to Fredriksson, the employees argue that they produce bigger cars, have more varieties and occasionally introduce new models.

According to Fredriksson, most of Skanska's processes are standardised in one way or another, depending on which level is viewed. The construction projects are conducted according to a special project management method with checkpoints, checklist and other controls. In Skanska's projects there are gates with specific requirements which need to be fulfilled before the project can move on but sometimes it is necessary to pass such gates and continue with what can be continued even when the gates are closed

because of the time pressure. Fredriksson believes that Skanska is in the top tier in the Swedish construction industry within this subject, together with NCC and JM. Furthermore, within Skanska's asphalt division and the other more industrialised divisions, the methodologies are standardised. Also, within the housing division Skanska has about 50 different production methods which are standardised for example how to cast cement or assemble a specific kind of window. Fredriksson also adds that Skanska has guidelines for a specific headroom or how stairs should be curved. These guidelines can contribute to more standardising of some the methods used.

How new ideas are implemented and used at Skanska is followed up in different ways. If there is some kind of best practice, the district- and project managers are keen to use them because they have an interest in building as good as possible and such ideas can help with that. Also, it is the house builders who develop the standards and thus get knowledge about them automatically. Even though Skanska is a global company, the development of standardised methods is done country by country. Skanska has previously tried to implement standardised methods on an international level but according to Fredriksson it has been difficult to do so mainly because of differences in the local laws leading to compromises which benefitted neither side. Therefore, Fredriksson argues that Skanska has put focus on knowledge transfer on the personal level rather than the technical level. Fredriksson argues that it is incorrect to point out differences in national culture. However, he does argue that miscommunication and misunderstand can lead to problems from time to time but he does not want to speculate in if it is because of differences between nationalities or between personalities. In addition, Fredriksson argues that working with different nationalities and across borders has worked well. Furthermore, he credits part of the international success to Skanska's decision to let its Swedish employees go abroad to teach and learn from people in other countries.

Fredriksson argues that it is easy to blame insufficient work on bad conditions, not getting the right documents or stress and so on which could be the truth but in the end it is the individual's responsibility to deliver something to be proud of. Also, the individuals are responsible to communicate if they get bad conditions. Everyone must feel their own responsibility and proudness when delivering something to the next person. However, some actors, for example designers, within construction can have a bigger impact on the total quality than others. If the project is a Design Build project, Skanska takes the whole responsibility for it and in other delivery forms the responsibility is shared. Either way, Skanska takes over documents and has the responsibility to build correctly, to be professional and to communicate if something is wrong with the documents. In addition, Fredriksson argues that the fact that Skanska is the biggest construction company in Sweden means that they cannot blame any outsiders and it is obvious that they are expected to have a work performance which is of high quality and professionalism.

Skanska does not have any kind of log system based on for example GPS which shows exactly what everyone is doing at every minute but it is known for example who the responsible manager on site was and who the hired carpenters, electricians or subcontractors were. Also, the traceability of things such as who made the time plan or and inspected the documents and design is high.

Fredriksson believes that Skanska could increase the measuring of defects and variations. When visiting construction sites, variations can often be observed. For example, materials that are to be assembled can be damaged before assembly and assembled parts might show defects as well. Fredriksson argues that this is something

which is not logged as much as it should be. Some people think it is enough just to fix the problem and then move on to next task because they fail to see the meaning of saving notes or photos in a computer. However, there are people who are interested in collecting data, making notes and taking photos with development in mind. Furthermore, Fredriksson sees possibilities for improvement in the culture around quality awareness and the potential benefits a central database at Skanska could have. For example, if the same kind of error is made several times and no notes are saved on it, it will be impossible draw from the experience of fixing or avoiding the same type of error the next time. Unfortunately, Fredriksson believes that situations occur where foremen or production managers fill in the self-checking documents without a thorough check that all conditions are indeed fulfilled. Furthermore, Fredriksson argues that there is still a lot of paper and pen at the sites which has the effect that the self-monitoring documents are put into folders and stay there without being compiled for later analysis. However, Skanska has started to work with the implementation of more electronic IT-systems where they have complete projects defined and where the involved actors can access drawings or descriptions electronically. Thus, it should be possible to connect for example a measurement point to a database where a note can be made or a photo taken if something is wrong and display it with a red dot in the drawings. Fredriksson believes that most of the craftsmen are positive to collecting measurement data because they want show that they have performed well. On the other hand, some of the craftsmen do not understand why they should measure things if they are done correctly or do not see why they should pay attention to things if something has gone wrong but has also been fixed and the customer is satisfied. Fredriksson argues that it is easy to sympathise with such thoughts because they are about making things as simple as possible. However, knowledge sharing might be lost and the company might lose out on opportunities for improvement on a corporate level.

The quality of the sub-contractors is ensured in the same way that Skanska ensures its own quality. Every project has a control programme where it has been defined what should be measured through self-monitoring, function testing and so on. Fredriksson argues that in general, when it comes to big sub-contractors who do a lot of jobs for different companies and are experienced, Skanska puts trust in their ideas after a quick glance so that everything seems to be in order, although it is still necessary to follow up on their work, Fredriksson adds. Skanska works in a similar way to Volvo Cars when it comes to selling out risk and buying specialised competencies by using more Design Build type of contracts with their subcontractors and letting them take a bigger responsibility. Nonetheless, Skanska has a total responsibility to the customer for what they deliver.

According to Fredriksson, it is difficult to estimate how tough the competition is within the construction industry. He argues that the feeling in every project is that Skanska's people need to do everything they can to find smart solutions which can help them reach a lower price and perform as good as possible to ensure the relationships with customers. Also, there can be for example fifteen other companies competing for a project or sometimes three global market leaders, which contributes to a tough competition on the market. However, Fredriksson argues that the actors within the Swedish construction industry are fortunate today and he claims that the market has been good since 2009 without signs of getting worse, especially within housing in the greater cities and infrastructure in Stockholm and Gothenburg.

According to Fredriksson, construction companies do feel a pressure from the customers to develop their quality. Fredriksson adds that, if someone buys a real estate for 300 million Swedish Crowns, they expect and demand a perfect quality. The demands on low price versus high quality varies from customer to customer. For example, a Design Bid Build contract with the Swedish transport administration has quality predefined in the contract and is not negotiable so the tendering is only about price in those cases. However, if a project is carried out as a partnering project it is defined what level of quality is wanted and negotiations are sometimes needed on for example properties and locations in order to reach a level that fits with the budget. Fredriksson points out that the minimum quality is not used as a subject of negotiation. For example, "if the price is reduced, unscratched floors cannot be guaranteed", is not a way in which Skanska negotiates quality.

Fredriksson is unable to answer if some customers are more quality-aware than others. It is obvious that the customer should get what is agreed upon in the contract, he adds. If a customer wants some special properties, they are negotiated before writing the contract and if the customer wants something else after that it results in a contract variation. In addition, Fredriksson argues that if a customer wants to invest in making a building more sustainable, it can lead to a new type of discussions about the properties such as extra work to tape every corner more carefully, thicker walls or a better ventilations system. Such buildings are going to be more high-tech and there are a couple of customers like Akademiska Hus and Vasakronan who are pushing Skanska in their development. Fredriksson claims that some customers are willing to spend that extra money because it is good for the environment, their image and the value of the real estates. He jokingly adds that private customers more likely prefer to spend their money on a Jacuzzi than on extra isolation in indoor walls. Skanska has norms for things such as how thick the asphalt coating should be in different situations or how much a wall is allowed to buckle and the clients' definitions of their own demands are added on top of the rules, norms and guidelines of Skanska to act as a basis for reaching the right quality.

Fredriksson and Skanska have no numbers on how much time the employees at Skanska spend on correcting errors. However, Fredriksson claims that they are as least as good as the other companies in the industry when it comes to quality and hopefully a little bit better because they have enough resources to drive it at corporate level. He also believes that Skanska is an attractive employer which helps the company to get skilled employees who are willing to do little more.

6.3 Implementation researcher at NCC

The following information was attained from an interview on Wednesday the Fourth of November, 2015, with Janni Tjell who is working with the implementation and research of Lean construction at NCC. The purpose of this interview was to get an example of how the implementation of a methodology similar to Six Sigma has been carried out in practise.

Tjell argues that people in Sweden are generally hesitant of being first and often take pride in being second or even in the top half. Therefore, she claims that managers are often open to talk about new ideas but tend to push them forward to the next meeting instead of actually implementing them, unless they have been shown to work somewhere else. In addition, she believes that the low competition on the market has made the external pressure to improve quality seem secondary. Therefore, she believes

that in order for the new ideas to be implemented, there has to be pressure from inside the company and especially from top management.

According to Tjell, the implementation of Lean at NCC in Gothenburg was not a top-down decision but started with the initiatives of a few people. When Tjell was included in the work, the team at NCC, in collaboration with several professors in Gothenburg, tried to implement Lean in the planning stages of construction projects. At that time, Lean was already implemented at the workplace in the form of last planning. However, Tjell believes that the management did not know neither what they wanted from Lean nor what Tjell knew about it. Also, Tjell claims that NCCs implementation of Lean has been more successful in Gothenburg than in other cities due to the interest which individuals had in the method.

Tjell metaphorically mentions that "it is closer from Gothenburg to Stockholm than the other way around" which means that top management in Stockholm are somewhat unwilling to go to Gothenburg and see the implementation of Lean or show interest in the idea. Tjell does believe that top management is getting better at supporting the idea but she also says that during the four years she has been working with the method, the management has been reluctant to take any risks on their own and have been open to rather than fully supportive of the method. For example, Tjell claims that all her co-workers who have used Lean have been positive of it and it has even spread to other Nordic countries but there has still been no push from top management to implement it on a larger scale or to make employees take Lean courses. Instead, Tjell mentions that top management has said yes when workers or middle managers have asked if they can educate themselves in Lean or implement the method. Therefore, Tjell argues that it has been difficult to spread the method throughout the company because everyone involved has to have the Lean-thinking which they do not have today. Also, she believes that a top-down implementation, rather than the bottom-up one seen today, would make the method spread more quickly throughout the company.

Tjell argues that people feel better about their work if they can see that they have contributed with something valuable. Therefore, she believes that more transparency would give the workers more joy from their contributions and motivate them to increase the quality of their work. However, she believes that top management is conservative and that they are afraid of losing power which they have attained from sitting on information which is unreachable to others. She does believe that the company is getting more and more transparent but that there are psychological barriers. In addition, she believes that there needs to be a threat to the company, for example succeed with the new ideas or go out of business, in order for the new ideas to be implemented on a larger scale. Tjell mentions that such an example can be seen in the company Lindbäcks Bygg which successfully implemented Lean throughout the company and thereby survived, a case which has also awoken interest in the bigger companies.

According to Tjell, the Lean method which NCC uses is called Lean construction, focusing more on soft parameters, customer satisfaction and quality issues as opposed to Lean production which focuses on waste management and what is monetarily valuable for the company. In addition, she argues that in Lean construction the user sees how to take care of variation which, in her opinion, the user is unable to do with Six Sigma. Furthermore, Tjell argues that NCC uses Lean to create the best possible flow in a particular project because the projects differ too much from one and other to create a best flow for all. She also mentions that NCC is trying to standardise as much as

possible. However, she believes that construction projects will always have soft parameters and she does not like the idea of mixing Lean and Six Sigma. Therefore, Tjell believes that Lean construction is a better fit for the construction industry than Six Sigma but argues that a construction adapted Six Sigma which depends less on measurement data could be an alternative.

6.4 Six Sigma expert at Volvo Car Corporation

The following information was attained from an interview on Tuesday the Tenth of November, 2015, with Maria Guttman, Six Sigma Master Black Belt at Volvo Car Corporation, (Volvo Cars).

Quality is one of three core values at Volvo Car Corporation, together with safety and sustainability, and is thus at the centre of focus for the whole corporation. According to Guttman, good quality can be achieved in several ways. One of the ways in which Volvo Cars measures its quality is the pure product quality, namely that the product does what it promises to do without breaking down. Another quality measurement is the customers' satisfaction with the products and services. Guttman argues that some of the quality reductions are difficult to observe before product delivery, for example a radio which is difficult to handle. During Guttman's 27 years at Volvo Car Corporation, quality has always been important because it is a crucial selling point. This perspective has made an impact on how Volvo Cars is organised and according to the survey company JD Powers, (JDP), the defect ratio for cars in general has gone down from 2.5 to 0.5 defects per car since the mid-1990s.

Volvo Cars has a special department which only works with the quality management of materials and products from their suppliers. The department has a project model for car development with several gates where each gate has several conditions that need to be met in order to move on with the project. In one of the last gates a requirement is to make a full production sample at the supplier and check so that the CPK-numbers are at 2.0 which corresponds to almost a six sigma level. Thus, Volvo Cars can use the gate method to control that the supplier quality is sufficient before they begin their own production. In addition, the suppliers must measure and secure enough quality according to specific measuring plans at Volvo Cars, depending on the product. For example, 100 % of the products connected to safety must be checked but for some of the other products it is enough to check a number of samples. According to the contract it is compulsory for suppliers to inform Volvo Cars if any variations are found, so that Volvo Cars can take the proper action. Guttman states that Volvo Cars is able to follow the materials from the suppliers on a one-unit level. Therefore, the company knows which specific units are used in which cars and thus which cars need to be recalled if problems should arise. Previously, the supplied materials were controlled by a specific department at Volvo Cars but now controls are made at the suppliers and Volvo Cars only makes such controls if variations have occurred or if the suppliers are not able to make the controls by themselves.

According to Guttman, the car industry is one of the most developed industries in the context of ensuring good quality and logistics. If a customers are going to use the cars, they need to know that everything will work correctly and a manufacturer of consumer products, such as Volvo Cars, has a clearer liability for products towards the end user than a construction company does. Strict regulations, for example in the United States where quality problems and defects often go to court, makes it necessary for Volvo Cars to secure its agreements with suppliers in the same way. Otherwise there would be a risk pf bankruptcy because of bad materials delivered by suppliers. Furthermore, Volvo

Cars has a special department which works with warranty claims against the suppliers if they have delivered something with insufficient quality. These types of business to business contracts contribute to an increased quality because the actors are responsible for their contributions to the end product.

The automobile industry is well-developed, has an overproduction capacity, is highly competitive and operates on a global scale with few trade barriers. In contrast to buildings, cars are relatively easy to transport which has further increased the market competition. Also, the manufacturer of a specific car is usually easy to detect, even if it is sold by a retailer, because of the company logo stuck to the car whereas the producer of an apartment is more anonymous and usually apartments are not marked with such logos.

The introduction of Six Sigma at Volvo Cars began around 1998-1999 when the owner company Ford decided to start working with the methodology because it was popular in the United States. Ford introduced Six Sigma, with the help of Six Sigma academy, within the entire Ford group of 500 000 employees at once in accordance with Six Sigma academy's top-down model. A model where all managers take the Six Sigma Champion course and talented employees with potential to be good leaders become Black Belts. Such Black Belts had Black Belt work tasks for two years and only worked with problem solving until the two years were up. At that time, Champions and Black Belts were the only levels of Six Sigma knowledge at Volvo. However, in 2002 the Green Belt level was introduced with the aim to give all project team members an understanding of the problem solving methodology through a one-week course. At the same time, the education of Master Black Belts was introduced because it got too expensive to keep using only Six Sigma academy for the training.

The American hierarchical approach is uncommon in Sweden. For illustration, Guttman makes an example image of American Six Sigma where a Black Belt comes riding in as a cowboy to save the village and then rides away in the sunset. The hierarchical governance where the managers know every project and decide about who does what, does not work in a Swedish organisation where problems are normally solved within a team and where responsibility is distributed to low levels in the organisations. However, some problems could be solved in a good way with this American approach. For example, a problem with big warranty costs was solved where a developing team with the help of a Six Sigma specialist and Six Sigma were able to calculate that if a particular problem was solved a corresponding amount of money would be saved. On the other hand, in some projects which were more operations oriented, for example a process or lead time which is more about "soft money", it was more difficult to calculate any gains. Therefore, the requirement to make savings was dropped but it is difficult to analyse if it was the right decision to make. It is an advantage to have numbers to show to the top management when making an argument. However, if management is decentralised and uses the Kaizen approach to see what should be improved, it might be better not to let formalities stand in the way of present processes but instead let the focus be on what the current manager thinks is important. The original form of Six Sigma is very formal compared to the model that Volvo Cars uses today. One thing that has contributed to the changes in the structure is that the aforementioned savings requirements were decreased by Ford so Volvo Cars stopped reporting such savings because they did not see any reason for it. However, Volvo Cars still saw advantages with the Six Sigma methodology and thus kept using it.

In 2008, employees at Volvo Cars started to question the idea with Black Belts who only worked as problem solvers for two years and then moved on. Ford has a stricter and more governed career plan where employees work two years as Black Belts and then become managers and so on. The employees did not apply for jobs, instead people were moving around in a system where the typical time at one place was two years. At Ford, two years was considered a long time but for the employees at Volvo Cars it was seen as short since they traditionally had the same jobs for ten to fifteen years. After some time, Volvo Cars integrated the Six Sigma knowledge with the roles of those working with problem solving thus further integrating them with the operation. They also put Six Sigma knowledge as a requirement for some roles such as field investigators or warranty cost people. People with good analytical and problem solving skills got Black Belt training. All officials got Green Belt training because all team members were supposed to have some Six Sigma knowledge. These requirements are still used by Volvo Cars and today all employees which work with any kind of problem solving get at least some kind of Six Sigma education.

In 2006, Six Sigma started to clash with Lean and Volvo Cars' employees started discussing which of the two methods that was the best. In 2008, Six Sigma academy introduced the new Golden Belts which were a combination of Lean and Six Sigma. At the same time, Volvo Cars was combining Kaizen events with Six Sigma which resulted in what they called Lean Six Sigma Kaizen. Such events are one-week projects where a real project is conducted with DMAIC and all resources needed are provided in the room. An example of this kind of project is where Volvo Cars got complaints about emblems on the cars which were crookedly mounted or had fallen off. The project started with the gathering of installers, production engineers and constructors. The team analysed the situation, found possible error sources and finished by presenting some improvement proposals. Volvo Cars runs these types of events a couple of times per year. Since the events only run for one week at a time and with regards to the control phase in DMAIC, Guttman argues that such events can only be held within industrial production. A frequent problem is observable within weeks when 47 cars per hour are produced, which is the production rate at Volvo Cars. Thus, the short cycle times where improvements are easily observed and measured are a reason behind the success of Kaizen and Six Sigma events in manufacturing. In the example above, a longer control period was necessary because of low frequency of the problems caused by low level of production of the affected model. The event resulted in a reduction of emblem mounting stations from three to two which resulted in better emblem placement and less variation.

The top management's support for Six Sigma has varied over the years because of varying results and the different mangers' opinions about the methodology. However, the methodology has survived some difficult years and after 15 years Volvo Cars still has a Six Sigma programme where they educate and certify their employees. Also, the company still conducts Six Sigma projects which all point toward the strength of the methodology. According to Guttman, Volvo Cars' implementation work during 2006 was probably a crucial reason for the continued use of Six Sigma to this day. Also, Volvo Cars has a couple of standard forms to solve problems which follow DMAIC. For example, is it compulsory to make a five why analyse when a problem arises in the production. Guttman believes that such forms have also contributed to the survival of Six Sigma at Volvo Cars.

Guttman continued to describe how she was taking part in a cross functional project, which Volvo Cars calls a mega project, as one of two Master Black Belts. The project was about lack of spare parts in storage when new car models were introduced and the

occasional need to repair the vehicles before delivering them to the customers. This project covered three different departments. The first department which was involved worked with the structure of spare parts. For example, there was a situation about how to handle a scratch in a chair, namely if the chairs should be redressed or if the whole chair should be switched out. The first department made its decisions based on costs and complexity and the structure was then delivered to the purchasing department for procurement and a purchasing order was placed. Finally, the spare part department took over and made sure that the needed materials got to the storage. In total this project included two Master Black Belts, three Black Belts and one Champion from each department. The team got measurement data from the materials in one of the last gates but because they did not introduce new cars very often, the team needed to wait two years to get three sets of measurement data, launching three new models. Guttman argues that it is necessary to have three different sets of measurement data to be able to decide distribution and location. This is an example of a project with long duration and thus it was difficult to following up the improvements. Similar factors could be a reason that Six Sigma is not very common in construction organisations since they are project based and have long cycle times.

Volvo Cars has developed Six Sigma in accordance with the different departments' needs at the company. The most recent work in the quality department has been about business analyses which are about how to handle all measurement data from the cars and from surveys. Therefore, there has been a need to get a substantial knowledge base of big data management, (BDM), which can be seen as a Six Sigma spin off. BDM is about how to see patterns in big volumes of data. One example of this is to analyse how people have clicked on a website and with that data make the site more user friendly. To avoid problems with data which is only gathered in binders, Volvo Cars save their data in easily accessible databases. The self-monitoring is mainly done electronically, especially within the production. For example, the screwdrivers are connected to computers so that it can be seen how frequently variations occur and so that the production line can be stopped if a defect occurs on a critical screw. Also, since this data is collected electronically it is easier to analyse it afterwards.

All car parts have their own specifications and every car model has its own complete set of specifications as well. Not only do safety features such as the steering and braking systems need to work but less safety oriented things also need be working properly. For example, a car should not make unwanted noises which could occur by a lost nut during the assembly. Therefore, every car is driven on a bumpy road to find squeak, rattles and clatter noises. Furthermore, random samples of about 15 cars per week are completely reviewed. The errors found are weighted differently according to factors such as safety. However, multiplication factors to increase the value of some errors according to Six Sigma's errors per million opportunities are not used but the errors are simply noted as more important or less important.

Guttman argues that Volvo Cars is being harder reviewed than some of the cheaper car brands due to their ambitions to be a premium brand. There is a correlation between the number of complaints and customer satisfaction where more complaints mean less satisfied customers, she adds. Also, Consumer Reports in the United States are testing different consumer products such as cars and appoint a best buy. Tesla used to have the best buy but recently lost it because of quality problems. However, 95% of the customers said they would consider buying another Tesla.

According to Guttman, SKFs implementation of Six Sigma around years 2004-2005 is based on studies at Volvo Cars. At the time, SKF had a top management and a CEO whom were dedicated in the implementation of Six Sigma and chose a strategy where they selected leaders which were meant to grow into the role of Black Belts. Also, there was a certification connected to a demand that a specific amount of money was to be saved on the corresponding projects. The big difference at SKF compared to Volvo Cars was the awareness of how the implementation of Six Sigma was supposed to be beneficial for the company, whereas Volvo Cars strictly got the instruction to implement it from the owner company Ford. Guttman argues that a committed management which understands why the implementation is conducted is key for its success. Furthermore, such leadership helps to avoid a situation of panic because of for example an insufficient number of projects leading to invention of pointless projects such as placing a Black Belt to decrease the number of chairs in the meeting room or to solve an impossible task like the eternal problem of squeaky brakes.

Guttman argues that it is not necessary that everyone is educated in Six Sigma but that it depends on the philosophy within the company. She adds that some understanding of DMAIC is good but that everyone might not need a week of Six Sigma education. On the other hand, it is a strength to have a group of Green Belts who know what they are talking about and could spontaneously set up a fishbone diagram, see Chapter 4.2.1, or look after data which could be used in a Pareto diagram, see Chapter 4.2.2. If the organisation has a culture where problems are identified by the manager and the manager then selects project leaders to solve the problems, it could be sufficient if only the project leaders have Six Sigma skills. According to Guttman, a lot of problems can be solved by using practical common-sense together with the seven quality tools which are a part of Volvo Cars' one-week Green Belt education. The focus of the one-week education is on graphical, brainstorming and prioritisation tools. Guttman argues that with these tools a Six Sigma project team can go a long way, especially within the process industry. Guttman argues that statistical tools such as scatter plots and Pareto diagrams are powerful, see chapter 4.2.4 and 4.2.2, but she believes that some people use histograms incorrectly when they do not sort the bars after size or make time sheets with bars. Also, Flow charts, see chapter 4.2.3, can be useful but if the processes are not performed by machinery the cycle times can vary a lot. The spaghetti diagram, see chapter 4.2.5, is also a valuable tool which Volvo Cars uses to analyse the movement of people or materials.

Guttman believes in the combination of Lean and Six Sigma and argues that in optimising a flow, the team can begin with Lean tools to eliminate the waste and if variations occur, Six Sigma can be used to understand and eliminate them. According to Guttman, people are talking about a three level education where the first level is about flows and the seven wastes, the second is about reducing variation and the third about optimising functions. If the problems are simple, it is usually possible to solve them with basic graphical tools. However, if the problems are more complex and about interactions, process industry, following processes or cross-functional projects it requires more advanced tools and the Lean tools without Six Sigma are usually not enough.

As an illustration of the potential combination of Lean and Six Sigma in the construction industry, Guttman makes the following example. It is possible to use Lean to avoid getting material delivered too early and instead make sure that it is delivered just in time. This is possible to manage by value mapping and making orders at the right time so that materials follow the flow of construction. However, if the project team

wants to find a system which secures that the concrete solidifies at the same rate regardless if it is 10 degrees and raining or 25 degrees and sun it could be necessary to use some kind of statistical research planning to find the optimised concrete mixture, which Lean tools cannot do. Therefore, Guttman argues that a team should use both Lean and Six Sigma if it wants to be successful with optimising the processes. Guttman believes Six Sigma could be used to analyse and minimise the risks for different phases in the construction industry. She argues that the best way to use Six Sigma would be to see where methodology fits best and adapt it after that.

According to Guttman, few actors within the automobile industry talk about only Six Sigma or only Lean but rather Lean Six Sigma. Guttman believes that the reason that some people prefer only one of the two methods could be that they are being blindsided because they focus too much on one method and that some consultants focus on only one of the methodologies and thus give a biased view in advertising and so on. To assess the sources critically and to look up the stakeholders is a good way of getting an unbiased viewpoint.

Guttman believes that many problems can be solved without much statistics and she argues that the power of Six Sigma comes from the DMAIC model, not the statistics. Also, the Six Sigma team needs to be aware of how much trust they can put in the data depending on deviations. The DMAIC model helps the team to see if their data is trustable. Another strength with Six Sigma is that the graphical tools are often enough. For example, a lot of things follow Pareto's rule which means that a Pareto chart is sufficient. However, a weakness is in the improvement stage if there is a lack of concrete errors and if problems are instead more about lead times and finishing on schedule. Those kinds of problems fit the Lean methodology and its tools better.

6.5 Client representative at Akademiska Hus

The following information was attained through an interview on Monday the Sixteenth of November, 2015, with Hans Hofflander, a representative for the major Swedish construction client Akademiska Hus.

Akademiska Hus see quality as long lasting constructions and environments for their customers' operations. They aim to be the best at knowing what their customers want by acting according to their present environment and thinking things through to the end. Also, Akademiska Hus highly values work environment quality and Hofflander points out that no accident should occur at the workplace. Furthermore, Hofflander believes that it is important for the construction organisations to keep quality in mind throughout their projects.

Akademiska Hus previously had quality requirements which varied somewhat from region to region but are now implementing standardised and documented quality requirements throughout the company. In addition, Hofflander argues that Akademiska Hus, together with their attendants, adjusts each project according to its requisites but without veering from their basic quality requirements. Also, in larger projects the company works with specialists to get the quality needed in the context of work environment, fire safety, energy usage and moisture.

Hofflander believes that it is more important for the client and contractor to meet in person and build trust and understanding than to rely on specified documents. More expensive materials with a higher quality are often a better choice since cheaper

materials tend to come with higher maintenance costs but Hofflander also adds that it depends on the situation and how much risk the client wants to take. Furthermore, Hofflander argues that Akademiska Hus as the construction client gets all the opportunities needed to control the quality work of the contractors during the projects and that the clients own level of dedication is what sets the limits.

Hofflander believes that the construction companies are getting more and more serious with their quality work. In addition, Hofflander argues that a negative culture which let the contractors twist the quality demands to their favour, was previously common but has now almost completely been erased. Furthermore, Hofflander believes that it is not sufficient that top management are the only ones who think about quality but that the whole organisational chain must be involved. Also, Hofflander mentions a clash between people focused on theory and people focused on practise and he believes that it is important for these kinds of people to meet and understand each other.

When asked if Akademiska Hus can push the contractors into developing the quality, Hofflander once again answered that they want to build trust between them and the contractors and that Akademiska Hus sees more motivational value in a compliment than in a scolding. On the other hand, Hofflander also mentions a local group of clients in Gothenburg called "Byggherregruppen" and a national group called "Byggherrarna" which he believes can put the necessary pressure on the construction companies if needed. However, Hofflander believes that the competition on the market is high enough for Akademiska Hus to be able to set up and receive the quality demands that they want.

Hofflander argues that quality is the most important factor during their procurement phases because Akademiska Hus see the projects as continuous work in which they have shared economy with the contractors through long-time partnering agreements. Therefore, the project procurement price has a low priority for Akademiska Hus.

The self-monitoring system, "Egenkontroll", is mentioned as a Swedish system which forces the construction companies check and validate if they have done what they are supposed to do but Hofflander argues that the data collected from such systems is mostly put in binders and not thought about again. Also, Hofflander worriedly states that when new quality tools are introduced, there is a risk that the user will depend too much on the tool and that nothing of benefit is done with the collected data.

When asked about "Sega gubbar!", (the assessment paper mentioned in Chapter 3.1.1), Hofflander argues that the document blames the wrong things. He believes that the biggest problem in the construction industry is that there is not enough being built and that the organisational structures are wrong. However, Hofflander also believes that the construction industry is generally more conservative and slower to develop than manufacturing.

Hofflander argues that more standardisation in the construction industry could have a positive impact on construction quality and open up for methodologies such as Six Sigma. However, he also points out that standardisation can have a negative impact and mentions the Swedish construction project "Miljonprogrammet", (where a million apartments were built in a relatively standardised manner), as an example with undesirable outcome due to negligence of end user wants and needs.

7 Analysis and Discussion

Six Sigma is a methodology which is used to increase the quality of processes and products by reducing variation. The findings in this thesis indicate that the strength of Six Sigma is the well-structured work method which is gained from the DMAIC model. When DMAIC is used, the Six Sigma team follows the same work path and each team member knows what needs to be done in each step. Also, because the team knows what they want to get out from each step, the tools which are appropriate to use in each step becomes clear. Furthermore, there is not a huge amount of education needed for each team member in order for them to understand what to do. For example, in the beginning of Volvo Cars' Six Sigma use, all the employees who had Six Sigma roles were either Black Belts or Champions but two years later a Green Belt level was introduced which helped the team members understand the basics of Six Sigma through only a week of education.

A big difference which was found between Volvo Cars' work methods and those at Skanska and Veidekke was that Volvo Cars puts greater attention to each step of the production. Also, Volvo Cars logs most of its measurements electronically and even if Fredriksson mentions that Skanska are beginning to move towards more electronic systems the construction companies still put most of their trust in the self-monitoring system which is documented on paper and gathered in binders. Therefore, the type of measurement data which is available for analysis at Volvo Cars is unavailable to the construction companies which makes it difficult to use the statistic Six Sigma tools since they are mostly based on statistical data analysation. Also, in the construction industry every product is unique while the automobile industry has certain models which they produce over and over again. This repetition also makes it easier to use Six Sigma because it is possible to find potential unwanted variation after a shorter period of production. The more standardised processes in car manufacturing compared to construction also makes it easier to measure productivity and quality. However, the construction industry actors interviewed in chapter 6 agree that there is a potential for more standardisation in the construction industry. If the goal is to improve the quality, it would be helpful to standardise more and do the same things more often to minimise the challenges of variations. The construction actors also assert that it is possible to increase measuring and data collection but the problem there seems to lie in making construction people more aware of quality development so that they are motivated to measure and report measurement data. Furthermore, while the outside pressure and globally tough market competition in manufacturing seems to have forced the car industry into constant quality development, the opposite conditions in the Swedish construction industry have surely contributed to the slower development of quality and the seeming culture of being content with present situations in that sector. As Alte mentions in Chapter 6.5, maybe the key is in construction companies taking more responsibility towards the end customers instead of towards an inspector, in the same way as Volvo Cars does.

As mentioned in Chapter 3.1.1, some researchers argue that the client has a responsibility to switch its focus from best price to best value. For this to happen, both the clients and the construction companies need to put more effort and thought into quality and quality development. However, the power of the client to push the contractors into quality improvement is presently not as great as it could and perhaps should be. In the automobile industry the customers have gained such a power not only

through the rough market competition or the companies' direct responsibilities towards the customers but also through people and groups who have evaluated the cars and presented the results in TV-programmes, magazines and online. For example, the magazine Consumer Reports is, as mentioned in Chapter 6.4, often testing similar car models from different brands in order to point out their advantages or disadvantages so that the buyers can make more informed purchases. However, few such results are presented in the construction industry which makes it harder for construction clients to make informed purchases. Akademiska Hus was pointed out by both Skanska and Veidekke as being informed when it comes to construction quality but in general it seems as if clients tend to have insufficient knowledge in the subject. Clients want and need different things when it comes to quality and spending money to increase quality but in order to make informed decisions many of the clients would need more knowledge in the subject.

To implement an organisational culture might prove difficult in an area where the people have deeply rooted norms from their geographical culture. For example, if an organisation tries to implement a hierarchical structure whilst the organisational members have basic subconscious believes that everyone should have their say, there is a risk that people will not comply and choose to challenge the management decisions instead, resulting in structure breakdown or even complete organisational failure. Similarly, it would probably be difficult to successfully implement and use a methodology such as Six Sigma in an organisation where the people have subconscious believes that present quality improvement systems, (or their non-existence), are sufficient and a new methodology would be seen as a burden.

In order to properly implement Six Sigma throughout a construction company, the organisational culture would have to involve quality thinking to a higher degree than today. Optimally, if following the theories on culture mentioned in Chapter 3, the quality thinking should be so deeply rooted in the organisational culture so that people in the organisation do not even have to think about it. If the people in an organisation do not have it as a norm to decrease variation and to do things right the first time, then there is probably no place for Six Sigma in that organisation. Similarly, as was learned from the Guttman interview, even Volvo Cars showed some resistance in the beginning and though that the owner Ford was in the wrong to try to force this major quality methodology on the company. However, doing things right the first time seems to have since become an almost subconscious way of thinking at Volvo Cars and has thus become part of its organisational culture. Unfortunately, even the major actors of Swedish construction Skanska and Veidekke who say that they value quality have not successfully made doing things right the first time a part of their organisational culture and there is no indication that any other construction company in Sweden has done it either.

Zero faults when handing over the finished project to the client seems to be a measure of perfection in Swedish construction today. However, two major parts are overlooked. First, the variations, defects and problems occurring before the handover are to some degree discussed and obviously some experience is gained from dealing with them but seemingly, almost as soon as the fixing and discussing is done, they are taken out of focus and forgotten. Also, there seems to be no significant amount of variation data collected and thus there is no way to see if the same type of variations are frequently reappearing. Second, what is included in the zero faults on delivery is only what is found during the final inspection. In addition, since there is no data on common

variation, neither client nor inspector have a way of controlling if such variations are properly dealt with so that quality problems will not occur later on.

The big contrasts between Volvo Cars' top-down approach and NCC's small scaled employee introduction shows the necessity of total support from top management when implementing a new work method throughout the organisation. Both Volvo Cars' and NCC's employees seemed to have difficulties in understanding why a new work method was necessary. However, the difference was that Ford's decision to implement Six Sigma throughout the whole Ford group more or less forced Volvo Cars' top management to be behind the idea while NCC's top management seemed to be neither supportive nor against it. Therefore, Volvo Cars was able to implement their method on a large scale early on but NCC have after four years still have only been able to implement their method on a local scale within a few project. A similar relationship could also be seen between the Six Sigma implementation at Ericsson, a bottom up implementation, and SKF, a top-down implementation over the whole SKF-group. A big difference between SKF and Volvo Cars, which both are based on the American top down approach, is that the implementation at SKF was much more planned from the begging and the executive management had a clear idea of what they want to get out of it. Furthermore, SKF were putting bigger attention on the culture at the unique units and individuals than Volvo Cars which is something that several researchers in Chapter 4.4 believe is an important factor for success. These examples indicate the importance of total support from top management if the ambition is to implement a methodology on a company-wide scale. Also, the literature points out the importance of beginning the implementation with the right people to avoid opposition and making it easier for the rest of the employees to accept the new ways of work. Furthermore, it is important that the top management has an understanding of why the company should implement a methodology such as Six Sigma to make it successful. A lack of understanding could lead to situations where the management sets up senseless goals and have ambitions which in the end lead to wasted money instead of the wanted improvement.

The top-down implementation at Volvo Cars with Ford's American approach was not introduced without discussions by the employees at Volvo Cars. The employees were unable to understand why the Black Belts should be moved from their ordinary work stations and work as full time Black Belts for two years. Also, Ford considered two years a long time for a job while Volvo Cars considered it short because in Sweden it is not uncommon to have the same job for ten years or more. This shows the importance of adjusting methodologies like Six Sigma to local norms and conditions. Today, Volvo Cars is integrating Six Sigma as a natural part of certain jobs instead which has led to higher acceptance by the employees. It is also important to remember that each business has its own conditions which makes it necessary to adjustments the methodology accordingly. For example, the construction industry has longer cycle times, less standardisation and lower volumes than the car industry. These differences could make it difficult or even impossible to use some tools in one business even though thy have been successful another business. Therefore, skipping the examination and appropriate selection of tools could result in unnecessary investment in pointless teaching programmes.

According to Guttman, it is impossible to reach a flow with all unnecessary waste removed, (which is considered perfection in Lean), without complementing with Six

Sigma because unwanted variation is waste and Six Sigma is needed to find its source. It could be a good idea to start working with Lean to get an understanding of what wastes to remove and then continue with Six Sigma to see where to tackle the problem. Even if this thesis is limited to focus on the pure Six Sigma methodology, Lean Six Sigma is considered a great possibility for the future and construction companies should not overlook one of the methodologies on the basis that they are using the other.

The construction industry is characterised by being based on projects which normally involves representatives from several different companies. People working on projects are often changing because they have different competences which are demanded during the different stages of it. Therefore, it would be difficult to make everyone understand why they should adapt their work to a methodology such as Six Sigma. To be able to use Six Sigma, it would be necessary to require that all actors involved in a project have at least some kind of Six Sigma knowledge such as the knowledge obtained from the basic Green Belt training programme.

In Chapter 5, researchers mentioned Six Sigma being successfully implemented and used in construction, health care, financial institutions, service industries and engineering organisations which are all essentially project based businesses. However, even if it has been shown to work elsewhere, there are no guaranties that it would work in the Swedish construction industry. In a calm market which is more or less guaranteed to keep introducing new projects, it is unlikely that a company would take the risk of restructuring its business. The company would have to make its employees educate themselves in Six Sigma, make them see the benefits of Six Sigma methodology and make craftsmen measure and upload measurement data both if they have done right or wrong, so that Six Sigma could be implemented. Furthermore, some researchers argued that Six Sigma would kill workforce creativity and even if most of the research found pointed against such claims, they might still introduce uncertainty in someone who is researching the possibilities of introducing Six Sigma. However, while some researchers have their doubts about the possible benefits of Six Sigma in construction, most researchers are positive to the idea and present examples of Six Sigma being used in both construction and other project based industries. Also, Atkins construction process improvement steps seem to be relatively similar to the main parts of Six Sigma which suggests that a successful implementation of the methodology could aid process improvement. Six Sigma could be used for both increasing the quality awareness throughout a construction company and to measure and improve the quality itself.

One example of a construction company that have benefited from using Six Sigma is Bechtel Corporation. Ever since they introduce their Six Sigma programme around year 2000 they have attained good results from it and educated hundreds of employees in the subject. Their use of Six Sigma as a method to optimise work processes and material flow on site is a good example of Six Sigma potential within the construction industry. The two Bechtel examples, see Chapter 5.1, in this study are both about problems which are characterised by repeatability. The examples indicate that it is important to standardise more within the construction industry and thus create a construction process with a higher level of repeatability which can be even more optimised by using Six Sigma.

For the greatest impact on quality, companies should aim for improvement on the complete construction process. Partnering in combination with a top-down implementation of Six Sigma could open up for such improvement. Partnering contracts could ease the standardising of data collection because of the long term relationships and such contracts often increase the clients' involvement in the projects which are

arguably both necessary factors for proper Six Sigma usage. Also, the traditional focus on price in construction might be deprioritised next to quality, trust and communication if Six Sigma is used in combination with partnering. Seemingly, construction companies have started to switch from best price to best value and more focus on quality would probably ensure that such development continues.

The project processes in Swedish construction are mostly non-standardised and soft parameters, such as how long it takes to construct one square meter, are commonly used to quantify the productivity. Meanwhile, much of Six Sigma methodology is based in statistics which requires hard numbers. If the construction sector wants to use Six Sigma, standardisation of processes and process stability is needed both to analyse current processes so that they can be improved and also to measure and control improvements to show that they were worth it. However, there seems to be a general content with the situation in Swedish construction. Swedish construction companies might on one hand have competition over specific projects but on the other hand seem to have enough projects to go around. Therefore, it may be easy to say no to a new methodology or not to pay particular interest in it without really trying it. If there is a demand for quality improvement tools in the construction business, such a demand seems to have a lower priority than to be on time and within budget. However, if an implementation of Six Sigma was successful, both time and money would be saved on not having to redo processes in construction projects.

The Six Sigma example tools mentioned in Chapter 4.2 might be relevant to construction companies even if they do not implement the complete Six Sigma methodology. Cause-and-Effect diagrams, see Chapter 4.2.1, are used for brainstorming. They could be used within construction risk management to find the potential causes for risks and give the people within construction organisations ideas of what might occur and give them time to prepare and plan for how to handle risks if they do occur. Pareto charts, see Chapter 4.2.2, are used to prioritise which unwanted variations should be removed. If problems in construction projects were logged, Pareto charts could be used to see which problems were most frequently reoccurring so that focus could be shifted towards solving those problems. As mentioned in Chapter 5, both Pareto and Cause-and-Effect diagrams were used in the example from a Chinese prefabrication company. Furthermore, Process mapping, see Chapter 4.2.3, can be used both to map present processes and to map anticipated steps of future processes. In chapter 5.1, Bechtel used process mapping to make the goals and compromises clear in their Victoria tunnel example which shows that this tool can be helpful for construction companies even if their processes are not continuous or repetitive.

The scatter diagrams, see Chapter 4.2.4, are used to validate data used in data analysation. A problem with using this tool for the Skanska and Veidekke is that they do not seem to collect enough and appropriate data neither to analyse statistically nor to validate with a scatter diagram. Therefore, the scatter diagram might not be possible to use for those companies before they significantly increase their data collection. The same is true for other statistical Six Sigma tools which are dependant of collected data.

The spaghetti diagram, see Chapter 4.2.5, can be used for understanding and optimising the logistics within a construction project. Bechtel used a tool similar to a spaghetti diagram at the Ivanpah Solar Facility to make the construction processes more efficient. Since a lot of the activities at a construction site are connected, the spaghetti diagram could probably help Skanska and Veidekke make their logistics more efficient as well.

Furthermore, the spaghetti diagram is an example of tools within the Six Sigma toolbox which do not need a lot of measurement data to use. All that is required is a floorplan and knowledge about what is being done at each station and by whom. From that information it is easy to draw up the movements of people or materials so that they can be optimised.

As Guttman recommended, it might be good for Skanska and Veidekke to start with the more graphical tools which do not need any measurement data since there is insufficient amounts and gathering routines within the companies. Cause and effect diagrams, Process mapping and Spaghetti diagrams are all examples of tools which can help the users to understand problems and visualise solutions without measurement data. If electronic databases are implemented and data is regularly and properly collected, it will be possible to use a wider range of Six Sigma tools, including the ones which are based on statistics, to analyse problems and reduce defects. Some tools within the Six Sigma toolbox are already used in the construction industry but not in the context of DMAIC which is the backbone of the Six Sigma methodology. To be able to fully use the DMAIC structure it is necessary to make measurements and have electronic databases because the structure is based on and dependant of a combination of statistical and graphical tools. Without both graphical and statistical tools, it will be challenging to follow the structure and for example to control the effects of the improvements.

8 Conclusions

In this thesis, Six Sigma is seen as a structured guideline methodology for quality improvement projects with several tools fit for different areas of use. Six Sigma depends on the team members being educated in the methodology to different degrees depending on their roles.

The first conclusion reached in this study is that the construction industry needs to change its attitude toward quality work and measuring in order to improve its quality. The self-checking programmes can be considered insufficient and there is a lack of systematic data collection on defects and variations. An early step after raising quality awareness might be to start using the graphical Six Sigma tools which depend mainly on soft parameters. After that, the next step would naturally be to start measuring defects to a greater degree and gather the data in databases where it can be easily accessed and analysed. Also, more standardisation might aid quality development, decrease unwanted variation and help organisations avoid reinventing solutions to similar problems between projects. Furthermore, a goal of many construction projects is zero errors at delivery instead of zero errors during the construction process. Zero errors during the process would lead to the same result in the end but with less waste and redoing. Close to zero errors during the process is one of the main achievement goals when using the Six Sigma methodology.

Volvo Cars is ahead of Skanska and Veidekke when it comes to measuring and systematic quality development. Also, the automobile industry is affected by a harder inspection from outside sources and customers. Furthermore, the knowledge level of many customers in construction, both private and professional, is too low. Therefore, the demand for high quality seems to be lower in construction than in manufacturing or at least viewed differently, which appears to be a leading cause in the slower quality development.

To make the Six Sigma methodology work in the best way for the company implementing it, the following four points should not be neglected. First, the company should pay attention to both geographical and company culture. If the culture is neglected, company employees might struggle to make sense of and see the benefits with Six Sigma. Second, the company should make sure that the model fits to its specific industry. A construction company cannot simply take the model of Six Sigma which is used in a car company and apply it to its own company. Some tools and techniques could be used, such as the graphic and soft parameter based tools, but others would not work because of the longer production times, the variation between projects and other factors which differ between construction and manufacturing. Third, while some researchers argue for top-down and others argue for bottom up they all agree that full support by the top management is a key factor of success in the implementation of Six Sigma. The top management must fully support the implementation and have a clear goal of what they want to get out of it. Fourth, Six Sigma education should be integrated as a natural part of the current roles within the company in a way which fits in with the company's and geographical area's culture.

It does seem like the Skanska and Veidekke could benefit from using some of the Six Sigma tools straight away, such as Cause-and-Effect diagrams, process mapping and spaghetti diagrams. Also, Pareto charts might be useable to some extent with simplified data but since they are based on data, some type of data always needs to be gathered.

Unfortunately, the companies do not seem ready to successfully implement and use the complete Six Sigma methodology yet. However, if the companies would start to measure and document their defects and variations more, change their attitudes towards quality and increase their standardisation there is probably be a place for a construction adjusted Six Sigma methodology in the future.

Future researchers might want to study how to make construction companies more quality aware and how to make them aim to minimise the defects during the construction process instead of minimising them at delivery. Also, specific areas of the construction industry could be studied to see where Six Sigma would be most useful. Furthermore, research could be made on if Six Sigma can be used to find which construction processes are the most problematic to see where standardisation would have the greatest impact. In addition, a deeper study of Bechtel Corporation's use of Six Sigma could give an improved understanding of how Six Sigma can be used in a construction company.

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