CHALMERS

# Increased productivity by improved information flow in the NPD Process

## The reduction of feedback loops in the design adjustments process brings possible time free up

Master's thesis in Quality Operations and Management

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*To a grandfather that was a father, my grandfather Vasileios,*

*To a grandmother for the undying inspiration, my grandmother Evdoxia*

*To mothers that have to be a mother and a father, my mother Giouli*

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# ABSTRACT

The project is carried out as a case study at an international company that is responsible for manufacturing premium construction equipment, with its head quarter in Gothenburg. The presented study focuses on the New Product Development (NPD) process and especially on the Concept Development study phase that takes place in the plants of Arvika and Braås. The outcome of the Concept Development phase is to provide the later phases of the NPD with a design drawing that includes the first changes for the update of an already existing product or for the development of a new one. The design drawing that is a CAD model will be passed on to the phases of the NPD until it will reach the industrialization and realization phase. Along the process new updates will occur to the design drawing but the Concept Development phase is responsible of setting the base and exploring if the changes or new features to be implemented to the new product are possible.

The study examines the Concept Development process in terms of variation and noise factors that influence the information flow between the different departments that are involved in that process. The factors with high contribution to the information flow were determined through interviews, observations through meetings and design reviews and the use of ideas generation tools. The basis theory of the project was the foundation of Six Sigma (SS) which have been used as a guideline to arrange the next steps. The aim of the project is to determine the critical-to-quality factors that is creating variation in the information flow of the concept loop of the Concept Development process, as well as to examine how alternations in the data visualization in the concept loop can stimulate discussion that will possibly lead to the free up of time in the departments of design engineering, quality and manufacturing engineering. According to previously conducted studies in the company, the welding process has been mapped and the concept loop was identified together with the recognition of inconsistency between the communication interactions between the departments.

The findings of the study lead to the identification of the critical factors responsible for the variation in the information flow which were: (i) lack of information sharing (ii) not fully understood and integrated cross-functionality and (iii) lack of common language and point of view. All of the above mentioned, has a connection with data visualization, although it is not an obvious observation, and it has been investigated by the study how a change in the data visualization can pose as a conversation starter and change the point of view of the discussion and provide a start from product oriented point of view to a more process oriented. To examine that, a pilot study has been carried out based on the analysis from an on-going thesis study in order to examine the effects that a different data visualisation can have. The project demonstrated that a change in that domain can be a conversation starter and influence the point of view. It has also indicated possible factors that can enhance the cross functionality concerning the procedures the company has already in place for NPD project execution. One of the most beneficial were the possible use of the different representation from the pilot study in the processes of the company for the closing of the feedback loop in the Concept development phase and the possible economic profit the company will possibly enjoy.

Keywords: six sigma, information flow, new product development process, feedback loops, change management, push pull approach

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# Acknowledgements

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# Abbreviations

CE-Construction Equipment

DFSS- Design for Six Sigma

DMAIC- Define Measure Analyse Improve Control

NPD- New Product Development

PD – Product Development

PDCA- Plan Design Control Act

RQ-Research Question

SS - Six Sigma

# 1 Introduction

## 1.1 Background

The past years has been characterised of its information availability to anyone and at any time, and with its technological advances that affected most of the industries. Companies are focusing on finding their competitive advantage and differentiation point that will place them higher in the customer ranking, while keeping in mind to fulfill or even exceed customers' requirements. This demand of change did not only come from the desire of the individual companies to strive for better performances, but also from the globalisation of the businesses. Globalisation requires the companies to compete not only in their narrow borders of the country or broader region, but globally (Bbc.com, 2019). As it can be understood, the organisations need to develop flexibility to be able to comply with fast changes, as well as resilience to be able to maintain and recover from those.

The welding industry is part of this continuous change, which includes the pressure to minimise the environmental effect and at the same time, increase profitability (Öberg, 2016). The aforementioned pressure has lead companies that constitute the welding industry to re-evaluate their processes and especially their product development one which is one part that competitive advantage can be gained. Companies allocate vast resources for the development of new products or the re-innovation of existing ones. In this inquiry, most firms forget that the center of this journey knowledge is hidden within the company and especially in the cross-functional relations. (Slotegraaf and Atuahene-Gima, 2011)

Kehoe et al (1992) emphasize the importance of using the information in an effective way in manufacturing operations to support decision making processes in the whole organisation, in order to achieve the business goals and give a major competitive advantage to the company. Danielsson and Holgård (2010) point the attention on the presentation of managerial data, focusing on the usage of control charts and its correlation with the improvement of the support for decision making. Displaying variation over time with control charts, allows visualising it and therefore to take it into account when predicting the process output and the actions to take if a change is needed. Even though these methods are proved to be useful, their usage is hardly widespread within the industry, where, instead, the most common way of analyzing data is by focusing on the mean value despite the possibility of losing important information about the issues in the production system. For the mean value to be reliable, the underlying distribution must be stable, homogenous without outliers: neither variation nor trend is considered when using the information.

Furthermore, the data that are being gathered tend to be used for decision making no matter if there are the appropriate ones or are answering the questions of those that asked them completely. In the article "Selection of Evaluation Methods for New Weld Demands: Pitfalls and Possible Solutions" by Öberg et al (2012), it is described the push and pull approach of data gathered. The authors concluded and present a model

that describes the pull approach and start with the question: “Who needs the information?”. By recognizing the person that needs the information (who), the appropriate data will be gathered together with the tools that will be used to analyse them. This first step will gradually lead to decisions being based on the data that already exist inside the organisation and with the inclusion of variation and noise that can affect the process. As Ericson Öberg (2016) states, if a better pairing between information need and information acquired can be achieved then it could possible lead to a more productive decision-making. Unfortunately, this practice tends to be omitted by the organisations in the rush of fixing problems as they occur.

The pull approach connects with the fact that the information that is needed for decision making can be different visualized between the various departments of the organisation. The differences in visualization between the departments can lead to the creation of different languages which deepens the chasm of communication and understanding between the departments. Visualisation of the situation has been proven to be a powerful tool that can bring unity between the functions and direct decisions, if it is assumed that the appropriate data is taken into consideration. It also assumes that the various factors of the organisation have the same language to interpret and assess what it is presented.

In the search to reinvent their businesses and at the same time remain competitive into the market, an organisation consciously or not go through a change management process. The term has been defined as “the process of continually renewing an organisation’s direction, structure and capabilities to serve the ever-changing needs of external and internal customers’ (Moran and Brightman, 2001) (Todnem, 2005). Change can have an effect on the decision-making process and the tools used to reach the decision. A change process does not have to be big to influence the situation, i.e. from separate departments to cross-functional departments, but it can also be a selection of a different tool to visualise some data. It will require time for adaption and resources for the whole company to accustom in the new way, which will be met with resistance from the affected parties at the beginning.

The organisation in which the study will be conducted is successful in its business and has significant knowledge in the fields of design, welding, and quality assurance. The influence of variation on quality and productivity is fully understand, but an improvement of the cross-functionality, of the interdepartmental cooperation and of the data sharing and visualization can be investigated. The studies conducted in the previous years will be used as a base and to bring attention to an aspect that has not yet been investigated. The results obtained from this study will be used as a basis for further implementations in this domain, as well as an inspiration for going on with the research on new paths and yet unexplored topics.

## 1.2 Purpose

This thesis main focus is to unlock and understand the reason behind the disturbances that occur in the cross-functional communication of the NPD and especially between the departments of the Design Engineering, Quality and Manufacturing Engineering departments. When the factors that cause that disturbance have been identified, it allows investigating further to find the appropriate measures that will help to confront those factors. The primary message of the thesis would be to research how a small change in the data visualization can impact the interactions of the people involved in the NPD and stimulate discussion that will potentially lead to a change in the mindset from push to pull, from reactive to proactive. Eventually if this change is possible then the free-up of time will be a benefit that will happen from the decreasing of the feedback loops that occurred due to misunderstandings in the communication between the parties.

## 1.3 Research Questions

The structural changes that have occurred to the organisation with the intention of bringing simplified operations through cross functionality, with the hope that it will help on the initiation of innovation, brought onto the surface obstacles in the information flow and the interactions between the teams. Those obstacles appeared to be influencing the mind-set of the organisation and instead of a proactive and pull approach one, a reactive and push approach seems to be in place regarding the data sharing and information flow. The above lead to the need to identify those obstacles and in the formulation of the following Research Question (RQ):

***RQ1: What are the main critical to quality factors that are creating variation in the information flow of the concept loop in the concept development process?***

After the identification of the factors that negatively influence the data sharing between the departments, the question remains on how those factors can be changed in order to move the company for a more reactive attitude. Each of the departments that are the core of the study, generate their own data and knowledge and the findings from there have a different contribution to the NPD. The knowledge sharing through the data is essential for the progress of the NPD process in order to eliminate unnecessary feedback loops and misunderstandings that will be portrayed in the drawing early in the process. Therefore, data visualisation holds an important role in transmitting the knowledge the different department has and can have a key role in the conversations that take place during the meeting in between the stakeholders. The following RQ was formulated to examine the extent of the influence that data visualisation can bring:

***RQ2: How can a change in the data visualisation in the concept loop can stimulate discussions that will possibly lead to free up time in the departments of design engineering, quality and manufacturing engineering?***

## 1.4 Limitations

The study was carried out in the duration of six months from January 2019 to May 2019 at Volvo Construction Equipment (CE). Due to the time restriction as well as the resources on hand, the study was limited only in the units that the company has in Sweden and most precisely in Arvika. Another unit was also visited during the project as it fits the purpose of the project. The units were chosen according to the functions that they had. Special focus has been given to a specific part of the organisation that is responsible for the NPD process and in one specific loop that involves the departments under investigation of Design Engineering, Quality and Manufacturing Engineering. The findings deal with the knowledge that is generated between those departments and how it is handled.

The possible suggestions that might occur from the findings needs to be as organic as possible, meaning that there should be solutions that the company can use already the next day after the completion of this study. It can also be guiding steps that will help the company begin the corrective process that was indicated by the thesis. Furthermore, the possible suggestion needs to be formulated in a way that participation and understanding by the stakeholders is essential.

For the progress of this project, visits and meetings with the involved parties from the companies was fundamental to be arranged. The timing for the meetings was mainly dependent of the availability of the company. Therefore, the amount of time allocated and spent was arranged according to the workload of the involved parties from the companies.

## 1.5 The Company

Volvo Construction Equipment is a global company that is part of The Volvo Group. The company develops, manufactures and markets equipment for construction and related industries. The operations do not limit in the manufacturing of products but expands to offering worldwide service and a variety of customer solutions. The headquarters of Volvo CE are located in Gothenburg, Sweden and with a number of plants around the world such as Sweden, France, Germany, US, Brazil, India, China and Korea. More specifically in Sweden five units of the company can be found. The number of employees is 14.000 worldwide. The company has a long history of construction equipment manufacturing and through its history and products managed to be among the lead manufactures of construction equipment. (Volvo, 2019)

# 2 Methodology

In this section the methodology that was used for the execution of this study is presented and explained. As a base of the work the DMAIC process of Six Sigma was used to help navigate through the favourite steps that need to be executed through the study for the RQs to be answered and a solution that can be used by the company to be provided. The DMAIC process is composed by 5 phases: Define, Measure, Analyse, Improve and Control. Focus has been shed especially on the Define phase since the project is dealing with the information flow and interactions between them which can be difficult to grasp and map the full effect of them due to the implication that human factor can bring. As the study progresses focus was also given in the Improve and Control phase that are the phases that provide the factors that needs to be controlled by the company and how they can do that.

The DMAIC process is portrayed in the Chapter 4 called Empirical Findings where the different phases can be found as subsections. A description of what each phase entails can be found in the Theory chapter, and a smaller description are provided in each subsection of the Empirical Findings chapter.

## 2.1 Research Strategy

The project can be characterized as an action research due to the fact that the researcher and the company collaborated both in defining the problem as well as to reach a conclusion and a possible indication on where they can start their efforts from (Bryman & Bell, 2011).

The Qualitative research strategy was the one chosen for this study. The reason of the choice was the nature of the study. The material on hand is intangible since the study deals with the information flow and the interactions of the people involved in the NPD which is not measurable as defects on a specific machine can be. The collection of the qualitative data was done through semi-structured interviews with the various stakeholders of the company. According to Bryman and Bell (2011) the qualitative data are selected when the researcher does not want to direct the participants from the data collection and into what it is already believed by the company. The point with the qualitative research strategy and semi-structured interviews specifically is to discover new theories that exist inside the company. The results from the semi structured interviews served as a base for the formation of a hypothesis that was tested using the pilot study. On the pilot study quantitative data was used and analysed to be used for the collection of more qualitative data through the interviews to conclude on the hypothesis that was formed.

Due to the use of the hypothesis and pilot study, the study was primarily executed as an inductive research. The theory was firstly put in place and constructed and searched for after the results were known (Bryman & Bell, 2011). The idea of the hypothesis came out of the interviews and after the graphs were created for data visualisation were in place from a parallel thesis work. It is important to mention that an amount of references was already applied since it provided context to the execution

of the study from a Six Sigma point of view and the work that has been done in previous thesis work in the company that served as facts.

## 2.2 Research Methods and Data Collection

A combination of research methods was used for the collection of the data which will be presented in the following sections. According to Bryman and Bell (2011) a research method is a particular tool or technique that is used to collect data.

### 2.2.1 Semi structure interviews

In the duration of the study, various employees from the department involved in the New Product Development (NPD) were interviewed. Most of the interviews were held through video meetings and the rest of them were done face-to-face in the different units of the company around Sweden. The semi-structured was chosen as a technique of collecting qualitative data since the interviewer has the opportunity to ask follow up questions that can enable discussion and the further understanding of the causes behind the problems discussed (Bryman & Bell, 2011). The selection of the participants for the interviews was done according to the mapping process that has been done in a previous thesis work in the company and from the focus of the study. To ensure that an equal representation from the departments was reached, an initial plan of the amount of the interviews to be done was made (Bryman & Bell).

Totally 25 interviews were held with 10 of them being face-to-face in the facilities of the company around Sweden and the rest through video meetings. A list with the detailed record of interviews can be found in Appendix A.

### 2.2.2 Pilot study

A pilot study was selected to be carried out in this data due to the findings that were accomplished from a parallel thesis work. A pilot study can be carried out in both quantitative and qualitative study (Thabane et al, 2010). A pilot study can be referred as a small-scale preliminary study to assess the feasibility, time, and cost of the question. In the current study, a hypothesis has been formulated from the findings of the parallel thesis work and where put into a test to decide the feasibility and assess the change that has brought to the company.

### 2.2.3 Structured Observations

Together with the interviews at the units, the researcher had the opportunity to conduct also structure observations. According to Bryman and Bell (2011), as a method structured observation are giving the ability to observe on hand the behaviour and to describe details that might have been missed with the other methods such as the semi structured interviews and the pilot study.

## 2.3 Research Process

In the following segment the process that was followed for this study can be seen. It is the suggestion that comes from Bryman and Bell (2011) and will help with

understanding why specific procedures were chosen to be executed in the specific steps.

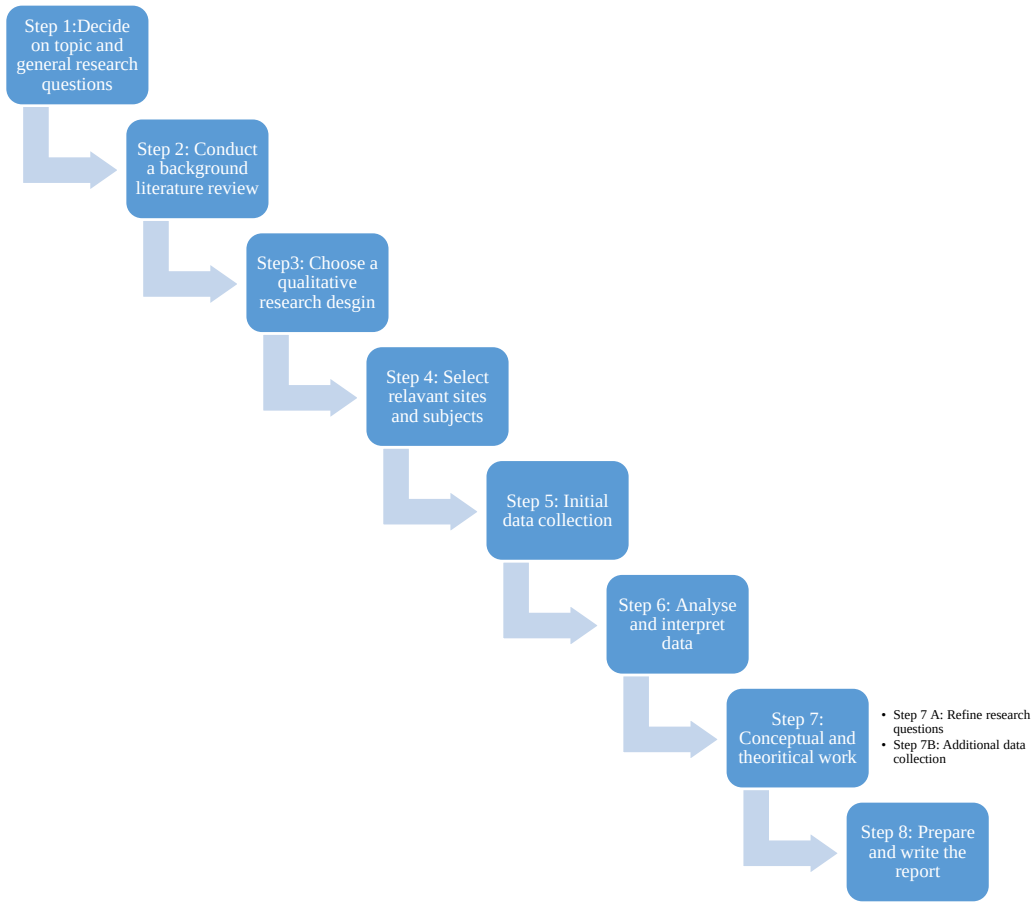



*Figure 1 Research Process (Bryman et al 2011)*

## 2.4 Ethics of the Research

The ethics principals that have been developed from Diener and Crandall (1978) are used in the study to defend and include the ethical aspects. The ethics principals will be presented and described below and how it was considered into this particular study.

**Harm to participants**

The study was developed to not bring any possible harm to the participants. With any possible it is meant that both physical and psychological harm was included. To be able to avoid harm, the participants were informed about the aspects that the study was intended to cover beforehand to avoid any misunderstandings and to reassure them that the anonymity of their identity will be kept throughout the whole study. The participants also had the possibility to ask clarifying questions before the session started. The declaration of the purpose of the study aimed to make it clear to the participants that the study is aiming to bring help and positive, if any, improvements to the organisation. To promote the safe guarding of the statements made by the

participants, the participants were also reassured by the management of the organisation that no harm will be brought to them according to their sayings.

**Lack of informed consent**

The participation on the study was not at any aspect mandatory but rather voluntary, therefore in order to able to decide if they would like to participate in the study, the participants were given as much information regarding the scope of the study to able to make the decision if they want to participate or not. In that aspect, the researchers should clearly declare their position and to not disguise it with something else. Regarding the video meetings, information and the purpose was sent to the participant prior to the meeting and the researcher was reassured from the participant for a further contact if the data collected was not enough or questions arouse.

**Invasion of privacy**

The researcher made sure that no participant felt that their privacy was intruded. The anonymity of the interviews and other sessions was one of the first things that were communicated with the participant together with the purpose of the study.

**Deception**

With the last principal Diener and Crandall (1978) wanted to ensure that the results of the study will not be used for other purposes than it was agreed and transmitted to the participants. The participants of the study were offered the possibility to see the results of the study and understand that their contribution was of value adding for the study.

## 2.5 Trustworthiness

For the evaluation of the qualitative research alternative criteria has been proposed. One of them is the trustworthiness of the study. The trustworthiness is examined through four criteria being: credibility, transferability, dependability and confirmability. The meaning of the criteria will be explained below.

**Credibility** is based on the fact that the findings of the study are being examined by the members of the social world and in that case, those being both the participants of the study together with the supervisor and examiner of the university. Credibility is based on the technique of respondent validation. The level of triangulation was ensured through the use of both qualitative and quantitative data.

**Transferability** entails the extent to which the findings of the study can be implemented by others. For this particular case, the findings will be most useful for organisations that bear similar processes and variation appears that is interrupting the information flow of the NPD process.

The **dependability** of the study is based on the fact that the results and records from the study are kept in order to be available if the need arises for someone external to go

through. At this point it is worth mentioning that the amount of data that can be generated from a qualitative study can be a lot for a single person to go through. However, all the documentation and notes from the study has been stored and backed up digitally.

Lastly, **confirmability** is the last principal which affects the objectivity of the project. Due to the nature of the project that is an Action research full objectivity is not fully possible to be obtained and a degree of bias can be expected.

# 3 Theory

In the following sections the theory base for the problem is presented. The theory of Six Sigma has been chosen due to the fact that the thesis belongs to a wider framework of research that investigates ways to reduce variation in the welding related industries. Also, the nature of the project called for the introduction of change management theory. The theory section has the role of the backbone of the study, to provide guidance for the completion of it and to support what is scientifically acknowledged versus what is currently observed in the company. As the study progressed, relate-able theory that supplemented the empirical findings was added.

## 3.1 Six Sigma

Six Sigma has not been carefully defined in either the practitioner or academic literature (Hahn et al., 2007). This has resulted in some confusion, since each author provides a different definition. In an attempt to develop the concepts and principles underlying Six Sigma, the following definition is offered: Six Sigma is an organized and systematic method for strategic process improvement and new product and service development that relies on statistical methods and the scientific method to make dramatic reductions in customer defined defect rates.

Six Sigma uses a structured method, whether the task is process improvement or new product design. In the case of process improvement, the method is patterned after the plan, do, check, act (PDCA) cycle (Shewhart, 1931, 1939). One popular method uses define, measure, analyse, improve and control (DMAIC) as the five steps in process improvement. A somewhat different set of steps called Design for Six Sigma is used for radical or incremental product design (define, measure, analyse, design and verify) (Lindermand et al 2002). Comparing the DMAIC method with the PDCA cycle, Lindermand et al., (2002) also mentions that the DMAIC method is compatible with the problem-solving phases that the PDCA cycle proposes. The DMAIC cycle just offers a bit more attention into using specific tools in the different phases.

In the DMAIC cycle the involvement of the different people from the examined process brings a sense of cross functionality into the organisation. Different roles have another part of contribution in the different steps of the process. This does not mean though that the roles once they are finished with their main contribution into the step, they are discarded but on the contrary a different role will be adopted (Schroeder, 2008).

For all the reasoning above, Six Sigma has been characterised as a precise, focused and highly productive implementation of already used and tried quality principles and methods. The aim of Six Sigma is to reach as close as possible to error-free organisation performance through the use of approaches and tools that have been around for a long time and have widely acceptance. The wide acceptance also comes from the fact that on the core message of Six Sigma, it is perceived the straightforward relation between customer satisfaction, cost and variation (Mikel J. Harry, 1998).

### Voice of the Customer (VOC) & Voice of the Process (VOP)

In the Six Sigma approach the roles of or definitions of VOC and VOP is widely used to help improve the performance of an operation. There is a difference between those two roles which needs to be acknowledged. The Voice of the Process is defined by Holgård and Danielsson (2010), as the "the process's natural behaviour" and the Voice of the Customer portraying "the specifications or goals" that has been set for the process. The use of specifications to control the process cannot be used, so instead it seems natural and by the definitions provided for both VOC and VOP that the start should be done by aligning the those two together, the VOP with the specifications.

In Six Sigma it is essential that the process can be predictable which can be achieved through: (i) change the process's aim, (ii) reduce the variation that occurs during the process and (iii) adjust the specifications to portray the realistic situation of the organisation. Understanding the interaction between VOC and VOP will give the opportunity to better design the processes. VOC and VOP can also be seen as the traditional point of view and a continual improvement point of view respectively. This is because VOP regards all the processes that exist inside the organisation and constantly looks to improve by either reengineering predictable performing processes or adjusting those that are not predictable (Holgård and Danielsson, 2010).

### Pareto charts vs Control charts

To be able to visualise the stability of the process and identify the variation that might occur, different tools exists that can do so. Those tools are called the Seven Improvement Tools that provide an analysis to the collected data and are, data collection, Pareto charts, stratification, control charts, histograms, cause-and-effect diagrams and scatter plots. Each of them provides another point of view to the discussion and are developed for the organisation to be able to base their decision on facts that occur through data gathered from the functions of the company. For the scope of this study attention were given to two of them, the Pareto charts and the Control Charts.

The Pareto Charts is usually of great help when the decision of sequence of the problems should be taken. The Pareto charts consists of bars that sequence of them represents the importance of the factor that is under investigation and is usually placed in the furthest to the left part of the graph and the smallest to the right representing less frequency of appearance. From the Pareto chart, the problem with the most severity is tackled first and then moving on to the next one (Bergman and Klefsjö, 2010).

Control charts are used to examine the behaviour of a process through time and to find out if assignable causes of variation exist for the possibility to make a process predictable (Bergman and Klefsjö, 2010). Inside the graph three lines are presented that are the upper control limit and lower control and the middle line that represents the average. From those, conclusions can be drawn about the variation of the process if it is predictable or unpredictable. (ASQ, 2019) The appearance of trends can also be

identified through the study of control charts since the ability to present process changes can be found in the control charts (Bergman and Klefsjö, 2010).

### Pull & Push Approach

Traditionally, when a pull approach is mentioned, the thinking goes directly to one of the principles set by Toyota. In a pull approach or system, it means that the production will produce when there is actually need for it. Therefore, the customers will receive the items when they demand for them. A similar principal can be applied about the information flow or internal processes inside the organisations. In this case the customer is an internal one such as another department from the organisation. In the opposite case which is the one of push, another department of the organisation pushes data to another department without examining if those data are for that respective person or in the appropriate form to be used further. No matter the situation, the push approach can create waste of time resources (Ericson Öberg, 2016)

When a pull approach is being used by an organisation and that includes the correct use of the information flow, then the possibility of the development of competitive advantage rises against their rivals that have realised the use of the pull approach in a data setting. Controlling the flow means that an overview of the variations that might occur can be detected earlier and therefore preventive actions can be set in place before it is too late By doing that, changing the focus from push to pull, a shift from product oriented organisation to process oriented can be detected and enabled, giving the organisation the opportunity to develop further in other domains as well Facilitating decision-making by choosing an NDT method based on information need, (Ericson Öberg et al, 2016).
The push approach that represents a more reactive approach, of letting the problems arise and then find a solution for them, can be also characterised as a fire fighting approach.

## 3.1.1 Design for Six Sigma

The role of Design for Six Sigma (DFSS) according to Ford Motor Company, (n.d.) and the author Larry, S., is to enhance the quality into the design by implementing "prevent" thinking and tools in the product development process. It comes to enable the solutions that have been found at the level of Six Sigma which role is to provide solutions to the problems in the levels of customer domain, product and/ or process. As a matter of fact, Design for Six Sigma is a unification of "preventive" methods at the pattern level across all four domains (Ford Motor Company, n.d.)

Design for Six Sigma is an enhancement to the Six Sigma method since it allows the company not only to inspect the reasons on why disturbances appear in the processes of the organisation but to also find a way to handle them long term by adopting preventive action. Preventive actions will help the company to remain competitive against their rivals (Antony, 2002).

To an organisation that have implemented the principles and concepts of the Six Sigma methodology realise that, once a certain level of sigma is achieved, usually five sigma, the only way to progress further is to redesign their processes, products and their services. This redesign can only be made through Design for Six Sigma. The advantage of the DFSS is among all the aforementioned characteristics are that it meets the needs of the customers and at the same time providing a possibility of cost reduction. The use of the statistical tools is an integral part of DFSS to be able to visualise the current situation of the processes and see which of them are stabilised and which not and the causes behind it (Antony, 2002).

Apart from the above reasons DFSS can also be considered as an enhancement to an existing new product development (NPD) process. It provides more structure and an improvement in the way that the deliverables are managed together with the resources and the trade-offs that occur. Usually a NPD process in most cases the process includes several high-level phases such as the seven-step systems engineering model: needs assessment, concept design, preliminary design, detail design, process design and construction, manufacturing and end of life (Mader, 2002).

According to Mader (2002) the ability of DFSS is found in the arrangement of the tools into a strategy that aligns with the NPD process and connects the different tools that are being used with everything else. Furthermore, a transition from "event" thinking to "pattern" thinking is also the transition from Six Sigma to Design for Six Sigma.

### 3.1.2 Variation

According to Shewhart (1931) the ability to lead a production process to a state of statistical control where only common cause variation can be found and managing to keep it stable and under control, it is essential to forecast the future output and therefore to handle an economic efficient process (Thornton, 2004). Variation can be seen as an origin of disturbance and a driver of costs when the discussion revolves around quality issues (Bergman and Klefsjö, 2010). The authors also mention that there are two type of variation depending on the reason that is causing it. Those are assignable cause variation and common cause variation. The common mistake that occurs when an improvement project is undertaken that aims to eliminate variation, is to identify the common-causes as the ones to be reduced instead of the assignable causes (Bergman and Klefsjö, 2010)

A definition for variation it is found hard to be formed. The companies that will understand the need to reduce the impact that is brought to their processes by variation will lead themselves to a competitive advantage. Variation can be found in all the processes regardless of the nature of the process, natural or man-made. There are two general categories of tools that can address variation, (i) Reducing Sources of Variation and (ii) Reducing Impacts of Variation. The important fact comes that when projects are going to be conducted with the aim to reduce variation in any why, it must be taken into consideration that variation preventive activities has a prerequisite that data are a vital part of that activity (Thornton, 1968).

## 3.2 Change Management

Organisation change is not a move that appears inside a company without any previous thought or motives that drove the company to indulge in a change process. (Anderson et., al, 2010). One of the definitions of change management is "the process of continually renewing an organisation's direction, structure and capabilities to serve the ever-changing needs of the external and internal customers" (Moran and Brightman, 2001: 111), (By, 2005).

Change management can be proven to be one of the most influential factors in a company's portfolio if the initiative proves successful. Without it, organisations would be stuck in a continuous loop which would lead to potential loss of the organisations competitive advantage (Mcnally, 2018). Especially changes that occur during the product development are found to be costly and inconvenient, yet necessary for improvement and growth. In unstable industries change is inventible (Steffens et al, 2007). According to Steffens et. al, (2007), the author quote Wu et. al and state that "Perfect design is unrealistic and thus design changers are inevitable".

Furthermore, Steffens et. al, (2007) claims that "A general change management process typically includes recognizing and justifying the need for change, evaluation the change impact, agreeing or making decisions on how the change is carried out, and implementing the change.". When a change occurs inside an organisation, usually it will be met by resistance. It expresses the reservation that those affected by the change have towards something unknown. Therefore, resistance unfortunately is linked with some negative that will happen in the organisation which leads to counter-productive responses by the employees. Even though the feelings of a change are mainly negative, it can also have positive reception from the people if it is understood that it can provide a control of the context that the change is being applied. It can prompt the employees to research for other alternatives from the one presented and come up with more ideas that can make the change more fitting to the environment of the organisation. The evaluation of a change, if it was beneficial to the company or not, can only be made after the completion of it and an appropriate period of time has passed (Wadell and Sohal, 1998).

### 3.2.1 Silo Effect

The Silo effect has been one of those business terms that have been discuss a lot in organisations. The term "silo" refers to an organisational unit that focus is only given internally and the units outside of there are not given the correct attention. This causes a broken communication and cooperation between the departments and the growth of fragmented behaviour and knowledge (Vatanpour et. al, 2013). A silo mentality can be developed as well according to Gleesson and Rozo (2013) that will reduce the efficiency of the overall operation.

## 3.3 Knowledge Sharing

One important factor of knowledge is that it should be confused with data. Data are measurements and raw facts as well as statistics. Additionally, knowledge is considered more complicated than information. Information can happen from simply gathering data and organising them in a meaningful order and form information results from organizing data into meaningful forms. On the other hand, knowledge results from the interpretation of the information but from the perspective an individual can provide and represents the holder. In the knowledge that is generated by the information one is presented with, it is reflected the beliefs, attitude and understanding (Lee and Yang, 2000).

Javerick-Will (2012) states that "Knowledge generation and transferring of the knowledge are crucial to sustain a competitive advantage for organisations". Additionally, Razmerita et. al (2016) says that "Knowledge sharing is designed to transform individual into organisational knowledge". Knowledge sharing can help the company achieve success through the facilitation of decision-making capabilities. The most important benefits of incorporating knowledge sharing inside an organisation can be found below (Postolache, 2017):

- Enhance the problem-solving experiences
- Enable better and faster decision making
- Stimulate innovation and growth
- Improve delivery to customers
- Reduce the loss of know-how

In the Six Sigma approach, the generation of knowledge comes out either through intentional or explicit learning according to Lindermand et., al (2002). Through this learning a natural improvement of the methods that are used occurs. When intentional learning takes place, it is understandable that the actions should be standardised by the members of the organisation (Lindermand et al 2002).

### 3.3.1 Visualisation of data

Visualising data is an essential component of scientific practice (Robertson, 1990). Data visualisation is the main aspect of promoting understanding and communication through data. It can be characterised as a visual portrayal of perplexing information, presented in a way that it stimulates understanding. The aim and at the same time the result of data visualisation is to support understanding (Alhadad, 2018).

Data visualisation can take many forms. Deciding which type of data visualization is the appropriate one so it can transfer the possible uncertainty, the association of statistical and/or methodological information; it is found to be crucial since the interpretation of the results can be altered if the wrong one is chosen. Alhadad (2018) states that data visualisation and analyses through statistics should be performed together because only together thee can be a full comprehensiveness of the portrayed results.

Data visualisation should be an integral part of the communication strategy that each company has. The reason behind this statement falls to the fact that through visualisation the complexity of information can be simplified or broke down to a level that everyone can understand that even sometimes words fail to make it understandable. Providing multiple ways of visualisation for a single point of data can add another point of view that can be helpful for the interpretation of the data (Alhadad, 2018).

According to Robertson (1990) “Visual representations of data aim to exploit effectively the ability of the human visual system to recognise spatial structure of the system and patterns”.

# 4. Empirical Findings

In this section, the step of the cycle DMAIC (Define, Measure, Analyse, Improve and Control) will be explained together with the actions that were taken that lead to the findings.

## 4.1 Define

The Define phase of the DMAIC method, has a purpose to define the problem, the improvement activities as well as the opportunities for improvement. Furthermore, in this phase the project goals are being set and the identification of the customer, internal and external, requirements is being made. A project charter is established. The project stakeholders should also be aware about the scope of the project. The voice of the customer is gathered, and a value stream map is either provided or mapped to have a holistic view of the entire process. (ASQ, 2019)

### 4.1.1 Project Charter

A project charter is established to determine the initial focus and motivation of the project. Also, in the project charter the individuals that will be part of the project team, are established. The project charter can be found in Appendix B.

### 4.1.2 AIM

The second tool that was used in the Define phase was the Affinity-Interrelationship Method (AIM). This method is a combination of two of the 7 management tools: the affinity diagram and the interrelationship diagraph. It is a problem-solving tool for analysing qualitative data, with its inspiration originating from the Step by Step approach of Shiba. It consists of 10 main steps with the starting point being the formulation of an opening questions, development of data from the participants of the session, establish a common understanding of the inputted data, a group processes for organising and last but not least, the structure and the prioritisation of the data to give a shared answer to the opening question.

(Alänge The Affinity-Interrelationship Method AIM A Problem-Solving Tool for Analysing Qualitative Data Inspired by the Shiba “Step by Step” Approach 2009)

The steps of the AIM can be found below:

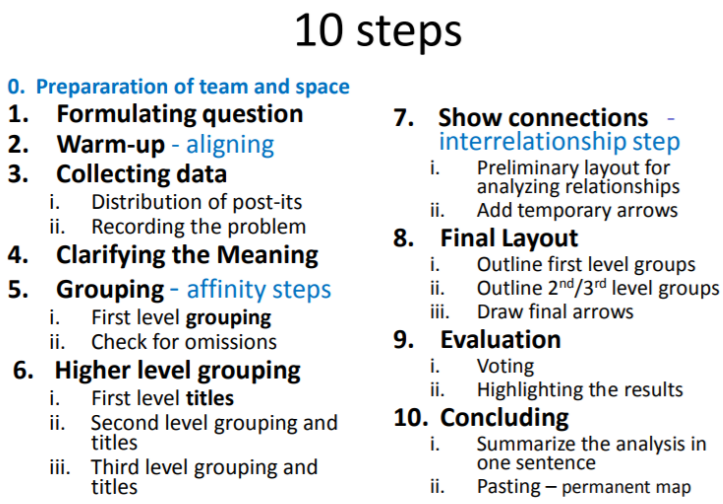



*Figure 2 Steps of the Affinity Interrelationship Method-AIM*

The steps that can be seen above, where followed to result to the shared answer of the starting question. As a starting question, the author together with the participants of the session chose a question that better captured the scope and aim of the study in general. The question was: *"What are the main related obstacles preventing the New Product Development process?"*

The outcome from the AIM session was the following:

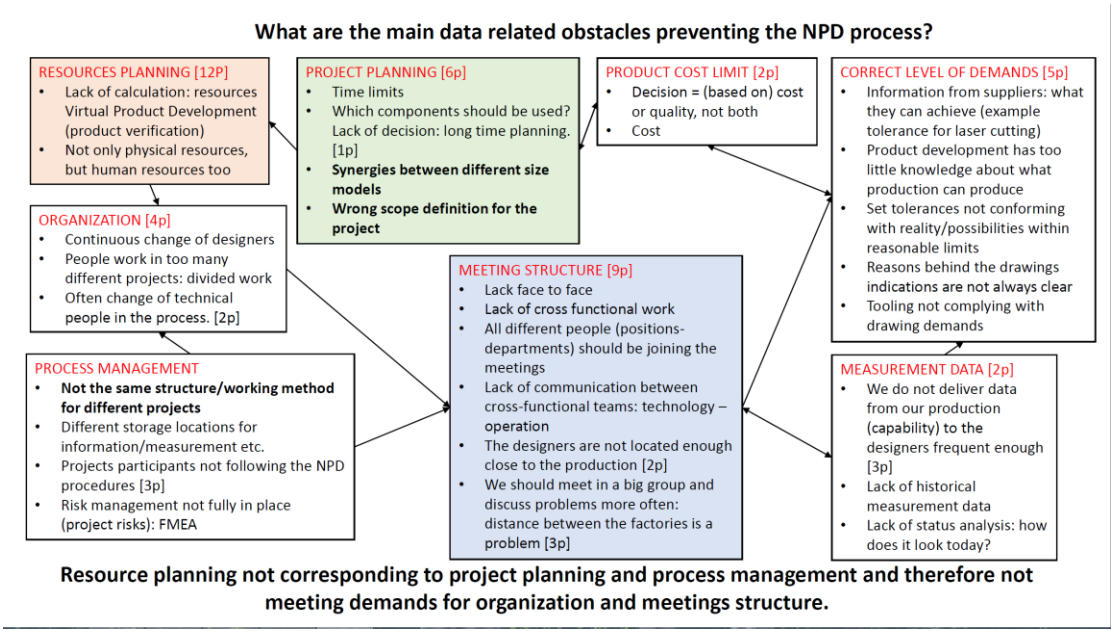



*Figure 3 AIM Results*

In the figure above, the main data related reasons that prevents the New Product Development process to flourish, can be seen together with the grouping that was done by the participants. Underneath each group there are the different points that

lead to the formulation of that group. The interrelationship between the different groups can also be seen. The groups with the most points were the Resources Planning (12points), the Meeting Structure (9points) and the Project Planning (6points). The points were given by the participants to indicate what are the main obstacles from their point of view, by marking the importance of them. In this way, the facilitator (the author) had the opportunity to get a deeper insight into the problem. During the session, there were room for clarification questions regarding what was being written on the post-its by the participants in order to ensure a common understanding and direction, as described by the steps of the method as well. Some of the findings were already mentioned in prior interviews that the author has conducted with employees from the company. It can be translated into a positive remark since there is a mutual perception among employees for the problems that they encounter, even though it might not be as discussed among them.

At this point it would be useful to mention that the participants of the session did not participate in any another interview session with the author before the AIM and that for the majority of them it was the first time that they took part in an AIM session. From the groups with the higher points, the closing statement was formulated as: *"Resource planning not corresponding to project planning and process management and therefore not meeting demands for organisation and meeting structures."* It was found beneficial by the author to take into consideration all main obstacles groups that was formed in order to be able to have a more distant/zoom-out perspective into the problem. The AIM session being one of the first things that was organised in the beginning of the study, helped to highlight certain areas of interest and to also guide the future steps.

### 4.1.3 Effective Scoping

All of the above methods and tools that were used together with the interviews that took place in between lead to the formation of the Effective Scoping. Effective Scoping is an analysis tool that was created by Peter Hammersberg, a senior lecturer at Chalmers University of Technology and Master Black Belt. He developed this tool mainly from his on-field experience on the industry based upon the SIPOC (Supplier, Input, Process, Output, and Customer) analysis tool, to avoid mistakes that have been done in the Define phase of improvements projects in the Six Sigma domain. (Martina Zanti effective scoping thesis, 2015). The mistakes that Effective Scoping tries to avoid are to lock teams into a specific mind-set of the physical process which can be hard to change later on in the process. The process of Effective Scoping is to wait with the framing and staffing until the team is certain that the measure to improve is actually relevant regarding what the customer really wants. It creates an explicit link between Y and y, also boosts the pull-thinking approach since it starts by identifying what it is delivered. (Hammersberg, 2017)

The Effective Scoping analysis tool was used to be able to verify the scope of the project within the team and enhance the common understanding. It took place only

after the initial rounds of interviews that had as a purpose to get a deeper understanding of the issue at hand and the AIM session took place. The entire results from the Effective Scoping can be found in the Appendix C.

### Supplier

The Supplier is the person or multiple people that provide the input to the whole process. From the thesis work done previously to the company (Zanella, 2018), a P-diagram has been conducted which helps to identify the suppliers that are more relevant to the current research. The Company appears in multiple ways as a supplier and it is the one factor that is the starting point of input for some of the other actors of suppliers such as the Weld Manufacturer. The Company have the main responsibility of providing guidance concerning standards but also restrictions coming from the budget. The Weld Manufacturer, which can be an internal or an external provider, are responsible of supplying the Company with all the important information concerning the specifications of the weld that is going to be used later in the process. The Product Manager, who also takes input from the aforementioned suppliers, is responsible about the product that is going to be manufactured and the restrictions surrounding it. Last but not least, the Laboratory Engineer, who comes later in the process of product development, will provide to the Product Manager along with other beneficiaries about the results of previous test or tests specifically done for the new product.

### Input

The input that the company gives to the process of the product development are the internal standards that have been developed through the years of experience in the area and ensure the performance of the products towards the customer, as well as the drawing standards, which give the information of what information the drawing must include, to convey the correct message to the people that will act according to it.  in The Weld Manufacturer will give all the necessary information that involves the weld specifications and most precise the factory production specifications which are utilized both from the internal standards and from welders that will know the possibilities and boundaries of the welding equipment. The Product Manager belongs to the communication team that is contact with the customer and therefore has the knowledge of the requirements and needs the customer has discussed. With this information, the Product Manager, forms the product's specification. Test results are the input that comes out the Laboratory Engineer and it might be test results from previous tests if it is a product update process or newly conducted tests if it is about the development of new product. The information sharing is essential part of the process and it creates feedback loops that are vital to the progress since they help to the distribution of the information internally.

### Process

The focus has been set to the process that involves the departments of Design Engineering, Quality and Manufacturing Engineering, since the interactions between those departments and the feedback loops that are created, are of critical importance to be closed in order to have a smooth transition and continuation of the process. The whole welding process has been mapped by a previous thesis work at the company (Zanella, 2018) in a P-diagram and can be seen in in Figure 3. In the author's and company's interest, the flow to be improved is the information distribution and visualisation. The reason behind this decision, can be partly seen on the AIM session conducted and partly from the interviews with individuals where most of them has mentioned that there are instances that there is an uncertainty on who to contact when questions arise regarding reworking the different parts of the product. From the AIM session it was also made known that certain information such as, test results, calculations, past measurements and analysis that have been done by other department(s), not reaching the parties that would have found the information valuable. All the above, contribute to the delay of the product development and for the feedback loop not being realised.

As it can be seen on the different loops, Concept, Prototype Industrialisation, Test Component Validation and Product Industrialisation Loop interact with each other, which sometimes results into loops not being fully realised, especially when it concerns information and data sharing inside the existing loops. The diagram was an outcome of interviews and visits by the author of the previous Master thesis work and based on the operations as described by the employees of the company. The three departments on hand, are spread throughout the whole process and belong in different loops, but the results or outputs of them, as well as the knowledge that is generated, can have an impact on the previous or following processes. The impact of the information should not be limited to the specific time, but the knowledge and lessons learned from that experience should serve as a base for future actions. The arrows on the loops have one direction only, no bidirectional arrows used, and to indicate the return of the information to one node that symbolises an activity from a person, an arrow to the opposite direction is used.

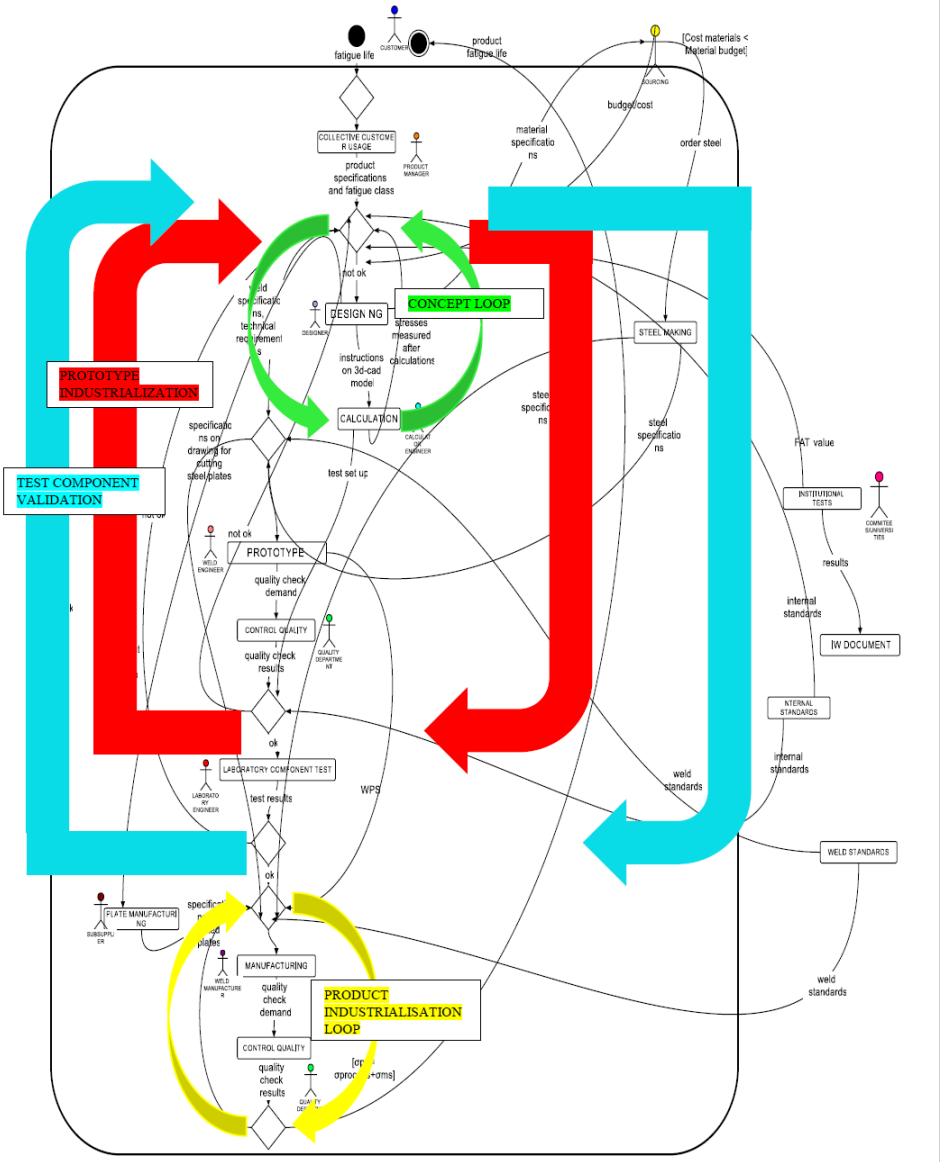



*Figure 4 The welding process and its loops, Zanella, 2018*

## Output

The output that comes out of the physical flow is the drawing from Design Engineering in the feedback loop of Design-Quality-Manufacturing For the same loop but from a different point of you, the output could also be the report that comes from data analysis. In the case of the drawing as an output, further details than just the drawing will be included depending on the receiver of the drawing. Those details can include specifications for cutting steel plates, requirements and further specifications, instructions on 3D-CAD model. For the drawing to reach its next internal customers/users, the tolerances that are going to be used, need to be reasonable. By reasonable, it is meant that they are informative and precise. More precisely, they need to be achievable by the Manufacturing department, resulting to y: process capability. Furthermore, tolerances should be able to be measured by the Quality department, resulting in the y: measurement data. In addition to those, the measures

that should be understood further are the defects, the design lead time, as well as the control lead time. For the output of data analysis-report, it is required to be easily read and understood from the recipients/users and the information included being useful to help reach the tolerances. To be able to improve those measurements, the communication flow and interactions between the different departments need to be understood so it can be assessed what is the appropriate knowledge the designers need to make it possible to deliver a design that will not need further information from the interested parties that are going to use the design.

#### Customer

The customer is the one that will make use of the output. The drawing output is going to be used by the Quality and Manufacturing departments. Each of those departments will have different use of it. The Manufacturing department will use the drawing to realise the product, frame by frame, part by part. The information on it, should be sufficient, understandable and precise for the people of the department to carry out the tasks. The Quality department will measure and control what has been produced to make sure that everything is under the given specifications. Analysing the results and make them available to the interested teams. Those reports can also serve as an output of the process and the user of those is the designer and the designing department that includes the calculation department.

### 4.1.4 Visits at units

In the project charter it is observed that the company has various locations across Sweden, as well as worldwide, and each of them includes different departments and functions of the company. For the purpose of the study, visits to the units in Arvika and Braås were scheduled and done because those two units were of particular interest for the scope of the study and also for the intention to have a Gemba walk. A Gemba walk is part of the lean management methodology and one that is being used also in the Six Sigma concept in order to have the opportunity to freely observe the reality of the work process, interact with the employees that work in this process and collect knowledge which will also be helpful in the step to look for opportunities for continuous improvement (Kanbanize.com, 2019).

Furthermore, interviews were conducted with managers and leaders of the departments of Design, Quality and Manufacturing to obtain a deeper knowledge of the current situation of the company and to work as the first step of the upcoming data collection.

#### 4.1.4.1 Interviews

A total of 10 interviews took place during the Define phase concerning different key stakeholders of the three different departments. At the early interviews, some questions were prepared to serve as conversation starters on the problem at hand, but in the duration of the interview the interviewed party was free to speak about the topic and lead the conversation as well. This method of semi-constructed interviews was chosen because of the characteristic of a certain level of freedom and sincerity that gives to the person being interviewed, allowing to the questioning person to try to

have a deeper insight to the problem at hand and reach closer to the root cause of the problems. Later, the interviews developed into themed conversations to questions or concerns that were raised when a more extended understanding came from the author towards the Analysis and Improvement phase.

### Design Engineering Department

The Design Engineer has expressed that the information coordination is being done through various sources that can make the collection of the correct and/or critical information hard. The distance between the plant of Arvika where Quality and Manufacturing is based and the Braås plant where Design Engineering is based was one of the first statements that were made by the designer as a barrier of communication. The meetings for the design review that has been recently established (less than a year) has helped with the communication and understanding between the different parties involved, therefore enhanced the cross functionality of the organisation. There is still room for further improvement though according to the designer. In those meetings apart from members of the Design Engineering department, members of the Quality department and Manufacturing department, that are involved in the process and parts that are being discussed during the meeting.

One of the most common problems that designers appear to emerge during their daily operations is the gap that appears between what can be achieved in reality and what is written in the drawing to be achieved. For the designers to be able to eliminate this gap, they require historical data and measurements that they are currently missing. Historical information will help to not repeat mistakes from the past and assist to a smoother product development process. It is the view of the designer that the focus should be more on the long-term perspective, which means that emergency situations and firefighting should significantly decrease. The uncertainty of who to contact to retrieve those data has also been mentioned as a big factor of stalling the product development process. The designer has also noticed a difficulty understanding certain documents such as the measuring protocols. The difficulty comes from the visualisation of the information that is not clear enough and demands time from the designer to be understood. Lastly, it was also voiced by the designers that when something cannot be achieved by manufacturing to be made known to have the ability to rework it early in the process and for future reference.

### Quality Department

Both the Measuring & Product Quality Manager and the Project Quality Manager Operations have stated that the cross-functionality of the organisation does not reach its full potential. Although the face to face meetings do help to promote and establish further the collaboration between the departments, it should not stop there. In that domain, both people agreed that the involvement of the Design Engineering department earlier in the process is crucial for the cross-functionality. In the past the

meetings only consisted of Manufacturing Engineering members. The Project Quality Manager Operations noted that due to the load of work and the emerging situations, the organisation has adopted a more reactive stance. For the product development or for the update of existing products though, a more proactive attitude would be more beneficial to prevent things from happening with the allocation of resources, human or material, early enough in the process. A common view from the Project Quality Manger Operations and the Designer is that there are instances where the scope of the project has been defined wrongly, creating misunderstandings and interest conflictions between the departments.

The Measuring & Product Quality Manager has expressed the concern about the other departments not knowing what to ask from the Quality department. The team the person is managing is responsible for a lot of measurements that they store and later analysed when an abnormality appears. The results though of this research are not reaching further out from the department, unless something specific is asked from them. The software is open for people to access it but needs training for the people to learn how to search for specific data. The Quality departments would ideally to share the knowledge that is generated but in an understandable and easy way for everyone that leads to visualisation concerns. Furthermore, it was noted that due to the fire fighting mentality inside the inside the organisation, the first concern is to solve the problem as quickly as possible without trying to find the root cause of the problem first. After the solution is provided, the solution will be incorporated into the development process as a step to be executed each time.

### Manufacturing Engineering & VPS Department

The Manufacturing Engineering & VPS Manager pointed out that they are aware of the existence of variation, but they do not know why it exists since they do not have the measurement data to assist in that research and help them get to the root cause. Their knowledge about what processes are more stable than others, comes from experience mostly. There is no recorded $C_{pk}$. The expression of variation in a functional and easy way is a concern they have inside the department since it can serve as the baseline to analyse the effect on changes, but it is not of critical importance right now. The Manager also expressed an interest of knowing the actual performance of the process regarding parameters and real variation to communicate more accurate data to the Design Engineering department.

An incompatibility between the fixed programs that the robots follow for the w welding process and the standardized procedures that the workers follow when positioning the parts, was also mentioned which requires adaptable parameters for fixing the program according to the parts position.

#### Management Systems and Data Analysis Director

The Management Systems & Data Analysis Director expressed her dissatisfaction towards information being spread in different places which makes it difficult to find the information that you need, in the way that you need them and when you need them in an easy way. A rework, configuration of information, is necessary. Also, the director mentioned that the time to focus on the information and provide analysis, since data analysis is only a fraction of the work to be done. It was also mentioned during the interview, that there is a lack of a common picture inside the organisation due to conflicting interests in departments overtaking cross-functionality.

### 4.1.4.2 Summary of the Interviews

During the interviews, there were some common observations between the departments. In this section the common issues are going to be presented, offering a preliminary round of the possible leads to be investigated later in the process.

**Cross functionality issues**

The level of cross-functionality it was discussed by all three departments. The data that are being collected are discussed with the Manufacturing Engineering department (Weld responsible) but it does not seem to get back to the Design department unless some problems arises that need to be solved. It was a common wish for an early involvement of the Quality department in the design phases with data to be able to be proactive and not only reactive.

**Lack of knowledge about the processes and of the causes of defect**

There is an awareness that some processes work better than others, but this knowledge is not based on facts, measurements and data analysis, rather it only relays on previous experience. One of those examples is that the capability is not measured but decided from experience. Another interruption of the process is that the solutions of the problems are being built in without being examined if they are solving a wider set of problems (root cause analysis). Moreover, since the actual performance related to the customer requirements is not clear, is not possible to decide which requirements are the most critical ones and which can be reduced: it is possible that without over processing the demand will not be met, but for the level of quality is not clear so reducing it is not characterised safe.

**Lack of knowledge about the actual performance on the plant**

The information that is being collected daily from the welding operators (Manufacturing Engineering department) is not shared in collective form as feedback for the designers. Therefore, a common knowledge and understanding of what is being achieved cannot be formulated to avoid reworks and problems in the immediate and long-term future.

**Lack of positional knowledge: who to ask what**

Even when information is being stored and analyses, it is not clear on who to contact to get the right information or to be given direction to navigate through the different software systems. Finding the right person that is connected on the data that is being search of is another issue that people face.

**Issues with analysing and reducing variation**

The acknowledgement of variation and where variation is bigger is something that the company is aware of. The reason though behind this variation and how it can be reduced considerably is something that the organisation is still lacking knowledge of. Also, it was mentioned above about the incompatibility between the fixed programs that robots follow and the procedures that manual workers follow, which will require for the parameters to be fixed according to the parts position.

**Issues with the point of view**

The focus of the company and the employees is mainly to control the product and everything that surrounds it including information/data. The process that helps guide the product through the functions is not at the same level of attention. The employees and the organisation are thus unable to zoom out and look at the whole picture of the situation. Being able to zoom out can help with finding the origin of the problem and adopting a common point of view to deal with them. Originally, the origin of the problem was found during the latest phases of the process or even worse on the field which is making even harder to deal with it accordingly and appropriately.

### 4.1.5 Identified big Y

After the visits to the units and the interviews conducted, it was possible to identify the capital Y at the end of the Define phase. It was identified as "**Information Distribution & Visualisation**". It concerns the closing of the feedback loops between the communication between the departments of Design Engineering, Quality and Manufacturing Engineering as well as, how the information is portrayed that enables the easy understanding and explanation of the data that are being presented. The integrity and quality of the data are not in question, since it was experienced by the author that in instances where data were further information and analysis was needed and/or requested, it was feasible and in a visualisation that was accompanied by text to enhance the understanding of the audience.

## 4.2 Measure/Current State Continuing

The purpose of the Measure phase of the Six Sigma is to understand what the current state of the process is and to collect dependable data on the process that will be later used to uncover the hidden causes of the problem (Maxey, Rowlands and Upton, 2004). Some of the data have been already gathered through the interviews and the AIM session and analysed in the Define phase. As it can be seen from the previous section, the project concerns an information flow project. The interactions and data shared, how those are visualised, as well as how that impacts the process is the main interest in this study. The focus therefore is intensified in the transactions between the different roles of the process which are going to be explained below.

### 4.2.1 Process Map/Flow Chart

In Figure 3 the different loops that are created in the welding progress are presented. As it was presented in the previous sections, the interaction between the departments generates information that complements the expected outcomes. In the scope of this project, the departments of Design Engineering, Quality and Manufacturing which have been defined as the focus have their first influential meetings and decisions in the very beginning. The beginning of the process is being mirrored in the Concept loop. The focused information exchange between those departments together with the teams that are involved to make it possible, such as the Product Manager, Calculation Engineer and Welding Engineer can be seen in Figure 4. The specific consequence of the exchanges is mapped and where the input of different departments is entered.

The process always starts with the Client and the needs that it will have. Those are translated later by the Product Manager into requirements that will be passed on to the Designer of the Design Engineering department. The task of the Designer is to translate the requirements to tolerances to be able to realise a 3D CAD model/drawing that when will be agreed upon it will be used by the Manufacturing department to build the different frames of the product. The features of the model need to be discussed with the Calculation Engineer since one of the outputs of the role is the stresses measurements after calculations. The Manufacturing Engineer is also involved in this discussion to help the Designer with design features on the spacing needed for welding to be possible. They should also comment on the achievability of the drawing in real life. If agreement is not achieved, then some updates are being reworked, until a satisfactory compromise and agreement is reached between the parties. After that, tests are being done in the 3D CAD model, where further inconsistencies will be discovered and sent back as feedback to the Designer to update the drawing. The step after an agreement is reached from this step, is for the Designer to realise the 2D model which will be checked by the Calculation and Manufacturing Engineer. The feedback from there will be again given to the Designer for rework and update. The agreement that will be made on this stage will reach the Design Review level. On the Design Review, the Quality and Welding Engineer are now included into the process to verify if those that have been agreed upon and already been

executed so far, can be checked and can be realised respectively. Those comments that are of equal importance than the previous ones will be given to the Design Engineer and will bring the process back the realisation of the 2D model after reworks from the field are being considered. The process will go all over again after the 2D model is being made. The agreement from the Design Review will lead to the continuation to the next phase of the process.

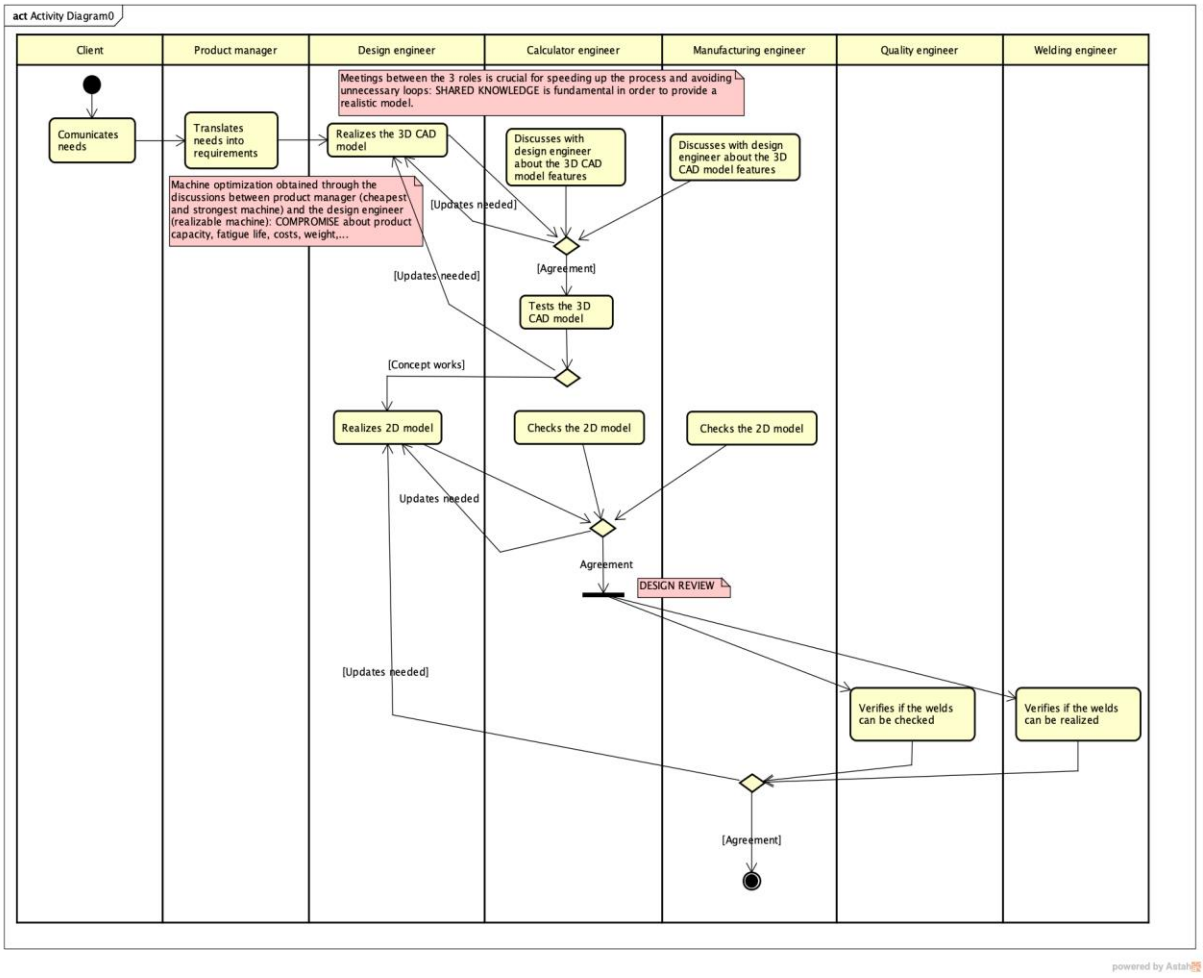



*Figure 5 Process Map/ Flow Chart of the Information Flow Interactions*

For the Designer to start the process of translating the inputs into a 3D CAD model, the person needs to rely into the experience of the past on what it has worked before. This method of decision-making does not take into consideration on why those have worked in the past and measurements together with analysis that might accompany them. The use of this method is not a personal choice that the Designer has but mostly comes out from the fact that they are unable to find the correct people to ask questions they might have from previous measurements and performances of the product after it was produced or where that information is stored to access. It was also commented from Designers that they are lacking the knowledge of the capability of the manufacturing and what is feasible to be executed.

As it can be understood from the explanation of the concept loop process above, the information and feedback exchanged are the main tasks that take place in that phase. Discussions in that level are based in the experience from the people involved and it can also be accompanied by some data analysis that has been done in the past to explain some decisions, although it is not a principal standard. This practice mainly appears when problems occur in the realisation of the design which is late in the concept loop phase and can cause the restart of the process. The department that brings this on the table for discussion is the Quality department. It also shows that the knowledge that it is needed to take decisions based on measured facts from the past, exists inside the organisation. Furthermore, it is good to mention that the visualisation of those data is presented; it is influential of the understanding and acting upon them later.

Recently, in October 2018 the company has taken steps to help with the completion of the feedback loop and information sharing by involving earlier in the process the Quality department and the Welding Engineers from the Manufacturing department with the help of Design Review meetings held in one of the sites of the company. This step has helped to promote the understanding of the cross-functionality of the organisation but the problems of integrating root cause analysis and considering the visualisation the data when presenting remains still.

## 4.3 Analyse

In the Analyse phase, the aim is to identify the critical factors, named x-factors, which are affecting the process and causing variation into it (George et. al, 2005). The prioritisation of those factors needs to take place in this phase as well. The data that are used at this phase are the one that were collected and analysed from the Measurement phase, together with the findings that occurred during the Define phase. The identified x-factors will be at a later stage tried to be controlled. In the following section the outcome from the Analyse phase will be presented.

### 4.3.1 Common Elements of Disturbance

From the interviews, together with the observations through the attendance in two Design Review meetings that took place in the duration of the thesis project, as well as the mapping of the current information flow in the concept loop of the welding process, the common elements that disturb the information flow of the process were summarised. Those were the following:

- General lack of knowledge about the production (quality & manufacturing departments) process performances. This leads to decisions being made on a big extent on experience and not through data measurements and analysis.

The above results to over processing during the realisation of the design as it has been described and pictured in the process flow mapping. By over processing it is meant that extra features are being added to the design of the frame that came from past designs that had a success rate. The addition of those features though is added without knowing their full contribution they had on the success of the frame since there is no data analysis that can confirm that. Furthermore, part of over processing is the addition of safety margins in different phases of the concept development process to ensure the quality of the product. Both of the ways of over processing come from the fact that the real robustness of the product is unknown. The same finding of over processing as a safety margin was also found by another ongoing thesis work at the same company (Månsson, 2019) and the practice has been found to have economical disadvantages.

- Short time focus that develops a fire fighting attitude towards problem solving

The pressure to solve problems right away in order to avoid mis happenings appearing later in the process and most importantly at the customers does not allow space to find the best solution that the root cause of the problem will be searched and the result of that will have a long-time perspective. The problem with the short time focus leads to a constant firefighting attitude in working out the issues just to work them out without taking into consideration the actual cause and solve that. In addition, the solutions that are developed are being added to the process as a step to be followed or as a feature to the frame without analysing the usefulness that it will bring. Adding probable unnecessary steps into the process creates an eternal loop between over processing and short time focus and firefighting attitude.

- Cross functionality is not fully integrated/feels forced

The enhancement of the cross functionality inside the organisation happened three years ago, where a change in which teams refers and collaborates with, between the different departments of the organisation took place. During the AIM session it was mentioned that the New Product Development (NPD) procedures are not followed by the participants of the product development project. Upon investigating on this matter, it was found that firstly the procedures are not wildly known inside the organisation and there is a difficulty of searching for them inside the documentation system called cOMMon that the company has. Secondly, in the design of the procedures, cross functionality is one of the first elements that attention is being given to be portrayed in them. The ability to give feedback upon the procedure exists from the parties involved in the process. The cross functionality inside the organisation is still rather new, which creates an uncertainty between the employees on how to act upon it and has the feeling of being forced to work in a group and the benefits that might bring. The Design Review meetings where employees from the departments involved with PD are gathered to discuss related issues, has helped to close the gap of cross functionality but more actions are needed for the fully integration and acceptance from everyone.

- Fragmented information

The partially integrated cross functionality has its consequences on the information flow and the fully completion of the feedback loop between the departments of design engineering, quality and manufacturing engineering. Each of the departments generates a different part of knowledge which is essential for the realisation of the product. The uncertainty on how exactly this generated knowledge should be communicated, who is the target audience as well as when is the right time in the process to do so, leads the organisation to have only pieces of information, blocked in different segments and phases. The consequence later is that the question and the conversation it might be created out of them are also kept in a minimum since people they do not know who to ask. Additionally, fragmented information tends to create an inconsistency in the language that is being used in the various departments. The language is mostly portrayed in the documentation and visualisation of the data that are being shared internally. As a consequence, a document that is given as input to a department to help as a base to realise the design, might take longer to interpret than expected and the interpretation might not match the original one.

### 4.3.2 The Pilot Study

As it is appearing now by the findings, the company is being focused on specifics problems that appear on the frame of the product and the focus has been on trying to fix those as soon as possible. In some cases, an analysis is being provided by the Quality department, but the discussion will not go further after a decision has been taken and the product has not been examined as one.

The ability to distance oneself from a situation and assess the holistic state, it is a skill that requires a lot of experience to be applied. Zooming out allows to get a full understanding of the current situation and how everything that has been accomplished so far, influence the final product that has been planned. It also gives the time to base the decision for the next steps or the reworks that needs to take place, in an analysis based on measuring data from the past. The process of being focused in a specific small part of the product like a specific welding ID, which can also be described as zooming in, has been taking into consideration only the Voice of the Customer (VOC) and how this will limit the fatigue and life of the product only. Versus the process of looking at all the welding IDs in a frame, or zooming out, provides a view of the variation of the process which leads to the Voice of the Process (VOP) where the product's lifetime as well as the operation performance is taken into a consideration.

At a first reading it seems that the common elements of disturbance of the concept loop do not have an immediate correlation with data visualisation. In fact, the connection between the two can be found in the change that it will bring in the way of thinking. The conversation shifts from the product into the process and gives the ability to zoom out to see the whole picture and the roles that are involved to make the frame happen. From the conversation being about a specific ID point on the frame and how its performance can be enhanced, a change in the data visualisation can help to alter the discussion to the whole frame and how the interactions of all the ID points on it influences the final product.

Through the interviews it was also found a contradiction about the information that is needed to provide analysis. Some of the subjects claimed that they do not measure because of absence of historical data, whereas other subjects stated that measurements from the past five years are in place making data analysis possible. When data are used for problem-solving they are presented through various statistical tools depending on the situation, among them being pareto charts, pie or bar charts and control charts. The use of control charts inside the company has been steadily increasing as a method of visualisation from data analysis. Although control charts can have a variety of usefulness as it has been described in the theory section, it requires a level of familiarity with the method to get the most out of it.

All the above lead to the formulation of the following hypothesis:

**Hypothesis**: *"Since the data is already being measured and stored inside the company and a portion of them is being used for problem-solving through data visualisation and promotes understanding, then data visualisation can enhance information sharing and be a conversation starter".*

The purpose of the pilot study is to investigate if the understanding is enhanced through visualisation and how this can bring a change in the point of view and boost process understanding. The execution of the pilot study is being done with the help of another on-going thesis work (Santoni, 2019). Especially the graphs that has been produced to help investigate the main message of the work which is to test if a

standardised information flow can be the answer to decisions based on facts and work as a robust design tool and a variation reducer.

The aim of the pilot study is not limited to find the graph that will describe the situation with every detail and will discard personal communication. It is rather to find a graph that will help the company to zoom out and assess the entire situation of the frame, while it will provoke discussion among the members of the NPD. The graphs that were explored are going to be presented along with the possibility to initiate discussion. The reactions from the members of the Design Review meeting are also going to be included to determine if the hypothesis was correct or not.

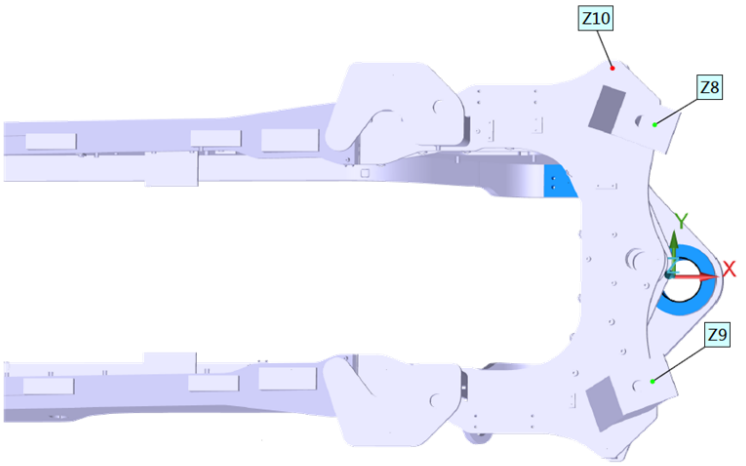
### The graphs

The data that was used for the graphs are measurements that have been acquired from the rear frames of a specific product of the company that is under review. The measurements were acquired through the different process changes the frame goes through until it reaches its final state. The process changes are:

- "0"- the starting point where variation was first observed.
- "Change frame side"- where a number of adjustments are done to the welding fixture for the Left/Right frame sides.
- "Changed final fixture"- where again a number of adjustments are done to the welding fixture for the Left/Right frame sides before it moves to the next stage.
- "B Build"- where a number of prototype frames are made with a number of new parts.
- "P Build"- where a number of prototype frames are made with a number of new parts after a final change.
- SOP- Start of Production.
- "A Build/Update H"- where the first frames with the new design affection in different parts are produced.

The company has marked the rear frame of the product with various welding ID points that are of importance to monitor. Those welding ID points are portrayed in the measuring protocol that the designer receives. In the measuring protocol, the performance of the ID points regarding the tolerances is displayed. With red the ID points that either exceeds or under performs the tolerances. Usually the company will focus on the ID points that fail one way or another and try to improve only those. In Figure 5, a part of how the protocol that is current use can be seen.

Although the protocol it is designed to provide an understanding on the performance of the different welding ID points and the contribution they have on the whole frame, difficulties has been found on interpreting the protocol itself as well as the actions to be taken to better the situation. Also, the current view allows looking only into the defects which leads into a fire fighting actions and has a product point of view falling back to VOC point of view.




| | | | |
|---|---|---|---|
| | DETALJNAMN : | | februari 18, 2019 19:01 |
| | VERSIONSNR. : | SERIENR. : 2 | STATISTIK-ANT. : 1 |

Häftad/Svetsad : After the last welding
Uppmätt av : J-E K
OBS!! Gissad tolerans.

| ⌖ | MM | DIM1 - Z8 | | | | | |
|---|---|---|---|---|---|---|---|
| AX | NOMINELLT | +TOL | -TOL | MÄTT | AVV | UTOMTOL | |
| Z | 1397.89 | 0.50 | -0.50 | 1397.74 | -0.15 | 0.00 | |
| T | 0.00 | 0.50 | -0.50 | -0.15 | -0.15 | 0.00 | |
| ⌖ | MM | DIM2 - Z9 | | | | | |
| AX | NOMINELLT | +TOL | -TOL | MÄTT | AVV | UTOMTOL | |
| Z | 1397.89 | 0.50 | -0.50 | 1397.52 | -0.37 | 0.00 | |
| T | 0.00 | 0.50 | -0.50 | -0.37 | -0.37 | 0.00 | |
| ⌖ | MM | DIM3 - Z10 | | | | | |
| AX | NOMINELLT | +TOL | -TOL | MÄTT | AVV | UTOMTOL | |
| Z | 1096.89 | 0.50 | -0.50 | 1095.79 | -1.10 | 0.60 | |
| T | 0.00 | 0.50 | -0.50 | -1.10 | -1.10 | 0.60 | |

*Figure 6 Measuring Protocol currently used by the company*

The first attempt in Figure 6 resembles a control chart, with the lines green lines representing the specification limits (upper and lower) and the blue line helps to identify a trend in the ID measurements as they evolve over time. With this view, the information about the process capability for every point is not being presented, since the points in the graph are the mean value of the ID measurement. It concentrates onto the visualisation of the development of the ID measurements in a time period as well as the various process changes corresponding to the tolerance limits.

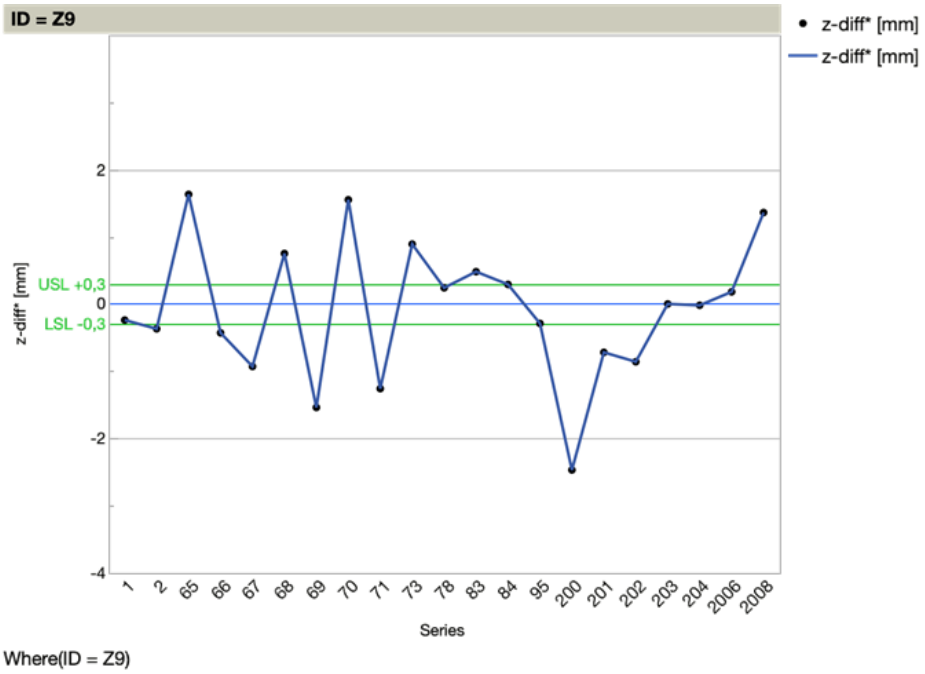



*Figure 7: Looking for patterns in the IDs: values in time*

In Figure 7, all the welding ID points can be seen from the different frames in their specific part on the frame from the front (1) to the rear (5) and over the different process changes as they have been described above. The specification lines are again represented from the green lines, with the bars representing the mean values of the ID measurements and the dots are the single measures. As it can be understood, in this representation, the whole frame together with the points can be seen and encourage to have a better understanding and overview over the frame but it is not very clear that this is a frame in the graph. Since the bars are the mean values of the ID measurements, in order for specific decisions to be made for a single ID point extra analysis needs to be done. The advantages and disadvantages of this graph are of equal value adding. There is also a possibility for the discussion to shift more into the process changes because of the structure of the graph and look more about the root causes, promoting a long-term solution. Still, though it can be considered as a graph that it will not be understood by people that are not familiar with statistical representations which therefore is missing the target.

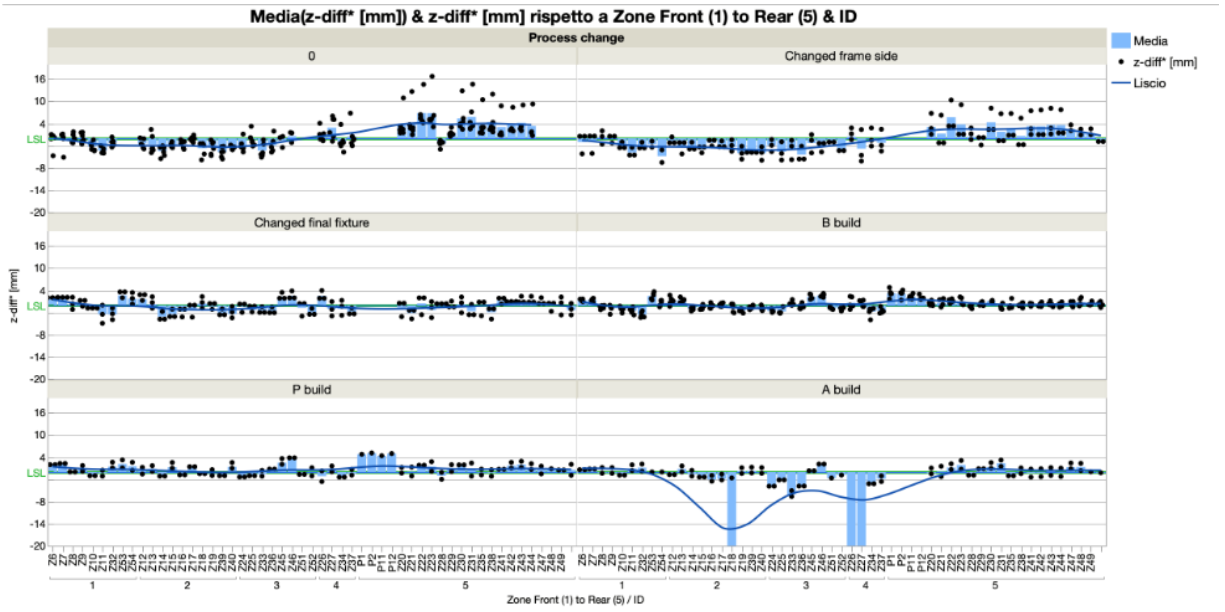



*Figure 8 Looking for the critical IDs: Mean Bars & Measurement points organised by front-rear position on the frame*

The graph in Figure 8 has similarities with the one from Figure 7, with the difference being that this time the measurement points are divided by the side of the frame they are located on, left or right. Many similarities can be found with the previous graph regarding the information that can be conveyed and this time it is easy to see the differences that appear between the sides. Again though, prior knowledge of the anatomy of the frame is needed to understand where exactly the IDs are located in the frame. Although asymmetries can be found as extra information, it is again not easily understood by everyone and it is not helpful to promote discussion towards the process capability.

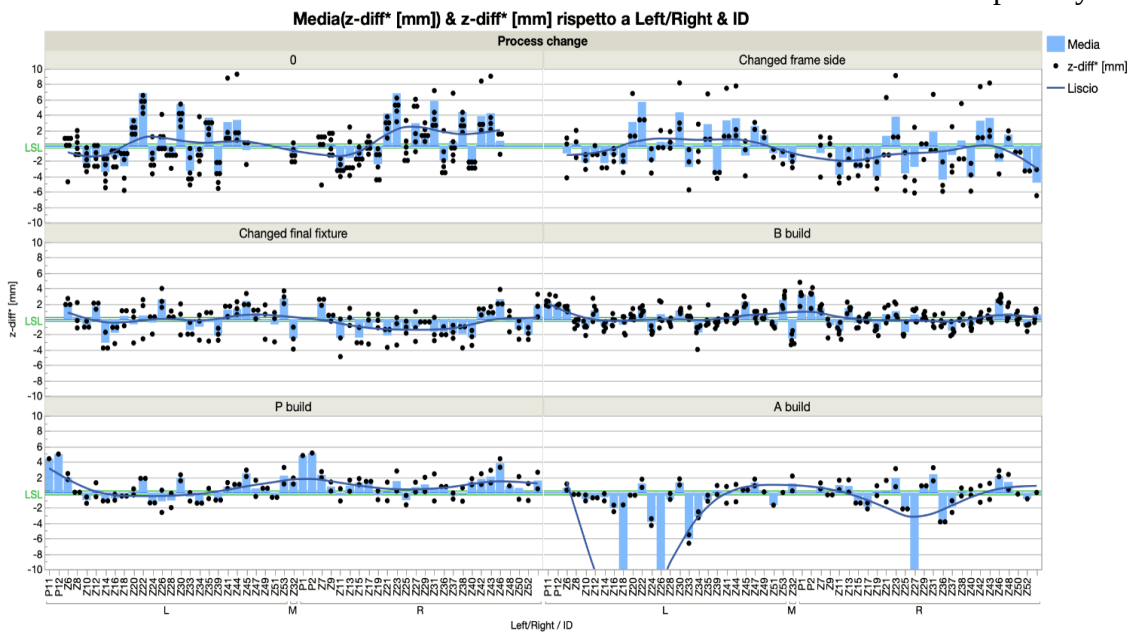



*Figure 9 Looking for asymmetries: Mean Bars & Measurement points organised by left-right position on the frame*

Figure 9 is a combination of the two figures above. From this graph, the whole frame can be seen together with the ID points through the sides and the zones. The variation in the different zones on the frame can be seen together with the trend of the material variation distribution. Through this view the asymmetries can be seen, although the patterns in IDs and the variation it might be created cannot be portrayed. In spite of being a good summary for the above graphs, it will not be able to stand alone and provide the information with one glance. It will require more information to be provided for a holistic picture and decisions to be taken.

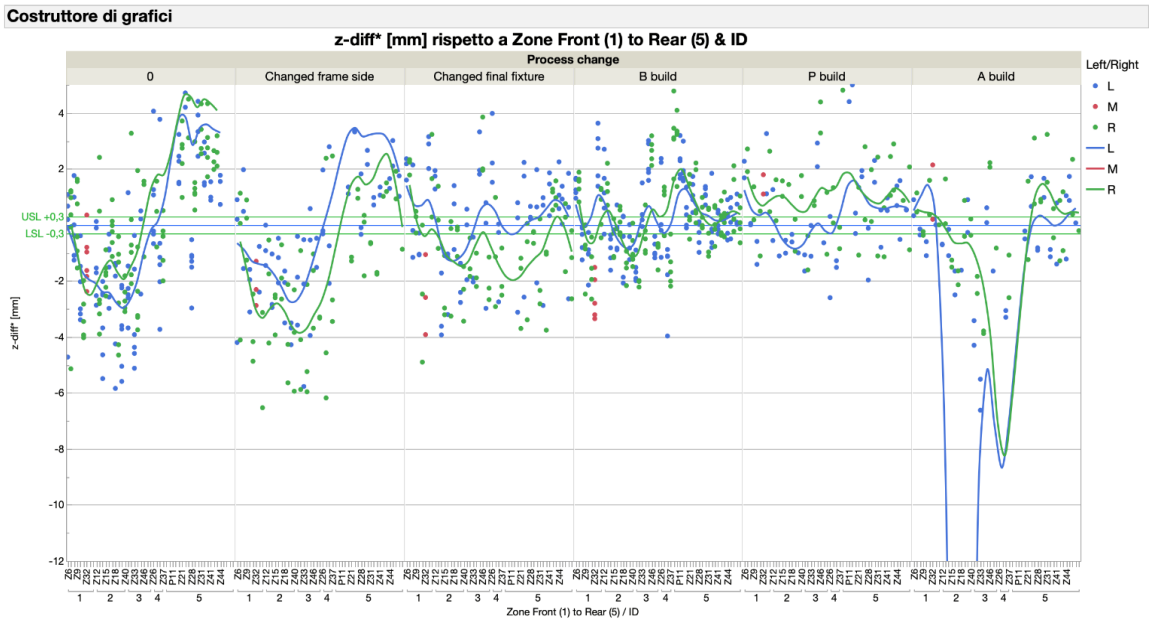



*Figure 10 Looking for patterns in the measurement's distribution on the product: checking points organised by position on the frame side*

On the final attempt, Figure 10 provides a top view of the frame. The black dots represent the welding ID points. The colours that appear on the frame represent the variation on the quantity of the material. Blue represents too little material, grey right on target quantity of material and red excess of material. This graph is a close to the structure of a real frame as it can be and therefore it makes it effortless for people that are familiar with the frame, to convey the information that is needed. For those that are not so familiar does not immediately understand that the contour plot showcases a frame. This specific graph, the contour plot, contains most of the information that is needed to ignite a discussion between the people that are involved in the NPD process and also to help them zoom out and reflect on the whole frame and the decisions that have been taken in that domain.

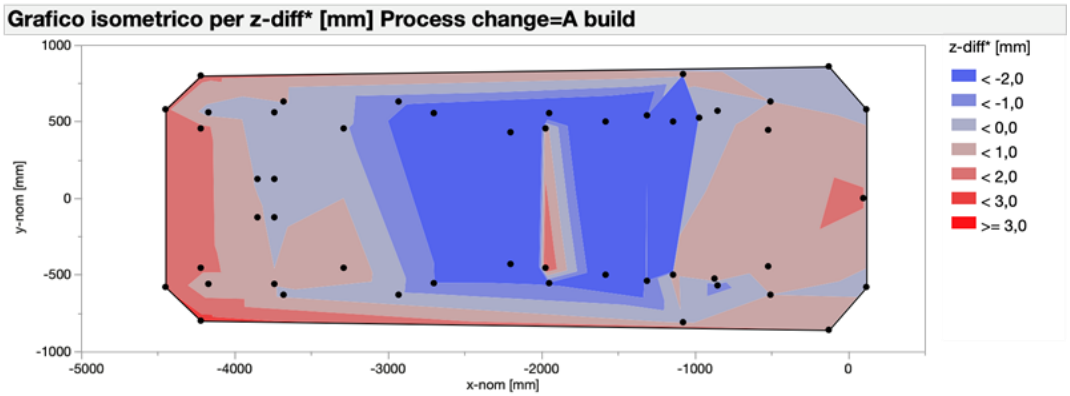



*Figure 11 Looking for asymmetries and critical IDs: Contour Plot*

### 4.3.3 Identified x-factors

Based on the findings from the interviews, observations and through the pilot study, the critical x-factors of the process that generates the variation in the information flow have been determined. Those are the following:

- **X1= Lack of information sharing,** in the Concept Development loop information sharing between the departments that are involved, Design Engineering, Quality and Manufacturing, needs to happen to help the process move forward. Currently the information is being kept inside the departments due to the fact that people are not aware of what others are doing and they do not know to who they should direct their questions to get answers.
- **X2= Not fully understood & integrated cross-functionality,** it is a fact that can be also seen in the previous factor X1. Although cross-functionality it is present from the procedures that the company has in place for NPD, the people do not seem to be fully informed about them. The lack of cross-functionality leads to conflicting interests between the departments which also creates the lack of information sharing.
- **X3= Lack of common language & point of view**, comes as a consequence from the previous two points. Since the information tends to be fragmented and cross-functionality is used when it is needed, creates a gap in the language that is being used between the departments which is also creates a difference in the point of view since people are occupied with the tasks and problems of their function only.

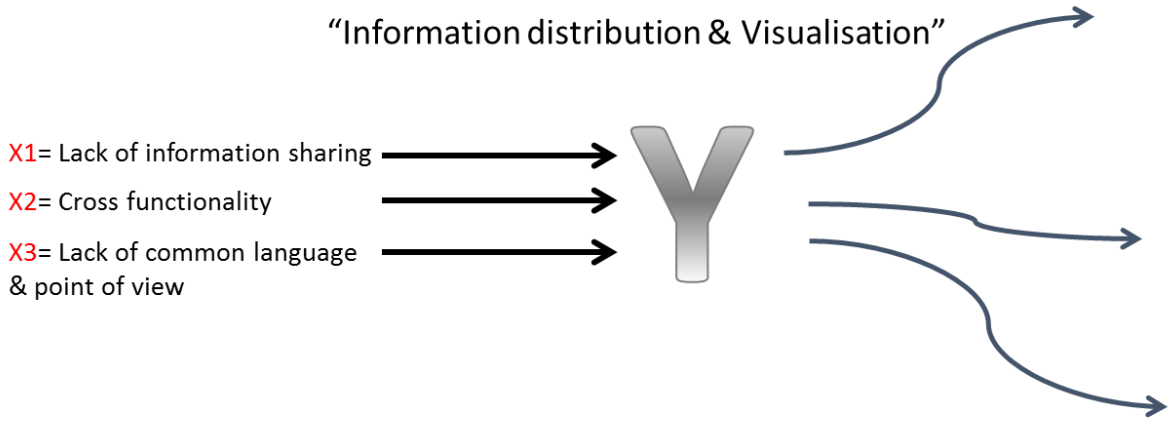



*Figure 12 Illustration of the process capital Y and the identified x-factors*

## 4.4 Improve

From the graphs provided above, the one that seemed to be the most favourable to convey the message that was needed, more specifically to be able to be understood by everyone, to portray as any information as possible and to help the company to reflect to the whole information (zoom out) and not continue its focus to single details only. Therefore, further experimentations as were done on Figure 10, the contour plot, to see if it is possible to bring its form as close to a frame resemblance as possible. Figure 10 was chosen because it had all the desired characteristics that were wanted apart from the one of being immediately understood which was fulfilled by half.

Upon further deliberation, Figure 12 was created. It is again a contour plot but with a different appearance. This time the contour plot takes the shape of the frame on showing the variation that appears on the quantity of material. It was also possible for the dots that represent the welding ID points, to take the colour from the corresponding variation. Blue represent too little material, grey almost no variation appears thus just right quantity of material and red an excess of material. Regarding the discussion, it appears that this view if much more favourable compared to the one from Figure 10. This is because now it is obvious to see even from a person that is not very familiar with the rear frame, that the plot resembles the top view of the frame. The same characteristics of discussion are initiated, with the only difference that this time with the shape of the contour plot it is understood by everyone that this is the top view of the frame no matter the level of familiarity one can have either with interpreting graphs or with the actually rear frame of the product.

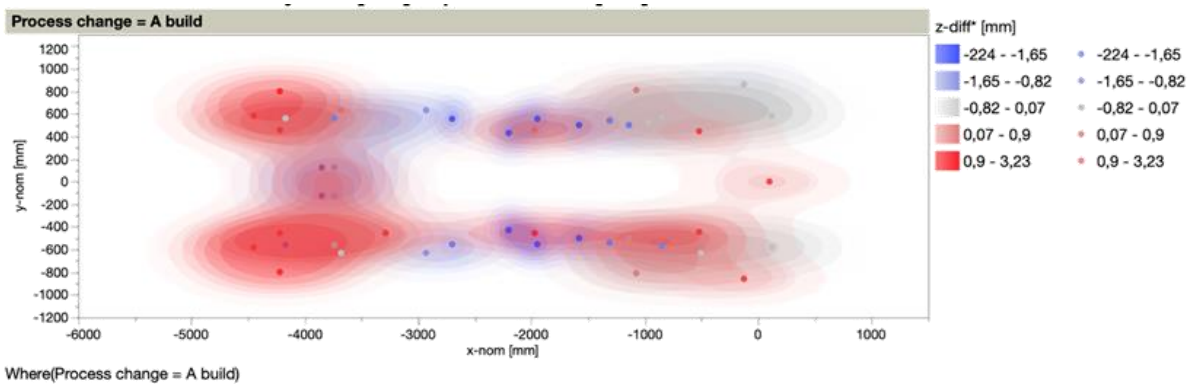



*Figure 13 Looking for asymmetries and critical IDs: Contour Plot Shaped view*

The first attempts from the graphs were also shown to employees of the company that are part of the NPD process and were also interviewed during the initial phases of the project, to gather feedback. From this feedback session, a suggestion proposed to overlap the contour plot from Figure 12 with an actual CAD design of the rear frame to help with the problem of not understanding immediately that the graph resembles the graph. The suggestion leads to the creation of the graph in Figure 13.

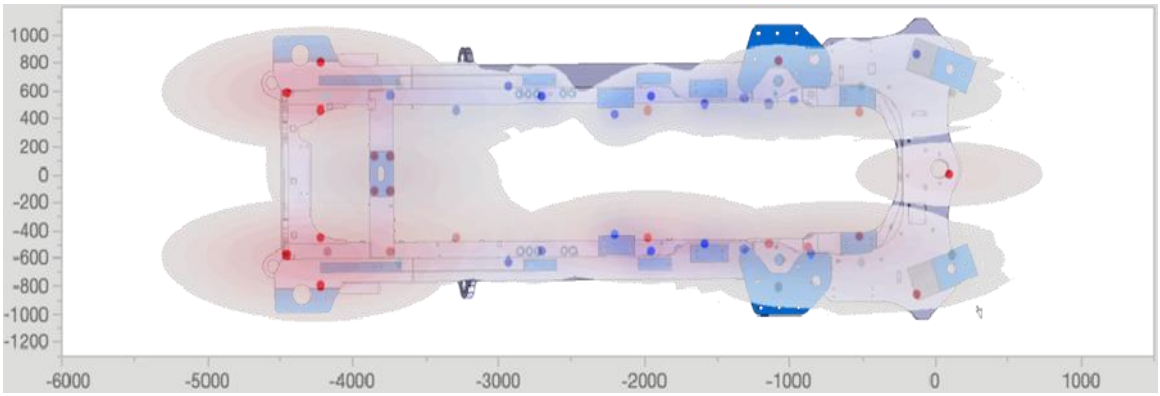


*Figure 14 Looking for asymmetries and critical IDs; Contour Plot overlapped with a CAD*

The result of that suggestion in Figure 13, gives the extra advantage of visualisation compared to the previous attempts. The CAD design underneath enhances the view and understanding, as well as it includes everyone into the discussion while transmitting the appropriate knowledge to be able to decide what should be investigated further to base decision on facts.

The sequence of evolvement of the graphs was presented to a Design Review meeting to be able to capture the reactions and comments from all parties involved in NPD and to test for the first time the hypothesis that was build earlier. One of the first reactions was that they have never been confronted with such visualisation before that let them have a view of all the welding points. This view allowed them to see the interactions between the different points. On the contour plot it is possible to show the sequence of changes in the processes going from 0 to A Build, which provides the opportunity to see how the changes that occurred between the builds affected the overall frame.

Apart from the information and insight the overlapped contour plot brings forward, it shed light into the usefulness of the gathered measurements and thus the knowledge that the company has. It was an outcome that was addressed through the presentation of the graphs.

It can be observed that after the presentation of the graphs and the discussion that followed for further explanations, questions and thoughts on where the graphs can be placed in their process, that a shift in the mind-set among the participants. As the discussion took place, the participants had various ideas on where this kind of analysis it could be of use and the benefits behind the usage. One of the proposed usages of the graphs was in the help to closing the Geometrical Assurance communication loop and more specifically in the last step called "4.b Utilise data input for new design". In that step the aforementioned measuring protocol is included as information carrier, which as stated it was not understood at the same rate of information for everyone in the process.

Another idea on where to use the graphs was early in the NPD process, on the Pre-study and the Concept Development phases to assess where the efforts of the group should be concentrated. It was stated in that suggestion, that currently there is no real tool on how or where to start the process of developing a new product or developing updates on an already existing product. It usually started from people's experience on the matter, thus it will be good to have a tool in place to help this process in a base of decisions made on data. Along with this suggestion came an improvement point on the visualisation of the overlapped graph to the CAD drawing, to add the tolerances on all the points or at least on the critical points. Colour coding the points to see which are out of the limits or on the verge to be able to pay special attention on their behaviour on the changes applied in the entire process, was also suggested.

At this point it is important to mention that on the creation of the graphs and the analysis, the tools that have been used was of the similarity of the tools that the organisation is using for their analysis. The reason behind that is that both theses work (Santoni & Pantazi, 2019) wanted to keep the possible suggestions that would have come out of the theses as organic and as close the company tools as possible to avoid any further training that would have added time the execution. Additionally, the purposes of the theses were not to offer another tool suggestion but mainly for one to prove that for every technical decision, data and the information that emits from them is the backbone of that said decision (Santoni, 2019). Secondly, what would be the real impact of the data visualisation and the shift of the discussion, from zoom-in to zoom-out, that will bring inside the company.

An interview was also conducted with Santoni (2019) to discuss what the changed visualisation will bring to the company according to her opinion. From the analysis conducted on that thesis work, the short time focus of the solutions provided to the problems that occur was also noted. The firefighting that emerges from there is pushing the thinking of the process to be more of a push and zoomed in into specific problems, than pull and thinking about the process. The hope that the graphs will be

the first step onto making the company realises that a process way of thinking instead of a product only way of thinking will get them further was expressed. The proactive way of thinking will also help them to comprehend that cross functionality is an essential part of the NPD process which requires extensive communication between the members. If communication it is done in the way that promotes cross functionality, inclusion and interwoven with a common language, then the information needed will be more spread out in the process. The interviewee mentioned that is not realistic to believe that everyone will know about everything, but at least a level of overview will be available.

As for the use of the graphs, the goal according to the interviewee would be to have them be integrated into the NPD process. If the effects are similar to the effects that were presented in the previous sections for the NPD, then the interviewee expressed the ambition that a similar practice to be further implemented to other processes apart from the NPD one. The reasoning behind this argument is based on the fact that the processes should be the same as the following: 1) to identify who of people want the information and 2) in which of the phase the process they would like to know that.

A similar approach has also been developed by Ericson Öberg (2016) for the context of the evaluation of welds, and can be seen in the Figure 14 below:

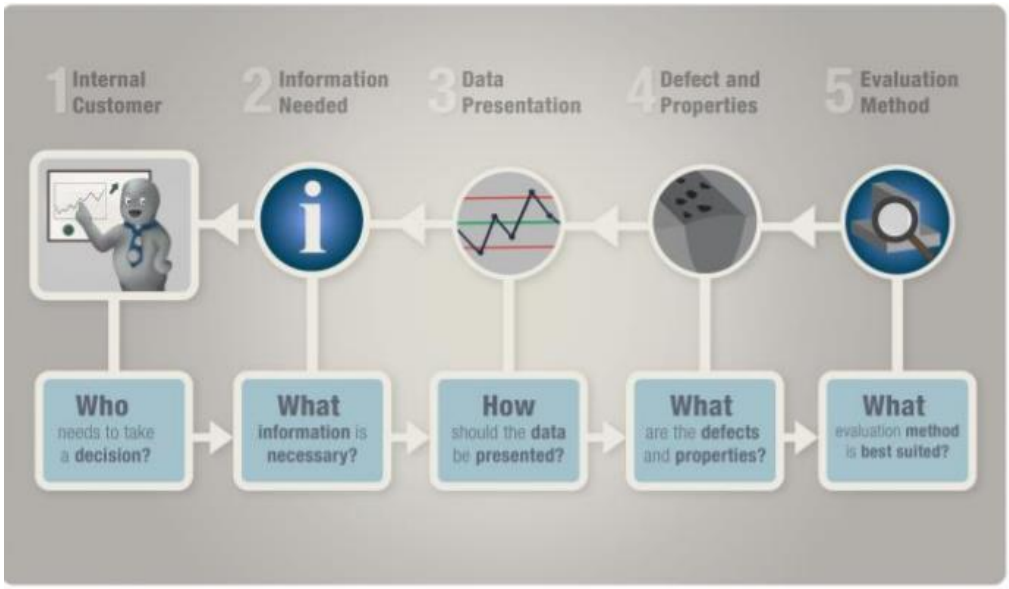



*Figure 15 The PULL approach for evaluation of welds. (Ericson Öberg, 2016)*

### 4.4.1 Summary of the Pilot Study

To summarise all of the above and examine if the hypothesis of the pilot study has been answered in a satisfactory manner, the improvement points will be presented in the following section.

One of the x-factors that were identified earlier in the Analysis phase was the lack of information sharing which is enhanced by the fragmented information that each department holds. Finding a way to coordinate the information sharing between the departments will have an impact on the rest of the x-factors such as cross functionality and the improvement of the common language & point of view. Through the change in the data visualisation as it was presented in the previous section, the perspective that the members of the NPD changed. From a product-oriented mind-set, a shift towards a more process-oriented mentality has been detected.

The goal of the pilot study was to spark a conversation between the different departments that will lead to further collaboration and understanding of each other's unique contribution to the general picture. Of course, it needs to be mentioned that the graphs as a conversation starter needs to be tested for a longer period of time to observe the extent of the shift in the mind-set from product to process.

In Figure 4 in the Measure phase it was described the communication between the different departments. Some crucial parties for the development of the Concept phase of the NPD were involved too late in the process. From the gathered findings so far, it is important that the involvement of those parties to be included earlier in the process. In Figure 15 the suggestion can be pictured. The changes concern the involvement of the Quality departments earlier. More specifically, the Quality department will be included already in the discussion about the design of the 3D CAD model by sharing information about the previous product issues that have occurred and what design features can be avoided. Later on in the process, a verification concerning if the welds that are being proposed can be checked and finally just before the agreement reached in the Design Review the 2D model will be checked and information will be gathered as well for future references. In further stages the sharing of information towards past issues that could be avoided and help to accelerate to some extent the process.

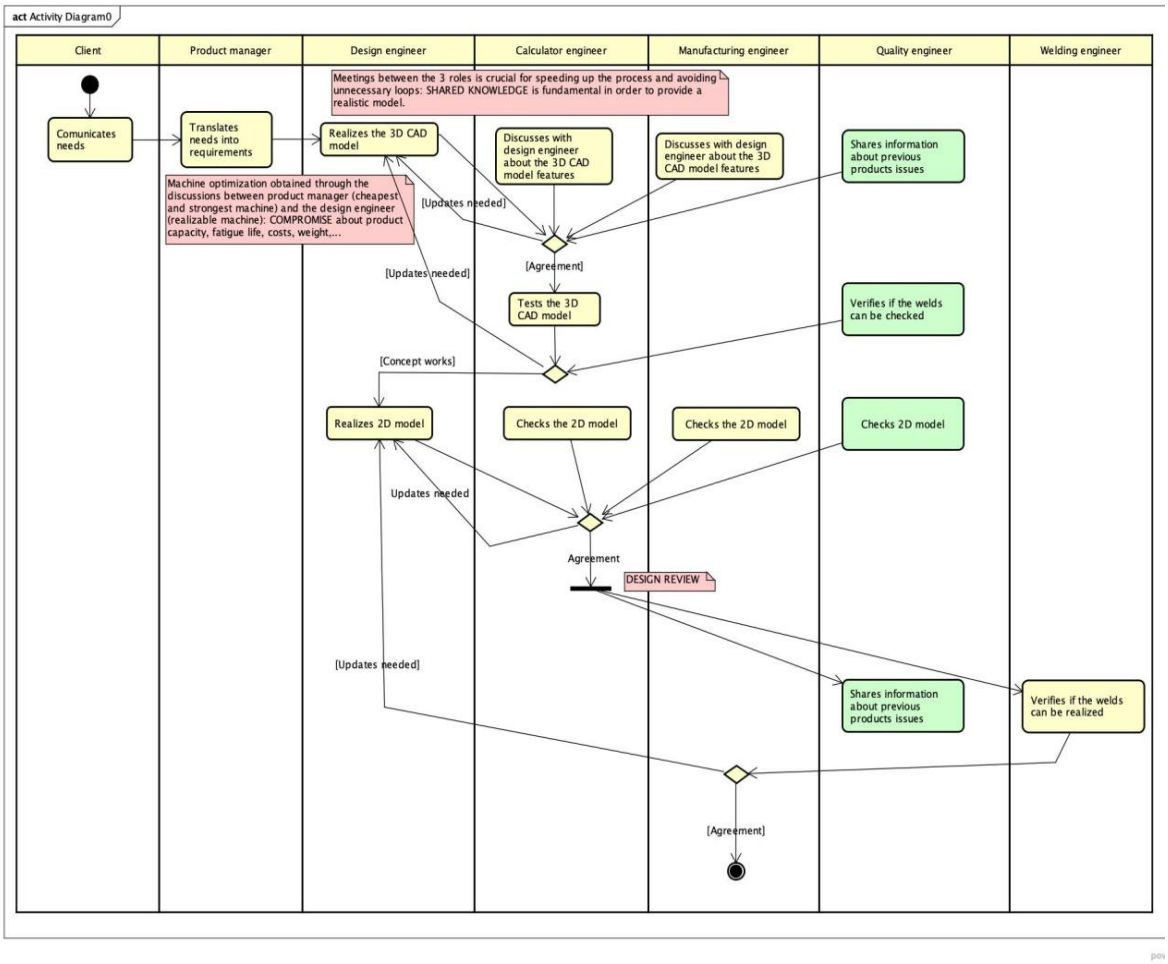



*Figure 16 Process Map/ Flow Chart of the Information Flow Interactions as it should be*

Additionally, the benefit that comes out from the graphs is not the graphs themselves but the realisation that there is power behind them. Power that translates into knowledge which can be used to base decisions upon. It is of importance to be understood that making use of the existing data it is not time that could have been used for other activities, but it is rather an enhancement to the activities of the company since it can prevent the mistakes of the past and set the pace for another way of thinking.

It can be concluded that from the discussions that has started between the members of the different departments related to NPD upon the presentation of the different data visualisation (graphs) and the usages of the graphs that have been proposed by the same members that the hypothesis has a ground of truth. Data visualisation that stimulates understanding and therefore discussion and collaboration which in its turn will possibly lead to better ideas and a competitive advantage to the company, should have a favourable place inside the company.

## 4.5 Control

As the last step of the DMAIC model, the Control phase has its main focus on ensuring that the identified x-factors of the Improve phase together with the improvements that have been suggested, to be realised and remaining process proof from the mistakes of the past.

In the Improve phase, light has been shed to the ways data can be visualised in a way that is understood by everyone and brings another mind-set on the table. It has been also demonstrated by the pilot study that a small change in the data visualisation that brings other interests on the table, can enable the discussion that will lead to the further collaboration between the departments through a recovered information flow and sharing.

To be able to do so though, the company should first address some other issues that serve as preconditions for the enhanced information flow and data sharing in the Concept loop of the Concept Development phase of the NPD to take place that would also be of help for other processes of the company.

The first precondition is to shed light into the **processes** that are in place inside the organisation and they indicate how the different activities and processes such as NPD will be executed. In the early findings of this study, it was stated in the AIM session that “Project participants are not following the NPD procedures”. The same issue has been noted in the Analyse phase as one of the elements that disturb the information flow. It was stated that one of the reasons that the processes of NPD or other processes are not widely known it is because the employees are not familiar with the cOMMon platform where information about the running of the company is being kept. An interview with the manager of those processes informed that the line organisation, through the managers of each function and sub function, is responsible to inform and educate the rest about them. For example, upon doubt from an employee on uncertainty on how the person should handle a task, the manager is responsible to refer to the guidelines or instructions and refer the person to the cOMMon system. It was observed through the same interview that employees that have been working for a long period of time inside the organisation, found rather new the information offered by the Process Manager.

Since it was told that the Process Developer is the person or team that tries to synchronise the different sub processes in the NPD process with cross functionality as primer guidance, it can be understood that cross functionality is regarded from the organisation as a priority. Although the functional level of the organisation has been trying to follow through with what being cross functional means such as shared meetings and information sharing, a deeper understanding about it seems to not have reached all the levels of the organisation. The benefits of cross functionality go beyond the share of the knowledge and is rather helping the company to have an understanding of its own abilities and competences that might have been hidden.

In the light of all the above, it would be beneficial if the processes are re-established by being made more accessible to the employees. That could happen through the form of trainings to get everyone informed or reminded about the existence of the processes.

The most important task though it would be that after the retraining sessions, for the employees to take over the responsibility for the up keeping of the processes. To ensure the maintenance of the processes, all the employees have the possibility to put forward a "change request" if a mistake is found or an improvement is being suggested. This action will help everyone that they are involved and assist to the better build of processes that align with the activities as they take place in reality. This will also help the Process Developer to define the right level of detail. As it could be understood this is not an easy task for the company to undertake but it will help the information flow along with the other activities to teach its full potential as it is the backbone of all the above.

Secondly, another precondition that needs to be handled beforehand, would be the **process capability of the processes**. Again during the AIM session, it was stated from the members of the session, that "the PD has too little knowledge about what production can produce". The above statement was also followed by some one-on-one interviews with two Managers where conflicting statements were made. One of the claimed that the capability of the processes of the department the person is responsible for is unknown, but it is rather known which processes inside the department are stable by experience. It was also stated that such measurement might not be necessary to do since they cannot see the effect that will have in their functions. On the other hand, the second Manager affirmed that the process capability for the various activities they measure, that also concerns activities outside their function, is being measured and known.

Understanding what is really possible to be accomplished in terms of abilities and efficiency can have a direct positive effect with the information sharing and help smooth out the disturbances that are currently observed. For one the Design Engineer who is responsible for the realisation of a 3D CAD model, could have the opportunity to fully understand what is possible to execute in the Industrialisation phase of the PD and adapt the design according to the misses from previous times. Responsible to identify those misses and transmit them to the responsible parties as of how the situation is currently mapped it is the Quality department. This department has been noted to keep an extensive record of measurements being done on the various frames that is needed for a product to be completed. Information and root cause analysis to comprehend on why what was done in the previous times might not be as beneficial for the development of the new product or an update of an already existing one this time around.

In the case that all the process capabilities are in place as well as passed around to the people that would make use of the information to base their decisions upon, then the feedback loop on the concept loop of the concept development is being assisted to

close. The steps that are required to be taken from the company side could be regarded as not major if the measurements that lead to the calculation of the process capability is being made already. In that case the company needs to think of what the most efficient way is to share this knowledge without overwhelming one of their departments. If not, then what needs to be identified first is what is the key measurements that will allow the calculation of the process capability. Furthermore, the people that will require this information should also be recognised by the company to promote efficiency and avoid the creation of further feedback loops that will not have any value adding to the party that might receive the information.

Thirdly, a **common point of view** and **language** used to share information, from the documentation till the oral communication, needs to be handled ahead of the use of the data visualisation as conveyer of information. The lack of common language has been noticed through the attendance of the Design Review meetings and it has been later voiced in different interviews. It was made more prominent when feedback about the new visualisation of the graphs was being discussed and especially what is the picture that different individuals with different roles inside the company are getting out of the. It was then stated by the Design Engineer that it acquires a lot of time for the person to decode all the feedback information that is being given through the measuring protocol which needs to be translated into the design drawing later on.

The lack of common point of view or common picture inside the company, has been created because the cross functionality was not fully integrated inside the company. Even though as it has been noted that the processes are designed with cross functionality into the mind, since a lot of people are not aware of them they unintentionally ignore them. The departments all have their functions and activities that contribute to the creation of the final new or update product. Lack of full comprehension of cross functionality leads the departments to be more focused into their own activities. That led to the creation of a kind of silo effect and teams. Each department has its own goals that even though that is acceptable inside businesses they tend to concentrate only to them and forget about the general picture of the company. By sequence leads for the departments to have conflicting interests that are not aligned with the project's or company's interests.

The silo effect can only be encountered when the cross functionality it is in place and everyone understand that the goals that are set inside a department is to contribute to the growth of the whole organisation. The understanding that the actions of one department will influence the decisions of another department since everything tends to be interlinked together, needs to be accepted and respected for the real effect of cross functionality to take place. There is one goal and one team that the employees already understand but need to commit to it even more now. Team building and considering the power that teams can provide when they work harmoniously together, can assist on lifting the silo effect together with restoring the place of the processes. It can also help to promote a common language inside the organisation which will

further help the information sharing and closing of the feedback loops in a more efficient way.

To conclude, all of the above have each own contribution on controlling the identified x-factors that were found in the Analyse phase. They were named preconditions because it will beneficial to improve and control those in order for the change in the data visualisation to take place in more favourable grounds.

### 4.5.1 Implementation

The preconditions described above are going to be helpful for the company to realign their activities with each other as well as promote cross functionality. It can be proven difficult though to find the correct step to start from that will initiate all the preconditions being followed. Therefore, to complete this study and help the company with that step a suggestion will be made towards that direction.

As it was mentioned in the Empirical Findings section, one of the identified critical-to-quality factors was the lack of common language and point of view among the members of the NPD process. That lack was found through the interviews with the individuals and especially during the interview with the Designer on the pilot study. The Designer mentioned its inability to decode the information that was transferred through the protocol which lead to not realising all the updates that the other departments have requested through the document. Through the data visualisation on the pilot study it was proven that it is possible to convey the correct information to all the parties involved without building extra documents for everyone.

To ensure that the communication between the departments will be as it was presented during the pilot study, the company needs to evaluate the information that are being shared between the departments. This move will help the company understand in which areas that information portrayed are not understood by the intended parties and find ways to overcome this obstacle. To be able to do that, a feedback form concerning the quality of the information that is shared needs to be established and a responsible person from the different departments will oversee the distribution of this form, analysing the results and gather the other people from the departments to discuss on improvement points upon the information sharing and its visualisation. Through this form, a first concrete step is being established towards the improving of the precondition of having a common language and point of view between the departments of the organisation. Furthermore, the cross functionality is worked in a way that more trainings or trainings in that domain is not used that might not have the same affect to the cause. Having a first step to start from will help the company get a start in a long process that can seem terrifying to undertake. It unleashes the pandora box of information by making it everyone’s responsibility and not just a specific department job.

# 5. Discussion

The main point to discuss is to understand how a small change in the data visualisation will influence the interactions of the people that are involved in the process as well as to stimulate discussion for more important changes to take place such as changing the mind-set from a product point of view to a process.

Currently the company at hand is depending on the experience of the employees and the quality that has been building over the years through its access to engage with all the aspects of the company. Data analysis is used to evaluate problems that have already happen either inside the realisation of the design in the industrialisation phase or, in the worst-case scenario, at a client. It has been observed from the beginning of the study that preventive data analysis has helped the company reach better results during the NPD process, but it is a practice that is not being used as on daily operations due to different factors such as lack of time or resources. As it can be understood continuing this practice on the long term cannot be sustainable for the company as the demands from the market grows every day for the best quality in the production and faster solutions and realisation of those, factors that cannot always be paired together. It would be therefore sustainable for the company to continue as they have and overlook the knowledge that they have been building all of those years. One of the profound examples of that as it has been mentioned earlier in the study, is the over processing that is done in order to secure quality. In a parallel thesis worked conducted at the company (Månsson, 2019) concerning geometrical parameters of the welds of a specific frame, it is in most cases surpassing the tolerances limits that has been set inside the company. Although the company was aware that a percentage of over processing is added, they were not aware of the extent of the variation. It was also stated in that thesis work that if the throat size can be reduced and the variation controlled a certain amount of cost would have been reduced as well. Thus, it would be beneficial for the company to utilise the knowledge that already exists inside the company to improve their processes and in extension their products.

The graphs that have been used in the pilot study were to examine what change and how much of a value can bring in the discussion that takes place in the Design Review meetings where all the stakeholders involved in the NPD are gathered. Those stakeholders were representing a sample of the company and have been examined regarding how adaptive can be when a change appears. A lot of employees when they think about change inside their daily operations, they think of a complete redesign of the operations. On the contrary through the pilot study it was meant to showcase that the change it does not to be big to bring the desired results, neither is it equaled to the use of more or less resources. To enhance this view, the tools that have been used are statistical tools that have been already in use inside the company. The same applied to the data that was used from measurements already done previously by the company. Thus, it is important to underline that a small change can influence the current situation, build upon it and later on have a bigger effect and can lead to bigger changes.

The following have already been mentioned with different expressions during the study, but it is found essential from the author to be highlighted again in this part of the study. In the preconditions that the company must control in order for the identified x-factors to be improved and eventually reduced, it was briefly stated the power that can be found in data. The measurements that have been gathered into the company to have the ability to monitor their efforts, tell a story of how the activities has been executed so far. From this story the improvements points can be extracted that will lead to an enhancement of their abilities. To know what it is possible to be done and what it is not, it might not seem like the most important competitive advantage that a company can have. A lot of companies regard its measurement as a part of something that needs to be gathered in case it is needed at some point along the way, discarding the fact that they might be ignoring a hidden competitive advantage of them. Investing in data analysis, data visualisation in today's world that the speed of time-to-market is increasing rapidly and knowing your competences in order to keep up is of paramount importance. Additionally, the power in the data is found in the ability that decisions can be based on reliable facts and not in speculations. It decreases the risk of the wrong decision to be made and allows more factors to be put into test.

Furthermore, some observations have been made regarding the execution of the study that includes some lessons that were learned. Firstly, an execution of a Six Sigma project that is investigating into an information flow can be challenging because it requires the coordination of interviews from various people inside the company to have the ability to cross check the statements from the different subjects involve and the integrity of the work is not compromised. Also, because the questions were based on the ability to gather information on how the daily different people handle the tasks related to NPD and their role into it, it requested a level of reflection from the interviewed subject which can be found difficult to explain when the interview was starting. Time was spent into that part to ensure that the participants were on the same level of understanding with the interviewer. The majority of the subjects found interesting the conversations that was sparked during the interviews and showed a genuine interest towards the problem. This was really important since the study was based on the interactions of the people and the information flow that comes out of it, therefore the participation was integral to the project.

The project can be characterized as an alternative Six Sigma project since it does not cover the financial savings that can be made from the use of the results but rather focuses to unlock another part of the company that might lead to increased productivity through the reduction of the feedback loops and time free-up as the title of the work suggests.

# 6. Conclusion

In the following section a connection between the research questions, empirical findings and the established theory will be provided as answers to the research questions.

***RQ1: What are the main critical to quality factors that are creating variation in the information flow of the concept loop in the concept development process?***

The factors that were identified as critical to quality were: (i) Lack of information sharing that is critical to the Concept Development loop, (ii) not fully understood and integrated cross functionality that leads to conflicting interests and (iii) lack of common language and point of view that creates misunderstandings in the communication and problem solving.

Concerning the first factor, similar observations have been made in the theory section of this study where Ericson Öberg et al., (2016) from another study that happened in the company states that the data collection together with the information emitted from there are not made for the company to extract decisions out of them. It also mentions that the way that data are structured is mainly focused on the quality of the product rather to assess process parameters. It is concluded from the author that this reaction leads to a more reactive attitude. The above also relates to the
A better match between information need and the information acquired could lead to more effective decision-making (Anna Ericson Oberg et all, 2016)

If the information flow is handled in the right way, the companies will have certainly a competitive advantage over the rivals. In fact, if the firm is able to control the flow at the same time is capable of perceiving the variations into the process and can intervene as soon as possible to avoid re-works, a process quality decrease, or a productivity fall. The above demands a level of cross functionality between the departments and in the organisation as whole. The findings from this study indicate a different aspect from the company side that seems to influence the functions and decisions. Steps to tackle the cross-functionality issue have been taken by the organisation but are still in a primer level to bring the desirable effects. The lack of common language and point of view comes out as a sequence of the lack of cross functionality. All the identified factors are interlinked with each other.

Why it is important though for a company to examine the information they already have? There are two reasons behind that which are (i) to lower the level of uncertainty which originates from the absence of information and (ii) to make up for the lack of understanding that exists inside the stakeholders (Ericson Öberg et., al, n.d).

The second RQ was the following:

***RQ2****: How a change in the data visualisation in the concept loop can stimulate discussion that will possibly lead to the free up of time in the departments of Design, Quality and Manufacturing?*

In order to answer this question a Pilot study was conducted to examine in a real case the effect that will have in the identified factors a change in the data visualisation. As it was stated in the purpose part of the thesis the main message was to examine the impact that a change in the data visualisation will have in the interactions of the stakeholders of the NPD and how it can work as a conversation starter and in the end the first step to change the mind-set of the organisation from product oriented to process.

The different representations of the data helped to find one that will bring common understanding and the ability to zoom-out to be able to see the whole picture of the frame together with the individual work that takes place for the realisation of the design. The different graphs bring a different point of view and can be used in different parts of the NPD to reach the desired result of understanding and mainly information sharing. For the graphs to be in full use it is important for three pre conditions to be in place. The processes that are already exist inside the organisation and are built upon the principal of cross functionality need to be brought forward and in use. The use of the processes requires the active participation and responsibility by everyone in order to be fully utilised. With the participation it is meant that since the employees have the opportunity to give feedback back to the process they should use this opportunity to tailor the process according to the reality of the process and help the Process Manager design the process with the appropriate level of detail.

Through the process change and the different point of views that are presented from the data visualisation, a shift towards a more process-oriented point of view can be expected. The process-oriented mind-set will give to the organisation the opportunity to reach higher level of satisfaction towards their customer while using the information that already exists inside the company. It is important for the organisation to realise that more resources do not always mean better results. From the findings it was discovered that the company has the competences to reach their targets if they focus on what already exists inside the company.

The change from a push to pull approach regarding the information sharing and understanding can be developed through the acceptance that root cause analysis is essential to take place inside the company to gain important knowledge through both the success and the failures that can be either used again in the future if applicable or to be avoided. Lastly, the author would like to mention that one of the most valuable lessons from the study was that organisations do not have to start big changes to get big results back. Small changes as the one presented in the study can be enough to

start a rather big and valuable change in the organisation that can only be beneficial in the long term.

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# Appendix

## Appendix A Detailed Record of the Conducted Interviews

| Role | Type | Date |
|---|---|---|
| Measuring and Product Quality Manager | Skype meeting | Dec 18th 2018 |
| | Face to face meeting | Jan 25th 2019 |
| | Skype meeting | Mar 14th 2019 |
| | Face to Face meeting | Apr 8th 2019 |
| | Skype meeting | Apr 15th 2019 |
| Project manager | Skype meeting | Dec 19th 2019 |
| Manufacturing Engineering Manager | Skype meeting | Dec 20th 2019 |
| | Face to face meeting | Jan 25th 2019 |
| | Skype meeting | Mar 12th 2019 |
| Designer | Skype meeting | Jan 11th 2019 |
| | Face to face meeting | Mar 8th 2019 |
| | Face to Face meeting | Apr 11th 2019 |

| | | |
|---|---|---|
| Management Systems and Data Analysis Director | Skype meeting | Jan 15th 2019 |
| | Skype meeting | Mar 29th 2019 |
| Two Production Engineers, two Welders, the project Quality manager, the project Geometrical assurance manager, the project Design leader and a project Designer | AIM session | Feb 6th 2019 |
| Project Quality Manager Operations | Face to face meeting | Feb 8t 2019 |
| | Skype meeting | May 6th 2019 |
| Change Manager | Skype meeting | Mar 18th 2019 |
| | Skype meeting | Mar 28th 2019 |
| Senior Welding Engineer | Skype meeting | Mar 26th 2019 |
| | Skype meeting | Mar 26th 2019 |
| | Face to Face meeting | Apr 11th 2019 |
| Production Engineer | Face to Face meeting | Apr 11th 2019 |
| Welder | Face to Face meeting | Apr 11th 2019 |
| Geometrical assurance | Skype meeting | May 3rd 2019 |

## Appendix B Project Charter

# Project charter

## Project title: Improving the information flow to facilitate efficient decision making and mitigate variation in a new product development process

**Unit Department: Volvo Construction Equipment**

| | | | |
|---|---|---|---|
| **Executive** | | **Senior Deployment Champion** | |
| **Deployment Champion** | **Anna Ericson Öberg** | **Project Champion** | |
| **Master Black Belt** | | **Finance Champion** | |
| **IT Champion** | | **HR Champion** | |
| **Responsible Black Belt** | | **Telephone/e-mail** | |
| **Sponsor & process owner** | **Hasse Olsson** | **Site or location** | **Arvika, Braås, Eskilstuna** |
| **Project Start Date** | **December 2018** | **Project completion Date** | **June 2019** |
| **Expected impact level** | **Moderate** | **Expected financial impact (savings/revenues)** | **NA** |

| Element | Description | Charter |
|---|---|---|
| **1. Delivery affected** | A short description of what is affected | Improvement of the information flow and the cross functional work between the departments of Design, Quality and Manufacturing which in the end will have an effect of the time availability of the stakeholders involved and the new product development process smooth. |
| **2. Benefit to customers** | Define internal and external customers (most critical) and their requirements | Customer satisfaction on the final customers (external).<br>Potential free up time to the stakeholders involved especially for the teams of Design, Quality and Manufacturing. |

<table>
<tr><td>3. Benefit to the business</td><td>Describe the expected improvement in business performance</td><td colspan="3">Improvement of the time needed in the new product development timeline</td></tr>
<tr><td rowspan="2">4. Measure to improve</td><td rowspan="2">Define the baselines, your realistic goals for the project and the best case targets for improvement.</td><td>Actual value (baseline)</td><td>Realistic goal by project end date</td><td>Best case goal</td></tr>
<tr><td></td><td></td><td></td></tr>
<tr><td>5. Impacted process</td><td>The specific processes involved in the project where changes can be implemented</td><td colspan="3">Design Engineering</td></tr>
<tr><td>6. Team members</td><td>Names of the participants in the project (area of competence)</td><td colspan="3">Evdoxia Glykeria Pantazi (Master Thesis Student, Chalmers University of Technology)<br>Gaia Santoni (Master Thesis Student, Politechnico di Torino, Senior Welding Engineer (Volvo Construction Equipment)</td></tr>
<tr><td>7. Other people involved</td><td>List technical experts and other people who will be part of the team (area of competence)</td><td colspan="3">Quality Manger,Manufacturing Engineering manager,Designer, Management Systems and Data Analysis Director, Hasse Olsson, Peter Hammersberg, Senior Welding Engineer</td></tr>
<tr><td>8. Project delimitations</td><td>What will be excluded from the project</td><td colspan="3">The remaining departments that is part of Volvo Construction Equipment</td></tr>
<tr><td>9. Required support</td><td>Support in terms of resources (human and financial) required for implementing changes</td><td colspan="3">Time concerned resources for people to be interviewed and consult for the duration of the project, management support</td></tr>
<tr><td>10. Project summary</td><td>A short description of the project</td><td colspan="3">Investigation, analysis and identification of possible factors that affect the information flow between departments causing increasing workload into functions and consequently creating delays in the new product development process.</td></tr>
</table>

| | | | |
|---|---|---|---|
| DEFINE phase completion date | **March 2019** | MEASURE phase completion date | **April 2019** |
| ANALYZE phase completion date | **April 2019** | IMPROVE phase completion date | **April May 2019** |
| CONTROL phase completion date | **May 2019 / ongoing for the company** | PROJECT results presentation date | **End of May 2019** |

# Appendix C Effective Scoping

| Process owner (org): | Project sponsor: | Six Sigma champion, MBB: |
|---|---|---|

## Effective Scoping of continuous improvement projects

***The sequence in itself, of questions Q1-Q4, Q5-Q7 and Q8-Q9 below, is key to facilitate consensus in the shift of an organisation's mindsets from push to pull, in accordance with the principles of Lean Six Sigma***

| Supplier | Input | | Process | Output | | Customer |
|---|---|---|---|---|---|---|
| 8b. Who supplies the inputs? | Q8a. What are the inputs to the system? | Q9. What does the system require of the inputs? | Q7a. Team/project jurisdiction of changes | Q1. What comes out (of the physical flow) - OUTPUT? | Q3. What is required of the output from this particular user (List of big Y's and improvement proposals) | Q2. Who uses the output? |
| Company, Weld manufacturer, Product Manager, Laboratory Engineer | Internal standards Drawing Standards, Factory production specification, Product Specification, Test Results | Feedback loops are required for the information to be distributed | Design, Manufacturing, Quality teams/departments | The drawing from the design engineering department that includes measurement specifications according to the interal processes of the company. | Tolerances can be reached & reasonable for Quality & Manufacturing Precise calculations (informative as well) Measurable | Manufacturing Engineering, Maintenance and Tooling and Quality Departments |
| | | | Q7b. What competences are needed in the team (WHO)? | | **Q4. What ONE MEASURE (y) should be understood and improved? The y that scope the project and drive further exploration.<br>Each small y has its own underlying system of influencing parameters, sometime overlapping. Use one template per y to reduce complexity<br>Scope on y (not x - upstream) and don't proceed until Q1-Q4 is thoroughly understood!** | |
| | | | Design (1st) & Quality (2nd) => Manufacturing as a consequence | | y communication flows & interractions ( information, data sharing & knowledge (what is being given & what's required by people data wise) - y procress performance & variability | |
| | | | *Name of the flow to be improved:* | | Q5. What is the baseline of the y and can that precis y be measured today (and can old data be trusted)?<br>In other words: What is the **facts** behind the problem that form the base for our improvement promise? Show the data/proof of a problem! | |
| | | | *Information Distribution & Visualisation* | | Data collected & trust proff but not shared - to be understood by everyone they need to portrayed simple enough (visualisation) | |
| | | | From where is the physical output shipped? | | Q6. What other Y can not be lost in the process (constraints)? | |
| | | | Designing | | long term focus & proactivity, focus on the root cause & not fire fighting | |