Improving Analysis of Key Performance Measures at Four Middle-Sized Manufacturing Companies

Moving Focus from What Has Happened to What to Do

by

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Diploma work No. 32/2010
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Gothenburg, Sweden

Diploma work in the Master programme Quality and Operations Management

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Chalmers Reproservice
Gothenburg, Sweden 2010

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Abstract

This thesis project aims to improve decision-making at four middle-size companies by helping them to understand variation and analyze key performance measures. The authors wanted to move focus from what has happened to what to do. In today's "Information Age", much of the information presented is in the form of numbers. One of the major problems in organizations today is that often, such as in the monthly report, only two points are compared to each other. This is a nonsense analysis which generates chaos in the organizations (section 8.2.1.1). Before information can be useful it must be analyzed, interpreted and assimilated. It is this process of digesting data that often is missing in organizations today. The purpose of this thesis can be formulated in three research questions; *How did the companies change their attitudes and behaviour as a result of understanding variation? How should a method to understand variation be implemented?, What aspects are important to consider when undertaking an implementation process?*

The companies involved in this project spent a lot of time and resources on discussions about processes improvement. However, without a tool that enabled them to listen to the process and really understand the process' behaviour, the conclusions were often arbitrary. What was needed was a new way of analyzing data and a new way of thinking concerning their processes. The new method is the process behaviour chart and the new way of thinking is understanding variation. With better understanding of the processes and better knowledge about how and when to improve them, the organizations will free up time and resources to be allocated on other business areas.

The most significant change identified was a change in how the companies use performance measures. With a better understanding of the behaviour of the performance measures used to control the processes over time, a change of focus from "*What has happened*?" to "*What can we do about it*?" could be observed. The performance measures were not just used for information purposes anymore, but actually used for improving the processes. The thesis also discusses why the method and tool have not been implemented before. A model for implementation of the concept was developed. It is a step-based model based on moments of standardization. Moments of standardization are significant points in the process were learning occurred. A very important enabler for successful implementation is common method and concept understanding of the group. By only training individuals, the implementation did not have the same impact, which was partially observed in the project.

The project concludes that a full implementation requires patience and motivation; patients because it involves organizational change and motivation to realize the long-term benefits. The results of this project can be used by Skärteknikcentrum to further spread the concept to other member companies.

The most interesting findings can be found in chapter 4 and for a quick read-through it is recommended to go to that chapter immediately after introduction.

Keywords: Six Sigma, process improvement, understanding variation, key performance measures

Acknowledgements

First and foremost we want to thank Peter Hammersberg for his commitment, guidance and good ideas throughout the entire project. We also want to say a big thank you Thomas Petersson, our project leader, for all of his help and support. Without them, this project would have been impossible to do.

We also want to thank Åke Ahlström and Börje Dahl for giving us the opportunity to execute this interesting project as our Master's thesis. We want to thank the involved people at each company for taking part of our study: Pernilla Dovskog-Wiman (Finnveden Powertrain AB), Linda Fransson (Gnosjö Automatsvarvning AB), Mikael Holmgren and Kalle Meijer (Värnamo Industri AB), and Tobias Svensson (BUFAB Lann).

A special thanks to Carlssons Pensionat for their warm hospitality and to Smålands Affärsresor AB for excellent service. Last but not least, we want to thank our friends and family for their support during the project.

Abbreviations

CNC: Computer Numeric Control
DMAIC: An improvement methodology for Six Sigma improvement projects
PDCA: A cycle for problem solving and learning
PM: Process Measure
SPC: Statistical Process Control
VoC: Voice of the Customer (customer demands/specifications/goals)
VoP: Voice of the Process (process behaviour)
XmR (ImR) chart: Shewhart control chart for individual values with moving range, process behaviour chart

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1 Introduction

1.1 Background

In today's "Information Age", much of the information presented is in the form of numbers. Before information can be used as basis for decision-making it must be assimilated, analyzed, and interpreted. It is this process of digesting data that is missing in many organizations today. By understanding variation and analyzing appropriate key performance measures, focus is shifted from what has happened to what actions to be taken. The solution is not about lifting the roof to more advanced heights; it is rather to raise the floor on which the organization stands. This means increasing the general knowledge of how to interpret and communicate information throughout the organization. A very important enabler for successful implementation is to have a common method and concept understanding among all group members involved in the process. Unless the group speaks the same language, no matter if individuals have expert knowledge, the progress of interpreting data will be directly or indirectly hindered; directly by questioning and or resisting the experts methods, and indirectly by not participating in discussions and hindering synergy effects of the group.

This master thesis is a continuation of the cooperation between Chalmers University of Technology and Skärteknikcentrum Sweden AB. Two former theses[1,2] and a problem visualization (Appendix A) together with CEOs and responsible persons from four member companies of Skärteknikcentrum AB, set the starting point for this thesis. The problem visualization is simplified in figure 1.1 below. The conclusions of the former theses were that the daily disturbances occurring in the companies' manufacturing processes were symptoms of an overall problem. As these disturbances ties up a lot of time and energy, they prohibit the companies from focusing on other important parts of their business and long-term development.

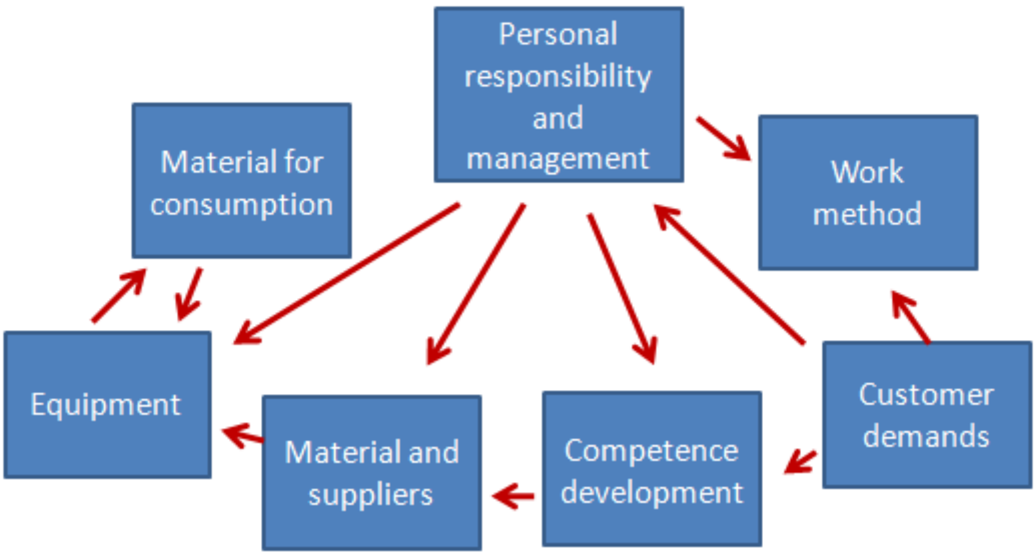

Figure 1.1. Figure 1.1 is a simplified version of the original problem visualization performed before this project in response to the question: "What are the greatest challenges with creating safe and predictable processes?". The boxes show critical factors, or parameters, that affects the question. The red arrows show in what way they affect each

[1] Jansson, Diep, *"Kartläggning av osäkra processer inom skärande bearbetning", 2008*
[2] Figielman, Wenngren, *"Material och kvalitet, en studie för skärande bearbetning i stångmaterial", 2008*

other. From the figure, it can be seen that, besides personal responsibility and management, the work method and customer demands have critical impact. The latter two factors also became the themes of the project.

A visualisation of the overall problem shows a network of entangled parameters shown in figure 1.1. From this, two basic themes for development could be concretised. These two themes are connected so that improvement in the first theme would free time and energy for the organizations to focus on the second theme. The two themes were:

1. Methods for process improvement and development
2. Increase focus on how to deliver customer value

The themes can be viewed as two pervading lines through the organizations. The first theme has a vertical connection in the organization and is about how process data is analyzed and communicated vertically trough the organization. By implementing and standardizing methods for data analysis and communication, improvement in theme 1 can be established. The second theme goes parallel with the value chain and is about increased customer focus and changing the organization's view of their external environment from push to pull, shown in figure 1.2. Theme 2 cannot be improved as directly as the first theme. Improvement should rather be a consequence of standardizing new working methods in theme 1. By using the two-theme approach, the potential for improvement can be generalized into a wider context, meaning that direct improvement efforts can be connected to a long term perspective. Without themes 2's dimension the improvements in theme 1 may only be seen as value adding in the short term. This is not the case.

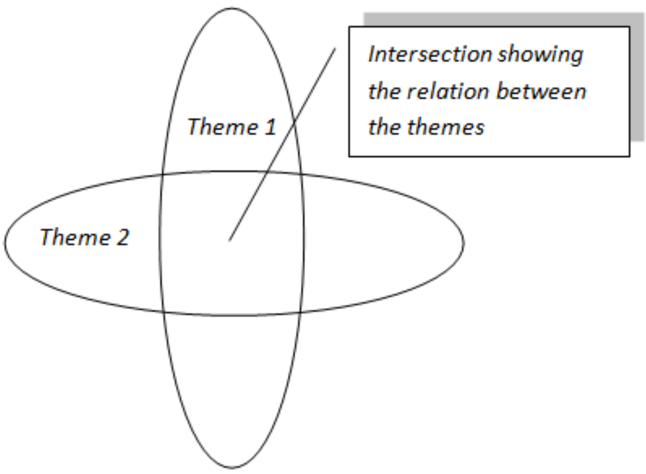

Figure 1.2. The relation between theme 1 and theme 2 can be described as where analysis and communication of process data is connected to increasing customer focus.

To further demonstrate how the themes are related, a situation is described in figure 1.3. Theme 1 represents methods for data analysis and the information flow vertically through the organization and theme 2 represents the value chain horizontally through the organisation. Without understanding their relation and the importance of develop them together, process improvements will be almost impossible because decisions will not be based on facts. Figure 1.3 describes when this relation between the themes is not understood and the process or value chain is controlled by customer demands, that is, without using the methods in theme 1. When the process shows unpredictable behaviour and does not satisfy the customer demands the customer demand is met by adding ad hoc supporting processes, or so called "fire fighting" actions. These actions are often not standardized and require a lot of time and resources. The focus (in the organisation) becomes, therefore, on the result instead of the system generating the result. This way of working will not improve the process; it only fixes the individual case and does not build up any systematic knowledge about the underlying system. The approach presented in this thesis is to use the methods in theme 1 to improve the process instead of the outcome.

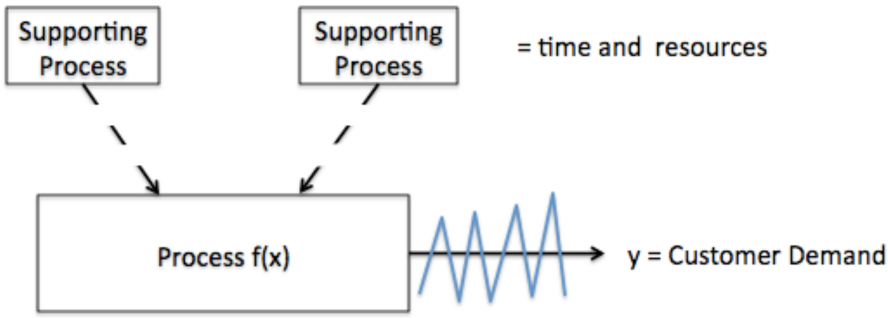

Figure 1.3. Disturbances in fulfilling customer demands (theme 2) should be attacked by improving the process (theme 1), rather than adding supporting processes that cost time and money.

1.2 Project Case

A very large portion of the jobs within Swedish engineering and manufacturing industry is threatened, according to a study by the Swedish Governmental Globalization Committee. The threat from low-wage countries such as China and India is believed to be the major reason and the automotive industry with its suppliers is the most vulnerable group. If this prediction falls out to be only partially true, this would mean a huge setback for the Swedish metal-cutting industry (Skärteknikcentrums newsletter, 2008).

To further describe this project case, three characteristic areas will be touched upon. First it is relevant to introduce the facilitators, sponsors and drivers of the project; Skärteknikcentrum Sweden AB. Next up is a short description of the unique environment, in which the companies operate, with its strong tradition of entrepreneurship and skilful practice within industrial manufacturing technology. Finally, the companies involved in the project will briefly be introduced.

1.2.1 Skärteknikcentrum Sweden AB

Skärteknikcentrum Sweden AB operates on the interaction between companies, suppliers, research institutions, development institutions and universities that together create conditions and an environment for knowledge in metal cutting. Areas of activity are development within technology, skills, and productivity, which is offered to companies linked to the metal cutting business. The company is 100 percent owned by the Swedish Society for Metal Cutting Technology, which in turn consists of some 70 member-companies (Skärteknikcentrum Sweden AB).

1.2.2 The region

Three out of the four companies in the project operate in the Gnosjö region, the fourth company operating close to the region. This makes it relevant to describe what is known as “the spirit of Gnosjö” that has become a well-known conception over the years. It is strongly associated with an enterprising attitude, a network for know-how, high quality, and modern industrial technology. The constant development of the concept has been made possible through the cooperation and helpfulness between companies, which has always been a characterizing feature of the Gnosjö companies. The municipality has never given any cash subsidies, but always stood up for the industry through the creation of a business promotion infrastructure (Gnosjöregionen website, 2010). The level of knowledge and understanding in process improvement methods is high, especially for manufacturing companies.

1.2.3 Company presentations

This section briefly presents the companies involved in the project.

1.2.3.1 Gnosjö Automatsvarvning AB

Gnosjö Automatsvarvning was acquired by the Fransson family in 1974, but was founded in 1947. The company employs about 30 workers, each with their own area of responsibility. Gnosjö Automatsvarvning AB specializes primarily on CNC lathe machining of complex details in large series. A unique characteristic of Gnosjö Automatsvarvning AB is their focus on delivering advanced cleanliness analysis if requested. The customers are primarily within the automotive industry and the engineering industry in Europe and the United States (Gnosjö Automatsvarvning AB website, 2010).

1.2.3.2 BUFAB Lann AB

BUFAB Lann is located in Värnamo, and is part of the BUFAB group; a leading producer of a range of products within metal cutting and has operations around the globe. The BUFAB group was founded in 1977 and has grown consistently. BUFAB Lann manufactures special details in most metallic materials, but specializes on difficult materials. BUFAB Lann is a supplier for large and small companies, and only builds to order, not on stock. Customers come from a wide range of businesses within automotive, offshore, construction, and process industry (BUFAB Lann AB website, 2010).

1.2.3.3 Värnamo Industri AB

Värnamo Industri AB (VIAB) was founded in 1968 and was privately owned until 1985. In 2007, the company was acquired by the XANO Industri AB concern. The company produces and sells various components and systems within the field of metal cutting in materials such as steel, iron, and aluminium. Besides tooling, the company also offers services such as tempering and surface treatment. Customers are primarily the industry for heavy vehicles and machine builders located in the Swedish market (VIAB website, 2010), (XANO Annual report 2009).

1.2.3.4 Finnveden Powertrain AB

Finnveden Powertrain has operations in Sweden, the UK and Germany. The company develops and manufactures complex precision components and subsystems for engines and power transmissions. The Powertrain Components business unit of Finnveden (Finnvenden Powertrain AB) was, in 2007, sold to the Italian company Gnutti Carlo S.p.A., creating one of the leading manufacturers of precision components for heavy diesel engines in the world. Finnveden Powertrain’s main customers are within the automotive industry (Finnveden Powertrain AB website, 2010).

1.3 Aim

Because of the reason described in the background, the first theme is a part of the solution for the second theme. This thesis main focus has been on methods on analyzing data and how process information is communicated through the organisations. A part of the aim was to implement a methodology for <u>analyzing data</u> at the four companies, but the focus was also on <u>changing the way of thinking</u> when it comes to process improvement. As described in the project case, these companies already have a high level of knowledge and understanding in process improvement methods. This is why the thesis focuses on the interaction between the method and the user, in other words to develop an understanding and knowledge on how to use the method more effectively and throughout the whole organisation. The way to determine how well the companies adopted the method was to evaluate the changes in attitudes and behaviour.

1.4 Scope and limitations

As four companies were involved in the project, the method for implementation was kept the same for all of companies. Besides this, two additional stakeholders were involved, namely Skärteknikcentrum Sweden AB and Chalmers Institution of Material and Manufacturing Technology. This implicated that the project needed to be kept on a general level that could benefit all. The issue is to find the smallest common denominator that facilitates operational development for all stakeholders involved.

The expertise of these companies lies in manufacturing and the knowledge they have in process improvement is mainly concentrated around manufacturing. That is why this thesis focuses on a higher management level concerning key performance measures. This was where the opportunity for improvement was the greatest. Because the aim was focused on the companies understanding, and usage of, the method for analysis, the technical level of the solution had to be kept relatively simple. One of the stakeholder, Skärteknikcentrum, required the theory and solution to be easy to understand and accessible. As the method is a catalyst for understanding and working with processes, this approach provided more time to document how the organisation's perspective and way of thinking regarding process improvement changed.

The second theme will not be elaborated upon in detail in this thesis. Instead, the second theme will be used to put theme 1 in a wider context. The companies should be aware of the intersection point where these two themes meet and understand how they affect each other, see figure 1.2. And the underlying assumption is that development of theme 2 is prevented by lack of structure in development of theme 1. In other words, in order to free time and energy to become proactive towards variations in customer expectations the internal information processes needs to be visualised and understood.

For progress to be made in the project, it was essential to arrange as many meetings as possible. The created a strong dependency on the companies' ability to accommodate the suggested meetings on a regular basis. The amount of time in meetings was therefore dependent on the workload of the companies throughout the project duration.

The effective time for the project was approximately five months, including time for writing the report, developing a framework for implementation, and producing a user's manual.

1.5 Research questions

The background and project aim can be formulated in a set of research questions, which serve as a basis throughout the project. They will be answered by using relevant theory to implement a solution and draw conclusions from the empirical findings.

1. *How did the companies change their attitudes and behaviour as a result of understanding variation?*

   This research question aims to create knowledge about what organizations can expect from understanding and implementing the theory used in this project. An implementation process will require time and resources and it is important know what will change as a result of it.

2. *How should a method to understand variation be implemented?*

   The second research question is the most tangible one and is aimed at developing a plan and a method for creating understanding of variation. As Skärteknikcentrum is a member's organization with many more members than just the ones participating in this project, this question is very important for future implementations.

3. *What aspects are important to consider when undertaking an implementation process?*

   The third research question will give insight into what is required to perform an implementation project that changes the way the organization works. This project is about lifting the foundation (understanding and knowledge) that the organization stands upon, as it is interesting and relevant to know what is required for such a big change. The fact that SPC is used as an analysing method in production but not used to analyse key performance measures makes this question even more interesting.

1.6 Method

A literature study was conducted to identify a suitable theory to solve the problem. The theory needed to match the limitations, meaning that it needed to be simple, accessible and be applicable to the case. The theory by Donald J. Wheeler matched these criteria and therefore used to build the theoretical framework. The objective was not to challenge the theory but rather to apply it at the companies.

This project is unique in the sense that the result is not only to provide a means for how to improve processes, it also includes documentation on how well the companies respond to the proposed improvements. Because the result is not only a solution but also rather a new way of thinking and working, an important part of the result is related to the fact that the companies share responsibility for success. The companies' involvement was a crucial part of the project, as standardizing the methods was a prerequisite for continuing the learning process, and could only be done by the companies themselves. The result is therefore not just a solution that can be delivered physically to the companies – it is a new way of working that requires participation from their sides as well.

Emphasis was put on quickly providing the companies with a method to start listening to their processes, namely the process behaviour chart. Once this was done, it was important to help the companies to start using the tool in real time, and to discuss the companies' own process behaviour data. Eventually, an important part of the project became to analyze how the tool was accepted, what where the challenges and what were the gains.

Qualitative interviews were conducted to stimulate discussion. This gave a more nuanced picture of the situation, rather than if predefined questions would have been used. The answers would possibly have been shorter and less interesting, had this method been used instead.

The framework for executing was based on the Six Sigma DMAIC cycle. The reason for this was that the authors had experience in using the methodology, and considered it to be a well structured and effective project framework. Another reason why the DMAIC framework was used is that it places large focus on defining project components, customers, scope, and factors that are critical to quality for the project; more so than in conventional project frameworks.

2 Theory

The theory chapter is divided into primary theory and secondary theory depending on how it has been used.

2.1 Primary theory

This theory is called primary theory because it is directly related to the project; it is theory that has been actively chosen to obtain the results. The theory below is organized in four main parts: Current situation, the solution, how to reach the solution, and the goal. This structure was formed based on the method, and makes the primary theory coherent with the project.

2.1.1 Current situation

This section explains what is wrong with the method used at many organisations today.

2.1.1.1 Two point comparison

Today, almost all companies use historical data to make decisions that will affect the future. Unfortunately, the most common type of comparisons encountered is comparisons of the current value with another value, a so-called two-point comparison (Wheeler, D., 2000). For example, the outcomes for this month are compared to the outcomes from the preceding month. If this month's outcome has changed for the better, then everything is good. If this month's outcome has changed for the worse, then something needs to be done. A situation when this approach is common is the traditional way in which business data are reported in the monthly report, as showed in figure 2.1.

Monthly Report for July

Quality:	Dept	July Actual Value	Monthly Average Value	% Diff	% Diff from July Last Year	Year-to-Date Values Actual Value	Plan or Average	% Diff	This YTD as % Diff. of Last YTD
On-Time Shipments (%)	20	91.0	91.3	− 0.3	− 0.9	90.8	91.3	− 0.6	− 0.3
First Time Approval (%)	12	54	70	− 23.0	− 10.0	69.3	70	− 1.0	− 0.4
Pounds Scrapped (per 1000 lbs production)	19	124	129	− 3.9	0.0	132	129	+ 2.3	+ 1.5

Production:	Dept	July Actual Value	Monthly Plan Value	% Diff	% Diff from July Last Year	Year-to-Date Values Total or Average	Plan	% Diff	This YTD as % Diff. of Last YTD
Production Volume (1000's lbs)	13	34.5	36.	− 4.2	− 2.0	251.5	252	− 0.2	− 8.0
Material Costs ($/100 lbs)	13	198.29	201.22	− 1.5	− 1.9	198.46	201.22	− 1.4	− 3.6
Manhours per 100 lbs	13	4.45	4.16	+ 7.0	+ 4.5	4.46	4.16	+ 7.2	+ 9.3
Energy & Fixed Costs / 100 lbs	13	11.34	11.27	+ 0.6	+ 11.3	11.02	11.27	− 2.2	+ 9.2
Total Production Costs/100 lbs	13	280.83	278.82	+ 0.7	+ 0.9	280.82	278.82	+ 0.7	+ 0.4
In-Process Inventory (100's lbs)	17	28	19.7	+ 42.0	+ 12.0	21.6	19.7	+ 9.6	+ 5.9

Operations:	Dept	July Actual Value	Monthly Plan Value	% Diff	% Diff from July Last Year	Year-to-Date Values Total or Average	Plan	% Diff	This YTD as % Diff. of Last YTD
On-Time Closings of Accounts (%)	06	74.3	95	− 21.8	− 23.5	87.8	95	− 7.6	− 2.7

Figure 2.1. A typical management report (Wheeler, D., 2000)

This monthly report gives the decision makers a lot of information, and displays the four most commonly used comparisons. It compares the current value to a planed or averages value and compares the current value to the value for the same month last year. The report also compares the current year-to-date value to a planed or average value and current year-to-date value to previous year-to-date values. However, the problem with this report is that the comparisons may provide contradictory messages since each of the four comparisons are limited. This limited and weak comparison flaws the attempt to provide a contextual background for the interpretation of a given number. The reason why this comparison is limited due to the amount of data used, and it is weak because both of the numbers are subject to variation. The variation makes it very difficult to determine just how much of the difference between the values is due to variation in the numbers and how much, if any, of the difference is due to real changes in the process (Wheeler, D., 2000).

2.1.1.2 Comparisons to Specifications

Specifications are, for example, plans, goals, budgets and targets. Those can be defined as the Voice of the Customer. According to the findings in this project, management often compares data with specifications. The reason for this is probably that, not only is it easy to do, the idea stems from manufacturing where product measurements often are compared to specification limits. This approach will result in that the outcome becomes the basis for a simple judgement; the outcome is either acceptable or unacceptable. Unfortunately no further analysis of the process that generates the outcome can be done, which also makes improving the process impossible.

Specification limits and natural process limits are not the same, as shown in figure 2.2. Having only two states the outcome can take, favourable or unfavourable, will lead to a binary worldview. If management has this binary view, a natural consequence is fast changes between states. Things can change from being good to bad and back to good again very fast. Thus, the specification approach to the interpretation of data is destroying any attempts for long-term continual improvement work. The specification approach does not reveal any insights into how the process works, because it focuses on outcomes and not the system that generates the outcomes, and therefore makes it very hard to improve the process. Comparing to averages from the process itself will give the same problems as the specification approach because it is also a binary view, either above or below average. Since the average is generally near the mid-point of a set of data, half of the values will be above the average and half below the average (Wheeler, D., 2000). Executives desire to work with "a number", to plug in an average figure, is legendary. But whenever an average is used to represent an uncertain quantity, it ends up distorting the results because it ignores the impact of the inevitable variations (Savage, S. 2002). As (Savage, S. 2002) puts it; "Decisions based on average numbers are wrong on average."

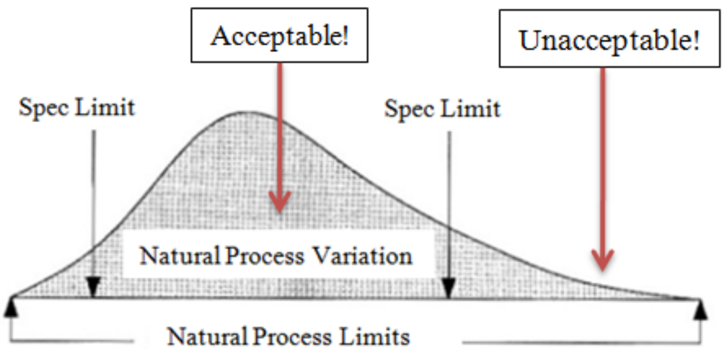

Figure 2.2. The figure shows the difference between the voice of the process and the voice of the customer. It also shows the binary view by using the specification limit as basis for making decisions (Voice of the Customer).

2.1.1.3 Consequences of two point comparison

Both comparing to specifications and planned values can easily create chaos of conflicting messages. This chaos is the result of faulty interpretation of numbers that is based upon the idea that; "two numbers which are not the same are different" (Wheeler, D., 1998). By acting on the assumption that any numerical differences is a real difference and praise some departments and reprimand other departments constitutes a man-made chaos. These actions will ultimately be arbitrary. This is a consequence of the fact that actions like this ignore the effects of variation. Variation undermines any simple and weak attempt to interpret numbers. Monthly reports and other descriptive summaries can be interesting, but should never be mistaken for analysis. The focus of analysis has to be on why there are differences. Just because two numbers are different, does not mean they represent things that are different. The uncertainty of interpreting data lies in the discrepancy between the numbers and those things, which the numbers represent. This is why descriptive summaries will not work, by themselves, to provide the insight needed for a useful analysis (Wheeler, D., 1998).

2.1.2 Solution

This section explains the solution that is required to improve the situation.

2.1.2.1 Avoiding man-made chaos

First of all, description, as in the monthly report, is not analysis. Description will not provide the needed insight into the system that produced the values, but rather hide the underlying system. This is why description will not provide the basis for predicting what will happen. It only deals with what is past, without providing a clue to what may happen in the future. While prediction requires knowledge, explanation does not. Description may be sufficient for explanation, be it right or wrong, but analysis is required for knowledge. This is the reason why a new method for presenting and interpreting data is needed (Wheeler, D., 1998).

When it comes to analysis, the only meaningful comparisons are comparisons of a measure with itself over time, for example monthly or weekly. All data contains noise and some data contains signals, but before any signals can be detected within any data set the noise has to be filtered out. A method to filter out noise that is present in all data by separating the variation that is due to common causes from that which is due to assignable causes is needed. This is the basis of avoiding chaos since actions taken differs for these two types of variation. This analysis provides the insight needed for process improvement. The foundation of continual improvement is to be able to listen to the Voice of the Process (Wheeler, D., 1998).

2.1.2.2 Predictability

Since prediction is the essence of management, the ability to know what to expect when a process is behaving predictably is invaluable. Managers want to know if a change in the process has occurred or not so that they can respond appropriately. Managers also want to be able to predict what the next value will be so that they can plan for the future, as shown in figure 2.3. However, the numbers can change even when the process does not. The key question then becomes to find a way to distinguish changes in the numbers that represent changes in the process from those that are essentially noise. Good management requires planning, not reacting (Wheeler, D., 2000).

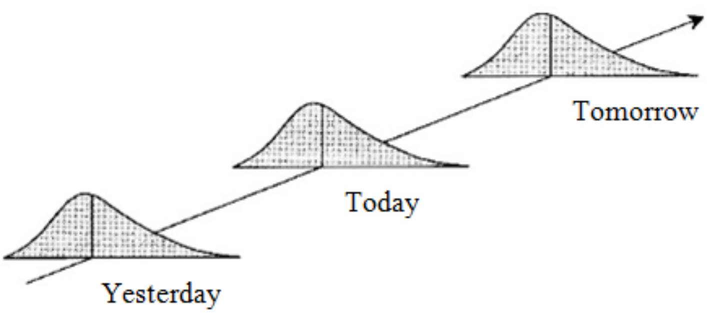

Figure 2.3. The past predicts the future (Wheeler, D., 2000).

2.1.2.3 Walter A. Shewhart's approach to interpret data

Dr. Walter A. Shewhart successfully brought together the disciplines of statistics, engineering, and economics and became known as the father of modern quality control. In 1931, Shewhart published his most important work, “Economic Control of Quality of Manufactured Product”, which is regarded as a complete review of the basic principles of quality control. Shewhart held bachelor’s and master’s degrees from University of Illinois, where he later taught, and a doctorate in physics from the University of California at Berkeley. He was a member of the visiting committee at Harvard’s Department of Social Relations, an honorary professor at Rutgers, and a member of the advisory committee of the Princeton mathematics department (ASQ website, 2010).

Shewhart is most widely known for the control chart (more in section 2.1.3.1), a simple but highly effective tool that represented an initial step toward what Shewhart called “the formulation of a scientific basis for securing economic control.” Shewhart wanted to match statistical theory with the needs of the industry, and always searched for ways to do things better (ASQ website, 2010). Shewhart has made a distinction between two types of variation in numbers and developed a tool to separate them from each other. This will be further discussed in the next sections.

2.1.2.4 Variation

Some variation is routine, has no specific cause, and can be expected even when the process has not changed. This can also be referred to common cause variation, or noise. Other variation is exceptional, it is outside the bounds of routine, and can therefore be interpreted as a signal of a change in the process. This type of variation is referred to as exceptional variation or special cause variation. See figure 2.4. (Wheeler, 1998).

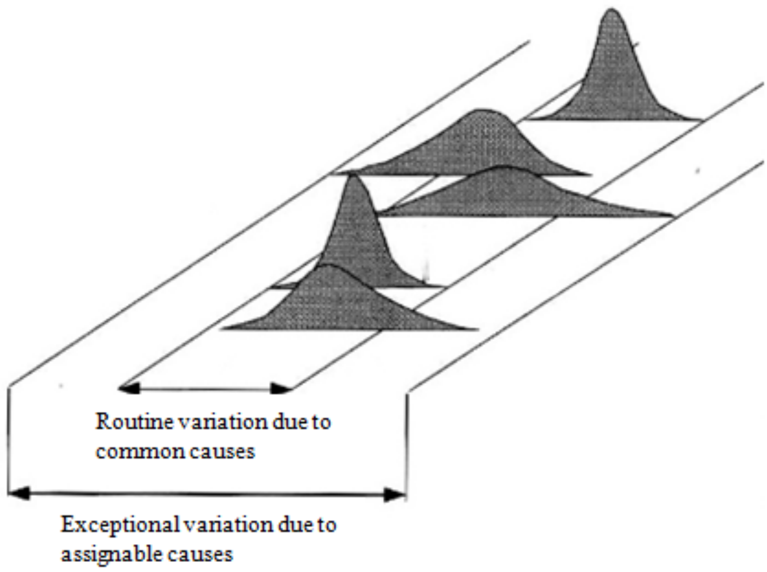

Figure 2.4. The difference between routine variation and exceptional variation (Wheeler, D., 2000).

Routine variation

Routine variation is always present and unavoidable. Since this type of variation is routine, it is also predictable, this makes it possible to predict this variation over time. It is consistent. A predictable process will only contain routine variation, as the presence of exceptional variation will make it unpredictable (Wheeler, 1998).

Exceptional variation
Exceptional variation is not always present, as opposed to routine variation. This type of variation is exceptional, making it unpredictable. Since it changes over time, one can never depend on the past to make predictions about the future. Processes that are unpredictable, by definition, always contain exceptional variation due to assignable causes (Wheeler, 1998).

2.1.2.5 Data collection

Collecting good and focused data is a prerequisite for effective decision-making. If the values are not collected in a consistent way, they will not be comparable. Wheeler (2000) states, "No data have meaning apart from their context". This statement has three direct consequences. First, data cannot be trusted if it is not presented in its context. Second, data should not be presented as comparisons between pairs of values. And third, graphs should be used to present current values in context. Analysis starts with context, is driven by context, and ends with interpreting the result in the context of the original data. There must always be a connection between what the data is used for and the original context of the data (Wheeler, 2000).

2.1.2.6 Tampering

Organizations tend to have wide gaps in knowledge regarding the proper use, display and collection of data. This results in a natural tendency to either react to anecdotal, or "tamper". The most common form of tampering is treating common cause variation as special cause (Mitchel, 2004). A process not subject to any external causes of variation always shows some random variation. If you adjust the process in response to such random variation, you would be over adjusting the process. Over adjustment actually induces more variation in the process than would occur if a random cause process is left alone (Symphonytech, 2010).

2.1.3 How to reach the solution

This section explains the tool needed to reach the solution.

2.1.3.1 The process behaviour chart

In order to separate the two types of variation, Walter A. Shewhart developed the control chart, also called the process behaviour chart. The control chart is a device for describing in a precise manner exactly what is meant by statistical control; as such, it may be used in a variety of ways (Montgomery, 2005). The chart consists of three essential elements; the data plotted in a time series, a central line on the average, and limits that are computed from the variation of the data. The limits filter out probable noise so potential signals can be detected. The process behaviour chart tells the user when a change has occurred, but not specifically what has happened (Wheeler, 1998).

The XmR chart for individual values
Shewhart's process behaviour chart can be used for *individual values*, referred to as *XmR* or *ImR*. This type of process behaviour is especially effective in situations when, for example, every single manufactured unit is analyzed, when the time between measurements are relatively long, and when attempting to measure business processes (Wheeler, 1998). This type of chart was therefore used extensively throughout this project. The *XmR*-chart contains some different elements that will be discussed below.

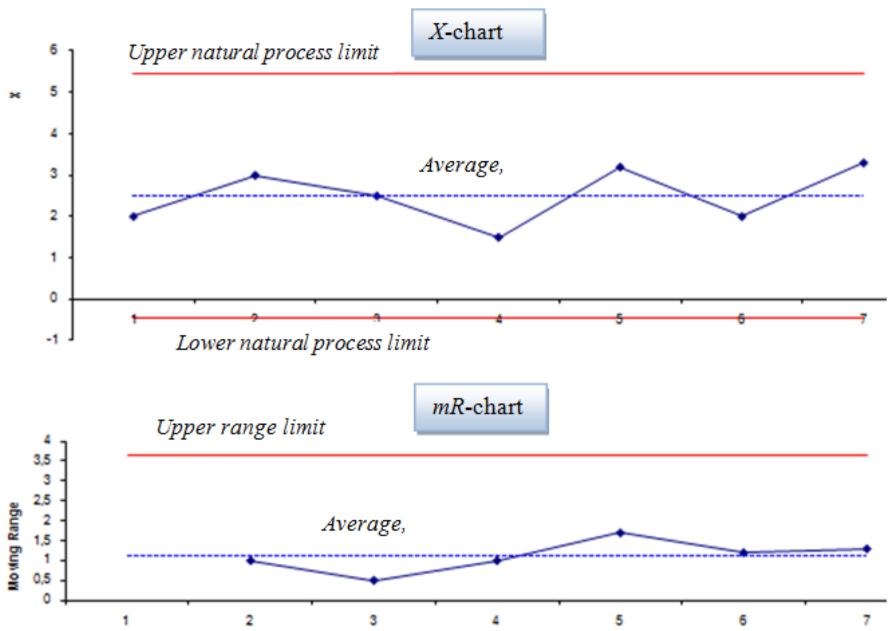

Figure 2.5. The control chart for individual values (above) with a moving range (below), with description of each part discussed in the text.

The upper chart is called the *X-chart*. It plots each individual value in a time series. A central line representing the average, $\bar{X}$ runs through the chart. This graph keeps track of historical data and is more frequently used than the second graph when monitoring and analyzing processes (see figure 2.5).

The lower chart is called the moving range chart or *mR-chart*. It plots the difference between each individual value and its successive one on an absolute scale. A central line showing the average difference between all pair of subsequent points, $\overline{mR}$ runs through the chart. This graph gives the user an idea of the ***variation*** in the measured process (see figure 2.5).

The *X*-chart includes an upper and a lower *natural process limit,* and is dependent on the variation, which is represented by the moving range. The limits in the X-chart are thus a function of the mR-chart. The upper range limit in the mR-chart is calculated in a similar manner as in the *X*-chart but a different constant is used (see figure 2.5).

Natural process limits for the *X*-chart = $\bar{X} \pm (2,66 \times \overline{mR})$
Upper range limit for the *mR*-chart = $3,27 \times \overline{mR}$

With $\bar{X}$ = Average of individual values, *X*
$\overline{mR}$ = Average of moving range, *mR*

A complete picture of the XmR control chart with calculated limits is shown in figure 2.5.

Why are these specific constants chosen for the limits? The answer is based on the fact that Shewhart drew the line between routine variation and exceptional variation at three standard deviations from the average (±3 sigma). The three-sigma limits were chosen such that, according to Shewhart, “when [an observation] is found outside these limits, looking for an assignable cause is worthwhile”. Experience has shown that three-sigma limits seem to be an acceptable economic value, and they have been thoroughly proven in professional practise.

The constant in the formula for the *X*-chart is mathematically derived to provide the three-sigma limits, based on the variation (Wheeler, 1998).

Two mistakes

For a data analysis to be meaningful there must be a distinction between signals and noise. The process behaviour chart does this with its control limits. However, if the control limits are too close together there will be *false alarms*, when common cause variation causes a point to fall outside the limits by chance. This is type 1 error (see table 2.1). If the limits, on the other hand, are too far apart, signals could be missed. This is called type 2 error (see table 2.1).

Table 2.1 Two types of error.

Error	Mistake	Comment
Type 1 error	*Interpreting noise as if it was a signal.*	This mistake will lead to unnecessary actions, thus causing wasteful activity.
Type 2 error	*Failing to detect a signal when it is present.*	This error may be encountered if only using the specification limit as guidance, instead of properly understanding the Voice of the Process.

The process behaviour chart finds a balance between the two errors. The use of limits to filter out the noise of routine variation will minimize the occurrences of both types of errors. In other words, it minimizes both the number of times that signals are missed, but also the number of times that noise will be interpreted as a signal. Shewhart's choice of limits will bracket approximately 99% to 100% of the routine variation (Wheeler, 1998).

Flexibility of the XmR chart

The three-sigma limits provide flexibility by covering virtually all of the common cause variation. This means that the process does not have to be perfectly normal distributed for the limits to work; they are completely general and work with all types of process behaviours. If the process is heavily skewed, resulting in limits that are not exactly 3.0 sigma, this has no practical significance. If the chart ends up with limits at 2.5 or 3.5 sigma, they will still virtually filter out all of the noise making potential signals detectible. The objective is not to find the right number, but rather to take the right action. Three sigma limits are not used because they correspond to a theoretical probability; they are used because they work. This has been proven by thorough practise. In figure 2.6 some examples are shown of different distributions in the XmR chart (Wheeler, 1998).

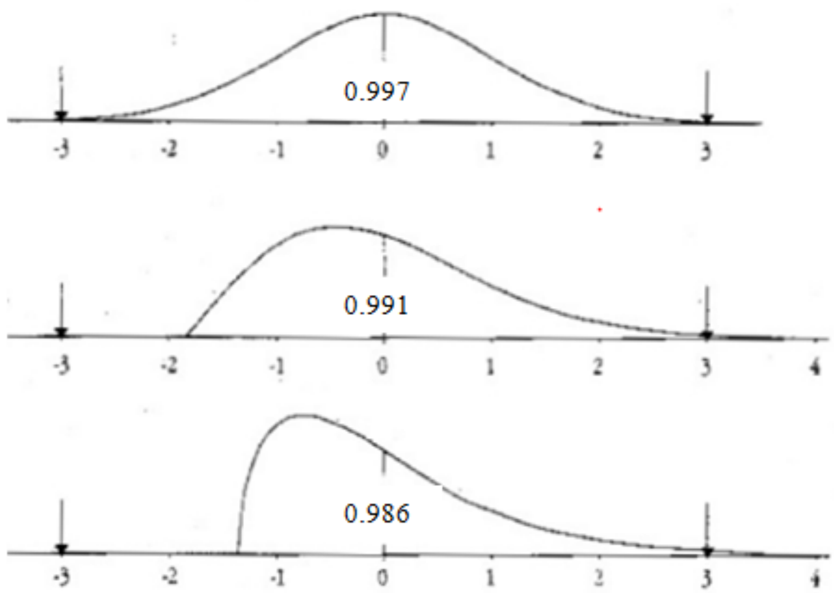

Figure 2.6 shows the flexibility of the 3 sigma limits, regardless of distribution. The numbers represent the fraction covered by the 3-sigma control limits. Figure showing an excerpt from (Wheeler, 1998)

Detection of exceptional variation by signals

In order to obtain signals of exceptional variation the limits must be calculated from historical data. The idea to establish limits will make it possible to distinguish between routine and exceptional variation. Signals can manifest themselves in three different ways in an XmR chart:

1. A single value beyond the limits of a process behaviour chart.
2. At least 3 out of 4 consecutive values which are in the upper or lower 25% of limits.
3. 8 successive values above or below the central line.

Signals are not only a sign of that something has happened in the process; they are also opportunities to discover how to improve the process. Shewhart's research, and experience, has shown that it is economically worthwhile to investigate all such signals of exceptional variation (Wheeler, 1998).

Detection rule (1),(2), and (3) are appropriate for the X-chart, whereas only detection rule (1) is applicable for the mR-chart.

2.1.3.2 Aggregated measures

Aggregated measures are commonly used as totals, which also generate aggregated noise. This is why aggregated measures will sometimes end up having wide limits on an X chart. The more highly aggregated a value is, the greater the amount of noise that has been accumulated, and the more likely it becomes that the values will fall within the commuted limits. When a highly aggregated measure shows evidence of an assignable cause, it is very probable that it really is an assignable cause. However, when a highly aggregated measure behaves predictably, that does not mean that all of the components of that measure are predictable. Aggregated measures may give nice charts, however, to identify opportunities of improvement the measure may need to be disaggregated. Aggregated measures can still be very useful in an XmR chart, as it can detect if a change has occurred. When aggregated measures are placed in an XmR chart, and a signal is found, it is best to look at the disaggregated measures separately in order to determine what is happening (Wheeler, 1998).

2.1.3.3 Obtaining the full potential of process behaviour charts

Implementing and using control charts have great potential. However, it is not always easy to reach the level where the real benefits can be achieved. A reason for this limited use of control charts are that they are used in manufacturing only and as a tool limited to monitor and adjust processes.

The many different ways of using control charts can be described with five categories (see figure 2.7). The first category is when control charts are used for information about how things are going, or for verification that something has occurred. The charts are often kept for the files and not used in real time for improving the system. The next category consists of control charts used for preserving status quo. The information from the chart is used in a feedback loop for making processes adjustments. The third category is a big step in the right direction, because this is the first category where control charts are used to really analyze data. This category consists of charts used to analyze data from tests or experiments upon the process. The third and fourth category is similar. However, the fourth takes analyzing one step further by using multiple control charts to simultaneously track several related characteristics in order to discover just which charts provide the best predictors of process or product performance. The word predictors are very important here because that is the essence of analyzing data, to be able to predict the future. The fifth category is the use of control charts for continual improvement. It is hard to reach this usage of control charts and it often requires going through category three and four. The key in using control charts for continual improvement is the ability for those involved to identify and remove assignable causes of uncontrolled variation. Out-of-control points must be viewed as an opportunity. Continual improvement and analyzing data is a way of thinking and control charts are ultimately a catalyst for this thought process. The emphasis should be focused on the interaction between the user and the chart (Wheeler, 1997).

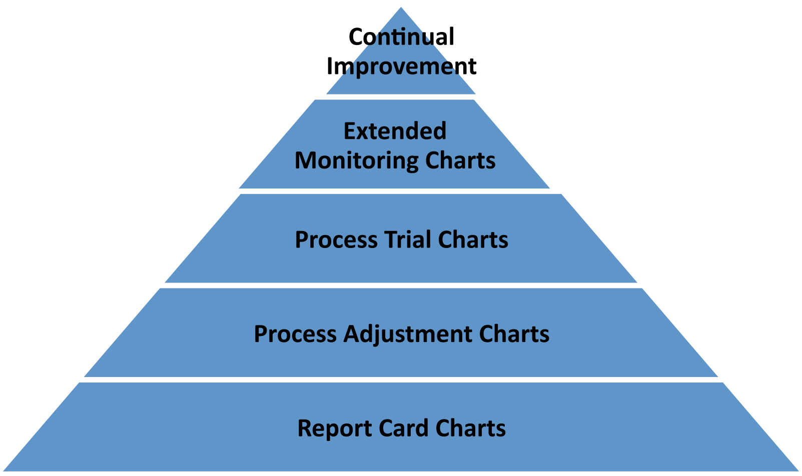

Figure 2.7. The figure shows the different ways to use Shewhart's control chart. These five categories are arranged in order of increasing sophistication.

2.1.3.4 Improving the process

If the process is not operating to satisfaction, there are a number of ways to improve it. It is essential to distinguish between the Voice of the Process and the Voice of the Customer. The Voice of the Process is the process' natural behaviour and the Voice of the Customer is the specifications or goals. As described previously, specifications cannot be used to control the process. Instead the starting point should be to align the Voice of the Process with the specifications. As long as the process is predictable, this can be done in three ways; either shift the process aim, reduce the process variation or change the specifications. The insight of understanding the difference between VoP and VoC provides a new way of describing processes (see figure 2.8). Words as good or bad are exchanged with operating to full potential or not operating up to full potential. This provides a new revolutionising way of working with process improvement. The traditional approach advocated that a good process should be ignored or at most tweaked and a bad process should be improved using radical methods such as reengineering, and may demand large investments. The new way thinking advocates the opposite. A so called good process is operating at its full potential and therefore in need of a radical change to be improved. On the other hand, a so-called bad process is not operating at its full potential and can therefore with small means be improved; assignable causes may have a quick solution. The process behaviour chart enables the user to listen to the VoP and thereby determine what type of action is appropriate; tweak or reengineer (Wheeler, 2000).

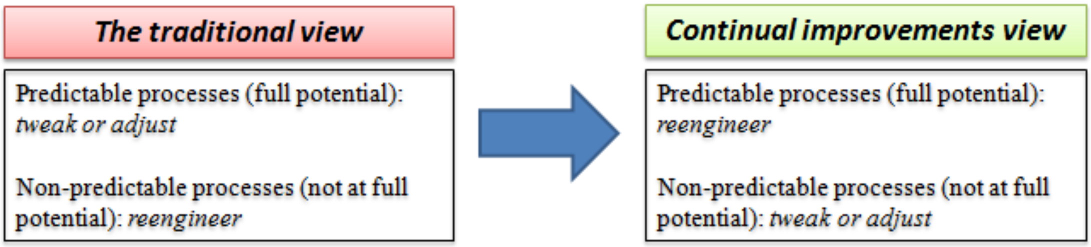

Figure 2.8. The traditional view of process improvements contra the continual improvements view.

2.1.4 The goal

This section explains the ultimate goal that can be reached by using the tool and understanding the solution.

2.1.4.1 Continual Improvement

The most important use of a control chart is to improve the process. In identifying assignable causes, it is important to find the underlying root cause of the problem and to attack it. A cosmetic solution will not result in any real, long-term process improvement. Developing an effective system for corrective action is an essential component of an effective SPC implementation (Montgomery, 2005).

In order to use the process behaviour chart effectively, a specific way of thinking has to be developed. This way of thinking can be summarized as the ability to characterize all processes as either predictable or unpredictable depending on the behaviour of the data they generate. The use of process behaviour charts will therefore always involve an element of judgment. They derive their power from the way they stimulate the user to think about his or her processes. It is the interaction between the chart and the user that generates the thinking that results in continual improvement (Wheeler, 1998).

The process behaviour chart gives the user the ability to;

- understand the messages about the process contained in the data generated,
- differentiate between routine variation and exceptional variation,
- and understand the difference between noise and signals

These three abilities provide the basis for continual improvement by generating a new powerful way of thinking that ultimately will enable effective business. Continual improvement consists of many frequent improvements spread out between periods of predictable and unpredictable performance. Using process behaviour charts routinely throughout the organization is a good way to start this journey (Wheeler, 1998).

Sifting focus from results to process

Instead of focusing on outcomes, such as expenses and profits, or management by results, the continual improvement way focuses on the processes and systems that generate the outcomes. Rather than trying to directly manipulate the results, possibly by data distortion or any other method, it works to improve the system that causes the results. This makes continual improvement a way to simultaneously increase quality, boost productivity, and ensure an advantageous position. In the traditional way of working there is often a strong focus on reducing costs. This way of thinking may well be undermining events in the future, just to make the current numbers look better. Instead, continual improvement focuses on the causes of those costs, or more specifically *the processes that generate them*. Continual improvement focuses on eliminating causes of poor quality, and thereby on reducing the complexity of the process. This enables costs to be reduced, while at the same time, improving the operations (Wheeler, 1998).

2.1.4.2 Why continual improvement?

As previously mentioned, Theme 2 places the importance of data analysis into a wider context. By continually improving processes, waste and disturbances will gradually be reduced, hence free time and energy. This will create an opportunity for the companies to increase focus on how to deliver customer value. Ultimately it all comes down to creating superior value for the customers.

The relationship between theme 1 and theme 2 can better be described with what is known as *The Cornerstone model* (see figure 2.9). This is the basis for what is often referred to as *Total Quality Management*, TQM, which according to (Bergman, B Klefsjö, B., 2003) means "a constant endeavour to fulfil, and preferably exceed, customer needs and expectations at the lowest cost, by continuous improvement work, to which all involved are committed, focusing on the processes in the organization". Based on top management commitment a successful work with quality improvements can be built. This shall rest on a culture, based on the following values; focus on customers, base decisions on facts, focus on processes, improve continuously, let everybody be committed (Bergman, B Klefsjö, B., 2003). The concepts of TQM strongly reflect how theme 1 should be applied to achieve theme 2.

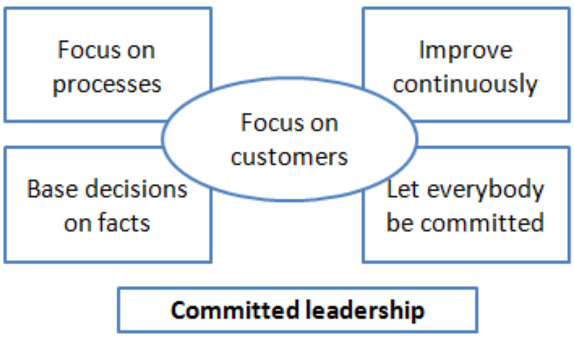

Figure 2.9. The cornerstones of TQM.

The only way to know how superior value for customers can be created is to understand what the customers really want. This is not a simple task, since the definition of customer needs shifts over time; they are dynamic. What is successful today may not be successful tomorrow. This situation is coupled with uncertainty and creates a need for organizations to adapt to these shifting conditions. Being flexible and observant for shifting conditions requires a lot time and energy, however companies who can keep up with the changes will always come out more successful than companies that do not. It is also important to continuously develop the knowledge of employees to ensure that future adaptation to customer demands is possible. The only way to have a chance to adapt to the changing customer needs is to have a clear understanding of the business environment (v. d. Heijeden, 2007) (see figure 2.10).

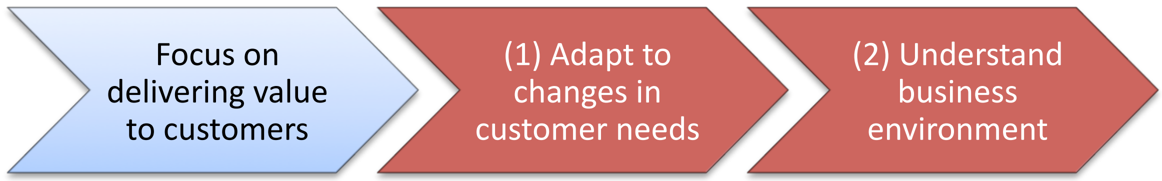

Figure 2.10. The key to improving the delivered value to customers is; (1) to adapt to changes in customer needs, and (2) understanding the business environment.

To be able to increase focus on how to deliver customer value, the main focus must be on how the companies can improve their capability to perceive what is going on in the business environment. By doing so, the intention is that the companies will be able to adapt to the changes in customer needs, or more specifically think through what the situation means for them and have time to act upon this new knowledge.

There are many benefits to be gained by spending more time and resources on focusing on the external environment. Enhanced perception will make trends and upcoming events visible, so that they can be understood as they occur. This will remove the "element of surprise" and make the organization more proactive. By observing the environment, change and uncertainty can be recognized and understood, which in turn stimulates creativity and learning in the organization. Besides this, planning for possible future scenarios is good way to deal with the complex situation of understanding the customer.

2.2 Secondary theory

This theory is called secondary theory since it is theory that has not been used directly, and therefore does not have a significant connection to the results. However, this theory should still be formally explained as it has been used in the project.

2.2.1 Six Sigma

Six Sigma is a strategy for breakthrough and ongoing improvements with the core objective of contributing to the strategic goals of corporations, with a major focus on variation reduction (Magnusson et.al., 2003). Together with a structured improvement strategy called *DMAIC* (explained below), Six Sigma is based on four important principles; top management commitment, stakeholder involvement, training scheme, and measurement system, shown in figure 2.11 (Bergman & Klefsjö, 2008). The comprehensive knowledge base that Six Sigma embodies and to keep this knowledge within organizations there exist fairly standardized training courses, and a system of educational levels where individuals can be certified as white belts, green belts, black belts, and master black belts. Senior management commitment and stakeholder involvements are all-encompassing in the framework. Without these, the improvement projects, training scheme and the measurement scheme are useless (Magnusson et. al., 2003).

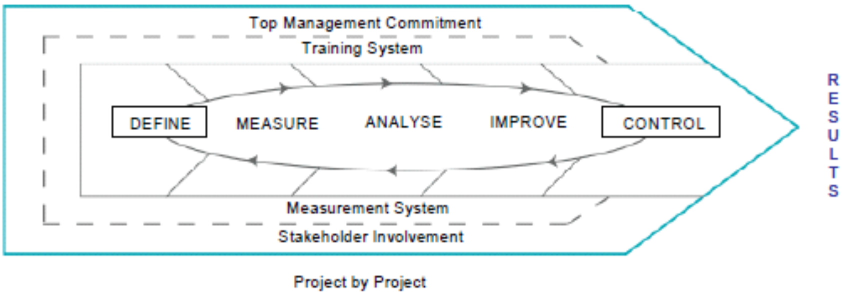

Figure 2.11. The framework of Six Sigma, from Magnusson et. al. (2003).

For process improvements, the improvement projects always follow a formalized improvement methodology, termed DMAIC (Define, Measure, Analyze, Improve, Control), shown in figure 2.12, supported by a selection of improvement tools and mental models (Magnusson et. al., 2003). It consists of five phases as follows (with some examples of common actions in each phase):

Define phase: to define project components, the customers, the scope, and factors that are critical to quality for the project.

Measure phase: to measure the process performance, indices, collect data.

Analyze phase: to identify sources of variation, the gap between current performance and the goal performance, to identify root causes of variation and defects.

Improve phase: to propose and implement plans for improvement according to the project specifications and requirements.

Control phase: to control the process to stay in line after the improvement. It is very critical to prevent reverting to the old method. Standardization is critical.

Following the DMAIC strategy usually leads to the most efficient use of resources. The strategy provides the framework for progress as it forces good decision making. It will lead to fewer dead ends, detours, and fruitless work, by facilitating a steady progression of activities toward a solution (Seagate, 2007).

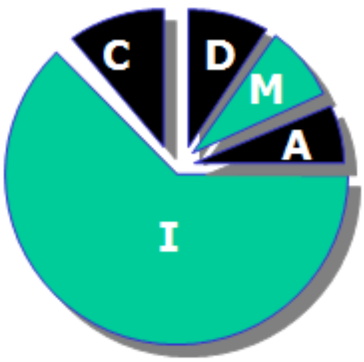

Figure 2.12. A visualization of the DMAIC cycle. (From Professor Bo Bergman's lecture in the Six Sigma Black belt course introductionary lecture slides 2009).

2.2.2 The role of standardization in continual improvements

The DMAIC method is a cyclic process of the same type as the improvement cycle *Plan-Do-Study-Act (PDSA*), a method for solving problems in the continuous work presented by Deming (Bergman, Klefsjö, 2008). The *plan* step includes identifying a project, appointing an improvement team, analyzing the problem, looking for causes of the problem and evaluating the result. The *do* step means taking the steps. In the *study* phase, results are measured and evaluated. The last step, *act*, is of special significance. If the steps taken were successful the new and better quality level should be made permanent, but if the steps were not successful, the cycle should be repeated once more. The objective of the act step is thus to make the improved quality level permanent (Bergman, Klefsjö, 2008). Another word for this is *standardization.* Without standardization, continual improvements are impossible, as shown in figure 2.13.

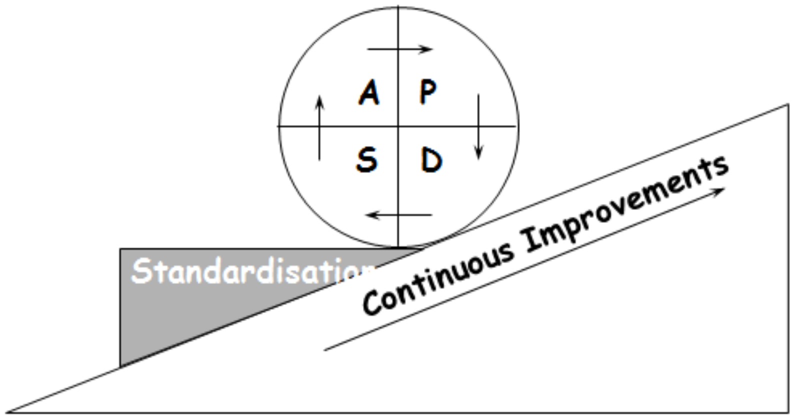

Figure 2.13. The picture shows how standardization is the key to continuous improvements. (From Professor Bo Bergman's lecture in the Six Sigma Black belt course introductionary lecture slides 2009).

2.2.3 Tools used

2.2.3.1 Affinity diagram

The affinity diagram is a method for organizing large amounts of verbal data, such as ideas, customer desires or opinions in groups, according to some form of natural affinity. The affinity diagram in combination with the interrelationship diagraph illustrates associations rather than logical connections. It is sometimes referred to as the KJ-method or KJ Shiba (Bergman et. al., 2008)

2.2.3.2 SIPOC

SIPOC is used to document a process at a high level and visually show the process, from suppliers' inputs to the products or services received by customers. It also helps in identifying data collection needs. The name comes from the column headings on a SIPOC chart: Suppliers, Input, Process Output and Customers (GOAL/QPC, 2002). The SIPOC is an excellent way to start an improvement project as it creates a good baseline of the current situation. Using SIPOC starts with the right side and the five basic questions listed below and is a cornerstone when turning the organisational approach and common view on the process from push to pull:

1. What comes out of the process?
2. Who should have it?
3. What do they require?
4. How are we going to measure that?
5. And are the measurement system capable (adding less noise than the process)?

It also identifies if the root cause to the problem with variations in the output origin up stream, beyond control of the process owner.

2.2.3.3 Project charter

A project charter defines the customer needs, project scope, project goals, project success criteria, team members and project deadlines (GOAL/QPC, 2002).

2.2.3.4 SAS JMP 8

JMP 8 is statistical software that lets the user to interactively explore data and visualize it (JMP website, 2010). The software was used for analysis and visualization of historical data at the companies during the project.

3 Implementation method

The companies were kept actively involved in the project as it progressed, since this would increase the understanding of the methodology and encourage the companies to start using process behaviour charts on their own as early as possible. A typical way of involving the companies was to use the companies' own data in charts and then discuss them. A typical example of a chart that resulted in a constructive discussion is shown in figure 3.1.

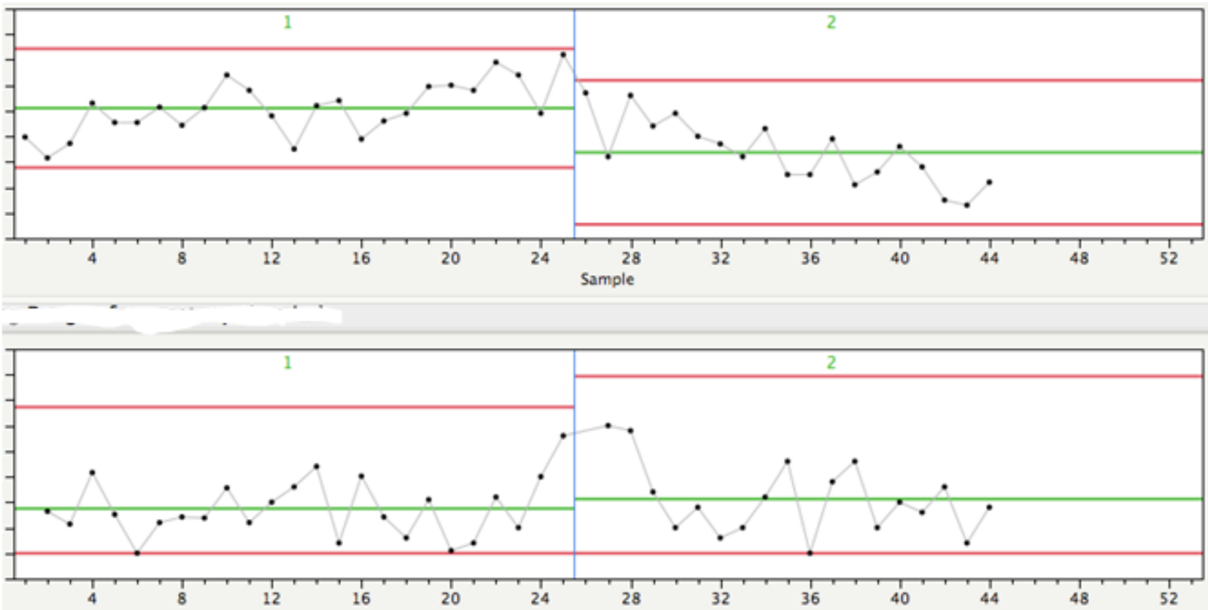

Figure 3.1 depicts an interesting graph showing a process in two stages. The second stage shows process behaviour after a process improvement. The mean has decreased however the variation has increased.

3.1 Motivation

A part of the project purpose is to change the way that the companies analyze data, and for them to continue to develop their skills in using the process behaviour chart supplied to them. The first way to motivate the companies was to explain what was wrong with how they use data today. The manual compiled and provided to the companies is a guide for continued learning. It is the start for continual improvements. As described in the background, the reason why the companies wanted to be more effective and efficient working with their processes is to free time and resources for customer focus, theme 2. This relation between theme 1 and theme 2 was used as an overall motivation throughout the project.

An initiative dedicated to increase the customer focus at the companies was encountered during the project. The initiative consisted of a validation process for operators and aimed to develop the knowledge and skills of operators working in the metal cutting industry. By developing the knowledge and skills of operators the companies are better prepared to respond to future customer demands. As this validation process required both time and recourses it made a very good example of the relation between theme 1 and theme 2. By analyzing data and working more effectively and efficiently with their processes the companies will be able to concentrate more time and resources on initiatives such as a validation process for operators. The validation project was therefore used as indirect motivation for implementing process behaviour charts and developing theme 1.

3.2 Baseline studies

At the start of the project, a baseline study was performed to create a clear picture for all stakeholders where opportunity for improvement existed. This consisted of the two former theses; one problem visualization, and a general SIPOC.

3.3 DMAIC cycles as the basis for progress

The project was structured using the DMAIC cycle, which served as the basis for the project progress and a vehicle for creating learning in the companies. Due to the limited time, only three cycles were possible to do, but there is no limit to the additional learning cycles that can be done individually by the companies. However, the three cycles covered in this project, laid a sturdy fundament on which the companies can continue to work with continuous improvements.

The first cycle is called *"How processes behave"* and is aimed to teach the companies about the Voice of the Process (VoP). The second cycle*," Difference between the VoP and the VoC"* taught the companies how to align the specifications, or Voice of the Customer (VoC), with the Voice of the Process (VoP), and also to show the current gaps in the organizations. The third cycle, is called *"How to work with process behaviour charts"*, and the main difference in this cycle is that the company representatives played an active role. With this three-cycle approach, the companies could acquire the fundamental theory as well as practical experience in using process behaviour charts. Below is a more detailed description of each learning cycle:

The first DMAIC cycle can be called *"How processes behave*", and the key steps consisted of:

- Define: One or two key performance measures were selected at each company to be monitored after verification.
- Measure: Historical data of the selected measures was collected. The data was filtered and cleaned so it easily could be analyzed.
- Analyze: The historical data was analyzed in XmR charts, and alarms were explained and removed to get an idea of the process potential. Besides this, general statistical analysis was done to check the distribution and correlation of the data.
- Improve: The companies were shown how the data could be represented, especially with XmR charts as well how they could interact with the charts. The drawbacks of the current methods were explained, and the benefits with the new method were displayed to the companies; especially separating noise from signals and being able to predict future outcomes.
- Control: Based on interviews. Where problems and opportunities had been identified.

The second cycle can be called *"Difference between the VoP and the VoC* " and consisted of:

- Define: The companies where thought the difference between VoC and VoP, and brought to the understanding that you cannot control a process by setting goals.
- Measure: Process data was collected. Goal and targets where identified.
- Analyze: The historical process data was plotted in XmR charts, alarms were explained and removed to visualize the process behaviour. The current process mean was compared to the targets to visualize the current difference in VoC and VoP.

- Improve: The traditional view of process improvements was put in contrast to the continual improvement view. For predictable processes, the three ways of aligning VoC and VoP were explained.
- Control: Interviews were done to see if the companies had understood the concepts, checking if the knowledge had been standardized.

The third DMAIC cycle can be called "*How to work with process behaviour charts*" and consisted of:

- Define: Explain the responsibilities of the manager. This part includes when and when not taking action, and the consequences.
- Measure: The company representatives themselves compiled graphs.
- Analyze: Graphs were analyzed together with the company representatives.
- Improve: The companies' graphs together with presentation material served as the basis for explaining how to work effectively with process behaviour charts.
- Control: Interviews to verify understanding.

All of the cycles have partially been reviewed at least two times.

4 Empirical findings

The empirical findings are divided into *current state, validation project,* and *field study.*

4.1 Current state

It was important to determine the current state at each company to get a picture of how the companies worked with, acted upon, and analyzed data at the start of the project. The next step would be to specify why and how this was done, to finally attempt to improve the methods.

4.1.1 General

To gain an overall picture of the process from raw data to final decision-making, the SIPOC tool was used. This was done at each company, and even though the data collected differed for each company, the method for collecting and analyzing the data was quite similar; hence a general SIPOC was possible to make, and is shown below. Besides the main process (2), two additional sub-processes within the SIPOC were identified, denoted (1) and (3). See figure 4.1.

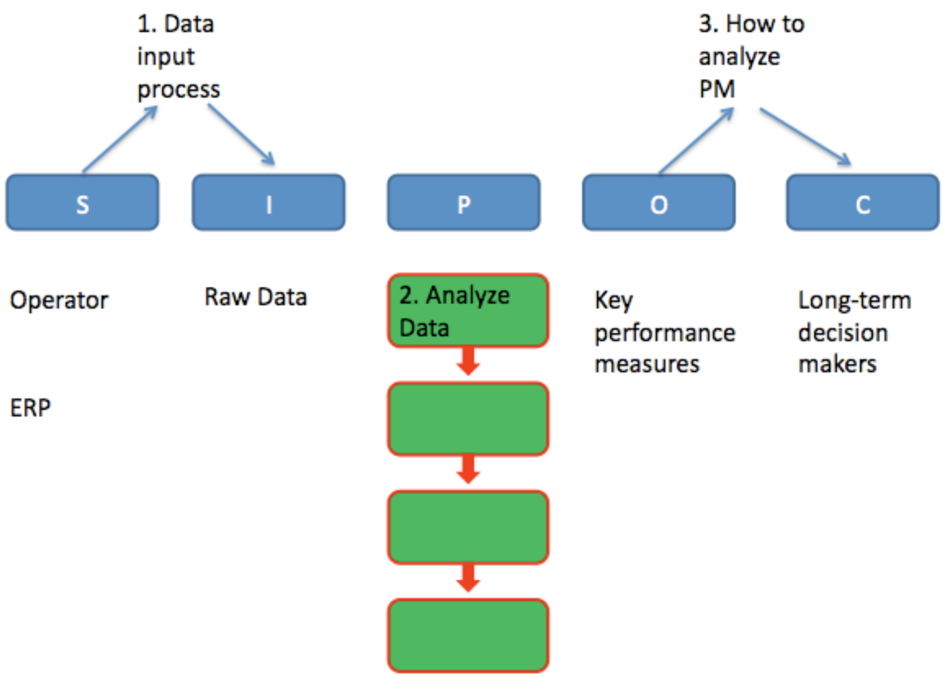

Figure 4.1. The figure shows a general SIPOC for the decision making process.

1) **Data input process.** Often, an operator manually enters the data. But sometimes this is done automatically by the IT system. This data is used for the generation of key process measures. Some examples of this data may be individual counts and values, set-up time, on time/late etc.

2) **Main process.** This is where raw data is converted to key performance measures, which are the basis for making decisions. It may consist of one or more steps and differs depending on the company. The key performance measures are often aggregated or in

relation to something, for example set up time for a group of machines and scrap in percent of turnover.

3) **Key process measure interpretation process**. This is where the decision makers interpreted the key process measures. To be able to make the right decisions, the key process measures need to be fully understood and they should be compared to historical figures, as well as viewed in the right context.

The analysis of the SIPOC showed that process (1) and (2) was not as critical as process (3), meaning that that the companies had sufficient capability to collect raw data and compiling it into relevant process measures. The greatest potential for improvement could be found in process (3).

4.1.2 Focused (on sub-process 3)

The current state of process (3) was determined by conducting interviews with representatives at each company. Questions were asked regarding how data is used for decision making, and how it was analyzed at the moment. Emphasis was put on determining what data, or process measures, were primarily analyzed and why. Most companies showed a similar behaviour when it came to process steering and decision-making. This can be described as:

- 2 point comparison – the belief that "2 numbers that are not the same are different" leading to a binary view; either good or bad. When better than last month or same month last year, its good, otherwise bad – type of conclusions. Key performance measures were classified as either good or bad because they were compared to a previous outcome or planned target. Actions taken as a response to the good or bad outcome did in some cases worsen the situation. For example, one company used set-up times in production as a key performance measure and compared the times from month to month. This situation can lead to conflicting messages when the manager responds to the monthly set-up times if no real change has occurred. The change in times can be due to natural variation not a change in the process of setting up the machines.
- Description by explanation but not analysis based on knowledge, making it impossible to predict future outcomes. For example when the outcome of key performance measures are described in a monthly report, and explained by showing the percental difference between the current and a previous outcome or planned target. Describing key performance measures this way will prohibit any attempt to predict future outcomes because the outcomes has not been analysed.
- No clear understanding for the difference between signals and noise. No way to filter out noise existed. In 2.1.2.4 this is explained in theory.
- Acquainted with SPC in production but not as tool for guiding decision making. Many companies use SPC regularly in production, but do not see the parallel with PM data, often due to the fact that PM data is not collected as often as machining data, but is in principle the same thing.
- Process steering by specification (VoC), not by VoP. Customer specifications are not the same thing as process behaviour that is described in 2.1.1.2, and the problem with this confusion is explored in 2.1.1.3.

The next step was to identify one or two key performance measures at each company so that they could start to actively track processes and, most importantly, to get acquainted to the process behaviour chart. The reason for this was not to improve specific processes, but rather to use the method as a learning tool; "learning by doing", meaning that the best way to learn the method is to actually use it. However, before they could start, the process measures needed to be verified by assessing the importance and ability to steer decision-making in a long-term perspective. This was basically done by asking the managers specifically what impact they had on the decision making process, and will be discussed below.

4.1.3 Verifying performance measures

This section describes how the selected performance measures were verified at each of the participating companies. It was essential to choose measures that play a central role in the management team meetings and that was key for managing the operation.

4.1.3.1 Gnosjö Automatsvarvning AB

The measures used at Gnosjö Automatsvarvning AB were on-time shipments and internal rejection. Internal rejections are directly associated with profit and are therefore very important for Gnosjö Automatsvarvning AB to understand and control. On-time shipments are connected to customer satisfaction, which is something Gnosjö Automatsvarvning AB historically has worked very hard to increase. Both measures are well documented and measurement data has been logged in the database for many years. On-time shipments and internal rejections were used at Gnosjö Automatsvarvning AB because of their importance for the company and the well working measurement system that produced the data.

4.1.3.2 Bufab Lann AB

At Bufab Lann AB, on-time shipments and internal rejections were used as performance measures for the same reasons as at Gnosjö Automatsvarvning AB. However, Bufab Lann AB has since more than 10 years back been working hard to reduce their set-up times in production. This was due to that historically Bufab Lann AB had always been operating at full capacity and had gone through periods of expanding their business. In these periods of expanding, set-up time reduction worked as an important tool to increase productivity. For these reasons set-up times was added to the list of measures to be plotted in a process behaviour chart.

4.1.3.3 Finnveden Powertrain AB

Finnveden Powertrain AB had a policy in place that ranked the importance of key performance measures. Ranked as number one were health and safety measures, with potential accident incidents being most suitable for a process behaviour chart. Potential accident incidents were measured once a week. However, only the incidents reported to the health and safety manager was included in the data, possibly giving an unrealistic picture of the situation. The system of data collection was not therefore not fully developed. To correct this was outside the scope of the project. Two other process measures, included in Finnveden Powertrain AB's policy, were selected as measures in the process behaviour chart; customer satisfaction (on-time shipments) and quality (internal rejections).

4.1.3.4 Värnamo Industri AB

On-time shipments and internal rejections were used as performance measures at VIAB. Internal rejections were chosen due to the fact that the company representative involved in the project was the production manager. On-time shipments were chosen because VIAB wanted to use the charts to evaluate different performance measures that could be used to improve the process. Both these approaches were in line with the project purpose and supplemented each other to give a good foundation for the learning process.

4.2 Validation Project

During this thesis project, another project was undergoing at Skärtecknikcentrum. This project, called CNC Teknik 2010, was a validation and certification project for operators and process technicians. The CNC Teknik 2010 project was undertaken to assure the competence level for employees to meet future customer demands. It consists of four components:

- Validation of individual competence levels
- Evaluation against predetermined demands for certification
- Individual development plans
- Certification for different competence levels

The whole system is based on competence demands developed for operators and process technicians within the metal-cutting industry. It consists of both theoretical and practical knowledge. The most interesting aspect of this project is that organisations can identify what their employees do not know, and then focus their teaching efforts on that. This project is a good example of a time and resource consuming effort to increase focus on customer demands, and can therefore be strongly related to theme 2 in our thesis. By using process behaviour charts on performance measures time and resources can be freed, which in turn can be used on projects like CNC Teknik 2010 (Petersson, 2010).

4.3 Field study

A field study was conducted at SKF Actuators in Gothenburg. SKF Actuators AB manufactures electro-mechanical linear and rotary actuators, and associated drive and control electronics. Their products are used to provide motorized positioning in a range of application areas in for example industry, medical technology, care and rehab, furniture & ergonomics. SKF Actuators AB is a wholly owned subsidiary of AB SKF (SKF website).

The reason for the study was to benchmark the results achieved and to use SKF Actuators' results as reference point for the companies involved in this project. The material from the study was also used to guide the companies and to provide a framework for working with process behaviour charts.

At SKF Actuators, process behaviour charts are used on performance measures. It started as a project led by a Six Sigma Black Belt and had been running for about one year prior to the project start of this thesis. Initially in the project, managers from different departments underwent a three-day course with the purpose to clarify and to create a common view and language in the management team when and why to start Six Sigma projects related to variations in strategic business key performance measures. The course involved learning quality tools, with one among them being the process behaviour chart. Process behaviour charts were mainly viewed as a tool for communication, both internal and external. Communication was also the area where SKF Actuators found process behaviour chart to be most beneficial. Because the chart shows the voice of the process in a way that is clear and easy, the communication and therefore the discussion was lifted to a higher more concise levels. Members within the management group saw how the process behaved in the same way, whereas before everyone had their own opinion concerning the state of the process. This shared process view led to a shift of focus during management meetings, from what has happened to what should be done. As the discussion was lifted to a higher level and based on facts instead of opinions, hopes and wishes were replaced by analysis and predictions. It was a Six Sigma Black Belt leading this project, whose role in implementing process behaviour charts was initially to construct the charts upon request from managers. Then the representative brought the charts to the meetings and described what they showed.

The most important improvement as a result of introducing process behaviour charts at SKF Actuators has to date been that the management group now clearly can see where they are with their processes and where they want to be. Management meetings takes a lot less time and the decisions are better because of this insight. However, the SKF project also shows that this type of implementation takes time and that it is vital that there is an educated leader who keeps momentum in the project. It requires patience both from the members of the group and from the leader but small steps such, as improving communication, do lead to big improvements (Pauli, J., 2010).

One important factor at SKF Actuators was to ensure that the management group had a common understanding of the theory and the tools, especially the process behaviour chart. They were therefore trained as a group to create a common language with focus on key performance measures, in order to facilitate group discussions. A poorly trained management will not recognize problems without visible symptoms and missed opportunities of learning and improvement will be an affect of that. All members of the management group need to know how to listen to the Voice of the Process, and be able to communicate this to others. Smart individuals don't automatically result in a smart group. This is why the most important aspect of training management is to train them as a group so that a common understanding evolves. Without common understanding people tend to misinterpret each other even if they are talking about the same thing. This training prevents the management team to fall back to the old behaviour and to have an alibi for not recognizing changes in variation and not being aware of the key performance measures used for controlling the processes (Hammersberg, P., 2010).

5 Result

Part of the aim of this thesis was to study how the companies changed when implementing control charts, and based upon that study develop a method for future work. This focus led to the realization that the results would partially be intangible and observed throughout the whole project, and not just at the end of the project. It was also important to understand why the companies have not used control charts on performance measures before, since the method is known and has been available for decades.

The results were collected in several different ways. Organizing and bringing together all these fragmented parts of the results was an important part of this thesis. To organize the qualitative data an affinity diagram was used. The final summarized affinity diagram is shown in figure 5.1.

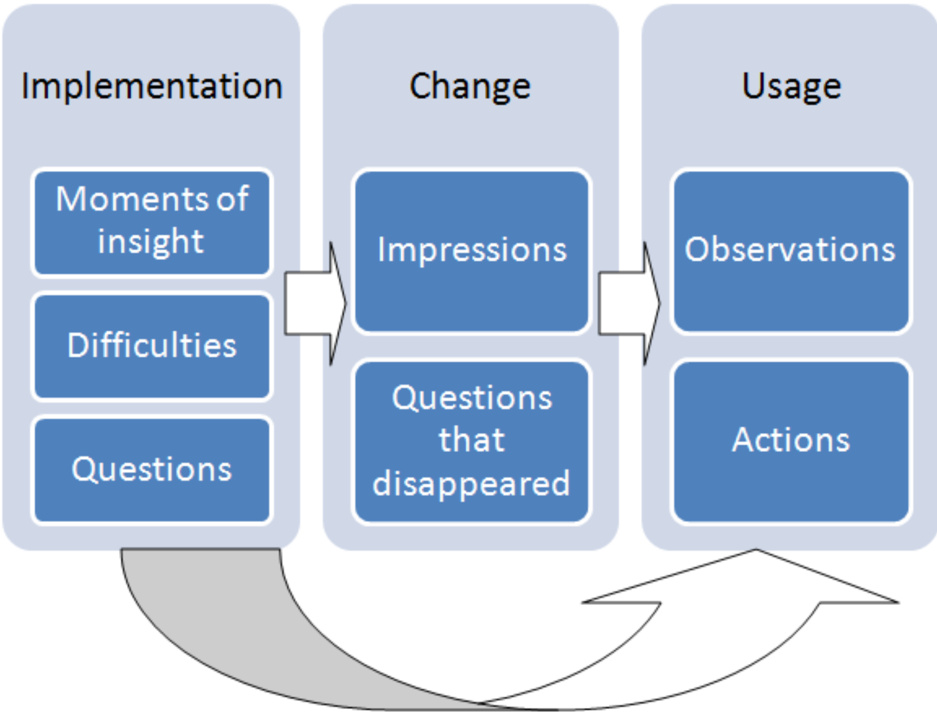

Figure 5.1. The result grouped by affinity. Details are explored in the text.

As Figure 5.1 shows, the data was sorted into groups and three main headings were created. The first heading, *implementation*, involves all data concerning the implementation process. The implementation, in turn, then affected how the companies' behaviour changed (under the *change* heading). The third heading was *usage* and involves data about how the companies actually use the control charts, and this heading is heavily affected by both implementation and behavioural change.

5.1 Implementation

This section describes the implementation part of the results.

5.1.1. Developing a model for implementation

The implementation model is based on what is referred to as *moments of insight*. The *moments of insights* were identified by listening to the response from the companies and defined by the situations when significant understanding was reached. The *moments of insight* can therefore be seen as milestones in the companies' learning process, and were the basis for the implementation process, and also the model.

Even though a lot of questions were received during the project, they were almost always related to one of three categories; the XmR chart, alarms, and communication. The questions were good indicators of awareness of potential, understanding, and desire to learn more. This is also how they were used when developing the model.

Difficulties were often related to the questions; however some difficulties could be signs of lack of understanding and therefore did not result in any questions. In these situations it became evident that key knowledge needed to be standardized before moving on to the next step. Without the standardization of knowledge, the succeeding steps will not have a foundation. This will result in that the evolutionary step-model loses its power. Difficulties were observed during interviews and discussions. When difficulties started to become evident, it was better to go back and review previous information, indicating an interesting point in the companies learning process. This way, difficulties became important indicators while developing the model.

The *moments of insight* encountered questions. Difficulties related to these questions were collected throughout the project and after analysis it formed the basis for a series of components, which are called *moments of standardization*. The *moments of standardization* are, in turn, the basis for the *implementation model*. Figure 5.2 depicts the process of developing the *implementation model*.

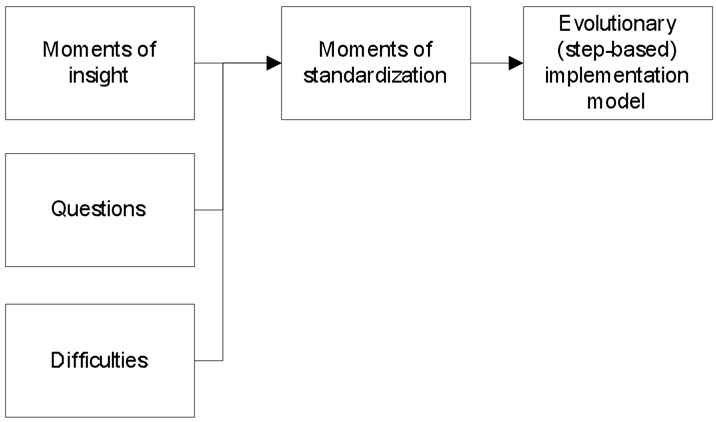

Figure 5.2. The process of developing the implementation model. First, the moments of insight, questions and difficulties generated the moments of standardization, which secondly, created the foundation of the evolutionary (step-based) implementation model.

A real example from the project of how a moment of standardization was formed is shown in table 5.2.

Table 5.2.The moments of insight, questions, and observed difficulty leading up to the forming of the moment of standardization called "Understanding how to control processes".

Moment of standardization: **Understanding how to control processes**	
Moments of insights:	• Understanding that just by setting a goal for the next year will not do any good unless listening to the VoP. • The insight of using specifications to steer the process will

	lead to a binary view. • Just because two numbers are different does not mean that anything has changed.
Questions:	• How can we involve the goal in the chart? • How can we evaluate when we have fulfilled the goal?
Difficulty:	The question “how do we steer the process?” reoccurred several times. There was an observed difficulty of how to align the VoP and the VoP.

The reason why the critical components in the model are called moments of standardization is to emphasize the importance of standardizing each step before moving on to the next, which requires patience and motivation. After analysis, a suitable sequence for the moments of standardization was developed for the model. The moments of standardization are described below, in this sequence.

1. **Problems with the traditional way of looking at key process measures.** The realization of the current problems with reports, scorecards, creating conflicting messages and manmade chaos. By using general examples to illustrate the error of comparing numbers outside their context, the companies could appreciate that analysis was needed to base decisions on facts.

2. **Understanding the nature of variation and process behaviour.** Understanding the different types of variation; signal and noise, and how to separate them from each other. Understanding the Voice of the process and the insight that management requires predictability, which can only be achieved by having an in-control process. This step is important for everyone in the organization to understand, not only the person responsible for compiling the charts. This is where a critical mass can be created. The step is one of the most important ones as it is the foundation for the following steps.

3. **Recognition that tampering may increase variation.** An example case depicting typical result based behaviour was shown, followed by an interactive example displaying that different adjustment methods actually increased the standard deviation from the target. The example case described a newly hired quality manager that actually worsened the process outcomes by responding to natural variation, or so called noise, in the process. The manager noticed a positive change in the internal rejection rate compared to the previous month and treated his employees with cake. The following three months the internal rejection rate went down and the manager turned to a “no more Mr Nice guy” attitude. By analysing the data using process behaviour chart it became clear that no real change had occurred during the period since the manager was hired, however is actions had created more variation in the process. The conclusion that variation actually increased by unnecessary tampering seemed to make an impression. Using Deming's Funnel Experiment Simulator showed the effects of tampering. The principles are illustrated by simulating adjustments in a random cause process of dropping beads through a funnel. Various methods of process adjustments are simulated through four rules. The rules adjust the process in different ways and let you observe the outcome (Symphonytech website, 2010).

4. **Understanding how to control processes.** Processes cannot be managed by only setting goals. To improve the process, something must be done and this demands understanding of the difference between the Voice of the customer and the Voice of the process. Assignable causes may only need a quick fix, whereas to improve a predictable process always demands a more thorough improvement, not isolating any specific points. It is also important to understand what key performance measures should be analysed and where in the process they should be measured. Processes that are managed by setting goals are often only measured by the outcome of the process. By then it is very hard to know how to improve the process. Instead it is better to find measures earlier in the process that can be used to actually improve the process.

5. **Relating the companies' situation to a reference.** The companies were shown how process behaviour charts were used at SKF Actuators, what role the responsible person has, and the received benefits. This seemed to increase the credibility of the method, and the response was generally positive.

6. **Logging and discussing the companies own data in charts.** Using process behaviour charts to initiate discussion. Instead of discussing something general or in theory the discussion was about areas or processes that the contact person has knowledge about. Having discussed and explained the process behaviour chart with the companies after plotting some values in the charts themselves seemed to increase understanding. Using the companies' own numbers to produce insight of the process, historically and in real time.

5.1.2 The Evolutionary (step-based) model

The proposed model is organized in a step-based sequence and represents an evolutionary approach to implementing process behaviour charts in organizations (figure 5.3). The model consists of six components that have been ordered in a logical sequence. Each step lays the foundation for the next. The purpose for the model is twofold; the first is to guide future implementation of process behaviour charts further into the organizations that were involved in the project. The second is to enable Skärteknikcentrum to introduce process behaviour charts at other member-organizations in a structured manner.

The model has intentionally been kept simple and as intuitive as possible. The components in the model are strongly anchored in the empirical findings, so the constant dialogue with the companies of outmost importance when developing the model. All of the contents in the model have been explained to the companies during the project, at one time or another.

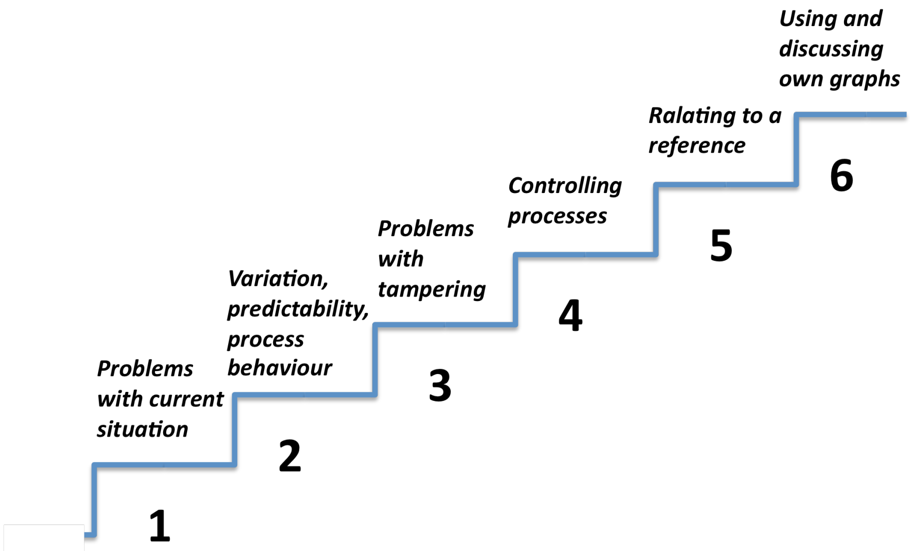

Figure 5.3. The Evolutionary model consists of moments of standardization organized in a logical sequence.

5.1.3 Time needed to understand theory

To create proper understanding of each step in the model, a certain amount of time is needed for presentation and review before it can be standardized, and may vary depending on the type of theory. Some of the moments of insight in the project demanded relatively long time to attain for different reasons. The factors that determined how long time it took before a moment of insight could be reached were;

- theory-intensiveness of the step (*complexity*)
- the number of, and the time between, meetings needed to present all the relevant components of the step (*scale*)
- dependency on the companies pace to work with the step individually (*interactivity*)

The theory that took long time and effort to standardize was often essential as it included fundamental concepts and therefore demanded several meetings to fully explain. This theory was related to; understanding variation and the importance of analysis, understanding the faults with the traditional method of working with process measures, and how continual improvement can result from usage of process behaviour charts. These parts of the theory cannot be stressed enough. Although it may demand time and effort to create full understanding, these parts are essential for successfully implementing process behaviour charts of key figures. Another important aspect is that the parts mentioned above should be common knowledge in the company, which can be achieved by training employees in a group.

5.2 Change

In this thesis, change refers to how the companies have developed new attitudes towards their processes as a consequence of implementing process behaviour charts. Change in attitudes and behaviour is not easily measured and therefore impossible to quantify. Instead the amount of change was determined by impressions during discussions and observations.

The most obvious and biggest change occurred in their view of which performance measures to analyze. At the start of the project all of the companies listed the performance measures they used on a regular basis. After plotting these measures, one of the most interesting developments during this project occurred. The companies expressed an insight into the importance of choosing the right performance measure, finding a measure that really represents the process. The discussion focused on how the process can be improved instead of just using the measures for information on how things are going. The discussion was usually process oriented and often resulted in a "cause and effect" related reasoning. The process behaviour could be put in context to parallel processes, changes in demand, seasonal variation etcetera. Not uncommonly, one of the results was that other key figures, inside the process, could be even more interesting to monitor, to quickly catch abnormal behaviour. One example of this is on-time shipments. On-time shipments can seem very accurate with little variation if no consideration is taken of the actions required to reach a high level of on-time shipments. One of the companies suggested that it would be more interesting to plot orders started on-time instead of orders shipped on-time. With the understanding of variation and process behaviour chart the companies viewed their processes and how to measure them in a different way. Without the process behaviour charts this insight is hard to reach for the individual and almost impossible for the team to get a common view upon, since it is mighty abstract without the charts.

Another noticeable change of attitudes was that the companies realized that process improvement requires a long-term perspective. They understood that tampering with the process could by itself damage the process. It was very noticeable in discussions that they understood their own part, as managers, in the processes, that their actions affected the process outcomes. Sending conflicting messages by acting on noise due to lack of understanding of variation is one of the ways that processes can be tampered with.

However, a more tangible measure of change was to analyze questions asked, how they changed and which questions disappeared during the project. It was not questions concerning understanding that were analyzed, but rather questions regarding data analysis and process improvement. The questions were transformed from "What has happened?" to "What to do?", meaning that the questions focused on the future instead of the past. The understanding of variation and how to interpret data resulted in a clear picture of the voice of the process. This understanding of the voice of the process led to a change in attitudes and behaviour, in both actions and discussions. An example of a question that disappeared is; "Is this outcome good?". Questions like this arose from lack of knowledge about variation and a tool to filter that variation. So the final impression was that the implementation of processes behaviour charts emphasized a focus on process improvement. If this change can be transferred into management meetings, less time will be spent on discussing the past and more time will be spent on discussing possible improvements or other important business activities. One of the companies did de facto cut two hours from management team weekly meetings by using the chart skipping the discussion about what actually had happened.

A reason why control charts have not been used on performance measures before was, according to the companies, due to the culture of how business is done. There has not existed a demand for these types of tools before from their customers due to the fact that the potential of control charts have not been recognized. As the background of this project explains the real demand was to free time and resources to be focused on customer demands, but the relation between internal process and the external environment was not clear. The companies did not recognize control charts as the solution to their problem.

These results are very similar to the results achieved by the project at SKF Actuators. At SKF, they also found that opinions on whether the process was operating good or bad disappeared and the discussion focused on what to do instead of what had happened.

5.3 Usage

By the end of the project the company representatives were still in the learning phase, however they had completed all steps in what is now organized as the step-based evolutionary model. The next step is to train the rest of the management as a group. To complete the learning phase and to spread the knowledge, the best way to continue was by actually using the tool; learning by doing.

All of the companies were actively using the process behaviour chart in real time on, at least, one performance measure each at the end of the project. For these performance measures a new way of presenting process behaviour was implemented. An example of before and after can be seen below in figure 5.4 and figure 5.5.

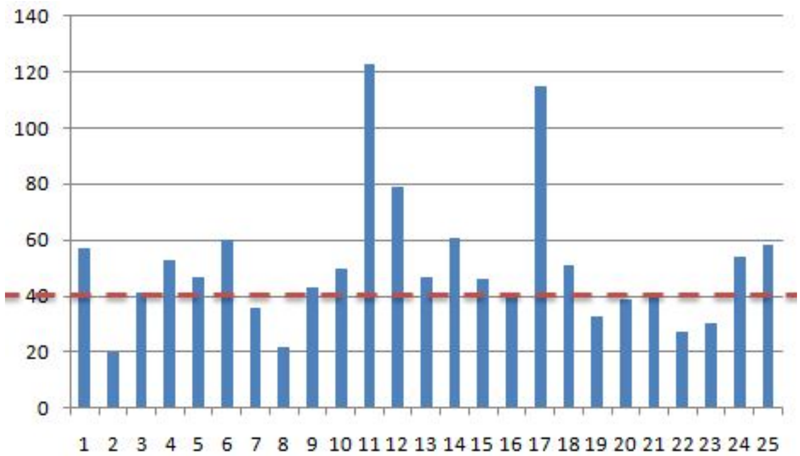

Figure 5.4. A common example of how process behaviour was shown before implementation of process behaviour charts. The target goal was often showed in the same chart.

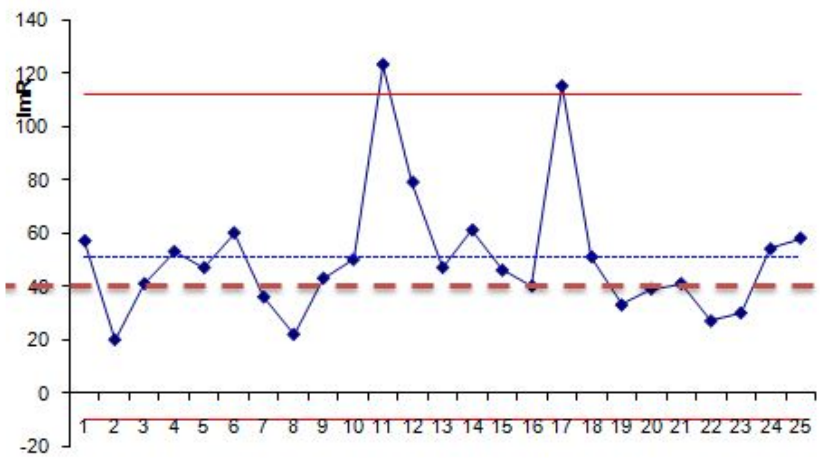

Figure 5.5. How process behaviour was displayed after the implementation of process behaviour charts. There is a discrepancy between the target goal and the process mean.

The work with the charts only involved one or two people at each company but the process of spreading the usage had started. The individuals involved were the persons that had been educated during the project. This model of having one or two people responsible for the usage of control charts was adapted from the study conducted at SKF Actuators. At SKF Actuators it was shown that one person being responsible for managing and compiling the charts was sufficient for maintaining the initiative, but it was important that the understanding of how to interpret the process behaviour chart was a common knowledge in order to lift decision discussions. The benefit with having one person responsible is that the other employees involved do not have to learn all the technicalities but rather focus on understanding the charts and how to improve the processes.

The companies had different approaches to exploiting the potential of the processes behaviour chart. It ranged from using it as a communication tool to using it to analyse the outcome from improvement work. As a communication tool, processes behaviour charts were mainly used in meetings instead of traditional presentation methods, providing a clearer and easier way to understand the picture of the current situation. One company started to use the chart to identify results of improvement work undertaken in the manufacturing department.

As mentioned above in the change section, one of the significant benefits of this project was the discussion that arose regarding the process performance measures; how the companies changed their view of how they measure and steer their processes. This discussion led to critical assessment of the underlying mechanisms and parameters that govern a given process measure; a discussion opening up for increased understanding and continual improvement. This trend was visible in all of the companies at the end of the project.

6 Discussion

The main point to discuss is the reason for why modern companies in the metal cutting industry have not already adapted process behaviour charts on key performance measures for strategic decision-making. All of the companies in this study have worked with statistical process control for a relatively long time and are definitely accustomed to it. This, together with the fact that the specific theory for the project is easily available and has been so for many years, surprises us. During the project we identified some aspects that, if related to each other, may potentially serve as an explanation. It all starts with a problem: a lack of available time and resources to be focused on increases and changes in customer demands. By not relating the problem to what is actually consuming time and resources in the organization, the answer becomes to work harder and set higher goals. This increases the level of stress and can sometimes be contra-productive. Even though the solution is readily available at the companies, SPC and control charts are used in manufacturing processes; it is not used at its full potential. We believe SPC is used in a valid however weak way because of the way it was implemented; it was pushed into the organizations due to customer demands. A lack of understanding of how to fully utilize the method prohibited the organizations spread the method in a wider context, meaning to use control charts on key performance measures. It is this lack of understanding about the potential of SPC and control charts that makes it impossible to relate the problem the real cause and to see control charts as the solution. A reason for this is the lack of a common language and understanding, within the management group, for all the components in the theory. This is why training the whole group together is so important. A group is not more effective than the number of words the members have in common, no matter how smart or well educated the individuals are. Without a common language, it is impossible to discuss process behaviour charts, variation, and performance measures effectively in the management group. Every member who is not familiar with the language inevitably halts the discussion and will try to drag it back into the old patterns of thinking.

From the results, it was shown that the a part of the solution is to point out what is wrong with the traditional method for making decisions based upon key performance measures, which faces the next problem; organizational culture. All of the companies involved in this project are successful in what they are doing, which creates a strong belief in, and dedication to the methods used. This creates a situation where even though one employee sees the need for change, faces a hard time convincing others. A critical mass for changing work methods has not been allowed or seen necessary to be formed. To summarize, even if the solution is available the incentives has not been strong enough to implement it.

To show how the results are aligned with quality theory, a comparison to the values in the Cornerstone model were discussed. First of all, theme 2 is the core of the Cornerstone model, and the values represent theme 1. By using process behaviour charts and adapting a new way of thinking, focus will be on processes, decisions will be based on facts, continual improvement will be possible, and everybody will be committed. On top of this, all this requires committed leadership. Focus on processes is directly connected to theme 1 as process behaviour chart describes the VoP. Charts show the situation as it is, meaning that hopes and wishes disappear at meetings and are replaced by facts on which decisions can be made. Continual improvement has been the ultimate goal throughout the project and process behaviour charts are the vehicles for reaching this goal. It cannot be stressed enough how important it is to have everyone's commitment when using process behaviour charts, especially in regard to understanding variation. As mentioned, the best solution is to educate employees as a group in order to make a permanent change. We have discussed the importance of committed leadership by suggesting that one person in the management group is responsible for compiling the charts, and that the rest of the management group understands the theory and how to interpret the charts. Additionally, Skärteknikcentrum plays an important role in this, in a future perspective, to assure this foundation is available.

We believe that this project succeeded in three main ways; implementing the use of process behaviour charts on key performance measures, changing the way of thinking and having the companies using the charts in a long-term perspective. The question is, why? We were aware of the strong and entrepreneurial organisational culture present at the companies and region. The companies are very good at what they are doing and this shaped our approach. By allocating a lot of time at the beginning of the project to define how the companies work today, we were able to fit the solution to their situation. Focus was aimed early on showing what was needed to be changed and why it had to change. By explaining what was wrong and in need to be changed, we created a pull for improvement. The fact that we related the method to a wider context as being a part of the solution for the problem defined in theme 2, emphasized the need for change. The pull for improvement created a very good working environment for the project. We also strongly emphasized on having full understanding of every step in the learning process before moving on to the next, especially understanding variation and the importance of analysis before handing over the process behaviour chart to the companies. The goal was always to have the companies using the charts as soon as they were ready, instead of us doing it for them. These aspects are what we believe made the project successful. However, the results are not yet implemented to the full extent, as a method used on a daily basis by the whole organisation. The responsibility for spreading the results and implementation throughout the whole organisation lies now with the company representatives that were trained during this project.

7 Conclusions

The conclusions for this project, based on the results to answer the research questions, are mainly concerning the implementation, change in attitudes and usage of the process behaviour chart.

The project has given insight into how a method together with a new way of thinking should be implemented. First of all, for the technical part of actually compiling the charts, the organisation needs at least one person to be responsible for driving the projects and act as a project manager for new implementations. This project and the project at SKF Actuators showed that it is sufficient, at the start of the implementation, to have one person compiling the charts. Focus of training management should instead be put on understanding how to interpret the charts. To overcome the barrier of changing organisational culture, as many managers as possible should be involved as soon as possible and preferably by trained as a group. This will create a very important critical mass, where no one has an alibi for not understanding the technique, speeding up the spreading of the implementation both within organisations and between organisations. The step-based model developed in this thesis is a good framework for training management. The framework includes all the important elements of the theory that are necessary for management to understand.

Two important aspects to consider when undertaking an implementation process that aims to change the way an organisation works was identified during this project. First of all, an implementation project like this, which involves changing attitudes and behaviour, takes time, and it has to be allowed to take time. The pace of this project was a bit slower than we expected, but when we used the study at SKF Actuators as a reference point, we understand that the process of changing someone's attitude simply takes time, never the less a whole organization. The reason that a project like this takes time is the importance of having a solid foundation to build upon. The foundation is in this case a common language and understanding of the fundamental concepts, variation and analysis. It is not advanced solutions lifting the roof that is required rather something that lifts the floor that the organisation stands on. This insight, once again, shows the importance of a common language that can only be achieved through group training.

With the right motivation and patience, changes in attitudes and behaviour can be achieved. The importance of patience is vital but motivation is also a key aspect. We learned that it requires a lot of motivation to change an organisational culture. We used two approaches for motivation. First, we explained what is wrong with the method for analysing data used today and second, we related the use of process behaviour charts to a wider context. Showing that the use of process behaviour charts actually will free up time and resources and therefore be a part of the solution for theme 2 was very important for creating motivation. The fact that we had a real project, the CNC Teknik 2010, to relate theme 2 to provided a more tangible and direct motivation for the companies. Change in data analysis is needed and we think these results would be similar in almost all kinds of organisations, especially within the metal-cutting industry. All it requires is that the right person with the right authority drives the projects and that the potential users have the courage and motivation to really use the method.

The most important change we observed at the companies was the way they changed their attitudes towards key performance measures. By being able to listen to the processes and to really understand the voice of the process, a new and very interesting discussion evolved. This discussion was focused on what should be measured and analysed. Performance measures got a new meaning to the organisations; they were actually being used to make decisions. With this new insight, more thought and time were put into choosing the right measures, measures that could actually be used to steer the processes and not just be used for information purposes, ultimately resulting in a shift of focus <u>on what to do</u> rather what has happened.

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Appendix A

The problem visualization used as baseline for the project.