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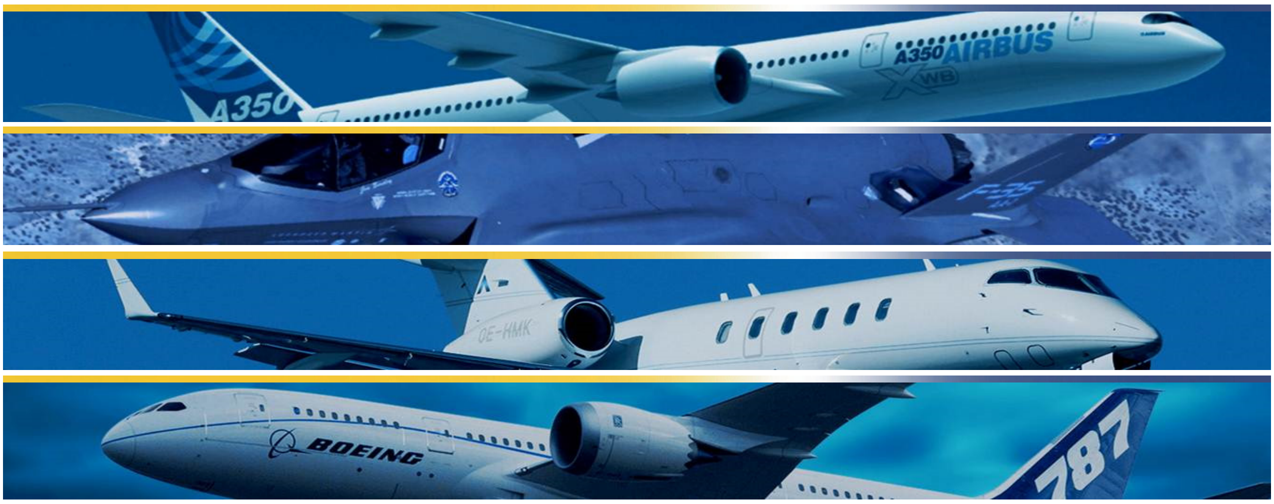

Improvements for Measurement Systems' Feedback to achieve Robust Process Control

A case study performed at GKN Aerospace Sweden

Diploma work in the Master programme Quality and Operations Management

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GKN Aerospace logotype and splash screen

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SUMMARY
This report presents the research performed at Center of Excellence Design for Robustness at GKN Aerospace, Trollhättan, Sweden. GKN Aerospace is a first tier supplier for manufacturing of components for civil and military aircrafts, and space propulsion. In manufacturing industries, variation is inevitable and can occasionally affect products and processes with undesirable consequences. To handle variation in manufacturing, it has to be measured and understood.

The baseline for this research has been to, on a holistic perspective, identify and depict insufficiencies in the current measurement systems´ ability to generate feedback from the manufacturing processes for initiation of continuous process improvement efforts. Apprehending information from the measurement systems feedback allows personnel to engender knowledge about the processes inflicting variation and behavior. Enquiring this knowledge is a major prerequisite for a fact-based decision strategy for correct improvement adjustments. When the feedback and generation of information is insufficient, data-associated projects are captivated to achieve their stated objectives of improvements.

By merging knowledge from theoretical and practical fields, improvement proposals were conducted in an aggregated model consisting of principles, practices and tools. The practical proposals recommends to disintegrate the manufacturing process into sub-process steps, and apply a registering approach towards the production flow. The theoretical proposals strive to illuminate practices and tools to embed in order to achieve disintegrated elements of the overarching goal, namely the principles to strive for.

By the conducted model and the empirical study, the result of the research answered two elements within the aim of the study, namely to describe the current state and develop an enhanced future state for the measurement system. In order to assist the organization in the transition between the different states, this thesis concluded the purpose of research by discussing two deliverables. The deliverables elaborated on management's role in the context and the need for establishing a unified language.

Keywords: Measurement system, measurability, traceability, reliability, producibility, statistical process control

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Gothenburg, December 2015

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Abbreviations

AIM – Affinity and interrelationship method. A brainstorming problem-solving tool, where relationships between different factors can be identified in order to create a more accurate understanding of the problem.

DMAIC – Acronym for define measure analyze improve and control

RQ – Research question

MSA – Measurement system analysis

KC – Key characteristics

SPC – Statistical process control

Rep-loop – A loop where a defected component gets lifted out of the manufacturing process, to be repaired and put in to the process again.

NEVS - National Electrical Vehicle Sweden,

VCE - Volvo Construction Equipment

GKN - GKN Aerospace Sweden, the facility located in Trollhättan, Sweden.

1. Introduction

In this chapter, the industry and the company will be described, followed by an explanation of a measurement system and the thesis angle of approaching the measurement system. The chapter continues by touching up on the current problems, leading to the research questions that established the baseline for this thesis. The chapter ends with delimitations and the disposition of the thesis.

1.1 Background

The aircraft industry consists of numerous global companies competing worldwide and is recognizable as capital intensive and technologically advanced. A first tier supplier for the aircraft industry is GKN Aerospace. GKN Aerospace is a global company that produces a world-class product portfolio mainly on components for civil and military aircraft, and space propulsion (GKN website, 2014). One of GKN Aerospace´s facilities, which will be the focus in this thesis, is located in Trollhättan, Sweden, and will henceforth be referred to as GKN.

There are numerous authors that describe variation as universally occurring and persistently interfering (Blomqvist, 2006). The causes for variation can be several and demands different approaches to overcome or compensate for (Ericson Öberg, 2014). In order to reduce or mitigate the effects from variation, the sources that affect and contribute with variation needs to be identified and understood as a prerequisite to allocate counteractions. A generic and structured approach within manufacturing processes is to measure and generate information about products and processes in order to identify the sources for variation. When the measurement system is incapable of engendering information for projects to identify the sources of variation, or the projects systematic approaches are inadequate to handle the information, the root causes for variation are left unresolved. Such unresolved root causes for variation will continue to interfere the processes and repeatedly generate quality defects, reparations and losses.

A measurement system is an organizational element to conduct measurements in order to determine information about the products and processes. A measurement system consists of several factors in terms of e.g. equipment, instructions, operators etc. The measurement system can, by performing a chain of measurement procedures, generate information for primary two interests. The first interest strives to determine manufactured products level of quality assurance, commonly by examining products condition towards specifications and evaluate if solely parts are ready for further steps in the manufacturing process. The second interest strives to retrieve feedback from the process in order to generate information about the process itself, e.g. in terms of variation, producibility and capabilities. The major difference between the two interests is that external forces, e.g. legislations and customer demands, primarily drive the first interest. On the other hand, inherent forces from the organization primarily drive the second interest, where data from the measurement system supports as a foundation to continuously develop and improve the products and processes. For this thesis, the second interest will be elaborated upon to enable designs of measurement system development for manufacturing process control in product development.

As a first tier supplier, GKN faces customer demands and legislations that their delivered products should endure zero defects. The firm also faces environmental demands to stay competitive, as a result of their partnership in Clean Sky. Clean Sky is a global partnership between the European commission and the aeronautical industry, with the primary focus to reduce the environmental impact from the aviation industry (Clean Sky website, 2014). As a competitor in the aviation industry, GKN accommodate the Clean Sky commission by adapting to new manufacturing technologies in order to produce more environmentally friendly products to continue to stay competitive. This adaption have lead GKN to change their historical manufacturing technology by castings of large components into fabrication of smaller sub-components. The manufacturing technology of fabrication allows GKN to utilize lighter materials and exploit more suppliers to reduce the cost of their products and manufacture lighter products with reduced environmental impact. Although the usage of fabrication provides several benefits to stay competitive, it comes at the expense of handling a manufacturing process with increased complexity in terms of more advanced fixtures and additional numerous degrees of freedom for their assembling. The transition of casting to fabrication can be illustrated in figure 1. In this transition, GKN´s kept their measurement system for casting, and applied it to their fabrication technology. A result of this were that the measurement system became incapable of intercepting feedback about the new degrees of freedom, and the outcome of the usage of complex fixtures. The lack of this information generally affected improvement projects with uncertainty when analyzing data.

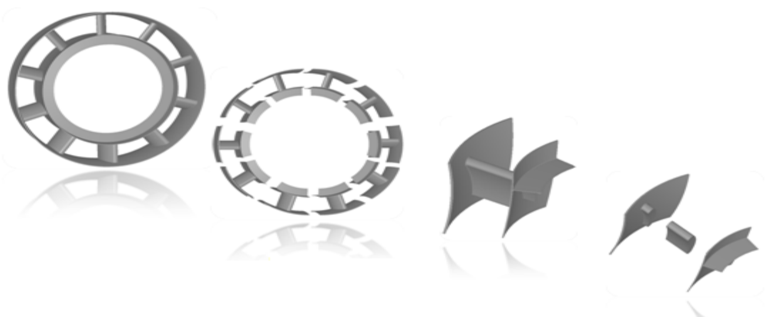

Figure 1 – Illustration of fabrication (adopted by GKN 2014)

For GKN to meet the demands of producing environmentally friendly products that endure zero-defects, the utilization of a measurement system and correlating approaches to handle data becomes essential to assure the absence of quality defects. As mentioned previously a measurement system serves of two generic purposes, to assure quality before delivering products and to generate feedback about the process. Currently the first generic purpose of the measurement system is well managed at GKN, leading to trustworthy quality assurances of their products before delivering to customers. On the contrary the measurement system is occasionally witnessed to be incapable of satisfying the second purpose, namely to generate feedback about the process. In order to improve the product or processes within manufacturing, the feedback from the measurement system becomes a foundation of data to base decisions upon. GKN strives to work with the handling of this feedback by their Lean Six Sigma data driven continuous improvement methodology. The current measurement systems insufficiencies in generating feedback restrain GKN from successfully conducting data-associated projects.

1.2 Purpose

The purpose of this thesis has been to descriptively map the current state for the measurement system, involving both the design of the measurement system and the accompanying approaches to handle data, in order to pinpoint insufficiencies. Once identified, the thesis will strive to propose improvements and recommendations to overcome the insufficiencies of the current measurement systems´ ability to generate feedback and information.

1.3 Problem analysis and research questions

A measurement system incapable of generating information and feedback from the process in alignment to the requests of project teams in need of enquiring knowledge captivates the organizations prosperity to improve and develop. Several of the projects conducted at GKN meet obstacles that captivate their progress of achieving stated objectives for the projects. Several of these obstacles are caused by an insufficient measurement system in correlation to inadequate approaches and methodologies to handle measurement data. The insufficiencies generate a lack of informative feedback, in order to enable fact-based adjustments in the processes to improve the quality of the products.

Since the measurement system fails to contemporary provide feedback about the process, the organization is occasionally incapable of interpreting the process behavior or predicting future occurrences. Quality problems are therefore hard to pinpoint before they surface, forcing teams to allocate their efforts to react on problems rather than working on preventing them to occur.

Once project teams focus on reacting on problem, an incapability of the measurement system to provide data and feedback on the historical events captivates project teams to identify the root causes to the problem. Without pinpointing the root causes for problems or unwarranted variation, quick fixes intend to be applied and variation continuous to interfere undetected until new problems occur.

In the overall perspective, the operated measurement systems and its design is causing GKN to be reactive, instead of proactive. Even though the problem is recognized in the company, there is an absence of knowledge and instructions on how to change the reactive measurement system into a proactive one. It is therefore desirable to analyze the current measurement system, to detect and pinpoint insufficiencies as well as areas of improvements. Once identified, the research will strive to support the GKN in the transition of adapting to a more proactive measurement system, by suggesting improvement proposals. To assist GKN in this transition, the following three research questions have been conducted:

RQ1 - *How does GKN currently work with their measurement system to enable the measuring of robustness in a manufacturing process?*

A basic premise for this question is that a robust process produces products that meet requirements in a predetermined range. Therefore, to measure this process will enable evaluations for the manufacturing process level of robustness. By that premise, this research question strives to map the current measurement system in terms of design and methodologies to handle data, with the aim of apprehending feedback from the measurement system. The research question will focus on pinpointing insufficiencies.

RQ2 - *How could a measurement system be designed so that studies on measurement data and improvement projects can be performed?*

This research question strives to, by literature affiliation and benchmarking, answer question of insufficient areas correlated and discovered in research question 1. By answering this question, a foundation for a future state with an improved measurement system could be able to be described.

RQ3 - *How could GKN adjust their current measurement system to enhance a proactive way of working?*

This research question is of an educational purpose. The first two research questions strive to answer and pinpoint insufficiencies in today’s measurement system and the practices around it. But to assist GKN in the transition to a future state, the third research question will strive to educate GKN and support them in “raising the floor” to enhance their organizational context.

1.4 Delimitation

The thesis will only emphasize on GKN´s facility located in Trollhättan. The global company GKN Aerospace has facilities in several countries, but these will not be included in the thesis, due to obstacles and differences in comparing measurement systems that rise when there are different products being produced, different cultures, different goals and visions etc.

In mutual agreement with stakeholders at the company, the reporting system from the measurement system was prioritized to be secondary to avoid a too broad scope for the thesis. A measurement system is strongly reliant on its ability to report, store and share the information throughout the organizations in order to be efficient. But due to time constrains, it is decided to only focus on the measurement system and the corresponding approaches of working with it. This means though that the reporting system will be mentioned and involved in the analysis, but not primarily focused on.

When handling data received by a measurement system, there is a wide range of applicable statistical tools to analyze the data to achieve increased understanding of the process. To mention a few, there is Dual-box analysis, Design of Experiments, ANOVA etc. But since the primary focus of this thesis is to analyze the measurement system to achieve process control, the thesis will primarily focus on statistical process control and control charts. Other statistical methods will have accommodation to be mentioned, but not thoroughly analyzed in this thesis.

1.5 Precision of purpose

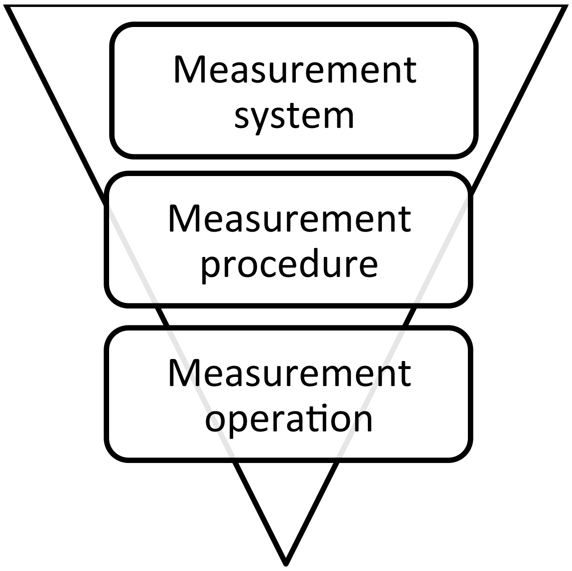

Figure 2 - A hierarchy view of measurement system

As previously mentioned, this research will emphasize on the measurement systems´ ability to generate feedback and information about the processes. A measurement system is from a holistic view an organizational element at the top-end of the measurement hierarchy, see figure 2. A measurement system consists of several factors, e.g. people, processes, environments, equipment, methods, but also factors that concern the approaches to work with the generated data, e.g. methods to sample, analyze, collect and interpret data or approaches to take decisions based on data.

All the factors mentioned above could be pinpointed and placed to different positions in an illustration of a measurement system hierarchy, see figure 2. Starting from the floor level is the *measurement operation* consistent of operators, equipment, instructions, preconditions etc. In the measurement operation, an operator performs a measurement of either physical or performance measure. Next step upstream is the *measurement procedure*, which involves the measurement operation, with addition of the reporting of the measurement.

At the top of the hierarchy is the *measurement system*, consistent of a chain of measurement procedures throughout the entire manufacturing process. The chain of measurement procedures can support to generate information for the quality assurance and the feedback from the manufacturing, see figure 3. In the measurement system, the approaches and methodologies to handle and work with data are included, as well as the decision making based on data.

As an objective of the research is to identify insufficiencies in the measurement system, there will be an absence of detail-oriented analysis towards specifics, e.g. no comparison of different equipment or handcraft tools etc. The orientation level will instead target overall design of the measurement system, as well as the correlating methodologies and approaches used to handle and work with the data. The holistic view of this research will involve the process steps from the initiating product development process, until the finalizing manufacturing processes step, where the assembled product is ready for delivery.

Figure 3 – Two information sources from a measurement system

1.6 Disposition

Further follows the outline and disposition of this thesis.

Chapter 2, **Method**, will describe the research methodological choices for the research and elaborate on the research reliability and validity.

Chapter 3, **Theoretical Framework**, will present the theory used for the baseline of this research. The theoretical framework will target elements of measurement system to enhance the understanding for questions of *why, what, how, when,* and *what to do* regarding different aspects of a measurement system.

Chapter 4, **Empirical findings**, will present the empirical study, starting by the findings from the observations and the review of internal documentation. The chapter continues by presenting the findings of the interview studies, involving the benchmark and the interviews of design and manufacturing

Chapter 5, **Result and Analysis**, will present a merge and summary of the findings in chapter 4. It will illustrate a current state map, a future state map and elaborate of the underlying affiliation of the insufficient areas. Lastly the chapter ends by presenting a aggregated model to observe a measurement system from a new perspective.

Chapter 6, **Discussion**, involves a general discussion of the disorder in the current practice of operating a measurement system, were two deliverables are presented to support GKN from the transition of current state to future state, as well as discussion towards the methods used.

Chapter 7, **Conclusion**, includes three areas, firstly a summarized revisit of the research question. Secondly an elaboration of how the thesis has contributed to the academic field and the industry, and lastly an elaboration on topics for future research.

2. Method

This chapter will explain and motivate the research methodological choices for this thesis. The chapter will briefly explain which strategy and methods that were chosen, and how data was collected and analyzed for the thesis. The chapter ends by elaborating on the research reliability and validity.

2.1 Research strategy

The research strategy of this thesis is primarily of a qualitative characteristic, but there is a small degree of quantitative aspects involved as well. The choice of qualitative strategy is motivated by the applicability to focus on a social environment, as in this thesis.

According to Bryman and Bell (2011), a qualitative research strategy focuses on describing findings in words, while a quantitative focuses on describing's in numbers. In addition, they advocate that a qualitative strategy focus on generating new theory, while quantitative focus on testing theory. (Bryman&Bell, 2011). Since the thesis will focus on describing a current state and suggest improvement proposals, the best-suited strategy will be of a qualitative characteristic.

The thesis will however include a small amount of quantitative data; to easier affiliate GKN with the organizational context they operate within and expose the importance of the current insufficiencies in their measurement system. The purpose to use quantitative data will be to, by numbers, easier describe the current measurement systems insufficiencies and reveal negative effects, e.g. financial and time-consuming effects etc. However, the quantitative data will not be revealed to any significance in the report, but rather to serve as examples to involve for the closed presentation of the research. The quantitative data will serve to confirm the occurrence of the problems, as well as enlighten the situation of the impact from different insufficiencies. The small involvement of quantitative data will in addition help to enrich the description of a current state and support to answer the first research question.

2.2 Research approach

Two generally common approaches for conducting research are the inductive and deductive approaches. Both Bryman et al. (2011) and Saunders et al. (2012) describe an inductive approach as an approach where theory is generated from the collection of data. The reverse approach, namely deductive approach, in opposite focus to conduct hypothesis affiliated from theory and later collect data to be able to accept or rejected the hypothesis. The general purpose of a deductive approach is to test theory, while an inductive is to generate theory (Bryman et al, 2011). Since the approach of a research rarely is linear, Dubois and Gadde (2002) advocate a systematic combination of both inductive and deductive approach, leading to an abductive approach. For this research an abductive approach will be used with predominantly an inductive approach.

The research will focus on interpreting and understanding an organizational context. The approach to achieve this will be to collect empirical data from the organizational context in order to generate theories and explanation about it. As the collection of empirical data proceeds, literature will be reviewed in order to enhance the prosperity to generate theories to explain the organizational context.

2.3 Research Design and Methods

The research design and methods used have varied in the collection and analysis of data. The research design is illustrated in figure 4, and illustrates the design of the study and the methods used for each step. A pre-study for the thesis was the performance of a Six Sigma project in the spring of 2014. In the context of this thesis, the Six Sigma project was conducted as an action research and served to settle the baseline and scope for this research. In continuation of this action study, research questions were scoped and defined and an empirical study was conducted. In the first half of the empirical study, two data collection methods were used, an observation study with semi-structured notes and a review of internal documentation in terms of three Six Sigma projects previously conducted at GKN. The following literature review was conducted in a parallel lag to the first half of the empirical study, where the findings of the empirical study partly guided to identify areas of interest for the literature review. The literature review also supported to increase the understanding of the findings from the empirical study, leading to the initial conduction of a theoretical model of the organizational context at GKN. In the conduction of an initial empirical model, the findings from the first half of the empirical study and the literature review became a foundation of data, which laid the basis for identifying suitable interview questions for the benchmarking.

The second half of the empirical study started afterwards with the internal and external benchmarking, where semi-structured interviews were carried out, one internal at GKN and two external. In addition, a second interview study was conducted to identify the cooperation and communication between design and manufacturing within GKN. The data from all the interviews supported to widen the perspective of the first theoretical model with approaches and measurement system design from other social environments. Afterwards, the theoretical model was revisited, and redesigned by analyzing and comparing the empirical findings, the literature review and the benchmarking. The entire data collections were grouped into sub factors, to correlate different deficient areas under corresponding categories, in order to in a structured way analyze the results of the data collection.

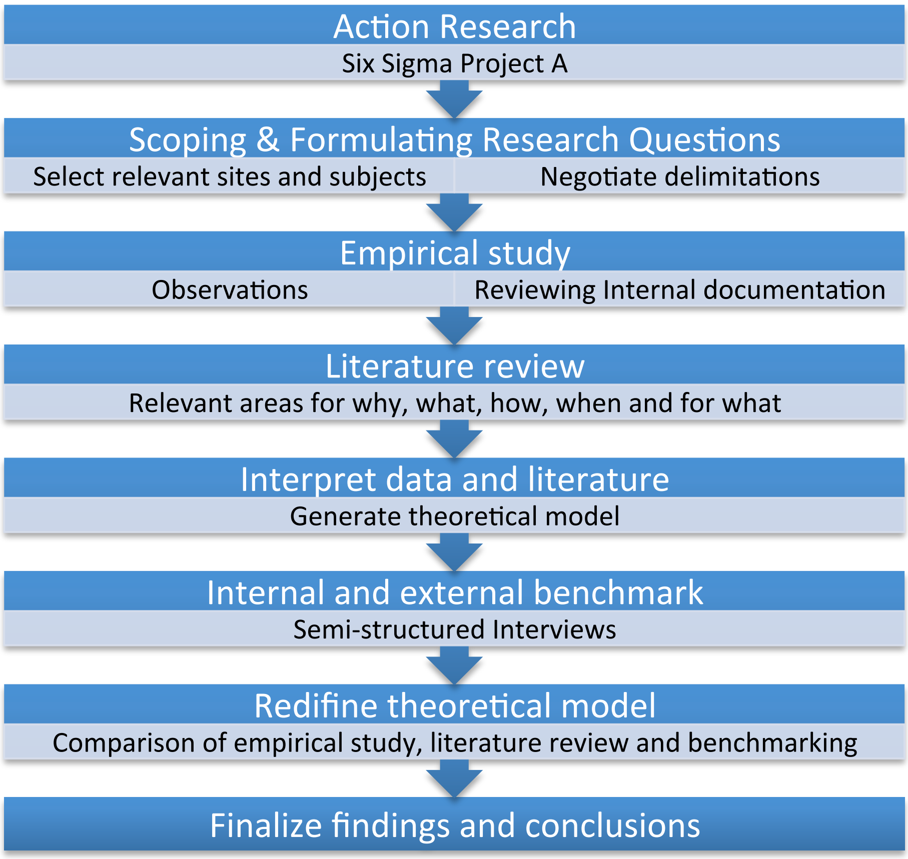

Figure 4 - Path of data collection and analysis

Within the data collection of the research, there were collections of both primary and secondary data. The division of secondary and primary data was divided as table 1 below.

Data collection method	Primary data	Secondary data
Action research	X	
Observations	X	
Internal documentation review		X
Interviews	X	

Table 1 - Division of Primary and Secondary data

2.3.1 Action research

The researcher of this thesis participated in a Six Sigma project conducted at GKN. In the context of this thesis, the project served as a pre-study for this research and was carried out as an action research in the spring of 2014.

When performing action researches, it is easy to forget the role as a researcher and influence by personnel within the studied environment. The project strived to avoid this by operating in a cross-functional team and utilize guidance from external supervisors.

2.3.2 Observations

In one of the cases, data was collected by observations. The observations were performed in combination with semi-structured notes. In addition to the observations, a small amount of participation by the performance of basic tasks was involved for this case.

When performing observations, there is a risk that the observer is looking for statements to enhance already pre-decided arguments, but to ensure that the observer did not affect the observations with his own interpretations, the generated findings from the observations were validated by other participants of the case project team.

2.3.3 Reviewing internal documentation

To enhance the interpretation of the obstacles that Six Sigma projects face at GKN, three reports of previously performed Six Sigma projects at GKN were reviewed. Regarding the review of the reports, a high level of caution to avoid subjectivity was carried out, with the purpose of avoiding that the researcher was looking for arguments to strengthen his own beliefs.

The supervisors at the company provided access to data and the ability to ask affirmative questions to participants in the Six Sigma projects. This generated possibilities to ensure the research to avoid any misleading conclusions or misinterpretations from the reports. The affirmative questions supported to enhance the reliability of the thesis, since reviewing the documentation is considered to be a collection of secondary data. This supported to ensure that the documentation review was carried out objectively and not subjectively.

2.3.4 Literature review

Literature review was done in lagging parallel of the empirical study. As the empirical study proceeded, it also created a direction for the literature study towards relevant fields of interest. The literature review was cumulative and enhanced the prosperity to revisit the empirical study for analysis. The literature review predominantly targeted five elements in order to generate a foundation of theory to answer the *why*, *what*, *how*, *when* and *what to do,* for operating a measurement system with a holistic view. The *why*, will focus to determine why to perform measurements and which benefits a continuous measurements work efforts can instigate for a company. The *what* is primarily focused on what to perform the measurements on, and will target the field of key characteristics. The *how* strives to determine on how to perform measurements to achieve reliable and trustworthy data and is primary focused upon measurement system analysis. The *when* is focused on determining how to monitor and control processes by handling the data of measurements, and will target the field of statistical process control. And lastly, the *what to do,* targets the field of how to scope projects by affiliation of data, primary targeting the practice of effective scoping and the pull approach. Further follows a summarized table.

Why – Continuous learning, how a company can improve by utilizing a measurement system and embed learning's from the data
What – KC, What characteristics to target the measurements on
How – MSA, to ensure generation of reliable measures
When – SPC, how to handle the collected data
What to do – Effective scoping and the pull approach, how to use data in the scoping of projects.

2.3.5 Semi-structured Interviews

Semi-structured interviews intend interviews with accommodation of discussions. This means that the interviews will be carried out in a mixture of structured and unstructured character, where questions generally will be open-ended and leave the interviewee able to elaborate freely on the questions. In semi-structured interviews, questions are prepared but not necessary followed in a direct order (Scheinberg, 2014).

The semi-structured interviews concluded the data collection for the research. By using findings from the empirical study and the literature review, a foundation of data facilitated to formulate interview question that could enhance the prosperity of the data analysis for the thesis. When carrying out interviews, Scheinberg (2014) advocates four important ethical principles to consider, namely *harm to participants*, *informed consent*, *invasion of privacy* and *deception*. Further follows some measures taken to avoid these occupations.

Regarding *harm*, it is important to consider that harm to participants can be caused in more ways than physical, e.g. stress, interviewee might feel offended etc. (Scheinberg, 2014). To avoid any harm, the researcher in advance informed the interviewee the possibility to withdraw to answer, and the possibility to be anonymous. This allowed the interviewees to only answer questions they were comfortable with and the anonymity allowed the interviews to avoid receiving any indirect harm in the shape of restricted personal development.

Regarding *informed consent*, the interviewer clarified the true purpose of the thesis and interview by a short introduction before conducting any interview. The interviewer strived to use the highest possible level of honesty, and did not have any hidden or double agenda for the interviews.

Regarding *invasion of privacy*, the interview questions strived to focus on the company and organization that the interviewee operated in, and avoided to question any personal agendas or information. Once again, the interviewer were given the opportunity to withdraw their answers at any time if the perception of the question at any level were interpreted as invading of their personal privacy.

Lastly regarding *deception*, the interviews were as mentioned earlier presented by its true purpose, with addition that the interviewee was delegated enough information to understand what the data from the interviews were to be used for. This will help to avoid any level of deception.

The interview questions were prepared in advance and reviewed with supervisors to ensure that the questions focused on determining relevant subjects, but also enquired the potential to enhance the data collection of the research.

2.4 Reliability and Validity

Alänge (2014) illuminate that reliability is mainly focused upon if another researcher could replicate the discoveries and procedures of the research at another time and the same conclusion would appear. Alänge (2014) also advocates that reliability is to question if the results are repeatable, and if the measures are consistent.

By Validity, Alänge (2014) advocates four areas when discussing case studies, measurement validity (also known as construct validity), internal validity, external validity and lastly ecological validity. Briefly explained, Alänge (2014) explains that the four areas strive to answer the following questions

- Measurement validity – does the measure reflect the concept that it's supposed to demonstrate
- Internal validity – does the casual relationship hold water
- External validity – can result be generalized beyond the specific research context
- Ecological validity – are the findings applicable to peoples everyday natural social settings

Bryman and Bell (2011) emphasize on four similar fields when discussing qualitative research, mainly internal and external reliability, as well as internal and external validity.

- Internal reliability – if there is more than one observer, whether or not members of the research team agree upon what they see and hear
- External reliability – The degree to which a study can be replicated
- Internal validity – Whether or not there is a good relationship between the research observations and the theoretical ideas they develop
- External validity – the degree to which findings can be generated across social settings. (Bryman et al, 2011)

Both Bryman et al. (2011) and Alänge (2014) discuss similar occupations, further follows the thesis interpretation to which the degree the occupations were fulfilled to ensure a trustworthy research, conducted in good faith.

2.4.1 Internal Reliability and External Reliability

Since the thesis was conducted by a single researcher, it was difficult to discuss any internal disagreements and difficult to verify that the observations correlated to the observed social settings for each case. The researcher used different methods to enhance the internal reliability for this research. For the internal documentation review, the researcher used affirmative questions for the reviewing of secondary data by validating the findings to participants in these projects. To avoid misleading interpretations in the findings of the observation study, participants in the observed case reviewed the findings. Lastly, the interviews used respondent validation to avoid any misunderstandings or misinterpretations. These measures can be argued to support the verification that the study was carried out reliable, and that the interpretations are not solely reliant on the researchers own beliefs or interpretations.

As a result of the preface action research, the researcher were moderately integrated to the organization in advance of the research. Before entering the research the researcher already possessed relationships and connections to personnel at the company, which eased the ability to come in contact with personnel and obtain data. This indicates obstacles for another researcher to replicate the research, at least in the same time frame.

The study targeted several different cases consistent of different products, people, processes, and similar findings appeared across the different cases. This indicates that the findings are not reliant or unique for the cases itself, but rather that the findings identified generalizable phenomena’s. The findings are on that aspect therefore not reliant on the researchers position at the company to any extended degree. Much of the data in these cases where historical documented and is therefore available to observe or interpret by any other researcher, at any time, to come up with similar findings and discoveries.

2.4.2 Internal Validity and External Validity

Internal validity focuses on the researchers affect on the collected data. The researcher strived to avoid any interference of personal beliefs or bias when collecting data. The purpose of the thesis was to accurately describe the organizational context and draw truthful conclusions from it in order to create a valid research. To enhance the internal validity of the research a workshop was conducted where participants of different cases, where allowed to participate and examining the findings and conclusions of the research. The purpose of this workshop was to validate the research procedure and create consensus among the findings and the results, to establish a mutual agreement of the research´s internal validity.

The thesis has focused on several cases, in which findings were able to dissect into sub factors to demonstrate affinities. This indicates that disregarded the observed processes, products or people, similar problems occurred. This proves that to some degree, the findings of this thesis can be generalized in to other social settings, where measurement system problems are occurring. A limiting factor for generalizing the findings could be that the company and the products observed are very accurate with tight specification limits, which can create a unique environment that is not suitable for other industries etc. Lastly, since the thesis was carried out with a holistic perspective in the analysis, there is an absence of detail specific measures for the analyzed areas, which can to some degree enhance the possibilities to generalize the findings to other social settings, due to the facts that a holistic perspective allows accommodation to shape the findings to other social settings.

3. Theoretical Framework

This chapter strives to present an overview for the foundation of literature that related to the baseline of the research. The theoretical framework covers several fields to illuminate tools and practices in a measurement system to achieve feedback from the measurement system.

3.1 Selected theory related to the research

Generally in a literature review, several topics and aspects can be included to supplement and enhance the interpretation of the underlying theory related to the topic. The empirical study of the research generated a foundation of information about the social environment at GKN and supported to lay the direction for relevant elements for the literature review. Five elements of a measurement system were selected by affiliation to findings in the empirical study in order to screen among the multitude of available theories, see figure 5.

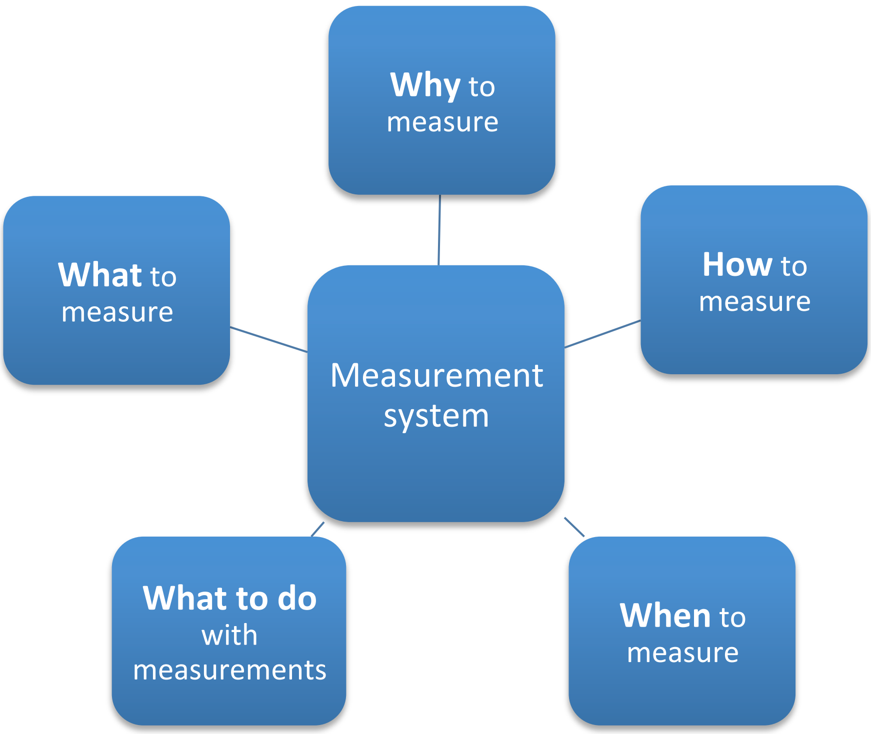

Figure 5 Cornerstones of theories for Measurement systems

3.2 Base decisions on fact

A universal objective for a manufacturing process is to produce quality assured products within the tolerance limits. A key element to utilize in order to fulfill this objective is the measurement system. The measurement system can control and monitor a process, detect patterns and tendencies over time and evaluate products by the aid of tolerance limits. In addition, the measurement system can support to identify the underlying factors that are generating the variation that jeopardize the producibility of the manufacturing process. By identifying these factors or root causes, adjustment can be made to eliminate or compensate for the contributing variation. In order to identify the right factors or adjust the right parameters, a fact-based strategy for the decisions is required.

Bergman et al. (2011) advocate that in production it is important to have a fact-based strategy for decisions. It is common that manufacturing companies perform a lot of measurements, but with low utilization of the information from these measurements to draw essential conclusions about the production process. They continue by explaining that measurements are commonly performed to understand single operations or components, and not to improve the process. Instead the measurements should be used as a foundation for statistical methods to reduce the variation within the process and enhance the quality of the process (Bergman et al. 2011).

On the other hand, a fact-based strategy for decisions is vulnerable to the certainty of the performed measurements. Poor accuracy in measurements procedures will affect the fact with uncertainty, which found the decision-making. Dehnad (1989) debate the importance of measuring the performance variation, and the importance of evaluating these measurements towards the nominal target value. Dehnad (1989) continue to elaborate that in industries, it is common to evaluate the performance variation towards a specification interval, creating an error where all the measures within the interval receives the same quality level.

By collaborating the theories of Dehnad (1989) and Bergman et al. (2011) the underlying approaches to achieve a fact-based strategy for decisions, is to measure specific values to evaluate the performance variation, and collaborate several of measurements to create a foundation of data for statistical software. Once there, adequate analysis can be conducted to identify root causes of variation, and reduce or compensate the impact of these factors.

3.2.1 Learn from continuous improvements

Wheelwright and Clark (1992) advocate the importance of post-project learning's. They recognize that companies successful in learning and improving are those that follow a path of continuous improvements. They identify that companies incapable of embed learning's from previous projects with regards to people's behavior, organizational structures et al, fail to follow the path of continuous improvements (Wheelwright & Clark. 1992). By this statements it is evident that improvements in singular projects to adjust a problem occurring for the moment, is not the most effective strategy to work against, since it will not capture other essential problems in a meta level within the organization. It is important to utilize the learning's not only on how the problem was solved, but also which insufficiencies the organization caused for the problem solving project, e.g. organizational restrictions, unorganized historical documentation etc. It is essential to capture these learning's to enhance the preconditions for future improvement projects. By adopting a continuous improvement methodology and cherish previous learning's, organizations can avoid that similar problems occur repeatedly and are solved over and over again (Wheelwright & Clark. 1992)

By adjusting the organizational insufficiencies, the preconditions for handling future quality problems will be enhanced. Wheelwright and Clark (1992) ends their argumentation of post-project learning's by emphasizing that to make continuous improvement a reality, the how, what, who, and where of such learning's needs to be addressed in post-project learning's. By this they mean

- How – project audit, identifying lessons learned and determine how to apply them
- What – involves investing in e.g. new tools, new skills, new staff etc.
- Who – consist of the entire organization, but often focused on the steering committees, and continual management attention
- Where – largely in the development projects and improving the organizations collective capabilities

3.3 Statistical methods for measurement systems´ feedback

As previously argued by Bergman et al. (2011) measurement data should be collected and used as a foundation for statistical methods to reduce the variation within the process and enhance the quality of the products. A recommended and frequently used statistical tool in the Lean Six Sigma methodology is statistical process control, henceforth referred to as SPC. Blomqvist (2006) advocates that no regards how well a process is designed or how accurately it is operated, there will always be an interference of natural variation. The natural variation is consistent of aggregated moments of coincident, which is inevitable. Blomqvist (2006) continue to explain that process control and control charts is a method to quickly discover if any interference for the process is caused by any factor not consistent of any causes of natural variation.

3.3.1 Common and special causes of variation

To work with SPC, it is important to understand the difference between common and special causes of variation. George et al. (2005) describes common causes of variation as random shifts in factors, a phenomenon that is always apparent. George et al. (2005) continue to explain special causes of variation as factors above or beyond the common causes of variation. Special causes of variation are appearing in the process as a consequence of factors that are not always appearing in the process (George et al, 2005).

The different causes of variation demands different approaches to overcome them. Ericson Öberg (2014) promotes that common causes of variation should strive to be reduced, while special causes of variation should strive to be eliminated. To eliminate special causes of variation is more financial appropriate since these are often caused by a few strong factors. The common causes of variation are on the other hand generally caused by several small factors. This leads to a financial inefficiency to try to eliminate all of them, indicating that it is more beneficial to strive to reduce the impact of common causes variation. Lastly Ericson Öberg (2014) advocates that common causes of variation are often stable and to some degree predictable, while special causes of variation is the opposite, unstable and unpredictable (Ericson Öberg, 2014). A precondition for capability studies are that the processes are stabile, indicating that the special causes of variation needs to be eliminated before examining the process capability.

A lack of understanding for each of the causes of variation can result in inadequate adjustments in the process, which can later result in more waste and an increased process variation. SPC is a good tool to initiate the decision-making, and adjustments on the process to be based on fact. But it is also an applicable tool in order to change the mindset of the organization from focusing on control limits into targeting their focus of the variation of the process instead (Hammersberg 2014).

3.3.2 Statistical Process Control – SPC

SPC is a vital element of any attempts to work with continuous improvement in manufacturing. Bergman et al advocates that by collecting and using new information from the process, new causes of variation can be identified and eliminated or compensated for. This will reduce the process variation and lower the costs for defects and enhance the quality of the process (Bergman et al, 2011)

Bergman et al. (2011) describes the purpose to use SPC as a method to identify factors contributing with variation, to eliminate as many as possible. This will allow the achievement of a stabile process with low variation, able to preserve or control over series of time. Bergman et al. (2011) continue by promoting that a key tool for SPC to discriminate causes of variation is the control chart.

Thompson et al. (2001) promotes that SPC is a tool that enables organizations to continuously improve the quality of the product and processes, but at the same time allow affiliation to work with day-to-day crises (Thompson et al, 2001). Thompson et al. (2001) continue to promote three main steps for SPC to stepwise optimize the production process. Where the SPC is a tool to support organizations to cherish the experience from previous learning’s and adapt these learning’s into working smarter, rather than working harder.

- Flowcharting the production process
- Random sampling in intervals at several stages within the process
- The use of discovering drifts in the sampling, and back tracing them to the origin root causes in order to remove them (Thompson, 2001)

Lastly, SPC is not only a method to identify and distinguish drifts in the products or processes in order to eliminate root causes for variation. It can also support with the reverse occupation, to identify opportunities where the product or process have exceeded the predicted outcome, and allow investigations to determine what aspects contributed to the improved outcome.

3.3.3 Control charts

A control chart is generally consistent with a target value, control limits and a number of observations from the process distributed over an interval. Control limits are not the same as tolerance limits, since the tolerance limits are set in relation to the customer demands, while control limits are calculated (Bergman et al. 2011). An example of a control chart is illustrated in figure 6.

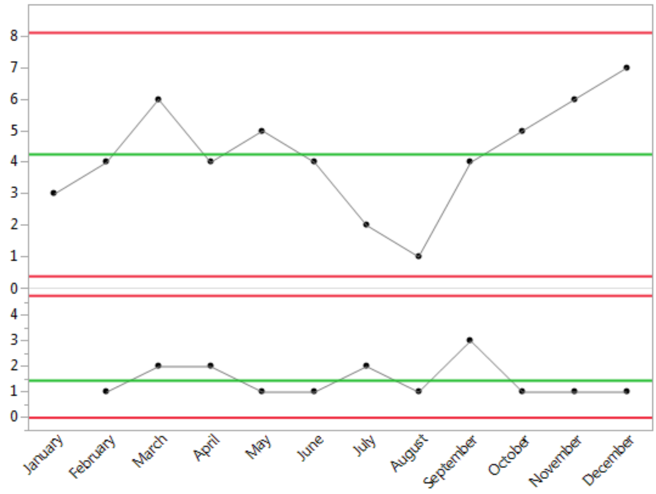

Figure 6 - An example of a Control Chart and moving range chart

By continuously inserting data from measurements into the control charts, information about the process and population can be achieved. Control charts are commonly used due to their prosperity of visualizing the process and reveal the variation within the process. And by revealing the variation within the process, many possibilities become accessible.

To start with, both George et al. (2005) and Bergman et al. (2011) advocates that control charts can support to detect changes and discriminate causes of variation. The control charts can also support to identify moments for drifts in the process, but also serve as a recipe of the stability of the process as well as enabling evaluation of the process producibility and variety. By allowing to discriminate causes of variation and identifying moments for drifts in the process, the control charts is extensively useful for monitoring processes but also for improvement projects to collect data. The control charts can also support to evaluate the outcome of improvement projects, in terms of e.g. reduced variation, increased stability or increased closeness to the target (Bergman et al. 2011).

3.3.4 Monitoring a process

Raharjo (2014) illuminate the following occupations as important to consider when working with SPC, namely false alarm, false alarm rate, number of samples, sample size, and sampling interval. Raharjo (2014) continue to explain that there are numerous more occupations to consider. Further follows a comprehensive review of some of the occupations relevant to describe the work procedure of SPC and control charts in order to successfully monitor a process (Raharjo, 2014).

Sample size is a corner stone when working with process monitoring. To sample has rose from the fact that it is often financially expensive to measure all components in a population, since measurements of a sample of the population might be able to perform less measurements and still achieve an acceptable certainty of the information of the process. For a control chart, George et al. (2005) emphasis on the importance of using time series order and promotes a use of a minimum of 25 subgroups or 100 observations (George et al, 2005).

Since its often economical expensive to measure all units in a process, sampling is used to only observe a sample representative for the whole quantity of the produced units. The sample size is strongly correlated to the confidence interval that is acceptable. George et al. (2005) identify a distinctive correlation between sample size and confidence interval. The correlation is that the larger the sample size, the more reliant becomes the confidence interval. Both Blomqvist (2006) and Bergman et al. (2011) advocates a procedure where a sample of observations is collected to calculate a mean value, in order to use the value as a quality indicator of the process. But to be sure that the sampling is not too low to provide enough information about the units variation between part to part, they promote a suitable sample size as 5, since a larger sample size only contributes with negligible information about the samples inherent variation (Blomqvist. 2006, Bergman et al. 2011).

There is always a chance for mistakes when performing a measurement. These mistakes can cause the measurement result to not truthfully display the measured parameters. When a reported measurement does not truthfully reflect the intended measure, the correlation between the real world and the data does not correlate. This can be caused by e.g. measurement system errors, but it generates possibilities that deviating points out of tolerances goes undetected or that points within the tolerances are measured and interpreted as outside the tolerance limits. Errors like these give rise to false alarms. To avoid false alarm, the control limits must be set to a level where the chance for false alarm is the lowest acceptable. Several authors, George et al. (2005), Blomqvist (2006), Bergman et al. (2011), advocates that a common level for the control limits are three times the standard deviation, also known as +/- 3 sigma, this leaves the chance for false alarm to be 0,0027.

Setting the control limits is strongly correlated to which risk an organization is prepared to receive a false alarm, the risk can be mitigated if e.g. it is easy to detect false alarm or that the cost of a false alarm is negligible (Bergman et al. 2011).

3.4 Capability of a process

Bergman et al. (2011) describes a process capability as a process ability to produce units within tolerance limits. In addition to identifying the process variation and the source of variation, it is important for organizations to focus efforts towards analyzing the process capability of producing within the customer requirements, also known as the tolerance limits. A distinguish difference between analyzing a process in terms of variation and control charts compared to capability studies are the difference between control limits and tolerance limits. Control charts use control limits while capability studies use tolerance limits. Bergman et al. (2011) describes the difference as control limits are focused on a process to determine the stability of the process, while tolerance limits are used to determine a single units performance in relation to the set tolerances (Bergman et al. 2011).

When analyzing a process capability, two parameters generally comes of interest, namely the distribution of the produced components in relation to the specification limits, and the alignment with the distribution to the target value. Both George et al. (2005) and Bergman et al. (2011) advocates the importance of ensuring that the process is under statistical control before performing any capability study of the process, statistical control is therefore considered as a precondition for performing capabilities studies. It is important to remember that a process can be outside tolerance limits and still be stable, e.g. when the routine variation exceeds the tolerance interval. It is therefore important to understand the difference, and determine if the variation are to be reduced and stabilized or if the process itself is stabile but incapable of performing in the capability required by the tolerance interval.

Bergman et al. (2011) continue to promote that capability studies for different processes supports to raise the awareness of variation and mean values in correlation to the tolerance limits. (Bergman et al. 2011) The previously mentioned control charts and process control is therefore strongly correlated with the capability studies, in order to achieve processes that are under statistical process control and producing components within tolerance limits.

3.5 Measurement system analysis

There will always be variation in a manufacturing process which, as a result, forces the organization to determine the level of certainty required of measurements to reveal the performance of the manufacturing process. One method of ensuring the certainty is to confront the measurement system with analysis, to ensure the absence of variation and measurement errors within the measurement system. A measurement system is as previously mentioned consistent with several factors, e.g. people, equipment, methods etc. Variation in any of these factors can result in uncertainty in the measurement data. To reduce this uncertainty, studies of measurement system analysis can be conducted in order to ensure that the observed values reflect from reality and not greatly affected by any variation within the factors of the measurement system.

In addition a measurement system is also vulnerable to small interference of variation over time, creating an increasing measurement error which hard to detect since its growing little by little. This can result in a situation where it is interpreted that the process is changing or in need of counteractions, while truth is that the measurement system gradually have been misreading, it is therefore essential to repeatedly calibrate and evaluate the measurement system.

The purpose of performing an MSA is to thoroughly analyze if the used measurement procedure is suitable and capable of performing the task. When performing measurements, it is vital to have a measurement system that is **capable**, **repeatable** and **accurate** in order to achieve a truthful and effective measurement process.

In other words, an MSA strive to determine that the resulting measure provides information about the variation between part to part, and not variation caused by the measurement procedure. For any improvement project reliant on analyzing data, it is essential to ensure that the data being analyzed is providing the right information about the variation in the process, and is consistent with an absence of misleading variation caused by the measurement procedure.

For a measurement system analysis, there are several occupations to evaluate if the measurement system is capable, as well as if the interfering variation in any factor is significant. George et al. (2005), Brantin (2014) and Hammersberg (2014) promote the following occupation illustrated in the figure 7 below.

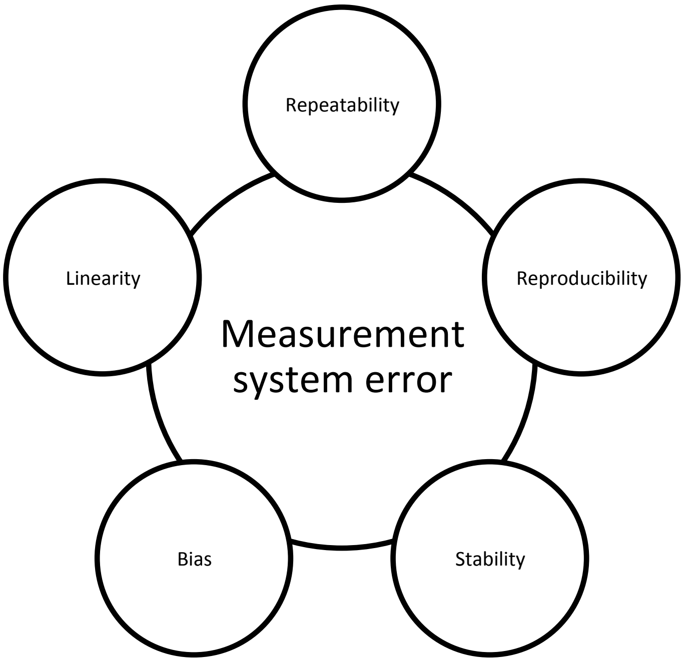

Figure 7 – Involving factors derived in a measurement system analysis

3.5.1 Bias

Hammersberg (2014) emphasize that bias is often referred to as accuracy, meaning the difference between the observed average and the reference value. The accuracy can help to determine how close to target the measured values are situated (Hammersberg 2014). George et al. (2005) agree with this statement by explaining bias as the distance between the observed average measurements and the true value, but George et al. (2005) continue to elaborate on the difference between bias and accuracy. They explain that the accuracy is the extent of which the average of the measurement deviates from the true value, while bias is the distance for the average deviation between the observed value and the true value (George et al. 2005).

3.5.2 Stability

Regarding stability, George et al. (2005) advocates that stability is the absence of changes or drifts in the measurements considered over a longer time. A lack of stability is according to George et al. (2005) often caused by a lack of standard procedures or worn-out measurement devices. Stability studies are generally purposed to determine how the variation change over time, in other words, how stabile the observed measurements are over a time frame (George et al. 2005).

A method to study stability is to performed repeatedly measurements on a single product over a timeframe and observe any drifts from the true value. In a stabile measurement procedure, the measures should endure minimum drifts over a timeframe due to the usage of the same equipment, component, operator etc.

3.5.2 Gage R&R – Repeatability and Reproducibility

Repeatability and reproducibility are two factors in an MSA that is commonly covered in a Gage R&R. The aim of a Gage R&R study is to determine the degree of present variation in a measurement system, with focus on repeatability and reproducibility. To clarify, a Gage R&R study strives to determine the variation within the equipment and within the system (George et al. 2005).

Hammersberg (2014) describes repeatability as the variation in measurements when the same operator performs measurement procedures with the same device, measuring an identical characteristic on the same part, but performing the measurement several times. Hammersberg (2014) continue to elaborate that the difference for reproducibility is the use of several operators but otherwise the same procedure as repeatability. George et al. (2005) agrees with this statement and elaborates that repeatability strives to determine the inherent variability of the measurement system, while reproducibility strives to determine the average variation between different operators when the preconditions are the same.

3.5.3 Linearity

George et al. (2005) describes linearity as the ability of getting consistent results from measurement devices or procedures over a wide range of uses. Hammersberg (2014) describes linearity as the difference between biases through the expected operating range of the gage. In comparison of these two definitions, the meaning of linearity is that the measurement devices should have the ability to receive results with low bias values within the measurement device intended range of usage.

A measurement device might have a drifting degree of being capable to measure, dependent on the predetermined range of use. To perform a study of the measurement devices capability of measuring within this range, a linearity study can be conducted. In the linearity study, the observed measured values should be compared to the true value in some intervals of the range. Within this range, the optimal comparison is zero, meaning that the measured value is equal to the true value. There might appear some deviation along the range of the measurement device use, indicating that the measurement device misreads in some intervals. These misreading's reveals an incapability to measure in these intervals. Once again, the deviation between the true value and the observed value needs to be considered in correlation to the required accepted level of certainty, in order to evaluate the measurement device.

3.6 Key characteristics

Key Characteristics, henceforth referred to as KC´s, is the characteristics of a product that are the key for the products quality and ability to meet the customers' demands. Berglund et al. (2014) consider Key characteristics as the characteristics of a product, that when disturbed by variation can have a perceptible impact on the products cost, performance and safety (Berglund et al, 2014).

Dehnad (1989) promotes that a products quality cannot be improved unless the characteristics of the products are identified and measured (Dehnad, 1989). Berglund et al. (2014), promotes a practice strengthen by Thornton (2004), of handling Key characteristics in three steps, identification, assessment and mitigation. Identifying and disintegrating key characteristics in e.g. flow down charts, enables characteristics of the final product to be disintegrated into sub characteristics. These sub characteristics can further be evaluated towards the risk of interfering variation and possible contribution of this variation for the characteristics. Once identified and evaluated, mitigating strategies can be implemented to reduce or eliminate the impact of the variation towards the characteristics of the products. A practice of this character allows organizations to divide characteristics of the final product into smaller sub-characteristics in the process steps, where variation can be identified and evaluated in order to establish countermeasures to avoid any interference of variation (Berglund et al. 2014).

Berglund et al. (2014) promotes that any characteristics have the potential to be key characteristics, depending on the evaluation of the variation risks of these characteristics. To evaluate the risks of variation, an accurate measurement system is a prerequisite, where the level of certainty of the generated information from the measurements is key to evaluate the risks of variation. To handle and work with key characteristics and identification of key characteristics is therefore strongly correlated to establishing a well-suited measurement system, to enable the practice of identification, assessment and mitigation. Lastly it is also critical for the final products quality that the disintegrated key characteristics are measured accurately and with capable measurement procedures to ensure that the information received as input to evaluate and handle the key characteristics are truthful and accurate.

3.7 Effective scoping

Once an adequate measurement system to generate feedback is established and appropriate methodologies are institutionalized to handle the data, it is essential to ensure a structured methodology to formulate projects affiliated to the data. A key practice for this is the Effective scoping, commonly used in the define phase in Lean Six Sigma projects. Practitioners in the academic field are divided towards if Effective scoping is a tool or a practice, this thesis will use the viewpoint of Effective scoping as a practice, while the SIPOC matrix is regarded as a tool.

Effective scoping is a key practice to determine if the current measurement system is capable of measuring the intended improvements of a project. It is a communicative practice, where team members can create consensus with stakeholders and other personnel in the organization (Hammersberg, 2014).

Hammersberg (2014) promotes effective scoping in order to support the organization to observe the problem with an inside-out viewpoint instead of an outside-in perspective. This indicates that the effective scoping support to zoom out and receive more embracing perspectives when observing the process or problem. Lastly, effective scoping supports to drive the mindset from push to pull (Hammersberg. 2014).

Effective scoping is consistent with nine questions; Hammersberg (2014) divided them into three subsections, namely focus on the output, focus on what to improve and lastly focus on the manning. The first section, focus on the output strives to by answering three questions, to determine who the customer is, what the process does and what will it be used for. The second section, focus on what to improve, strives to answer which measures to improve, which measures can't be lost and can the measures be measured. The last section, focus on the manning, strives to answer where changes can be made, what does the system require and what inputs are supplied (Hammersberg. 2014).

3.8 Pull Approach Model

Generally measurements and information consolidate in an iterative loop. Since information is a key for decision-making, the measurements have to align with the need of information to base decisions. This can be performed in two strategies, where information and data are pushed to the decision maker or the opposite, where the decision maker pull for data and measurements are designed in relation to their needs and interest.

Ericson Öberg (2013) developed a pull-approach for quality assurance, see figure 8. The model emphasize on the intended uses for the conducted measurements, creating a pull for the customers of the information. To stimulate the customers' different interests of data, different methods for presenting the data need to be utilized to form the measurements to satisfy the customers' needs. In similarity of the mindset of effective scoping, the model strives to chronologically address the *who*, *what*, *how*, *what* and *what* before conducting the measurement. In an overview, the method supports to conduct measurement formed for the decisions that follows to be based on the data (Ericson Öberg 2013).

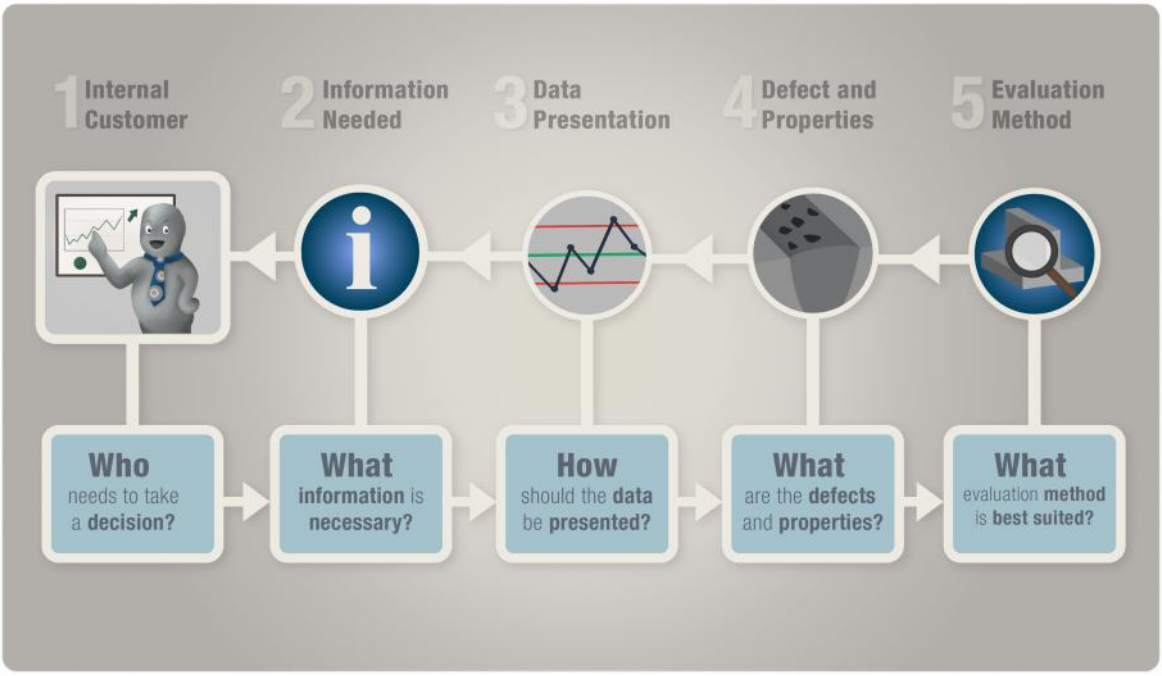

Figure 8 - The pull approach (adopted by Ericson Öberg 2013)

This model support to revere the mindset away from starting by determine on how to measure and on what, to further push the data upstream to stakeholders with the jurisdiction and responsibility to take decisions. Instead the pull-approach promotes the users of the data to express their needs of the data, generating defined needs of information where measurements are conducted in alignment to these needs (Ericson Öberg. 2013).

4. Empirical study

In this chapter, the data collection of the empirical study is presented in a comprehensive description. The chapter involves an observation study, an internal documentation review consistent of three Six Sigma reports, an interview study of internal and external benchmark, and lastly an interview study of the cooperation between design and manufacturing.

4.1 The six sigma projects

Further follows the data collection as a result of one action study in terms of a Six Sigma projects, in combination with reviewing internal documentation of three other Six Sigma projects conducted at GKN, see table 2. One of the projects focused on the same product as the action study, but with different agendas. The other two projects focused on two different products. All the Six Sigma projects followed the DMAIC-cycle, and all receive an equally time frame for conducting the project, even though one of the project was carried out one year before the other three. All the projects performed AIM-sessions, which where a key contributor in the data collection, since it provided data unaffected from the project teams interpretations.

	Six Sigma Project A	Six Sigma Project B	Six Sigma Project C	Six Sigma Project D
Product/Process	Product A	Product A	Product C	Product D
Team members	4	4	5	5
Methodology	DMAIC-cycle	DMAIC-cycle	DMAIC-cycle	DMAIC-cycle
AIM-session	2	2	1	1
Time for performance	First Half 2014	First Half 2014	First Half 2014	First Half 2013
Type of process	Slow phase	Slow Phase	Normal Phase	Unknown

Table 2 – Overview of the Six Sigma projects

4.1.1 The Six Sigma project A

The origin of this research started by an action research in the shape of a Six Sigma project conducted at GKN in the first half of 2014. The project will further be referred to as Six Sigma project A. Within this project team, the author of this research participated together with two students from Chalmers University of Technology, and one industrial participant from GKN.

The objective of the project was to eliminate quality defects at in terms of edge offsets on a sub component. The utilized methodology to achieve the objective was to follow the path of the Lean Six Sigma DMAIC-cycle. DMAIC is an abbreviation of the different phases in the methodology, namely define, measure, analyze, improve and control (George et al. 2005).

The project suffered from an insufficient measurement system, which captivated the project from achieving the stated objective. The measurement system was incapable of generating adequate feedback and data. The project teams were as a result faced with an irredeemable task to assimilate and analyze data, which forced the project to rest the objective of solving edge offsets in the measure phase. The project continued by a derivate path with new objectives, namely to identify the insufficiencies that captivates the continuation for solving the problems with edge offset.

Initially the projects were successful in defining and scoping the project, generally the problems were well known within the organization and areas of interest for investigation already surfaced within the personnel. After scoping the problem, four hypotheses where conducted and settled as the baseline for the project. When the data collection initiated to accept or reject the hypotheses, captivating obstacles started to arose.

The witnessed obstacles were that to initiate the data collection, extensive efforts were required to locate and assimilate data. Predominantly all data of interest consisted in physical written binder located in a diversity of locations within the facility. The availability to order new measurement existed, but was generally affected by long lead times, which were beyond the time frame of the project. The project was consequently forced to utilize the historical data, and apprehend it in alignment to the requirements of answering the hypothesis.

Once the digesting of data initiated, additional obstacles were witnessed. The historical data occasionally lacked in accuracy or a consistent use of reference points. The project team was as a result unable to compare series of data, since the underlying measurement procedures were not coherent. This obstacle was also witnessed for the interpretation of data, were several measurement procedures only focused on determine if the attribute were within limits. Attributes within limits were reported with similar quality index, which captivated the team to determine producibility aspects e.g. inherent variation or process behavior over time. Lastly, it was also witnessed that some of the measurement methods were incapable of fulfilling the purpose of the measurement. As an example, was the method to measure edge offsets incapable of determining if it actually were an offset it had registered, or just an irregularity in the surface.

The outcome and major delivery of the Six Sigma project A was the aggregated change plan. The aggregated change plan consisted of five elements, as illustrated below, and strived to support GKN to enhance a proactive way of working.

1. Understand the process areas where problems origin.
2. Understand the need of measurements in these process areas.
3. Identify the purpose of conducting measurements, which should correspond to producibility requirements.
4. Design adequate measurement methods that fulfill the identified purpose.
5. Assure a unified language.

The aggregated control plan witness of weakness from GKN that generated the problems the Six Sigma project suffered from. Namely that there where uncertainties towards were in the process quality problem origins, as well as deficient data to determine disintegrated process steps producibility. The aggregated control plan also witness of a diverse language and lacking communication when discussing, or requesting, data from stakeholders. In this communication they received answers repeatedly tended to differ. Point 3 and 4 witness that the approaches of the measurement system sometimes lack in planning ahead and establishing thoroughly considerate purposes of the measurement procedure.

4.1.2 The Six Sigma project B

A project team consistent of three students and one industrial participant performed a Six Sigma project in the first half of 2014; the project will further be referred to as Six Sigma project B. The Six Sigma project C focused on the same product and process as the Six Sigma project A, but targeted another quality defect, mainly to reduce cracks in the casting.

The Six Sigma project B initially struggled with setting a baseline for the project, since there were obstacles to identify the level of impact from the quality defects and what possible improvement could contribute with. The reasons for these obstacles were that GKN had an unstructured method for collecting and visualizing the data of the quality defects.

In the Six Sigma project B, two aim sessions were performed were the following discoveries were identified. The aim sessions from the Six Sigma project B revealed that:

- There was a low prioritization towards product and process improvements, compared to the prioritization to produce and deliver products. Problems and defects were not investigated thoroughly
- The concept choice was not elaborated with respect to producibility, instead emphasize was targeted towards fulfilling technical requirements
- Manufacturing preparation for the concept was not allocated, resulting in poor preconditions for some of the process operations

The project team presents a procedure where data was sufficient to identify the quality defects in terms of quantity, frequency and location. But the measurement system was insufficient to generate enough data for the project team to identify the root cause for the quality defects. In other words was the measurement system capable of identifying symptoms of the quality defect but not to disintegrate data to reveal the root causes of the defects. The project team established four hypotheses for the root causes, but was unable to collect enough data, or the correct data, to reject or accept their hypothesis. For example, the project team was successful in identifying deviating components in the fabrication, but unable to assign any data based explanation of why.

The Six Sigma Project B was overall captivated in their data collection, due to the fact that much historical data was in physical form, and not compiled. The collection and assimilation of data shaped much of the activities for the Six Sigma project B, which was also a key contributor to not fulfilling the objectives of the project within the stated time frame.

Even though the project team put low emphasize on discussing measurement data or the measurement system in their report, it is witnessed that 8/19 bullets from their control plan target adjustments to overcome obstacles associated to the measurement system and measurement data. Since more than 40% of their improvement suggestions target the measurement system and the data generated by it, it is likely that the measurement system affected the project noticeable with a negative impact, since they targeted their improvements towards it.

In addition, it is important to consider that the project was conducted at a slow phase manufacturing process, preparing to ramp up in the future. The slow phase manufacturing system was therefore insufficient to generate data out of new measurements, since it took a longer time to perform these in a quantitative amount then the project were able to wait.

4.1.3 The Six Sigma project C

A Six Sigma project performed in the first half of 2014, analyzed vanes as a sub part of a component, this Six Sigma project will henceforth be referred to as Six Sigma project C. The objective of Six Sigma project C were to implement a structured approach towards SPC and data analysis of the manufacturing of the vane. The project operated in a process where quality defects were appearing, and a strong contributor to the situation was a lacking usage of SPC among the supplier.

In the organizational context where the Six Sigma project operated within, there was a lacking cooperation with a supplier. The lack of cooperation created a reactive approach towards handling quality defects. In a historic perspective, the quality defects surfaced in an unpleasant quantity, and there were a lack of focus towards improvements targeting the root causes of these quality defects. Hence, in the occurrence of crises, the counteractions emphasized on reliefs in drawings rather than determining the underlying causes to the problems. Generally the problems to determine the root causes of the quality problems were caused by obstacles in isolating the process steps where problems origins.

The manufacturing process that the project team operated within was recognizable by poor delivery precision and an expanded manufacturing process, causing an increased amount of back-end quality recovery steps. The back-end quality recovery steps lacked in data and measurements, captivating the project team to detect the root cause of the quality problems.

The Six sigma project C identified that the current measurement system target their focus on evaluating part by part, instead of using the measurement system in a statistical process purpose to investigate the entire population. The measurement systems were incapable of disintegrating and register the received products by the supplier in the following categories:

- Disapproved but still delivered
- Undelivered
- Fault-free products

A lack of data regarding the quantity of these categories restrained the possibilities to conduct any comprehensive analyses, leaving Six Sigma project unable to determine the variation and behavior of the process for these categories.

In similarity to the other Six Sigma projects, the Six Sigma project C also witnessed of an organizational situation were the customer and technical requirements were thoroughly evaluated, while the producibility perspectives were subordinate. In addition, they also witnessed the lack of accessibility to digital data and an absence of process monitoring.

The Six Sigma project C conducted an AIM session in order to reveal the biggest problems with the handling of the suppliers' quality problems. The session was participated by a cross-functional team were they developed a mutual answer. The answer was that there was a lack of routines and communication with the suppliers. In addition there were also lack of coordinating and establishing distinguishable roles of responsibilities between GKN and their suppliers. These obstacles were identified as the key contributor to restrain the attempts to improve the current situation

At the end of the performance of the Six Sigma project, the project team delivered several improvement proposals. Summarizing the hand over improvement proposals given by the Six Sigma project C, it is evident that 6 out of 8 where directly connected to measurements, SPC and data storage, while the last two suggestions could be regarded as indirectly connected.

4.1.4 The Six sigma project D

A Six Sigma project conducted at GKN, henceforth referred to as Six Sigma project D, and consisted of a team of one master thesis student, one industrial participant and three students. The Six Sigma project D aimed to improve the manufacturing and assembling of a component, where the objective were to reduce defects and rework.

Within the operated environment of the Six Sigma project D, the measurement system emphasized primary on process inspections rather than process control. This focus leads to the condition that the richest data were the data from measurements performed at the end of the process. The low focus on the process control captivated the project team to collect historical data in order to determine the process inherent variation or behavior of the past. Since the observed process lacked in disintegrated measurements through the process steps, the Six Sigma project D were forced to focus much of their analysis based on the embracing measurements at the end of the process. This captivated the project team to on a data based premises stepwise determine the sequence of events through the sub-processes.

The project witnessed an uncertainty in the reliability in some of the collected data. The weakness consisted of a measurement procedure with high influence of the inspecting operator. An insufficient documentation over which operator that performed inspection for different parts captivated the project teams to analyze the repeatability or reproducibility of the measurement procedure.

The project generally struggled with traceability of the data. A majority of the activities for Six Sigma project D consisted of tracing information from databases. These activities commonly consisted of locating binders; copy papers from the binders and translate the information to digital software to enable statistical analysis. A captivating factor in these activities was that the binders were commonly located in a confidential archive, with restricted accessibility for the project team to entre.

There was also a hesitant relationship to suppliers to exchange data for defected products, forcing the project team to use old historical data, which captivated the project team to receive data that were up to date. The Six Sigma projects deliverables indicate improvement proposals that target primary the communication and the storing of data, but also improvements in terms of organizational knowledge transfer and process control improvements (Rosvall, 2013).

Six Sigma project D describe underlying problems to motivate their improvement proposals, by examining these underlying problems the following findings were identified. Firstly the measurement system was incapable of locating solely articles positions in connection to assemblies. Secondly, the project team faced obstacles in terms of extensive time consumption due to the measurements system incapability to digitalize data. In addition, the Six Sigma project D also suffered from an absence of control charts and measurement system analysis. The absence captivated them from determine historical behavior of process steps as well as affecting by uncertainty towards the reliability and accuracy of historically conducted measurement procedures. Lastly, the Six Sigma project D requested for an enhanced internal and external communication, primary to easier assimilate data.

4.2 The project E

With respect to the confidential restrictions of GKN, this problem-solving project will further be referred to as project E. The researcher participated in the project in form of observations with semi-structured notes and assisting in work task within problems related to the measurement system the researcher entered project E in a state where symptoms in the form of defects were witnessed in the process and creating a perceptible negative financial impact. A problem solving semi-structured team was assigned, where team members had daily meetings and were allocated to target the major part of their attention towards project E. There was a medium-high involvement of top and middle management.

4.2.1 Project E - Historically

In a historic perspective, similar problems occurred last year and a resembling project team was allocated to apply similar methodologies to overcome the quality problems. The project resulted in a successful improvement in several process steps, as well as successful implementation of an improved measurement system for these process steps where the problems occurred. Once the problems were solved, the project team was disbanded and subordinate objectives on the action list were left unsolved.

Previously this year, a project team was assigned with the objective of support to operate the manufacturing process to produce a buffer. Several of the project members involved at this time, were later involved in project E. Once again problem occurred, and similar methodologies and approaches were used to overcome the problems. The project team was recurrently disbanded with objectives on the action list unsolved.

4.2.2 Project E - Measurement System Design

In brief description, the project team was allocated with the objective to solve quality problems and increase the yield of the process. The process can simplified be illustrated as figure 9, where ingoing components were blasted and treated in several chemical baths until the component were ready for delivery. Between some of the operations, there were visual inspections where each component where either accepted or rejected. The rejected parts where lifted out of the process flow for reparations or rework and afterwards looped to a previous operation. In several cases, components were rep-looped more than one time.

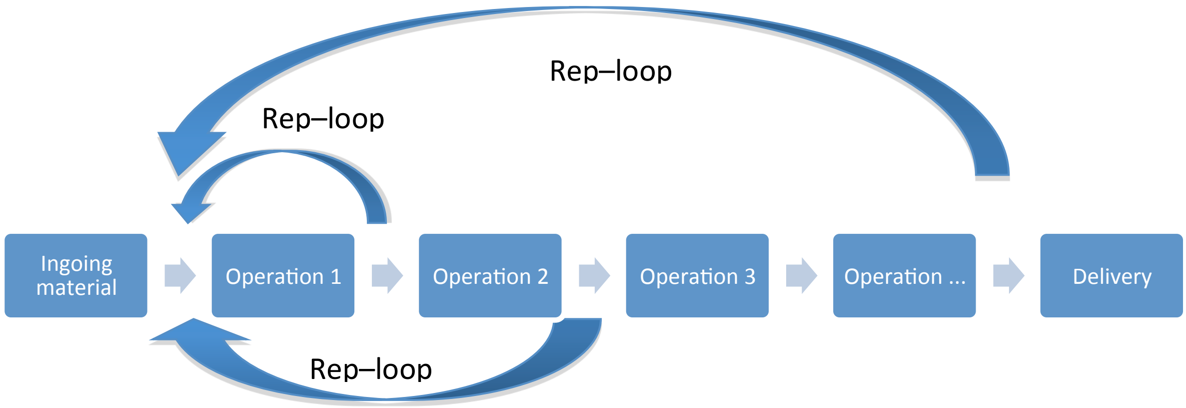

Figure 9 - Illustration of the process flow

There were an unknown amount of components in rep-loops between the operations. The quantitative flow of each distinguish rep-loop were unknown and recognizable by an absence of data to determine the historical amount of components driven through the rep-loop.

An example of the obstacles to determine the quantitative flow of the rep-loops can be illustrated in table 3. The table illustrates how operators, for a confidential amount of time, reported different quality defects that caused the component to be rep-looped. As illustrated in the table 3, the largest amount of reported quality defects where "other reason". This captivated the problem solving team to on a data based premises determine the actual problem causing the defects. The inaccuracy to report where in the manufacturing process the rep-loop existed, or the quantity of each distinguish rep-loop, created a lack of data to determine the producibility for each sub-process. The disposable data in software systems only determined the yield of the process at the final operation, meaning that there was an absence of data to accurately analyze single operations producibility.

Reasonable Cause	Number of defected components
Fault code 1	III
Fault code 2	
Fault code …	
Other reason	IIIII IIIII IIIII III

Table 3 – Check sheet for identified quality defects

Additional observations were that data with essential information for the problem solving team only existed in paper form in a single binder. The binder was commonly located nearby the process operations as the operator's contemporary transcribed measurement result. The information in this binder was crucial for the project team to acquire in order to understand the contemporary situation. For the project team to enquire the data and translate it to digital software for analysis, they first needed to identify windows of opportunities in the time frame where the operators did not use the binder. Further they also needed to transcript the data manually into software. This creates a time-consuming occupation in a severe situation, and forced the project team to lag in their analysis. As the data was transcript and analyzed, the manufacturing process had proceeded to produce new components, which captivated the project team to align their analysis with the contemporary produced products.

Lastly, there was data stored in different systems, generally consisted of information from different steps in the process. With unidentified reparation loops, henceforth referred to as rep-loops, and a lack of accurately reporting these, the number of unreported components generated a disturbance in the comparison of data. In several situations, the different systems of stored data did not correlate when compared. In addition to this, the reported numbers of rep-loops for each individual component did not correlate between the different data systems. An illustration of the phenomenon can be illustrated as figure 10. The figure present different operations and their system of storing data illustrated as a gate. And as unreported incidents appear between the gates, the comparison of data between different gates did not correlate. This affected the project with uncertainty, since the lack of information forced the team to, by intuition, interpret and evaluate the misalignment between different data storage systems. For example, it was difficult for the team to evaluate if a component delivered by gate A, have reached gate B or been extruded by a rep-loop. And the only strategy to determine this was to wait and see.

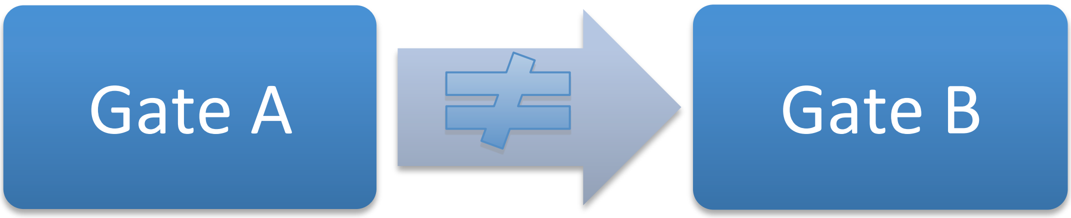

Figure 10 - Gateway illustration of misalign correlation between stored data

4.2.3 Project E, Measurement System Approaches

During the time frame of the observation study, several minor problems arose in the process, creating an unstable environment. The approach of the problem solving team where therefore a mixture of determining the root causes of the quality problems, as well as performing countermeasures to minor problems that arose. As the minor problems received countermeasures, new settings were applied and an uncertainty to overemphasize on historical data affected the project. As a result of this, the need for new measurements arose to interpret the effects and outcomes of the countermeasures.

As the capacity of manufacturing process was lacking, the main focus from the organization was generally to produce components to meet the quantity of the customer demand in time. The majority of resources and efforts were allocated towards this, in the expense of allowing operators to perform additional exploiting measurements to collect information of the process. The operators where highly utilized and under strict time pressure, leaving them with few opportunities to conduct additional measurements. Hence, the project team struggled to understand the historical data, and had low possibilities to order new measurements. Overall, the situation generated a condition where it was difficult for the project team to quickly enquire data to perform adjustments on fact-based premises.

With the small window of opportunities to conduct measurement, the enquiry of information generally consisted of the daily meetings, starting each morning. In these meetings the project team received verbal information of the latest information. Unfortunately, aspects where sometimes forgotten or team members were unable to participate, this created a mismatch in the information exchange. The mismatching information exchange resulted in time-gaps, where responsible process owners sometimes did not receive vital information until it was to late. Overall this created a reactive approach, partly due to two aspects of the insufficient measurement system. Firstly, the team had to wait for verbal information instead of being able to accumulate data from measurement systems on their own. Secondly, the insufficiencies caused time gaps, due to the time it took for the verbal information to reach the responsible persons.

The general activities of the problem solving team consisted of a conduction of a root-cause analysis, fishbone-diagram and action list, which became living documents that evolved as the project proceeded. The project team also collected data, performed calibrations and evaluate machine properties and settings.

Since the perception of the quality problems origin was vague, it complicated the project teams ability to grasp the quality problems. The project team thereby initially had to target several factors at once. The general approach of the project team was therefore to enhance the understanding within the areas that were out of control or where knowledge was deficient.

4.3 Internal and External Benchmark

The questions for the semi-structured interviews used for benchmark are presented in full extent in appendix A.

4.3.1 VCE

VCE, abbreviation for Volvo Construction Equipment, is a company with several facilities. One of these facilities is located in Arvika, Sweden, and will further be referred to as VCE. VCE focuses upon manufacturing components and assembly wheel loaders.

In the manufacturing of components at VCE, there are several welding operations vital for VCE to measure and control. The measurement system at VCE shares some similarities to the measurement system at GKN, even though there are distinguishable differences in terms of apprehending the produced volumes etc. A general similarity is that both VCE and GKN recognize a need to enhance their measurement system and methods to apprehend feedback from their process, and within this similarity they both face similar challenges. From this viewpoint, VCE serves to contribute with possible approaches on how to embark upon similar challenges appearing at GKN, and is therefore vital for the benchmarking of this research.

4.3.1.1 Measurement system design

The measurement system at VCE is consistent of several measurement procedures, both manually and automatically equipment's, e.g. probe machines and operators conducting manually measurements. The data from the measurements is inserted in the measurement system, allowing personnel to visualize data in correlation to their needs. The data system can on the other hand not directly provide graphs or other visualizations of the data, only storage the data. To conduct visualizations of the data, additional software is utilized and requires additional efforts from personnel to assimilate and digest the data.

The measurement system at VCE also involves embracing communication within the organization, where different departments in the organization meets daily and discuss relevant metrics. This communication pattern progressively travels upstream through the organization, until the daily closing meeting participated by management team at the end of the day. By the communication pattern of gradually meetings through the organization, the meetings support to share information but also to create and awareness among the personnel and force problems to surface and not go undetected.

4.3.1.2 Measurement system approach

The underlying belief of VCE that drives their practice of measurement system is that, to be able to base decisions on fact - information needs to be enquired. In that aspects, the measurement system provide the organization with information, and by terms becomes the essential core for generation of information.

For this underlying belief, there is a correlating approach of pull for data. Instead of pushing data on personnel to analyze it by unclear or vaguely understood preconditions, stakeholders and decisions makers are forced to pull data from the measurement system. By pulling data, the customer of the data is forced to define what he or she needs, and in which context the data strives to answer their questions. The pull approach supports to customize the data to enable information for the decisions of the customer of the data. The pull approach also supports to force customers of data to review their request of data and thoroughly think through their needs of data in order to achieve the right information to base decisions.

VCE also emphasize on visualizing the data into illustrations that are easy to communicate information through. They recognize that without communicating the information generated by the data in a visually and understandable structure, the preceding effort of assimilating and analyzing data is wasted since the information behind the data could not be apprehended.

VCE´s pull approach of analyzing data in combination with internal workshops related to process development and measurement system, results in progressive efforts to raise the floor within the organization. Historically VCE faced a similar transition in their change of manufacturing methodology as GKN, where additional process steps in terms of welding were added in order to disintegrate the manufacturing of their products. To support the measurement system to apprehend this transition, efforts were required to raise the floor within the personnel to create awareness within the organization. The extensive communication pattern of progressively traveling of information, in combination with the pull approach for data, has supported VCE in apprehending the measurement system in this transition of manufacturing technology.

To continuously develop, VCE utilize the opportunities to standardize improvements. By standardizing improvements, they continuously enhance their processes by terms of performance and quality. By standardizing improvements, the continuously receive new baselines to use as references for prospect improvements. VCE place emphasis on institutionalize the improvements, and not until there are used and spread in reality within the organization.

4.3.2 NEVS Automobile

NEVS, an acronym for National Electric Vehicle Sweden, is a company located in Trollhättan. NEVS is an automobile producer that differentiates by producing environmental friendly cars with focus to manufacture electrical cars, and to continuously carry the legacy of Saab Automobile (NEVS, website 2014-10-27).

The production flow capacity at NEVS, and former Saab automobile, exceeds the production flow at GKN. This generates differences for the underlying purposes and appropriate practices for the usage of measurement systems. However, some occupations are still the same independent of the produced volume, only implemented with a different perspective and therefore serve a degree of relevance for the benchmarking.

At NEVS, the measurement system serves of great importance in order to become acquainted with the products and processes, which is the key precondition for future improvements for the product or process, according to NEVS.

4.3.2.1 Measurement system design

The core of the measurement system is designed by measurements in several measurement points, where each measurement point has identification. The final products requirement is disintegrated into sub-requirements the entire path down to single components. The identification measurement points can further be traced through the entire path.

All measurement procedures report the measurements into digital software, or are directly received as output from machines. Hence, there is an absence of physically reporting measurements in e.g. binders. All the data is stored in software, where a broad range of the personnel has access to the data. The software is designed in collaboration with suppliers, to enable a smooth transition of data exchange between NEVS and their suppliers. In this software, there are user-friendly visualizations of the components and assemblies, within all the measurement points can be located and identified. The software allows data to be extruded by other personnel, only minutes after the measurements have been inserted in the software.

Within the measurement system, NEVS utilize both measurement machines and manual equipment to conduct measurements. For both, they emphasize to ensure that all measurement procedures are carried out the same, in order to enable comparison between data, and not between different methods to conduct measurements. Among the measurement machines, they utilize inline systems, which capture measurements on 100% of the produced population, in order to monitor and capture the internal variation in the process. The measurement system is also designed with alarming features that alerts the organization when components are without tolerance limits.

4.3.2.2 Measurement system approaches

An underlying driving factor for NEVS to conduct measurements is to create a foundation of statistical data to enable fact-based decisions. NEVS never take decisions or perform adjustments based on single measurements or measurements on single articles, leading to the condition were decisions are always based on a statistical foundation of several measurements.

NEVS also focus extensive efforts to define the final requirements, with focus on the customer’s perceptions of attributes and quality. These requirements are further disintegrated down to sub requirements through the manufacturing process chain. This enables NEVS to monitor the manufacturing process and predict the result in early process steps in correlation to the outcome at the final requirements. As support to work with this is by the usage of an extensive reference system, where all measurement points can be compared to nominal model, and accurate identification of the components deviations can be evaluated.

After each problem solving or improvement project, NEVS conduct evaluations of the project. Within these evaluations, they identify the obstacles faced by the project, and suggest improvements on an organizational level they identify as desirable to easier conduct projects in the future. They also identify objectives and occupations they desire to involve for future projects, e.g. to enquire more knowledge about sub-processes. Each of these objectives are evaluated and inspected before any future project is started.

Lastly, NEVS target extensive efforts to ensure the reliability of their measurement systems. They therefore conduct repeatedly MSA studies on their equipment's and personnel in order to ensure that their measurements accurately reflect on the real world, and endure the tolerances of each measurement requirements.

4.3.3 GKN´s internal F Process

A process at GKN, henceforth referred to as the F process, is internally known for its successful control of measurements and well-suited measurement system. The F process was chosen for benchmark for its applicability to answer how a well-managed measurements system can be designed, with the knowledge and preconditions available within the organization. The project F shares some similarities of the observation study in Project E, but with an enhanced measurement system.

The F process is recognizable by high involvement of complex methods and machines, where the outgoing product should fulfill strict tolerances. The F process can be simplified illustrated in figure 11. For the ingoing parameters, a Design of Experiment practice is carried out, to identify key contributing factors to the final product to identify the optimal level of these parameters. For the machine settings, a continuous use of SPC is utilized, to identify the impact of different settings, but also to continuously be able to adjust the process in purpose to improve it. By disintegrating the process, and open process windows where inspections and measurements are carried out, the measurement system is able to monitor the process producibility through the process steps.

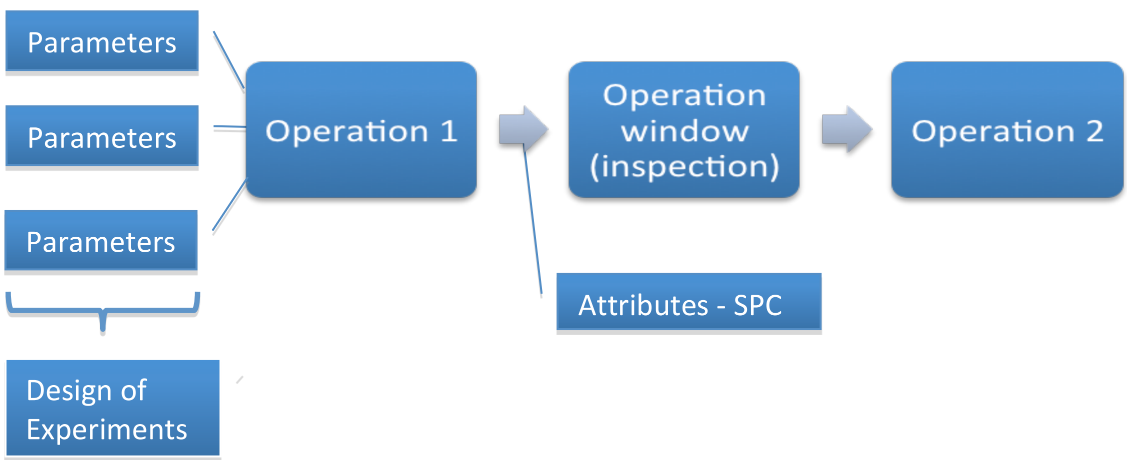

Figure 11 - The practice of the F process

4.3.3.1 Measurement system design

A few years ago, the process team and a consultant firm developed a custom made SPC software for the process needs. This software has been continuously modified and evolved into the core of the current measurement system. The current design of the SPC software is able to trace all components and their outcome of all the process steps. The data in the SPC can user-friendly categorized attributes into groups, where products produced by different operators can be visualized or illustrations of the outcome in different time frames etc. Lastly, all the personnel have access to the data system, but only a few responsible person has the permission to insert data, e.g. operators. In this data system, there is a large focus in designing the software user friendly and easy accessible.

The measurement system has an absence of hand written documentation, meaning that all data is inserted in software, and none is inserted into any physical form. To achieve this, the measurement system has computers located at the stations were measurements are conducted. When measurements data is inserted to the software, the documents are frozen, and the operator can only insert data that is purposed for the measurement procedure.

Some of the measurements are targeted to attributes that are hard to detect without destroying or harming the product. Therefore, usage of test pieces is integrated in the process flow through different operations, where inspections and measurements can be carried out on the test piece and expose information about the operations level of achievement for the other parts.

4.3.3.2 Underlying beliefs and approaches

Within the personnel of process F, an underlying belief is that a few people cannot solve all problems, but instead all personnel needs to collaborate and work together to overcome the problems and improve the project. This belief results in an environment where all personnel see their role and involvement in the effort of achieving a successful process.

An underlying belief and approach of the process and its personnel is that it is impossible to understand and control every aspect of the process. Variation will interfere by chance, irrespective of how well the process is designed, or how well operations are carried out. Hence, an understanding for the summary of all variation at each process step needs to be understood. To be able to live with this interference, the ingoing aspects need to be under control, by Design of Experiments analysis, and the settings of each operating machine needs to be supervised by SPC. This enables the personnel of process F to control the aspects that are controllable, but also to monitor the variation in each process step, and conduct adjustments and countermeasure when the interference of variation increase above the acceptable limits. By having SPC on the outcome of different process steps, it is easier to identify where problems origin, and where efforts should be targeted in order to stay effective. There is an understanding among the personnel that any implemented adjustments that is not based on the summary of all the variation, will only leave the improvement to chance. The personnel emphasize that without measuring every step, they would not be able to accurately know where they started before they implement an improvement, and would not have any truthful reference to compare with after the improvement is implemented, affecting the improvement with a degree of uncertainty.

Firstly, a key to success according to the F process is to visualize data so everybody can interpret and understand it. The key lies in understanding that the engineers are not the only personnel that should be able to understand it; rather it should be illustrated in a design that all personnel can grasp the information of the data. If everybody involved can observe the data, an enhancement of the understanding of the process is achieved, and fewer aspects are left to intuition or guessing. Generally, process F experience that the visualization of data and every personnel access to observe all data increase the awareness of all the personnel involved.

The second key to success is to establish the mindset that everybody has a roll in the process, and understands the need to perform measurements and the contribution of these tasks to the entire process work. The measurements also affect the operators with a level of comfort, since it enhances their precondition of knowing before any operation if the outcome will be successful or not. It also supports the operators of determining patterns and trends, leaving them able to alarm before any large malfunction.

The personnel within the F process witness difficulties to spread their knowledge throughout the rest of the organization. They do not witness any extensive interest or need to share their knowledge from other key persons. And without the request, or pull from the organization, a small degree of the information is spread through the organization. The F process, sometimes experience themselves as a company within the company.

4.4 Interview study of cooperation between design and manufacturing at GKN

Four interviews were conducted with personnel from design and manufacturing in order to determine the organizations ability to embark on concepts of e.g. producibility, measurability, but also to identify roles of responsibilities. Further follows the comprehensive outcome of the semi-structured interview study of the cooperation between design and manufacturing at GKN. The full extent of the questions for design can be read in appendix 2, and for manufacturing in appendix 3.

4.4.1 Designs viewpoint

Design initiate their work by negotiating with customers and cumulative develop a concept. The first received definitions of the concepts are commonly vague, which originate collaboration with customers to develop a concept that fulfills the technical requirements and customer demands. In this progress, aspects like e.g. strength, life length, and geometrics are primary focused upon. This results in clarified and accurate requirements and tolerances for the concepts before it reaches production. The producibility aspects on the contrary lacks in accuracy and clarification mainly because they are apprehended as organizational limitations rather than requirements.

Internally in the organization there is an extensive work to develop a strategy towards which concepts and methods the organization should be industrial superior at. This indicates that there is cooperation between different projects within the organization to enhance the organizations ability to develop concept by the usage of industrial competitive methods, e.g. fabrication.

Designs work methodology is strongly shaped by their design practices. The design practices are used as guidance throughout their work procedures. The design practices therefore influence the breakdown of requirements and settlements of tolerances. Occasionally the customers also influence these design tolerances to shape the methods to their needs and requirements.

Design has caution to avoid breaking down requirements to far downstream into sub requirements, since this occasionally can influence to lose perspective of miss out on the overall objectives. The main objective of design is to develop concepts that fulfill technical requirements and customer demands on product level. To overemphasize on the sub-level requirements can result in optimal settings for the sub-requirements but misalign to the top-level requirements. To avoid this the top level requirements are primary prioritized and thoroughly worked up on in order to fulfill safety, customer demands et al. Producibility aspects is as an result perceived as limitations that the organization should internally work to overcome in order to produce the concept. Basically this priority builds on the fundamental precondition that if the concepts do not fulfill technical and customer requirements, the company will not be able to sell products and stay competitive.

An obstacle from designs viewpoint regarding the cooperation with manufacturing concerns the communication of the processes capabilities and capacities. Design sometimes perceive that there is a lack of knowledge and awareness regarding processes capabilities, which captivates them from truthfully determine if their concepts are producible in alignment with the stated financial and technical perspectives.

Design perceives that the cooperation with manufacturing is strongly reliant on interaction. This indicates that the progress of the cooperation is strongly reliant on the participated stakeholders' competences, awareness and ability to communicate becomes essential.

4.4.2 Manufacturing's viewpoint

Manufacturing initiates their work by receiving concepts by design. Generally, the occupation of manufacturing is to determine how the concepts should be produced. From manufacturing's viewpoint it is commonly witnessed in the concepts that strength and cost aspects are thoroughly analyzed by design, but with a lack of attention towards producibility aspects. Within this lack of producibility aspects, it is commonly overlooked to involve aspects of the current processes capabilities and range of use. This lack of producibility consensus between manufacturing and design, force manufacturing to initially determine questions of if the concept is possible to manufacture, rather than how the concepts should be manufactured. Overall, this forces the progress of manufacturing products to cumulative enquire knowledge an adjustment late in the concepts life cycle, sometimes even just before serial-production. From manufacturing's viewpoint, they crave for a methodology of initiating by determining the available processes´ capabilities and accommodations to perform the required tasks. And out of this evaluation on single articles and processes, settle tolerances upstream trough the assembling to the final requirements. An illustration of the progress is presented in figure 12.

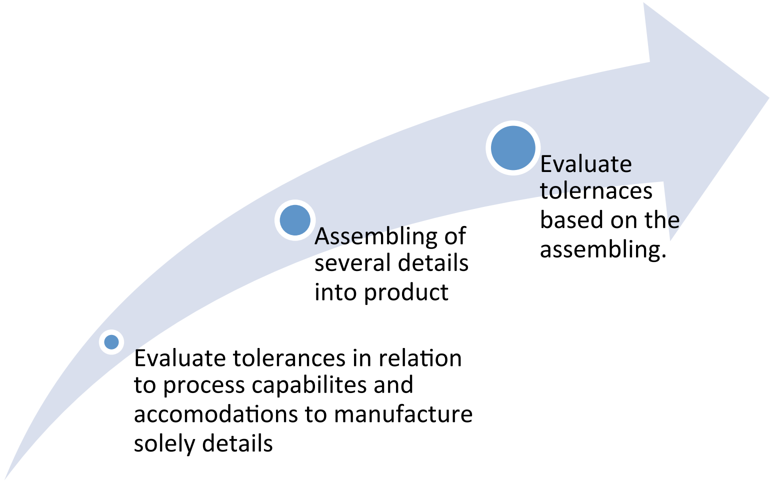

Figure 12 - Manufacturing's desire for developing concepts

In reality, manufacturing witnesses a reversed work path to settle tolerances, see figure 13. Generally starting from the requirements on final product and settle tolerances in alignment to these requirements. Further the practice continues to break down these tolerances trough the assembling, and conducts tolerances on single operations and details based on these. To clarify, this indicates that tolerances are settled downstream. The problematic with this approach is that the concepts occasionally miss out to thoroughly involve the processes capabilities and capacities to perform the work tasks. The current approach is illustrated in figure 13.

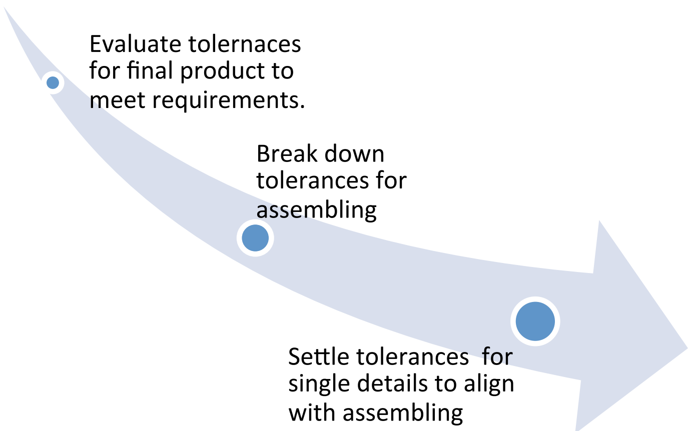

Figure 13 - The current approach for developing concept as interpreted by manufacturing

An overall baseline for the communication between manufacturing and design is that strength and cost calculations outweigh estimations of producibility. An underlying contributor to this situation is that the cost and strength analysis are commonly easier to conduct, while the producibility parameters are hard to enquire without statistical data. An overall embracing occupation for manufacturing is therefore to enquire this statistical data, to strengthen and influence the concepts and products with the interests of manufacturing.

An embracing obstacle for manufacturing is that the products are produced through a long time frame consistent of several years, which result in reorganizations within the projects

and different personnel enter and leave through the projects life cycle. Manufacturing therefore suffers from a lack of stability, where the awareness and competence among the projects iterate in loops of low and high.
A generic obstacle about the communication and collaboration between manufacturing and design is the requirement of awareness and competence. Once mismatch in communication and cooperation occurs, it is commonly due to an absence of awareness for the other departments' interest and occupations. An example identified to through the interviews is when design determines tolerances based on models expanded in software. Once design and manufacturing meet and observe the physical product, awareness is created towards to physicals components relation to the tolerances and renders possible negotiation for mutual agreements towards which tolerances aligns with the different departments' interest and capabilities.

4.4.3 Generic cooperation and communication between design and manufacturing

Within GKN´s organization, there are several product projects running with different levels of success. Sometimes the collaboration and communication in these projects are successful and other times more struggling. In order to increase the generalizability of the received answers, a holistic view was utilized in order to develop a model to describe the organizational context.

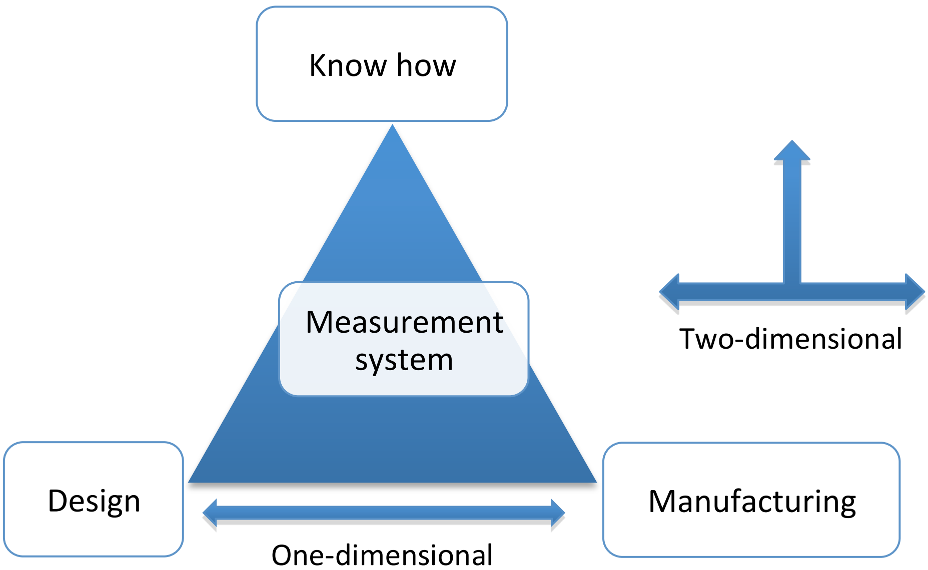

Figure 14 - One and two dimensional communication patterns

The communication pattern used today is generally in one-dimension, indicating that the communication goes back and forth between design and manufacturing, see figure 14. Designs in general develops a concept and propose it to manufacturing, manufacturing further test and evaluate if the concept is producible, rather than determining how they should produce it. By adapting to a two-dimensional communication pattern, the cooperation will have enhanced preconditions to utilize the "know how" and ease the current negotiation. This indicates that manufacturing would be required to conduct measurements and establish rich information of the occupied processes capabilities and capacities. This information can further ease designs work of evaluating methods and design practices. The “know how” should serve as a technological platform, were responsibilities are shared to held it updated and conformed to the developed concepts.

5. Result and Analysis

This chapter will start by presenting the result and analysis of the empirical findings in order to construct a general current state map. This will be followed by a categorization of identified insufficiencies. The chapter will continue by conducting a future state map. Lastly the chapter will elaborate on the correlation of the insufficient areas, and suggest a new model to illustrate a more appropriate approach to use a measurement system.

5.1 Result of Empirical Findings

The objective of this research was to analyze the measurement system at GKN with the approaches and methodologies used to handle the measurement system. The aim of this was to identify insufficiencies that restrain improvement projects to achieve their objectives. By the research data collection and literature review, a current and future state map were conducted in order to visualize the gap and bring insufficient areas to surface. The division of the activities connected to research questions can be illustrated in figure 15.

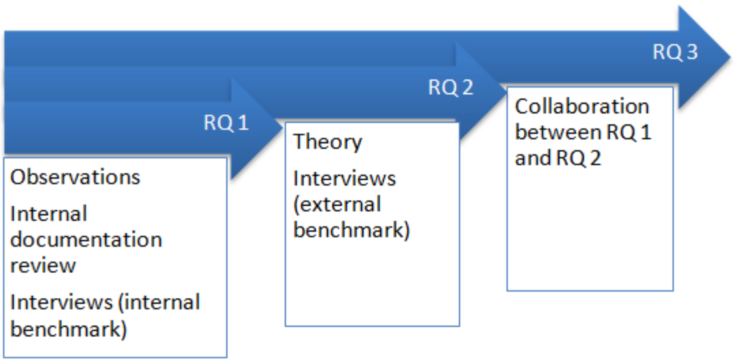

Figure 15 - Correlation between research questions

5.2 Current state map of GKN´s measurement system and approaches

By merging the different cases in the empirical study, similarities and tendencies were identified and will further be presented to reveal insufficiencies in the measurement systems design and approaches.

5.2.1 Current state map measurement system

Further follow a generic description of the current state measurement system, observed from a holistic perspective with low detail orientation. The current state is illustrated in figure 16.

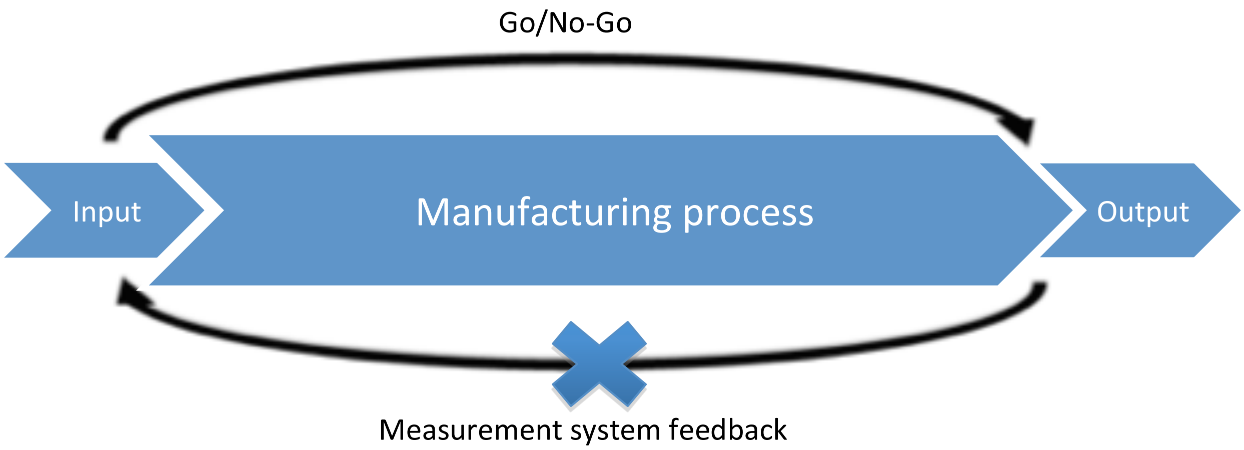

Figure 16 - General illustration of current state

The assignments of manufacturing are commonly based on concepts and tolerances that have been set by design. In this design work, the tolerances for the final product shape the tolerances for details downstream. This results in tolerances that are sometimes in misalignments to the capabilities for the processes within manufacturing. To overcome this manufacturing has occasionally settled their own tolerances, commonly more strict and shaped by intuition, in order to enabling assembling in later process steps. The misalignment in the communication between manufacturing and design often result in a lack of intercepting producibility aspects and impound internally settled key characteristics, which generally shape the prerequisites for manufacturing. In an overall perspective the input box is shaped by a lack to engender control for producibility aspects, forcing the manufacturing to produce products without distinguishable facts to steer their processes or compare their measurement towards.

Once the ingoing material enters the manufacturing process consistent of several sub-processes, the ingoing materials undergo the transition to an assembled component ready for delivery. At the current measurement system there are several untraceable components traveling through rep-loops throughout the process. The manufacturing process is commonly consistent of a comprehensive quality check at the end of process, purposed to capture all the defected products and ensuring zero defects among the delivered products. Defected products in this quality check are lifted of the process flow and send downstream for reparations or rework. In addition to this defected products identified earlier in the process flow are commonly extracted in earlier process steps, creating a degree of unknown products traveling back and forth within the process.

Within the manufacturing process, the conducted measurements are generally purposed to determine the level of achievement of technical requirements for different characteristics, but with a lack of attention to determine the performance in relation to nominal. A key contributor to this approach is the intuition based tightened tolerances, which are caused by unfinished concepts, and required to fulfill in order to make able the assembling of the products. This generates an environment where the nominal model as a reference occasionally falls out of relevance, since it does not correlate with the necessary compensations performed within the manufacturing process. In practice, this means that measurements are not compared to target or nominal since the nominal does not ensure that the assembly will be able to manufacture in later process steps. As a result of this, measurements are rarely conducted to determine the producibility of different sub-processes, rather than determine the level of technical achievement, leading to a situation where all the measurements within the tolerance limits receive similar quality index. By focusing on single components level of technical achievement, there is also a lack of understanding for the need to monitor and control the sub-processes variation throughout the entire population.

The manufacturing process itself is consistent with few process windows of measurement to conduct producibility measurements, in other words the manufacturing process is weak in its disintegration to cover measurements between the process steps. The absence of this data affect projects with restrains by low accessibility to determine parts transition to assembly. The accessibility of data is also extensively affected by the data storing system, generally consisted of physical written documents in binders. The all-embracing quality assurance at the end of the manufacturing process often generates rich and accurate data about the products, and is commonly accessible digitally by data systems. On the contrary, the data for disintegrated process steps is commonly stored physically in binders, creating captivating obstacles to trace and assimilate.

With the financial driving forces for deliverance to meet customer demands, the prioritization for manufacturing is generally to close any gaps in the production flow. Once quality problems surface the financial aspects becomes predominant and resources are allocated to close the gap. Hence, the resources and activities to determine the root cause for the problems and conduct new measurements becomes sub ordinary. In an overall perspective there is a short-term orientation saturating the practice of handling quality problems. The focus is predominantly on the contemporary process yield, and not on the long-term performance of the processes. An underlying contributor for this is once again that the strength and cost analysis of the products is interpreted superior to the analysis of processes producibility and capabilities. As a result, the process variation is occasionally not embarked upon, leaving the process vulnerable for when variation exceeds beyond the desirable control, and generating repeatedly appearing quality defects for the produced products.

5.2.2 General approaches and procedures of projects

As previously mentioned, the majority of projects to solve quality problems, or improve deficient processes, are allocated after the problems have surfaced, indicating that they are often of reactive characteristics rather than proactive characteristics. In this scenario, two distinguish features affect the outcome of the project. Firstly, the teams are often allocated late in the product life cycle, where it by fact is more difficult to implement changes and improvements. Secondly, the project teams are often consistent of personnel external from manufacturing. The personnel at manufacturing do not have the time or resources to handle both the improvement project to solve uprising problem, and at the same time close up the gap caused by the problem in manufacturing. The focus of the manufacturing personnel is therefore targeted towards closing the gap in manufacturing, and allocates external personnel from other departments to solve the quality problems. Since much of the data is written physically in binders, external personnel's knowledge and awareness about this data is insufficient. This causes project to initiate extensive efforts to achieve knowledge about the data, e.g. location, existence of data, as a precondition to start the effort of assimilating data in order to conduct analysis in software programs. The external personnel also have low awareness of the contemporary performance of the manufacturing since they are often situated apart from the manufacturing facility, creating a lag where information often reaches projects with a delay. Overall, this approach generates an environment where the people in contact with the problems are rarely the people allocated to solve the problem.

To summarize the current state, there are insufficiencies in the measurement system, which forces the organization to react on problems rather than working on preventing them. There are underlying financial driving forces which predominantly allocate resources to close the gaps in manufacturing when quality problems surface. When problems occur and a lag in the production flow appears, the focus of the personnel at manufacturing is to catch up the lag and meet the quantity of the customers demand. This captivates them from performing additional measurements to determine the root cause of the quality defects. This commonly results in a situation where resources towards investigating the problems on a data based premises become subordinate. Due to this priority, external personnel of manufacturing are allocated to investigate and solve the quality problems. The externals personnel's lack of awareness and contact to the problem, in combination with the measurements systems incapability to generate feedback of the process generates captivating obstacles for the project. In an overall perspective, the lack of a data driven methodology to detect sources of variation and enabling control of process, puts GKN in the conceptual loop presented in figure 17.

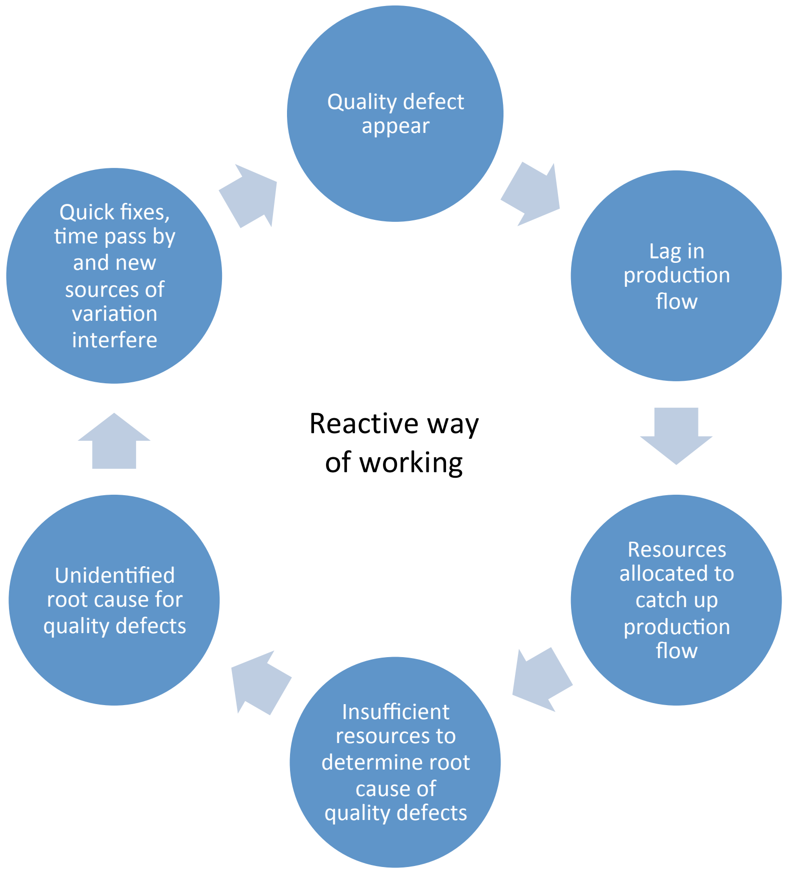

Figure 17 - The current way of working, illustrated in a reactive loop

5.3 Analysis and Categorization of insufficiencies

To gain new perspective on the identified obstacles in the empirical study, the research will further analyze and categorize the insufficiencies. By categorizing insufficiencies, the research will enable the possibility to identify affinities and underlying forces for the insufficiencies. The identified insufficient areas are briefly presented below in table 4.

Category	Description
Time consumption	Concerns factors caused by the measurement system, generating unwarranted additional time for projects to achieve their objectives
Lack of measurability	Concerns factors where project teams were unable to use data in correlation to the purpose of analyzing the data, e.g. as a cause of inaccurate measurement procedure
Lack of traceability	Concerns areas of insufficiencies to disintegrate measurements into smaller sub-parts.
Incomprehensive communication	Concerns areas where measurement insufficiencies cause the need for verbal communication to exchange information, and uncertainty that interfere by this.

Table 4 - Categorization of insufficiencies

5.3.1 Time consumption

The extensive usage of storing data in physical form is through the empirical study identified as a key contributor for time consumption. Several projects were shaped by large time-investments in order to trace, locate and translate data from binders. A great amount of time is used on activities like these with low value addition for the objectives of the project. In the internal benchmark, activities of tracing, locating or summarizing data were already performed within the measurement system.

A second weakness in terms of time consumption caused by the usage of physical storage of data is the generation of time gaps in the traveling of information. The measurement procedure where the measurement data is by hand written on papers and put in binders, commonly exclude the spread of information of the data. By the time the data is located and read by other personnel, e.g. stakeholders or process owners, a long time gap is generated since the manufacturing operation was performed. The time gap leaves the organization vulnerable in primary two factors, firstly, problems are allowed to undetected grew by this time frame, and secondly it forces projects to lag when collecting and interpreting data creating a situation where the investigation is infrequently up to date.

A general obstacle out of a holistic view of the measurement system is that many of the man-hours required to trace, collect and analyze data is caused by unstructured approaches to handle the generated data.

5.3.2 Lack of measurability

A strong underlying contributor to the lack of measurability is the emphasis on determining the level of achievement of technical requirements. Occasionally this generates binary measurements where the reported measurements align with determining go/no-go for the product. In terms of determine the producibility or capability of sub-processes; the binary measurements reveal inaccurate results for studies.

The design of the measurement system and measurement procedures to report level of achievement for technical requirements generates accommodations for how to perform and report the measurements. In practice this can be witnessed where products are only reported as extracted for reparations, but lack to inform how large the deviation were from target, where in the process it was extracted etc. The problems with lack of measurability are also witnessed in practice in terms of lack of using the same reference points when conducting measurements. By using different reference points, an acceptable level of certainty can be attained to determine the level of achievement for technical requirements when analyzing products solely. But when the measurement data is purposed to analyze the variation of the population, measurements errors like these affect the data analysis with a larger uncertainty.

In the design of the measurement system, it is often allowed to only report the largest deviation. Basically this means as an example that several points are measured on a surface, but the drawings only demand that the most deviated point is reported. And as only one point is reported, the usage of historical data of these characteristics often became deficient to determine the producibility. To only report the most deviated point can be illustrated as reporting the tip of an iceberg from the viewpoint of information value. Much is missed out when the data only presents one point of an entire surface. Asymmetry or unevenness is hard to determine based on the reporting of one single point. This measurement system design of only reporting the most deviated point, or only reporting points outside of tolerance, often result in irredeemable work efforts to determine the quality of the process and the producibility of the process.

5.3.3 Lack of traceability

As witnessed in the observation study and several of the Six Sigma projects, a repeatedly appearing obstacle is the lack of traceability in the measurement data. Several of the projects were incapable of disintegrating data and trace assemblies into single articles, due to undocumented procedures in the processes, e.g. which part where assembled at which position.

In a general perspective, there is a lack of information in the reporting of data in order to trace products upstream and downstream through the manufacturing process. By the lack of this traceability, several of the cases in the empirical study stalled in their analysis due to the incapability of disintegrating data in order to determine affiliation between data from different sub-processes. A general obstacle for projects to analyze data is the measurement systems inability to compare different sources of data. Without the information of which parts that were jointed together, comparisons of outcomes in earlier process steps becomes irredeemable.

The lack of process windows in terms of conducting measurements to determine the outcomes of sub-processes generates captivating obstacles for project teams to determine products transitions from single part to finished product.

Another captivating factor with the measurement system is the extensive change of serial numbers of assemblies in the transition of the manufacturing process. As the components proceeded through the manufacturing process, in some cases it changes serial numbers, which creates a traceability problem. To trace a single component downstream is generally possible but difficult, but to trace a component upstream, from start to stop is in many cases unachievable.

5.3.4 Incomprehensive Communication

Several of the Six Sigma projects witnessed obstacles in the data collection due to communication. A lot of the information exchange is by verbal communication. Generally this is information exchange to locate data, determine existence of data or to receive up to date information about a process. The extensive use of verbal communication as an information exchanger is partly caused by insufficiencies in the measurement system. In the Six Sigma projects, a lot of data existed in binders and the digital systems were incapable of revealing were the physical data was located. Project teams are therefore driven to find personnel with knowledge about the existence of data, as well as the location of the data, e.g. where in the factory the binder is located, who has the keys to the locker of the binder etc. All the Six Sigma projects witness of extensive efforts to inquire data of this sort, and the value of these efforts is generally of a low level for the projects objectives.

The patterns of communication also affect projects with uncertainty, partly because when requesting for data, the existence of data is based on individual knowledge of personnel. But also due to the witnessed obstacles that the questions of data receive different answers, depending on whom is asked. In several occasions, project teams asked personnel to locate data, only to receive the answer that the measurements do not exist, while the truth was the opposite. With a physical data storage system, unable to digitally trace data, much of the knowledge of data becomes reliant on personnel's knowledge and fragile memories.

5.4 Correlation of insufficient categories

The origins of the shortcomings in the measurement system are hard to pinpoint and prove by fact. In general they can be observed as an organization disorder, from that viewpoint the shortcomings are likely to origin as a cause to how the approaches towards measurement system is characterized at GKN. In an overall perspective is the measurement system successful in quality assurance and ensuring zero defects among the delivered products. The reason for this success depends most likely on the context that this is how the organization interprets the purpose of working with measurement systems. But in the purpose of apprehending feedback from the measurement system, it is no longer interpreted as a predominant purpose for the measurement system. The focus on quality assurance rather than generating feedback, permeate the organization, which leads to the situation were the measurement system is interpreted as an toolbox rather than a strategy for attaining information.

The interpretation of a measurement system as a toolbox, results in captivating obstacles from the spread and exploit of information. As witnessed through the research several of the measurements are conducted to evaluate a parameters location towards the tolerances. The information of this measurement supports to accept or reject the component, but it does not support the organization to continuously develop since the information rarely reaches any further in the organization.

This is most likely the reason why the insufficient categories exist in the current measurement system. By interpreting the measurement system as a toolbox, concepts like producibility, measurability and traceability tends to be missed out and is therefore not received proper resources and attention, which leads them to be insufficient.

5.5 Future state map of GKN´s measurement system and approaches

To enhance the producibility of the process in the future, an initial step will be to enhance the measurability of process. To enhance the measurability of the process, the process needs to be disintegrated with additional measurements between different sub-processes, see figure 18. By disintegrating the process and the measurement procedures, an increased knowledge can be attained, and it will ease to projects team to explain drifting factors through a shorter time frames.

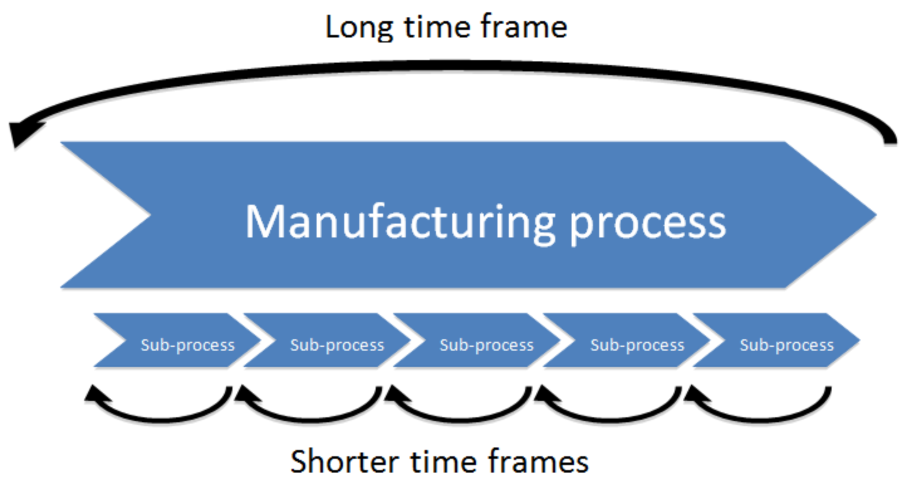

Figure 18 - Disintegrating process steps to achieve shorter time frames

It is an extensive and effort demanding task to collect the recorded data for occurrences over a long time frame. Also this complicates the progress of assigning reasonable root causes, since a large time frame adds several operations and therefore a multitude of parameters to involve. By degrading the process and analyze sub process apart, the time frame between the sub processes reduces severally compared to analyzing the entire manufacturing process singularly. With a decreased time frame, the number of involved parameters also reduces, and the effort to assign a reasonable root cause is reduced, creating a more confident condition to understand the process and enable improvements.

Once measurability of the characteristics within the process is attained, the practice of SPC could be applied. The usage of SPC can be a key contributor to enhance the proactivity in GKN´s way of working, see figure 19. A SPC consistent of control charts monitoring the process steps can enhance the prosperity to control the process steps and identify the optimal settings for the manufacturing process. In the SPC, patterns and tendencies can be visualized, and efforts can be allocated before products fall outside specification limits. By using control charts in disintegrated process steps, or process windows, the effort to identify where the variation origins will ease, and countermeasures can be allocated faster and more efficient. In other words, project would be able to avoid "turning every rock" to locate the origin of root cause for variation, since the SPC will support to illustrate where in the manufacturing process the variation is first emerging.

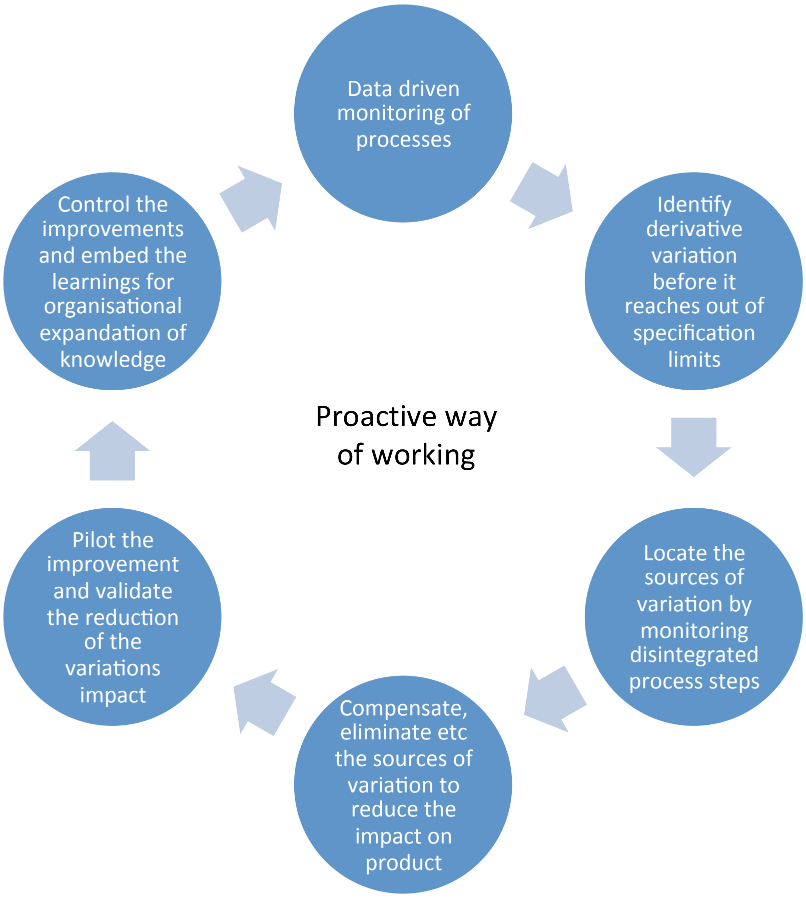

Figure 19 - A future state of working with SPC, illustrated as an proactive loop.

5.6 Measurement system as a principle, practice and tools

Hasenkamp et al. (2008) present a pyramid model of Robust Design Methodology in terms of principles, practices and tools. Each level of the pyramid strives to answer questions of why, what and how. In this model, the principles represent the overall goal, the tools represent the different available tools and the practices should interconnect the available tools with the goals. Hasenkamp et al. (2008) continue to elaborate that the practices should clarify the purpose of why to use the different tools (Hasenkamp et al, 2008). For this thesis, a modification of the model is conducted, in order to visualize how the measurements system can be witnessed as something profounder than only a toolbox, see figure 20.

The models strength lies in ability to present how the focus should go from principles to tools instead of tools to principles. In practice this means that the organization should start from its principles, and break it down to the activities and tools used to reach elements of the overall goal, namely the principles.

The model should serve to disintegrate the overall goal of the measurement system and the approaches of working with data into practices.

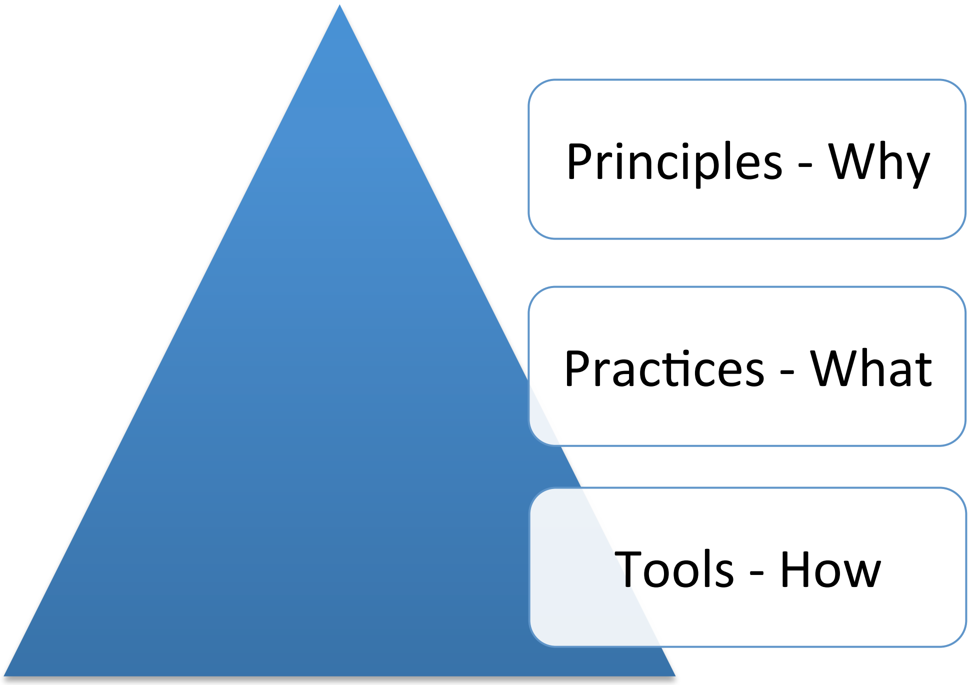

Figure 20 - The model of principles, practices and tools

5.6.1 Principles/Why

The principles should be disintegrated elements of the overall goal. For a manufacturing process, the research proposes an overall goal as to obtain a manufacturing process, insensitive to variation and producing zero defects products without reparations, at the lowest possible cost and time.

Several of the disintegrated elements for this goal will consist of principles relevant for the measurement system, as the measurement system is a corner stone and coherent to the manufacturing process. The measurement systems principles is by the research proposed to be:

- Reliable and accurate measurement system
- Process control in every step
- A measurement system insensitive to variation
- Ability to identify and perform counteractive actions before problems occur
- Be able to dissect parameters in the manufacturing process, and identify the optimal settings to achieve the highest possible level of quality on the final products.
- Provide information to base decisions on fact

5.6.2 Practices/What

Once the principles is established and institutionalized, all personnel within the process should have knowledge of why they work with the measurement system. In order to satisfy the principles, the organization needs to address approaches and activities to work against to fulfill the principles. These activities and approaches represent the hierarchy practices. The practices should serve to clarify the activities required to achieve the principles, but also to create a consensus of what we should work with. The proposed practices of this model are:

- Measurement system analysis
- Continuous learning
- Statistical process control
- Effective scoping
- Pull approach for ordering measurements

These practices have prospect to contribute the organizations efforts to be able to dissect parameters in the manufacturing process and identify their optimal settings to achieve the highest possible level of quality on products. This will indicate that the practices will support to detect sub processes inherent variation and behavior, and establish a foundation of data as a premises for improvement adjustments.

5.6.3 Tools/How

Once the principles and practices are clear, namely why we work with measurement system, and what activities we should work with, the last piece will be the tools. The tools section will strive to clarify how we should work and with which tools we should use in our practices to achieve our principles. The proposed tools of this research is:

- Gage R&R, Linearity, Bias and Stability analysis
- Control charts and Capability studies
- Evaluation of projects and post-project learning's
- The SIPOC matrix and the Pull Model

The strength of the model is to address the questions of why, what and how in chronological order. A success factor of the model is that it starts by explaining the true purpose of why the personnel do what they do. This is the first question that needs to be answered and understood, and should be superior to the questions of what and how. Next in order is the question of what we should do, and lastly how we should do. If the questions is answered or focused in reversed, there is a risk for confusion or misinterpretation. It also leads to greater risks that the principles of why we do things are left unaware or overseen.

To aggregate the theory of this research with the findings of the benchmarking, the hierarchy model is illustrated in a new perspective to illuminate the affiliation between the different practices and tools elaborated upon in this research. Figure 21 illustrates how different principles can be disintegrated into practices and tools in a structured strategy.

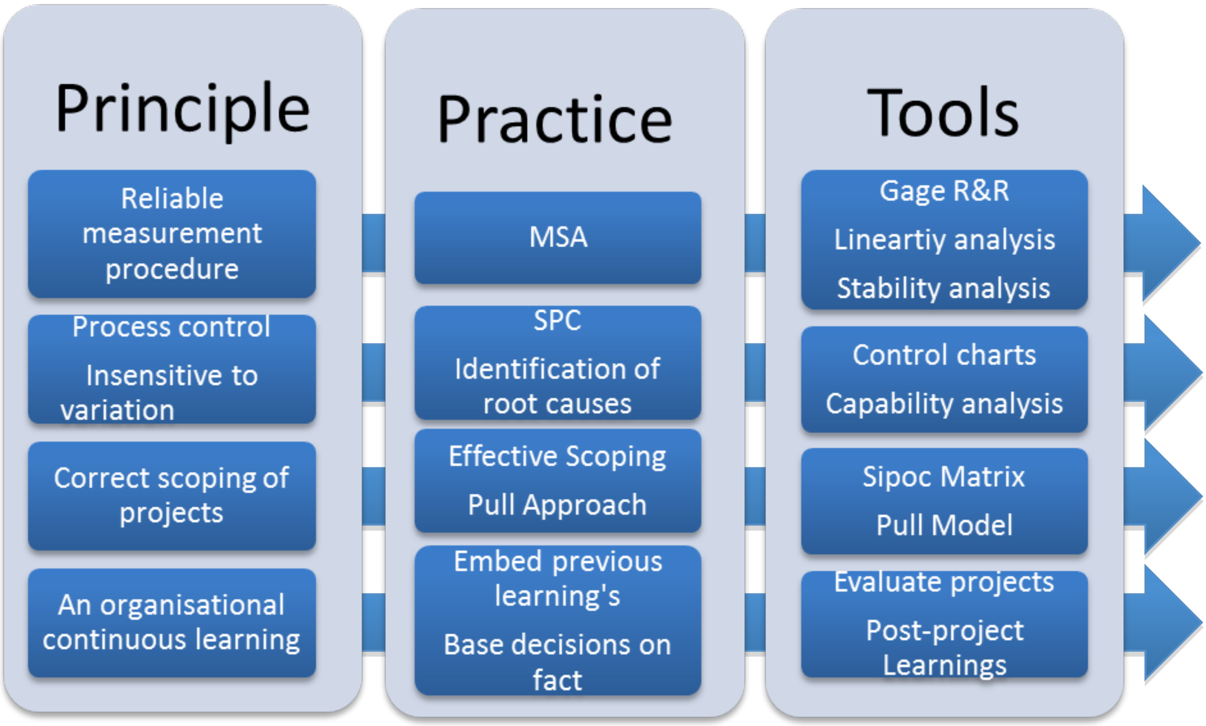

Figure 21 – Aggregated model of principles, practices and tools

6. Discussion

This chapter starts by a general discussion to summarize the result and conclusions of the research. The chapter continues further by elaborating on methods used and questions the validity of data collection methods.

6.1 General discussion

Through the research it is witnessed that the current measurement system is insufficient. The insufficiencies are most likely a result of the transition of the manufacturing technology from casting of large components to fabrication of smaller parts to be welded into large components. In this transition, the organization underestimated the need for a new measurement system to align with the fabrication. Hence, the organization anticipated that the historic methodology for working with measurement system would be applicable to the fabrication. As the fabrication contributed with new degrees of freedom in the assembling, as well as a need for more complex fixtures, the measurement systems were incapable of generating enough feedback to enable a fact-based strategy for improvement adjustments. This create an organizational context were projects commonly rush for solutions, rather than determining underlying factors or root causes for the problems. In order to reverse the current measurement system, it initially has to be recognized as insufficient for handling the fabrication, to found the need for a redesign of the current measurement systems.

To avoid a short-term work procedure, where personnel operate in the organizational context with nearsightedness and rush for solutions, the research proposes a new mindset to enhance a long-term work procedure. To reverse the mindset from a nearsighted observation of short-term gains to lifting the observation into long-term, the research propose a model and mindset to observe the organizational context with a convex lens. The current mindset is shaped by a lot of focus towards what to do, creating a measurement system similar to a toolbox, capable of determine go or no-go for products. In this astray, the mindsets in the organization were rather targeted towards what to do, rather than focusing on why or how to do things, which created a nearsighted worldview. In this mindset, the why and how is often dismissed or received lacking attention, which generated an organizational context where several activities are conducted with a lack of accurately stated purposes, or detail specifics on what to focus on. To illuminate the why and how will support the organization to avoid activities of rushing for salvation, or to avoid the “turn every rock” approach. As figure 22 illustrates below, and convex lens could support to illuminate the why and how, which will result to support what to be applied in a natural way. This will also support the organization to lift their view and observing the measurement system from its organizational context in a more pleasant perspective, and enable the insufficiencies to surface.

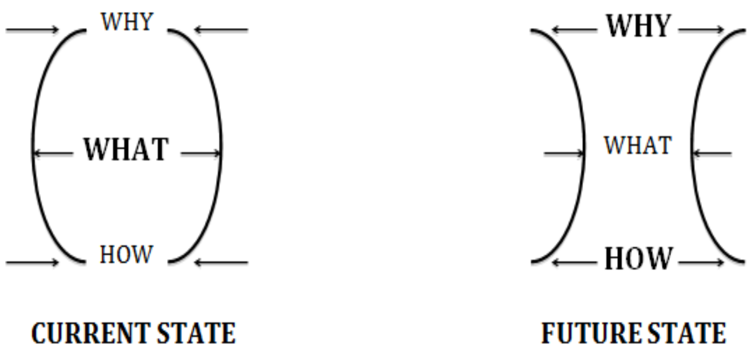

Figure 22 - Applying an enhanced long-term perspective in the work procedure

The research have determined the insufficiencies of the current state and proposed practical and theoretical proposals for the design of a future state measurement system. In order to achieve the objectives of the thesis, the research will further continue on how to perform the transition from current state to future state by elaborating on two fundamentals. Firstly, the research will elaborate on management's responsibilities to reach a future state. Secondly the research will elaborate on the organizations need for a unified language to enable the understanding between personnel, and the ability to collaborate efforts and competences as an initial step to overcome the current insufficiencies and start the transition to a desirable future state.

6.1.1 Managements role in starting the transition to future state

To overcome the obstacles witnessed in this research, management serves a key role in the context of changing the current working procedure into an enhanced future practice.
To start with, management needs to address more focus on the why and how, in their practice of working. For the measurement system, this can be initiated by addressing a task force to evaluate the current measurement procedures. The objectives for this evaluation would simplify to be investigated if there is any use for all the measurement performed today. For those measurement procedures where the data is not used, the number of measurements of this attribute can be decreased in order to disembarrass resources for measurement of other attributes. This would initially support the organization to start addressing why they perform some of the measurements, and how the generated data is intends to be used. Hence, it would also support to surface the current measurements where the purposes or detail-orientations are vague or unstated.

Secondly the management also needs to allocate projects earlier, meaning that projects should be involved to cooperate with manufacturing before quality problems occur. In the current organizational context, there are several areas were the knowledge about the process steps are vague or insufficient. Instead of waiting for problems to occur in these areas, and allocate projects to react on them, management should strive to allocate project to exploit these areas before problem occur. This would support the organization to work preventative and identify shortcomings rather then working reactive and counteract on problems when they have already appeared. Management can initiate this by allocating resources and address knowledge exploiting projects even when problems are not present.

Lastly, management needs to establish a structured strategy to work towards. An initial step would be to acknowledge that preventative work is more difficult to see quick results from, compared to reactive activates. Management therefore needs to avoid rewarding the short-term gains from reactive occupations, and start focusing and investing in long-term gains instead. An initial step for this would be for management to spread, through the organization, the importance of being patience and persistent.

6.1.2 Assigning a unified language

A limited baseline for the underlying meaning of words and concepts around the measurement system implicate flaws in the possibilities to communicate and understand each other. Without a common ground to understand each other, the possibility to collaborate efforts is irredeemable and likely to result with arbitrary implemented solutions. An initial step to increase the knowledge among the personnel at GKN is to establish a unified language to approach the insufficiencies by mutual understanding.

To establish a unified language, the research propose the following word and concept as crucial to settle a baseline for and share throughout the organization

To start with *measurement system* the research propose a hierarchy of principles, practices and tools, where the importance lies in understanding why the organization works with measurement occupations, rather than how or what to work with. In addition to this, the measurement system is not only limited to quality assurance but also an auxiliary element to retrieve feedback from the processes, and enable the foundation for improvement work. In addition, the most essential about the measurement system in a unified language is too diverse that a measurement system for casting is unequal to a measurement system for fabrication.

By *measurability* the research propose two aspects when performing a measurement, in order to achieve measurability. The first aspects indicate that there should be an ability to measure a parameter to determine the correlation to the outcome or result of the process. To achieve this ability, an understanding of the context for measurement needs to be achieved and the resulting effect of performed operations needs to be able to be measured and compared. The second aspect of achieving measurability indicates the ability to base on a measurement, be able to understand the behavior of the outgoing result. To achieve the second aspect, a reliable measurement operation needs to be ensured, to avoid any measurement error to interfere with the interpretations of the process behavior.

By *producibility* the research propose a definition of a process ability to produce within its predetermined capabilities. In this definition, two cornerstones becomes essential, namely the process ability to be effective and efficient. Trygg (2013) explains the difference of effective and efficient as being effective means *doing the right things*, and being efficient means *doing things right* (Trygg 2013). To unify the language of GKN, discussions around processes producibility should therefore strive to determine too which extent the process does thing right, and do the right things. If the process do the right things and do things right, within the process capabilities, any problem with the process should not be related its ability to produce, namely the producibility.

By *traceability* the research propose a definition of a measurements ability to be traced and identified in other contexts. The level of traceability will therefore serve to determine the identification of an attribute measured in one context, and enable the identification of the same attribute being measured in another context, in order to trace the different measurements to enable comparison. In practice, this should enrich the unified language with the ability of tracing different measurement points through the entire transition of the manufacturing process.

By *process control* the research propose a definition of where the knowledge about the process and process behavior correlate or excess the required knowledge to obtain certainty. Basically this indicates that a process is in control when there is an absence of uncertainty towards the process itself or the process behavior. Important to remember is that its impossible to achieve total control around everything, the process control will have to align with the demanded certainty required to ensure the quality of the products.

Lastly, it is of great importance to address the difference between *symptoms* and *root causes* when discussing problems. The researches propose a definition for the difference, as symptoms are the result of root causes, leading to the fact that symptoms are not solved without eliminating or mitigating the root causes. In the research, it is commonly observed that the both are grouped together and discussed generically as problems, there is consequently a need to divide them in order to increase the structure in the discussions to accurately target the underlying intentions for discussing the problem.

By unifying the definitions of these words and concepts, and spread the baseline of these throughout the organization, irregularities in the communication patterns can be identified and additional words and concepts will have accommodation to be included.
Once the baseline is settled, and personnel can start to communicate and understand each other, collaborated efforts can be initiated to achieve the other occupations described in this research, namely to change the interpretations of the measurement system or the mindsets towards working with data and measurement systems.

6.2 Discussion of methods used

In order to fulfill the purpose of this research, three research questions where established. Each of the research questions demanded different approaches in order to retrieve an answer, therefore different methods were used. Further follows analysis and critic towards the methods used for this research.

6.2.1 Action Research

The action research served primary as an entry gateway for the scoping of the research. Since the researcher participated in the project, there is a low chance for any misinterpretations when revisiting and examining the historical report. The researcher was also familiar with the underlying factors expressed in the report and how the results have been developed. For another researcher to replicate the interpretation of the documentation, there might be more risks for misinterpretations as a consequence of their absence of participation in the project. On the other hand is the report still accessible for personnel at GKN, and can be examined by any other researcher at any other time.

6.2.2 Observations

The observations were one of the key sources for rich qualitative data. The case for the observation study was strategically involved in the research since it entered a project where the measurement system and correlating approaches were topical for the period with high attention among the team members. In several of the other cases, procedures correlated to measurement data where interpreted as secondary occupation, and rarely the primary focus. But for the observation study, the measurement system complex of problems where a primary focus, and therefore contributed with rich primary qualitative data for the research. With respect to GKN´s security restriction, the semi-structured notes of the observations were destroyed after the research, creating an obstacle to replicate the research. But since the findings of the observations were proofread by the supervisor, the risk for interference of the researchers bias is still to be regarded to a minimum, leaving the possibility to replicate the research in the future to a satisfying level.

6.2.3 Internal documentation review

Reviewing the internal documentation in terms of three Six Sigma reports were one of the most risky data collection in this research. A risk with using this data where that its secondary data with other agendas. In some reports, it was a sense of embellishment in the description of the procedure of the projects. A likely reason for this is that the projects intentionally did not reveal all the faced obstacles since the projects were graded. The reports were therefore analyzed with caution, where subjective data were secondary to the data unaffected by the project teams in the reports, e.g. quotation from AIM sessions etc.

6.2.4 Semi-structured Interviews

The semi-structured interviews served as the primary data collection source to determine applicable tools and approaches to operate a measurement system in practice. The interviews contributed the research with rich and broad data. The participants in the external benchmark all operated in other industries and markets, and the likelihood for them to answer dishonest seems negligible since they do not have any discoverable reasons to hide the truth out of a competitive perspective or gains to answer misleading. In addition to the good relationships, GKN possessed with the interviewees, the judgment of the researcher is that the interviewees answered and participated truthfully and in good faith.

Regarding the interview study of the cooperation between design and manufacturing within GKN, there are more risks for misleading findings. Since there exist several product projects within GKN, there is a diversity of successful outcomes between these projects. Depending on whom participated in the interview study, the answers could differentiate severely between different participants, since the projects were operated with different success. The participants of the study warned for this and raised awareness for the researcher to interpret the answers, and especially compare the answers. To avoid any misinterpretations, the study zoomed out on the findings and applied a broader perspective. This enhanced the possibility to avoid that any specific answers contributed excessively when conducting the empirical model of the cooperation across the departments.

7. Conclusion

This chapter starts by explaining the aim of the research, and revisits the research questions that settled the baseline for this research in order to prove that they have been answered, and the purpose of the research fulfilled. The chapter continues by elaborating on contributions of the research, and ends by suggesting areas for future research and studies.

7.1 General conclusions

The purpose of this thesis has been to descriptively map the current state for the measurement system, involving both the design of the measurement system and the accompanying approaches to handle data, in order to pinpoint insufficiencies. The research further aimed to propose improvements and recommendations on how to enhance the current measurement system and how to perform the transition from a current state to a future state of the measurement system. Answering the following research questions fulfilled the aim and objectives of the research.

RQ 1: *How does GKN currently work with their measurement system to enable the measuring of robustness in a manufacturing process?*

Currently, GKN work in an insufficient way to capture the feedback from their measurement system, which captivates the possibilities to measure the robustness of their manufacturing processes. In an overall perspective, the measurement system is utilized to determine the quality assurance for the products, basically to determine the go/no-go for products, which creates a measurement system similar to a toolbox. In this organizational context, where the measurement system is apprehended as a toolbox, the approaches to capture and utilize the measurement systems feedback about e.g. process behavior or variation, is overlooked or sometimes missed out. The disorder of utilizing the measurement system from this viewpoint generates a lack of disintegrating the manufacturing process into sub-process. Without the disintegration, there is currently a lack of process windows to perform measurement within, which captivates the measurement system to monitor and observe e.g. variation and process behavior, between the sequential sub-process steps of the manufacturing process. The identified insufficiencies of this research are categorized in four elements, an unnecessary time consumption to collect and assimilate data, a lack of measurability, and lack of traceability in the historical data and lastly an incomprehensive communication for discussing measurements and data.

RQ 2: *How could a measurement system be designed so that studies on measurement data and improvement projects can be performed?*

A key element of the measurement system design, in order to enable studies of measurement data and improvement projects, is the measurement systems ability to generate informational feedback about the manufacturing process. The research have by merging knowledge of practical and theoretical fields proposed an aggregated model of principles, practices and tools to illustrate a possible design of a measurement system, capable of generating feedback. The principles are disintegrated elements of the overall goal for the manufacturing process, the practices are activities to work with in order to satisfy the principles, and lastly the tools describe on a detailed level the factors to focus on in each activity. The model strives to disintegrate the manufacturing process into sub-process steps, where process windows can enable measurement to retrieve feedback from the sequential process steps inherent variation and process behavior. This model serves to change the mindset and interpretation of a measurement system from a toolbox into a structured strategy. Within this strategy, the research proposes practices of statistical process control and continuous learning as methods to utilize as prerequisites to perform studies of measurement data and improvement projects. The model will support to enhance the measurement system´s generation of feedback information, rather than enhancing the quality assurance.

RQ 3: *How should GKN adjust their measurement system in product development to enhance a proactive way of working?*

The research proposed a proactive way of working by the aggregated model developed in research question two, but adopting the model will not solve all the organizational disorders. In order to enhance a proactive way of working, the research elaborated on two elements as a necessity for the transition to a future state measurement system.
Firstly, the research elaborated upon management's responsibilities and participation, where projects need to be allocated earlier. Within this prerequisite, reactive work task can be reduces in the long term by increasing the allocation of preventative work task.
Secondly, the research elaborated on the need for establishing a unified language. The unified language was determined as a prerequisite to initiate communications across departments. For this communication, a common baseline of tangible words and concepts are required to render possible the understanding across departments. In addition it also render possible the organizational ability to collaborate between different departments' competences and efforts to overcome the current insufficiencies. The research concluded the aim of the research by suggesting a common baseline for several words to initiate a unified language that facilitates the transition from a historical measurement system mind-set crafted for handling large castings to follow the manufacturing technology change to fabrication of welding many different parts and materials together.

7.2 Contribution of the research

In this section the researcher will illuminate some of the findings of the research, and the possible contribution of these for the academic and industrial fields.

7.2.1 Academic contribution

The thesis suggests a new approach on how to interpret a measurement system in terms of principles, practices and tools. The new approach helps to drive the focus from apprehending a measurement system as a toolbox to assure quality, into a strategy shaped methodology that focus on the importance of why to measure, instead of what to measure.

7.2.2 Industrial contribution

The research has supported GKN to pinpoint some of the insufficiencies in the general design of the measurement systems, as well as the approaches and methodologies for working with data. The research has developed an aggregated model of improvement proposals for GKN to use as a methodology to overcome some of the current shortcomings. In addition the research have proposed several words and concepts to initiate the establishing of a unified language. In the long-term perspective, several of the improvement proposals can by correct implementation support and contribute GKN to enhance a proactive way of working.

7.3 Recommendations for future research

It would be of interest to conduct an extensive business case for GKN to upgrade the technology of their data storage. As witnessed in the research, a large time consumer is the tracking and handling of all the physically storage data, e.g. measurement data in binder located in a cabinet somewhere in the factory. A business case would come of interest if the agenda where to determine the possible cost savings in implementing data equipment used by operators and to scrap the manually written paper form. A business case of this type could motivate to investigate in data equipment's like stationary computers and iPad in different process steps in comparison to the time spent by personnel to trace and summarize data from paper form. It is the researchers' inevitable personal belief that there are large savings to be inquired in this field, in terms of time and resources. An initial step for this continuation would be to start by investigating how project E were able to receive funding's to develop and implement their measurement system, since they operate within GKN´s environment.

With the portrayed models of this research, it is proven that there is a need for GKN to raise the view of measurement systems as something more than just a toolbox. To continue this research, it would be interesting to investigate how information travels within the company, as well as extensively investigate the awareness of variation in the low end of the organization. It is the researchers' belief that the witnessed problems with measurements system are not related to technology as much as to knowledge.

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Peter Hammersberg, 2014-01-21 “Effective scoping”

Anna Ericson Öberg, 2014-01-21 “Basic control charts, Visualizing variation in strategic measures”

Peter Hammersberg, 2014-01-28 “Measurement system analysis MSA – Continuous data”

Katarina Brantin, 2014-04-01 “DFSS at SCA”

Hendry Raharjo, 2014-04-29 “Statistical Process Control”

Sari Scheinberg, 2014-05-08 “Qualitative research methods, Curiosity & Interviewing”

8.3 Websites

GKN website, http://www.gkn.com/aerospace/aboutus/Pages/default.aspx (acc. 14-07-15)

Clean sky commission, http://www.cleansky.eu (Acc. 14-09-30)

Appendix 1 - Basis for benchmark interview questions

Namn
Anonymitet

Allmänt

- Är dina arbetsuppgifter kopplade till mätdata?
    - Vad är din position i organisationen
- Vad tycker du är syftet med att arbeta med mätdata
    - Varför arbetar ni med mätdata?
    - Vad använder ni mätdata för?
- Vilka verktyg använder ni när ni arbetar med mätdata
- Vad är ett mätsystem för dig/er, t.ex. är det en verktygslåda eller aktiviteter för att nå ett mål

Metodik för att skapa mätbarhet

- Hur skapar ni mätbarhet i era processer
    - Har ni mätbarhet för att utvärdera enskilda processers variation och kapabilitet? Hur har ni skapat detta?
- Hur ser en typisk tillvägagångssätt/approach ut för en projekt grupp ut när ni skall arbeta med mätdata?
- Har ni instruktioner/standarder som pekar ut hur ni skall jobba?
- Ibland när det finns dolda egenskaper, hur hanterar ni dem? D.v.s. när vissa attribut är svåra att mäta på?

Spårbarhet

- Hur hanteras mätvärden för en enskild produkt? Går det att urskilja olika produkter eller utfallet från olika processer för enskilda produkter
    - Hur har ni lyckats uppnå detta?
- Vet ni om hur många produkter ni har i processen, och under olika process steg/vart i processen de är?
        - Hur vet ni detta? Hur arbetar ni med detta?
- Hur kan du hitta och spåra mätdata? Databas/arkiv

Tillförlitlighet

- Hur försäkrar ni er om tillförlitligheten i era mät förfaranden
    - Hur ofta kontrolleras utrustning/instruktioner
- Uppstår de ibland problem för att mätdata inte var tillräckligt noggrant avspeglad av verkligheten?

Kommunikation

- Hur fungerar kommunikationen när ni söker mätdata
    - Kan man söka i databaser eller behöver man fråga folk
- Hur kommunicerar konstruktion och produktion om nyckelegenskaper
    - Hur ser ansvarsfördelningen ut

Bemöta problem

- Vilka hinder brukar ni stöta på när ni utför förbättringsarbeten?
    - Är det dessa som tar mest tid/resurser
- Vilka är era största tillkortakommanden när ni arbetar med mätdata
- Upplever du att problem ni bemöter är kopplade till teknik brister eller kunskapsbrister

Continuous improvement

- När en förbättring är implementerad, hur försäkrar ni er om att samma problem inte skall uppstå igen
- Hur sprider ni ut lärdomar från förbättringsprojekt till resten av organisationen

Egna reflektioner

- Sett till det som fungerar bra med erat mätsystem och tillvägagångssätt att arbeta med mätdata, vilka är de största faktorerna som bidrar till att mätsystemet fungerar bra?
- Sett till de som fungerar mindre bra med erat mätsystem och tillvägagångssätt att arbeta med mätdata, vilka är de största faktorerna som bidrar till att mätsystemet inte fungerar bra?
- Hur tycker du kompetensen är inom företaget när man talar om variation, medvetenhet om variation?
- Upplever du att det finns tillkortakommanden när det gäller tidskonsumtionen för att arbeta med mätdata, skulle det gå att arbeta på ett snabbare och effektivare sätt, isånnafall hur då tror du?

Appendix 2 – Interview questions for Design

Arbetsmetodik

- Hur ser era uppdrag ut? Från vem kommer beställningen och hur är de formulerade?
- Hur ser arbetsmetodiken ut när ni tar fram ett koncept?
    - Hur bryter ni ner kundkrav?
        - Hur bryter ni ner dessa till producerbarhetskrav, för att styra processen?
    - Hur arbetar ni för att kravsätta detta?
    - Hur utförs toleranskedjeberäkningar för att säkerställa att kundkrav går ihop?
    - Hur tar ni hänsyn till nyckelegenskaper, hur utvärderar ni dessa?
- För produkter som går i produktion, reviderar ni dem, hur går detta till?
    - Dokumenterar ni ”lesson learned”?
- Hur ser ni på producerbarhet?
    - Vems är ansvaret?
    - Hur vet produktion vilka krav som är kopplade till nyckelegenskaper på underliggande producerbarhetsnivåer?
- Hur ser ni på mätbarhet?
- Är ni involverade i hur attribut skall mätas och när i processen?

Kommunikation och samarbete

- Hur fungerar kommunikationen med produktion, med hänsyn till nyckelegenskaper?
    - Hur ser du på samarbetet med produktion?
- Är det något som fungerar bra med samarbetet med produktion, vilka är de underliggande faktorerna?
- Är det något som fungerar mindre bra med samarbetet med produktion, vilka är de underliggande faktorerna?
- Om du får öppet reflektera, hur tror du i framtiden man skulle kunna samarbeta med mer framgång?

Appendix 3 – Interview questions for manufacturing

Arbetsmetodik

- Hur ser era uppdrag ut? Från vem kommer beställningar och hur är de formulerade?
- Hur ser arbetsmetodiken ut för ert arbete
    - Hur bryter ni ner kundkrav till tillverkningskrav
    - Hur arbetar med producerbarhetskrav
    - Hur utförs toleranskedjeberäkningar för att säkerställa att kundkraven går ihop
    - Vilka möjligheter har ni att påverka ritningskrav
- Dokumenterar ni så kallade lessons learned i erat arbete?
    - Hur sprider ni detta i resten av organisationen?
- Hur ser ni på producerbarhet?
    - Vems är ansvaret
    - Hur samarbetar ni med konstruktion för att försäkra producerbarheten på era produkter
    - Reviderar ni produkter som redan går i produktion?

Kommunikation och samarbete

- Hur fungerar kommunikationen med konstruktion, med hänsyn till nyckelegenskaper?
    - Hur ser du på detta samarbete?
- Sett till det som fungerar bra med samarbetet med konstruktion, vilka tror du är de underliggande nyckelfaktorerna
- Sett till det som fungerar mindre bra med samarbetet med konstruktion, vilka tror du är de underliggande nyckelfaktorerna
- Om du får öppet reflektera, hur tror du man skulle kunna samarbeta bättre med produktion?