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Master's Thesis

STANDARDIZED CROSS-FUNCTIONAL COMMUNICATION AS A ROBUST DESIGN TOOL

Mitigating variation, saving costs and reducing the New Product Development Process' lead time by optimizing the information flow

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Abstract

The lack of a standardised information flow influences the Company's performances: the communication between different departments is not effective because the cross-functionality is poor; since the Product Development feedback loop is broken, the lead-time to the customer is prolonged and safety margins are added during the production processes to prevent the risk of failure. This has an impact on the Company's performances both on a quality and on a cost efficiency level.

The priority of the organisation is to reduce the product failures, but the focus is on the technical issues and not on the organisational ones. The random information flow and the poor knowledge spreading in the Company are both factors that negatively affect the variation in the welding process, but they are not considered since they are not tangible.

In this Master thesis, the author did a qualitative analysis of the Company's criticalities in order to guide the standardisation of the information flow in a specific phase of the New Product Development Process. A quantitative analysis has also been developed, but the data analysis was just a means to understand which visualisation tools were more effective to present the results of the analysis itself and how the visualization of it should vary depending on the role receiving the results. The purpose of the analysis was to prove that different visualisation tools can change the Company behaviour when analysing the data about both the product performances and the design efficiency and that the standardisation of the information flow can be used as a variation reducer in a Robust design approach.

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Table of contents

Chapter 1 1

Introduction 1

Background 2

The VariLight project: previous researches that lead to this Thesis 2

The importance of sharing useful information in the correct way 4

Robust design tools to reduce variation from the start of the New Product Development Process 5

Visual Six Sigma and the importance of communication tools 7

Voice of the process and Voice of the customer 7

The pull-approach and its advantages 8

Company's current situation and improvement points 10

Purpose 12

Problem definition and research questions 13

Restrictions and future work 15

Structure of the thesis 16

Chapter 2 17

Methodology of research 17

Research approach 18

Research strategy 19

Establishing research questions 21

Selecting relevant research sites and subjects 22

Collecting relevant data 22

Interpreting data 23

Conceptual and theoretical work 23

Findings and conclusions 26

Validity of the study 26

Credibility 27

Transferability 27

Dependability 28

Confirmability 28

Authenticity 28

Chapter 3 .... **29**

Theoretical framework **29**

Different types of knowledge **30**

Current use of the visualization tools **30**

Problems with the use and implementation of the visualization tools .. **32**

Six sigma: DMAIC cycle **32**

Six sigma tools **33**

Effective scoping method 33

Affinity and Interrelationship Method – AIM 34

Swim-lane flowchart 35

Visual Six Sigma **35**

Robust design **37**

Parameter diagram – P-diagram 38

Chapter 4 .... **40**

Empirical findings **40**

DEFINE - Current situation analysis **41**

The New product development process 41

Interviews results 45

Interviews results: Summary 48

Outcomes from the first design review week 50

AIM results 52

Parameter analysis: the communication flow considered as a noise factor 55

Resistance and draw backs 56

Different type of knowledge is shared differently 58

Define phase summary 59

MEASURE **64**

Data collection: different graphs presentation 64

Chapter 5 .... **67**

Analysis **67**

ANALYSE **68**

Different analysis point of view: graph by graph 68

Different analysis point of view: summary 86

A pull approach to the standardisation 89

Chapter 6 .... **91**

Discussion **91**

IMPROVE **92**

Standardisation of the information flow in the process analysed 92
Parameter analysis: what is the impact of standardising the communication flow 97
Standardisation of the information flow as a Robust design enabler 98
Guidelines to standardise the information flow 99
CONTROL **105**
Possible metrics to control the effectiveness of the integration of the standardised information flow 105
Comparison with another Company in the Automotive industry and involved in the VariLight project..106
Chapter 7 .... **109**
Conclusions **109**
Summary of the findings **110**
Adaptive feedback loop **112**
Importance of the organisational issues **114**
Answers to the Research questions **115**
References **118**

List of Figures

Figure 1 - The six steps of the Research development process according to A. Bryman and E. Bell 21

Figure 2 - Directions for conducting effective interviews according to A. Bryman and E. Bell 27

Figure 3 - Theoretical framework summary 29

Figure 4 - Swim lane flow chart representing the New Product Development Process' Concept development and evaluation phase as it currently is 43

Figure 5 - Disaggregation of the Concept loop into the three smaller loops. 44

Figure 6 - Simplified representation of the communication between the departments of interest: Design, Manufacturing, Quality 50

Figure 7 - Affinity and Interrelationship Method results 54

Figure 8 - Simplified Parameter diagram representing the New Product Development Process noise and control factors 56

Figure 9 - Summarised view of the Communication flow between the departments of interest 60

Figure 10 - Currently used tool: The measuring protocol 66

Figure 11 - Graph A 69

Figure 12 - Graph A extended 70

Figure 13 - Graph B 71

Figure 14 - Graph B extended 72

Figure 15 - Graph C 73

Figure 16 - Graph C extended 75

Figure 17 - Graph D 76

Figure 18 - Graph D extended 77

Figure 19 - Graph E 78

Figure 20 - Graph E extended 79

Figure 21 - Graph F 80

Figure 22 - Graph F extended 81

Figure 23 - Graph G 82

Figure 24 - Graph G extended 83

Figure 25 - Geometrical Assurance solutions development process 86

Figure 26 – Simplified example of the Information flow standardisation for the process analysed 94

Figure 27 - Swim lane flow chart representing a possible way to standardised the communication flow and the visualisation tool's usage 96

Figure 28 - Simplified Parameter diagram representing the New Product Development Process if the noise factors related to the information flow become control factors 99

Figure 29 - Information quality report example 103

Figure 30 - Proposed procedure to standardise the information flow at any level 104

Figure 31 - Graph of the ideal Effort amount in time compared to the possibility to change the final outcome (Project Management Institute, 2017) 111

Figure 32 - The Concept loop's information flow standardisation as a starting point to standardise the communication in the whole company 114

List of tables

Table 1- Interviews summary 24

Table 2 - Problem definition with the drawing-as-output view developed using the Effective Scoping Method... 62

Table 3 - Problem definition with the data analysis-as-output view developed using the Effective Scoping Method 63

Chapter 1

Introduction

This thesis is part of a research project called **VariLight** which has the purpose of reducing the variation in the welded structures in order to reduce their weight. The project started in 2016 and several theses and research papers have been written, therefore the current situation of both the industry and, in particular, the company that will be object of the study have been deeply described. What the previous analyses highlighted is that the **variation** is not considered in the correct way: most of the time non symmetrical distributions are considered taking into account only their mean value, leading to unnecessary **stringent requirements** and **over-processing** during the serial production. Moreover, there are problems of **miscommunication** on a **cross-functional** level and, even though the negative impact of those **soft-issues** on the company's performances is high, the management have difficulties to empower the staff to improve intangible supporting processes in relation to the primary production flows. The consequence is that the company attitude is **reactive** and its focus is on the **short-term** effects of the decisions regarding the primary flow. The way this thesis wants to improve the New product development process is related to the **information flow**. The final goals are: proposing a standardised version of the information flow and of the **data analysis** to share between different roles at the different stages of the process according to the information demands of the users, with the aim of reducing the variation amount related to the miscommunication and to the use of not-customised graphs; and to learn the effect of process changes during the early industrialization phase with a **robust design** attitude. The proposed solution will have different purposes: simplify the communication and save time, enhance the cross-functional sharing of information, change the company's attitude from reactive to proactive and the point of view from product to process focused.

Background

The VariLight project: previous researches that lead to this Thesis

This thesis is part of a research project, called **VariLight**, that has been going on since 2016, with the purpose to enable light weight welded structures by reducing variation both in the product development processes and in the load estimation. The weight reduction of the vehicles allows to reduce the fuel consumption. In the welding field, it is possible to act on the material used to gain a weight reduction, as a consequence there has been a transition towards thinner materials with higher strength which however require to have the process under control in order to reduce the breakdowns risk. Several papers and theses have been written during the VariLight and earlier projects. Anna Ericsson Öberg did an analysis of the variation in the welding process and pointed out that not considering variation leads to **unnecessary stringent requirements** and **over-processing**. Furthermore, the **miscommunication** between departments leads to focus on the wrong product characteristics: *important properties connected to the fatigue life of the weld do not translate well into specifications on the drawing, quality control and audits focus on the characteristics that can be measured instead of on what is important from a fatigue life perspective* (Öberg & Åstrand, Improved productivity by reduced variation in gas metal arc welding (GMAW), 2017). This means that important information is simply lost in the process. The problem, however, is not necessarily related to technical issues, but rather in the **soft** ones, like how the information is transferred and used in the company (Öberg, Johansson, Holm, Hammersberg, & Svensson, 2012).

A huge limitation for the decision making process is the variation perception: the focus is on the mean value and variation is considered to be a deviation from that value. Reasoning on the mean value, though, is effective only if the distribution of the measurements is symmetrical (e.g. normal distribution), which means that the level of variation does not influence the level of the mean. A lot of business decisions, though, are based on not symmetrical data such as cost, lead-time, number of defective parts, etc., therefore the results of the data analysis are distorted by the fact that the **variation impact** is not properly considered: it is easy to forget that variation is real and that the mean value used for most decisions in the daily life is an abstract calculation heavily dependent on how the sample is gathered (Öberg, Andersson, Hammersberg, & Windmark, 2016).

To overcome this information gap, A. E. Öberg suggested the usage of the **Control Charts** as a collecting, visualising and sharing information tool, as they allow to get a picture of the variation that is standardised for the different functions. With Control charts the focus could be shifted from product to **process oriented**, and the attention could be drawn to the prevention of the root causes instead of being on the correction of the defects on the products. Apparently, something prevents the diffusion of them, therefore the Company does not have a knowledge about its **processes' stability** and variation. This lack of knowledge is critical, since the actions to be taken to improve a stable process are different from the ones suitable in the case of an unstable one: when a process is stable, the variation is related to noise factors that can be removed only by a total change of the procedure, therefore the variation is controlled and the output of the process is predictable on a statistical base; an unstable process, on the contrary, is unpredictable, as the variation is related to special causes that cannot be predicted, but are not intrinsic to the process itself and should be addressed and then removed. The improvement of the already stable processes should be a management concern: it takes strategic decisions and long term system solutions. On shop floor level instead, decisions need to be fast, and focus on daily problem solving of the unstable processes. Anyway, if there is no knowledge about the stability and capability of the processes, the decisions cannot be the most suitable for each situation (Öberg, Andersson, Hammersberg, & Windmark, 2016).

The importance of sharing useful information in the correct way

This thesis will mainly focus on the **information related issues**: how data should be collected, organised and visualised at different levels of the organisation in order to facilitate decision making with the objective to lower risk of product failures. The analysis will use the results of a previous thesis project as a starting point, *Decrease the risk of product failure by managing the complex information flow in a welding fabrication industry*, conducted by Elisa Zanella as a continuation of A. E. Öberg studies. In her work E. Zanella analysed the information flow of the Product Development Process of a welding company, showing how many different roles and information are involved in each phase and identifying four major feedback loops: concept loop, prototype industrialisation, component variation and product industrialisation loop.

When the actions to prevent variation in the process output, whether it is a physical output (e.g. a product) or an intangible one (e.g. a decision), are taken as early as possible in the project, which means basically during the **Product development first stages**, the true benefit and impact of the efforts are never precisely quantifiable, but only estimable, since the cost-benefit trade-offs must be considered based on the expected values (Thornton, 2003).

The information flow is highly **cross-functional**: single components of the information structure and system, such as unsuitable demands or incapable evaluation methods, strongly affects the reliability of the manufacturing process as a whole (Öberg, Johansson, Holm, Hammersberg, & Svensson, 2012). The involved roles need to understand how variation in the multiple parts that are assembled in the final product and in the manufacturing processes **combines** to impact product performance and customer requirements (product to part interaction); at the same time, they need to understand also how their organisational functions should **interact** to help reducing the amount and the impact of variation (cross functional interaction). This means that a common metric is required in order to evaluate the cost of variation considering the impact of variation across the entire organisation (Thornton, 2003). When problems occur, the ability of

sharing the correct information between the different organisational functions is crucial in order to identify and correct the issues before they actually affect the product (Öberg, Johansson, Holm, Hammersberg, & Svensson, 2012).

Thomas Allen studied the **information sharing** during the New product development process in two different companies working on the same project, discovering that the most valuable information for experienced workers is the one gathered from their personal knowledge or from other employees and that the **interpersonal** communication has a key role in problem solving. Most important, he found out that it is not the intensity of the communication to make a difference in the success of the projects, but it is its **diversity**: involving people external to the team and to the technical function of the project provides a broader view of the project itself and helps to achieve better performances: cross-functionality and inter-department communication are crucial (Allen & Henn, 2007).

Since there are several departments involved in the Product development process it is necessary to agree on a **common language** in order to be able to discuss visualization tools, variation and performance measures effectively: since cost is the common denominator for every department, it can be used as an incentive for cross-functional initiatives (Öberg & Åstrand, Improved productivity by reduced variation in gas metal arc welding (GMAW), 2017). Information about the customer demands and about the product specifications are translated and modified several times while transferred between the different functions from the analysis of the customer requirements to the actual production of the welded structure; this can lead to a mismatch that generates significant unnecessary costs and waste of resources (Öberg, Johansson, Holm, Hammersberg, & Svensson, 2012).

Robust design tools to reduce variation from the start of the New Product Development Process

Robust design techniques can be useful in order to improve the process capability: the principles of robust design have the purpose to reduce unwanted variation in the product performances by taking into account the sources of variation from the first phases of the Product Development Process. This approach allows to obtain a design of the production process and of the product itself that is insensitive to the noise factors (Mashhadi, Alänge, & Roos, 2012). The importance of developing insensitivity to noise factors (e.g. environmental conditions, product deterioration, manufacturing imperfections) lies in the fact that they cannot be controlled, or are too expensive to be controlled under the daily operation conditions. According to the definition of Robust design provided by Arvidsson and Gremyr (2009), which is "*Robust Design Methodology means systematic efforts to achieve insensitivity to noise factors. These efforts are based on an awareness of variation and are applicable in all stages of product design.*", efforts are applicable and effective in every design stage, under the hypothesis of variation awareness. The practical consequence of the definition is that the activities to prompt insensitivity to noise factors can, and should, be stimulated, but they are not to be confused with the robust design tools which have the purpose to instructing on how to fulfil or accomplish these activities. In other words, when applying any robust design tool, it is mandatory to develop an **underlying knowledge** about the reasons behind the implementation and the employment of the tool itself (Hasenkamp, Arvidsson, & Gremyr, 2009).

That is the reason why in this thesis the focus will not be on the whole product development process, but on the **first phases:** focusing on a specific stage of a single process makes it easier to spread the knowledge about the usefulness of the tools; in addition to it, start acting on the variation from the very start of the process rises the possibility for improvement at their highest level (Thornton, 2003). The most involved departments at the early stages are **Design** engineering, **Manufacturing** engineering and **Quality**, standardising the communication and the data sharing between those three departments could be the key to limit the need to adjustments in the later stages of the process, where the costs are higher.

Visual Six Sigma and the importance of communication tools

On the current state, companies are not fully exploiting data-driven models to predict and understand the aspects of their business. This is related to the fact that, for a company, gathering knowledge is not the priority: companies have the responsibility of giving value to their customers and to their stakeholders. On a scientific point of view, knowledge is valuable for its own sake; on a business point of view instead, knowledge is value-consuming, therefore it is useful only if it allows to produce and deliver a product whose earnings will cover the costs of generating, storing and using the data that led to that specific knowledge. In other words, what pushes a company to use a scientific, data-driven approach is the fact that the company is failing to produce and deliver what is required from its customers and stakeholders. Using the Visual Six Sigma tools is useful to understand the different opinions about the company's mission and the different views on the company's purpose and to decide **which factor should be considered and controlled**. Using a scientific model to represents the company's behaviour is helpful to clarify which aspects are in control and which ones are not, to decide if the aspects out of control should be controlled and if the controlled ones are not the right one to act upon and, especially, to predict and to improve the behaviour itself. (Cox, Gaudard, & Stephens, 2009).

Voice of the process and Voice of the customer

The starting point of the **Product development process** is the translation of the customer requirements into product characteristics that reflect the demands of the customer itself. It is not possible to know for sure how the customer will use the product, as it is not possible to know for sure how the product will behave during his working life. Both the load of the product and the strength of it can be described with a normal distribution: the difference in customer usage determines the load distribution, the sensitivity of the design and the scatter in the production and welding process determine the strength distribution (Öberg & Åstrand, Improved productivity by reduced variation in gas metal arc welding (GMAW), 2017). When the customer curve and the product curve meet there is an increased risk of **failure**. In other words, when the customer loads the product up to the limit of its strength, especially when the product strength is one of the lowest of the process, the failure happens. This is the reason why understanding the process variation is the key for delivering a product with the right quality to the customer: as a supplier you cannot control the load variation, but you have to control the strength variation, otherwise you will need to use unnecessary stringent requirements, high safety margins and a lot of over processing that will lead to a cost increasing. The issue with **over processing** is that it is a hidden waste in production: welding is considered to be only adding value to the final product, but even if the product is made more than good enough, the customer will pay for the demands stated on the drawing. This mismatch between requirements and reality generates a cost that neither the welder nor the client is supposed to pay, therefore, for the company it is a **waste** (Öberg & Åstrand, Improved productivity by reduced variation in gas metal arc welding (GMAW), 2017). It is also important to be aware of the fact that, when customer requirements are exceeded, an over cost is made and, on the other hand, when customer requirements are not met and a failure occurs, a loss of trust in the supplier is created. Therefore, it is important to manage the trade-off in an effective way: giving the customer exactly what he expects from the product, at a sustainable cost. If the variation of the process is known, it is obviously easier to understand where this right amount of quality is located: if the strength curve shape is known, it is possible to move it closer or further from the load curve.

Communication between the Design department and the Production and Manufacturing departments is crucial in order to build products that meet the right specifications: if valuable information is not shared between the departments, important properties connected to the fatigue life of the weld do not translate well into specifications on the drawing (Öberg & Åstrand, Improved productivity by reduced variation in gas metal arc welding (GMAW), 2017).

The pull-approach and its advantages

In her PhD thesis, *Predictability – an enabler of weld production development*, A. E. Öberg stressed the importance of using a **pull approach** for communication, which means that the data demand depends on the decision to be taken: this approach focuses on the customer's requirements and allows to deliver exactly what is demanded. The start of a pull approach is identifying who is going to take the decision, the second step is defining what information is needed to make this decision, the third step is considering how to analyse and present the data to maximise the decision making support, the fourth step is the one when attention to the defects and qualities of interested are identified. The method to be used to obtain the information is chosen in the last step of the process: it depends on the internal customer needs and does not have anything to do with the most technologically advanced equipment (Öberg A. E., Facilitating decision making by choosing an NDT method based on information need, 2016). The complex part of a pull approach is that it needs a precise and customised problem definition for every role in the process, since the starting point is the decision to be taken and different roles in the process have to take different decisions. On the other hand, it enables to **standardise the information** sharing and therefore to improve the decision making process by giving the precise information needed, exactly when it is needed, to every person involved in it. It is important to point out one particular problem in the first feedback loop, the concept loop: the steep learning curve. It is important to be quick more than standardized since the following phases will require other information depending on the test's results. Therefore, the information need to be developed with the concept itself within the project. However, for a series of similar Product development projects, it is possible to standardise the information need according to the phase the concept is within.

It is important to share the critical knowledge that the **reason for testing** is not the testing itself, but it is gaining information useful for the decision making process (Öberg A. E., Facilitating decision making by choosing an NDT method based on information need, 2016). People in the manufacturing system need different kinds of information about the product or the process in order to come to the right decision and they also need a different presentation of the specific information needed. One of the central point to consider is, therefore, **what different data are needed** in order to take decisions at the different levels of the company: using the same type of data at different organisational levels prevents from having the right point of view and it can, for example, leads the top management to prioritise low level issues instead of focusing on the strategical level (Öberg, Andersson, Hammersberg, & Windmark, 2016).

Company's current situation and improvement points

As E. Zanella stated in her thesis The information needs to be instant and very precise for whom is going to use it. It has to be ready for being managed carefully because the production chain for realising these products is long, many different people are involved and numerous parameters have to be transmitted from one phase to another (Zanella, 2018). If the information flow is not consistent, additional sources of variation might be introduced in the production process: more and more often the root cause of severe issues is not to be found in the technical matters, but in the organisational structure, therefore, considering the **soft issues** is mandatory in order to fully understand the process complications.

If data are not shared, information is not standardised and a common language internal to the company is not developed, the product designed and delivered cannot represent neither the customer requests nor the manufacturing process capability; as a result, reaching the desired level of performance is not possible, the number of defects increases and the customer satisfaction decreases.

The company analysed is successful in the market, it uses the most updated technologies and the best resources, but, if the information flow will be standardised, it will achieve a higher productivity level by decreasing the over processing. Furthermore, the correct data sharing allows to control the process and, as a consequence, to detect variation as soon as possible and intervene on it before it results in defects. This means that a shift from a push to a pull approach to the communication, could be the starting point for a major shift from a product to a **process point of view**.

The Company studied is now in the middle between product and process focus: there is a lack of knowledge about the processes behaviour and capability, but the awareness of the importance of such information is spreading and the organisation is ready for a step in the process focus direction. Currently, the goal of the data analysis is to identify and eliminate the symptoms of the defects rather than to identify and eliminate the root causes of that symptoms and improve the process behaviour. As Marcus Danielsson and Johan Holgard explained in their thesis, *When the process shows unpredictable behaviour and does not satisfy the customer demands, the customer demand is met by adding ad hoc supporting processes, or so called "**firefighting**" actions. These actions are often not standardised and require a lot of time and resources. The focus (in the organisation) becomes, therefore, on the result instead of the system generating the result. This way of working will not improve the process; it only fixes the individual case and does not build up any systematic knowledge about the underlying system* (Danielsson & Holgard, 2010).

This focused on the product *modus operandi* does not allow predictability, as it focuses on whether the specifications are achieved or not and not on variation over time: the information delivered is binary, red or green, and it can hide problems in the production system. These data have been described in a paper from A. E. Öberg, S. Braunias, P. Hammersberg and C. Andersson as "**watermelon measures**" since, even if an indicator looks green on the **average**, it does not mean that it does not hide a red result when considering variation. They proved that considering and *understanding variation can reduce the risk for asking the wrong questions and thereby occupying the organisation with taking wrong unnecessary actions, creating investigations of random variation that have no single explanation* (Öberg, Braunias, Hammersberg, & Andersson, 2016). In addition to it, visualising the variation can shift the mind-set of the company from reactive to proactive as it allows **predictability**. T. Forsberg, L. Nilsson and M. Antony did an analysis of Swedish companies' process orientation in 2009, one of their interesting line of arguments is the fact that a signal of continuous improvement not integrated in the daily operations is the fact that the improvement work is mostly conducted during special meetings (Forsberg, Nilsson, & Antony, 1999). The hybrid approach is, however, consistent with the number of products delivered by the Company analysed, but a more process oriented point of view could prevent over processing, too stringent tolerances and unnecessary rework and, therefore, could improve the productivity and final product quality.

Purpose

The purpose of the thesis is to identify a standardisable information flow to apply during the New product development process in order to **simplify the communication** between the three most involved departments: Quality, Manufacturing and Design. The aim is, at first, to identify which decision every role needs to take and which information is critical in order to optimise the decision making process for every function involved. Once the **information needed** is identify, it will be important to understand which **visualisation method** is the most suitable for giving the specific role the most accurate and most immediate input for taking the right decision. In general, it will be important to get an insight of the current information flow between the three departments: what data are shared between whom; who gets the information and who delivers it; where is the **bottleneck** in the information flow; what are the most requested questions between the roles involved in the process; what are the issues that makes the information sharing hard and not immediate; what are the standardisable parts of the flow. Once the as-is information flow is understood, a proposal for a standardised one will be developed and presented to the company, so that they would be able to apply it in order to check whether there are some improvements in the daily working procedures or not. The purpose of the project is to **move the approach** of the firm towards a more proactive one through a better data and information management: the change should come from the firm itself, not from the procedure suggested, it is mandatory that the application of the advised methods leads the people involved to understand the importance and the advantages of that. In the practice, the roles affected by the changes recommended should realise by themselves that these changes are useful and lead to time saving, cost reduction, productivity improvement and easier working procedures: this is the only way to make them follow the new procedures avoiding resistance experienced in other projects.

To summarise, as a consequence of the company analysis, a new information flow concept will be developed and standardised in a way that the user of the data shared will gain advantage of that: the purpose is to **save time and money** with a more efficient data visualisation and sharing. The company will have new **visualisation tools** designed specifically for the role who will use them and will learn how to read them so that the shift will not be traumatic; on the contrary, the tools presented and the way of introduction will lead the people involved to spontaneously use these tools and adopt these procedures, in order to make time for proactive initiatives.

The findings can help the **academia** understanding the reasons behind the gap with the particular industry, and, possibly, understand how to present the academicals tools in a more suitable way to the companies in order to make them understand the advantages related to the usage of them. Furthermore, the **industry** will have an insight in the tools that can improve the companies' performances and a basic procedure for the application of that tools on an on-going process, so that other company would be able to use the knowledge.

Problem definition and research questions

The **Product control perspective** is a limit to the company improvement as it focuses on finding the defects once they occur and not on preventing them from happening: using data to get a view on the product is not enough to increase the production process performance, or to decrease the process' wasting, costing and timing. The **poor communication** between different departments is a source of variation in the process: people from different departments does not know how they really influence each other, how they can help each other, how they can make the process achieving better results outside their phases. If every department is focused on its results and problems, there cannot be improvements on a higher level.

The topic to be explored covers the **limitations to the spread of strategic thinking** and to the usage of **statistical tools** in the decision making processes in the Company with a focus on what are the most suitable **driving forces** that can lead to overcome these limitations. An important issue is that, in order to make the company use the tools suggested effectively, the people involved in the process need to feel that those tools can actually make their job easier, faster and better: this means that it is critical for a successful implementation of the suggested procedures to find the right way to make the individuals and roles in the company to feel the usefulness of adopting the tools. Once the gap is reduced and the right tools to share information are used in the involved departments and on the different responsibility levels of the company, the aim is to look into the **effects on variation**. The interest is especially on the **company focus**: the results of the process analysis and improvement can clear the path for developing procedures that can shift the view from product to process oriented in order to improve quality and reduce variation. This leads to the following research question:

RQ1: How can the visualisation of the data analysis drive the change of focus of a company from product to process oriented?

The scope of the second research question is mainly the **Product development process** and the focus is on analysing what data are gathered, used and transferred at each phase with the aim to manage and standardise the **information flow** in a way that leads to a better specification of the product tolerances. It is important to find out which is the critical stage of the process and what are the right methods to improve it in order to understand if the information flow involving Manufacturing, Quality and Design can be optimised and standardised to reduce the variation in the final product starting by focusing on the variation reduction in the information shared. Basically, the purpose is to discover if the main issues to take into account during the introduction and implementation of robust design theories are related to the information flow, which is an **organisational issue**, or to the tools effective usage, which is a **technical issue**. This translate into the following research question:

RQ2: How can the standardisation of the information flow be used as a robust design tool?

Restrictions and future work

The analysis will start by focusing on the **New product development process**, since the resources available are limited in time. The involved **departments** will be the Quality department, the Manufacturing department and the Design department, so the focus will mainly be on their specific **communication flow**. The solutions will deal with a **particular phase of the process**, which is both the most critical one, and the one with the higher impact on the whole process. A huge limitation is connected to the fact that the author is not being located inside the company: to get the information she has to rely on what people give and tell her and is not able to check everything. It will be important for the future work to keep looking into other criticality in other phases, so to find other improvement's possibilities. The loop the author will focus on is not defined in the Company, for the future it will be interesting to give a **definition** of it with a specific phase of the drawing as an **output**. Having a clear output will make who the user is and what the requirements for it are clearer. Having a well-defined output, it will be easier to identify measurable and addressable characteristics for evaluating it. As long as the output is not clarified, it will not be possible to talk about it and to communicate it effectively. The definition of the loop will have to be integrated with the current definition of the New product development process. the requirement on the product and the one on the process will have to be coherent. It will also be interesting to analyse the results of adopting the same procedures in **other companies** from different industries, to check if the information flow is equally important in different environments.

The improvement related to this thesis project will be just a starting point, it should be taken as a first step towards the standardisation of the communication flow and of the visualisation tools for the **whole company**. For the future work, it will not only be interested to look into other companies and industries, but also to keep working with the company under analysis in this report which can be used as a **pilot study**.

Structure of the thesis

The thesis will be organised in the following way:

1. Introduction
2. Methodology of research
3. Theoretical framework
4. Empirical findings
5. Analysis
6. Discussion
7. Conclusion

The Introduction chapter will contain the context and the problem definition. The second and third chapters will cover the methodology and the technical theory used to collect, structure and analyse the information in order to get to the findings that are described and analysed in the following chapters. The thesis structure is based on the DMAIC cycle, and the Improve and Control phases are included in the Discussion chapter. The final chapter contains the answers to the research questions and the conclusions' discussion.

Chapter 2

Methodology of research

The research approach used to conduct the research was a **mixed** approach: both qualitative and quantitative. A **qualitative** analysis was conducted to **understand** the context and the company's issues; a **quantitative** analysis was then conducted with the purpose of proposing a **solution** to the issues identified during the qualitative research. The quantitative analysis does not have the classical purpose of identifying the criticalities of the process analysed, its purpose was to give an input to the **discussion** during the cross-functional meetings in order to make the author understand the impact of different visualisation tools on the communication. The research is therefore mainly based on data collected during unstructured interviews and participating to the company's design review's meetings.

Research approach

Before starting the research, it is important to decide which research approach is the most suitable for the problem to address. The research approach chosen gives the direction to define the design of the research hypothesis, of the methods to be used for challenging them, of the data collection tools to be used, of the processing of the data and of the interpretation of the results up until the final presentation of the problem solution. A research approach is made by different components: philosophical world view, research design and research methods. Guba classified research approaches based on the belonging level to the following categories of philosophical views: post-positivism, constructivism, transformative and pragmatism (Guba, 1990). Merging the four categories is possible to obtain three approaches: quantitative (including positivism and post-positivism), qualitative (including constructivism and transformative) and **mixed** (corresponding to pragmatism) (Grover, 2015). Since the analysis to be conducted is focused on the information flow, and not strictly on numerical data, the quantitative approach is to be excluded as a suitable one for this thesis. The approach is therefore **mixed**, with a focus on the Product development process and on the interactions between the people involved in it and on the data shared between them. The approach is not completely qualitative: numerical data, in particular measurements on the welding process behaviour, have been analysed after conducting a qualitative research to explore the current situation and uncover the major issues to take into account. The **quantitative** analysis was conducted in order to find the **most suitable visualisation tool** for presenting the results, therefore as a main instrument for the thesis research. The quantitative research has been used as a **means** to improve the organisational issues that the qualitative analysis highlighted: the focus was not on finding the process' criticalities and to propose a solution for the technical issues, but to use those information as discussion's starters for deepening the qualitative analysis of the visualisation tools' effects.

After catching a first glimpse of the firm condition and of the current situation and after understanding the thesis role in the VariLight project, a **literature study** was conducted to identify a suitable theory to improve the company performances. The theory to follow needs to match the problem limitations: it needs to be simple, understandable and with an aim to free up time for the parties involved. After studying the theory, a further research phase has been conducted in order to update the first hypothesis and be sure that they were based on the right and, as much as possible, detailed information.

The wider aspect of the thesis falls under the category of **action research and an inductive research approach is chosen**, which according to Bryman and Bell is favourable when conducting a **case study** (Bryman & Bell, 2011). This means that the information is collected and generalised to address a set of **research questions**. The action research approach also considers the researcher a part of the research itself, whom cooperates with the client in order to understand what is the problem and, obviously, in order to develop a solution.

It would have been also possible to follow an Interactive research approach, which would have differed from the one chosen for the level of involvement of the researcher. In that case the problem definition, methods selection, analysis and results' dissemination would have been done together with the Company (Bryman & Bell, 2011). Based on the fact that the author would not have had the chance to be closely involved with the people from the Company, the decision was to follow an action research approach.

Research strategy

At first, qualitative unstructured **interviews** have been conducted on skype to enable further discussions and to gain deeper knowledge about the problems affecting the organisation. An alternative approach would have been to prepare a survey to send to the roles of interest, but the risk was to lose some important inputs for the further discussion: the goal was to get as much information as possible from the start, without biasing the interviewees or forcing them to stick to a script that would not allow them to freely express their point of view. Moreover, since the author was not physically located together in the Company, it would have been difficult to design an effective survey that would get the employees to express their real needs. It was also crucial from the start to gain the **trust** of the people working in the Company and talking with them and letting them discuss with the author about possible solutions was a good way to involve them in the analysis and to make them understand that the final aim of the project was to free up their time and to make their working life easier.

The research deals with strategic thinking and robust design, the focus is on the Quality, on the Design and on the Manufacturing departments: it was important to look into the reasons why the company was **not using the statistical tools that the academia provides** for sharing and visualising information. After the first round of **skype interviews** some **face to face interviews** have been made directly on the firm site, in order to gain the trust of the people involved and to get a deeper understanding of the process. After analysing the results of those interviews, and conducting a more focused theory study, other questions emerged, therefore a second phase of qualitative research has started, both using Skype calls and face to face meetings.

The participation to the first **meeting** for the design review of a *frame* was important to understand what the different departments require from each other in order to be able to work at the highest performances and, most of all, to actually see the way different information are **shared** and the way people at different levels and during different phases of the process **interact** with each other.

During those visit, an **AIM session** (Alänge, 2009) has been conducted to understand what are the main problems for the people involved in the process and to visualise them in a structured way. It was critical to make the people involved realising what are the main issues that make their work harder and that need to be solved, and during the AIM session they had the chance no only to think about their own issues, but also to understand the ones that they might cause to the other departments.

When the issues were identified, an analysis of the **possible solutions** was made in order to find the **most suitable** tools to suggest: if the usefulness in saving time and money of the tools suggested is **easily** acknowledged, then the company should spontaneously adopt them and embrace the change as a natural evolution of the as-is scenario.

The data shared and the way they are shared between departments has been already analysed in E. Zanella thesis, anyway it was important to be present during the review meetings in order to find the best way to make the Design department gets what it needs to provide the plant with more effective drawings.

The process adopted to develop the research is the one suggested by A. Bryman and E. Bell. The process consists in six phases and its **iterative** procedure allows to continuously improve the research questions specifying them in according to the data collected (Bryman & Bell, 2011).

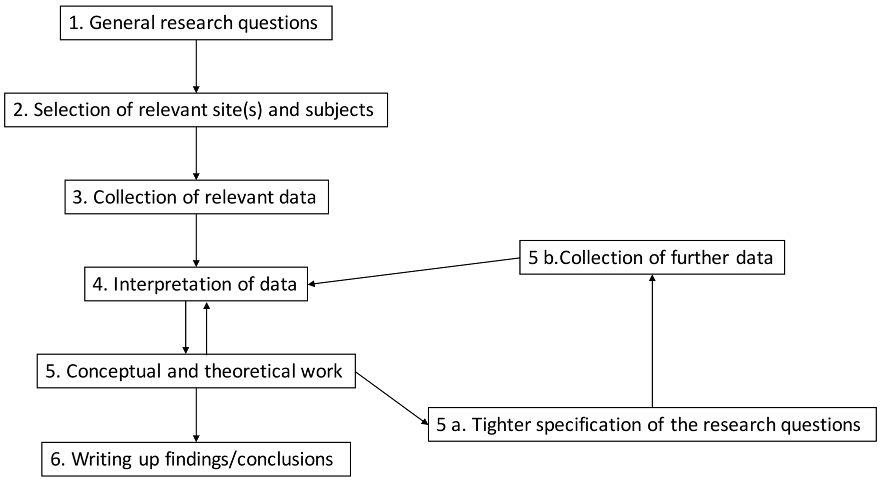


Figure 1 - The six steps of the Research development process according to A. Bryman and E. Bell

The steps are the following:

Establishing research questions

The first step of the research was to **find the focus** of it. The main theme was already decided by the supervisor and it concerned the criticalities in the welding process information flow, therefore the first version of the research questions has been established based on what the author was more

interested in, in order to have an indication about the topics to be researched in the first literature readings. The goal was to get a **broad overview** of the company procedures and, more specifically, its welding processes and to understand the issues that had already been studied by other researchers in order to know what the **current situation** was and what were the areas where improving actions could have been taken. The decision to focus on the communication loop involving the Quality, Design and Production departments came out of this first analysis of the literature.

Selecting relevant research sites and subjects

Based on the knowledge gained from the first analysis of the theoretical framework, the research site and subjects were decided. The focus was on one of the companies involved in the VariLight project, it had already been analysed in **previous thesis and research papers**. The roles to be interviewed were decided based on their involvement in the development process and in the selected departments. It was important to get an overview of the current situation from the **different points of view**: internal and external. The internal point of view was gotten using the **interviews**, the external one studying the available **literature** and documentation.

Collecting relevant data

The data to be collected needed to **reflect the current situation** of the people involved in the product development process, it was important to get a detailed picture of the **communication issues** between the people involved. A series of **interviews** was conducted: at first a Measuring and Product Quality Manager, a Designer, a Manufacturing Engineering Manager, a Management Systems and Data Analysis Director and the VariLight project manager were interviewed on ***Skype*** to know what information they use the most during their daily jobs and what are the problems they face regarding the product development process. Other follow-up interviews have been performed during the thesis development, both using Skype and during Face to face meetings in the company. The purpose of the interviews was **confirming** the thoughts and the findings of the author.

Interpreting data

The information collected from the different roles that have been interviewed has been organised with the purpose to find **connections**, **similar** and **conflicting** opinions and **most critical areas** of action.

Conceptual and theoretical work

- **Tighter specification of the research questions**: After the deeper analysis of the current situation, it was possible to make the research questions more precise. The focus of the research questions depends on the critical areas that the interviews have highlighted.
- **Further data collection**: After specifying the research questions a second round of interviews was conducted. The author participated to a Design review week meeting in which different roles were involved with the aim to discuss the tolerances on the drawings and the possible way to achieve them. In that context an Affinity Interrelationship Method (**AIM**) session was conducted with two Production Engineers, two Welders, the project Quality manager, the project Geometrical assurance manager, the project Design leader and a project Designer. The role of the Project Quality Manager Operations proved to be relevant for the research, so a face to face interview with him was arranged. Since the information collected during the AIM session pointed out the involvement of the Design department in most of the product development issues, a face to face interview with the Designer previously interviewed on skype was conducted to have his opinion of the reported issues. A follow-up with the Measuring and Product Quality Manager on a skype interview was done to finalise the AIM results, but the data collection phase was never considered over: the author kept interviewing the people involved both to confirm and to deepen her knowledge.

Table 1- Interviews summary

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
VariLight 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
	Skype meeting	Jan 15th 2019

Management Systems and Data Analysis Director	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
Structural Mechanics Engineer and Welding Engineer from a different Company	Skype meeting	May 31st 2019

The interviews conducted were all **unstructured**. The questions were prepared in advance and given to the person to be interviewed, but the discussion arising was more important than strictly following the predetermined questions order. During the interviews notes were taken in order to highlight the most relevant topics covered and to write down any ideas and suggestions coming up during the interview itself, however the interviews were **recorded** and a **transcription** of each one was made in order to be sure to have everything clear. In case of doubts the interviewee was asked for clarifications and explanations. The questions asked to the different people were mostly common, with some specifications related to the specific role of course.

Findings and conclusions

The thesis findings have been written based on the **data analysis** and on the results of the **qualitative analysis**, taking into consideration the parameters for the study validity as well.

Validity of the study

The interviews were conducted following the **directions** given by Bryman and Bell (Bryman & Bell, 2011): in order to makes the interviewee feeling at ease and free to talk openly about the issues being explored, the interviewer remained positive and attentive and not rigorous on the questions' order.

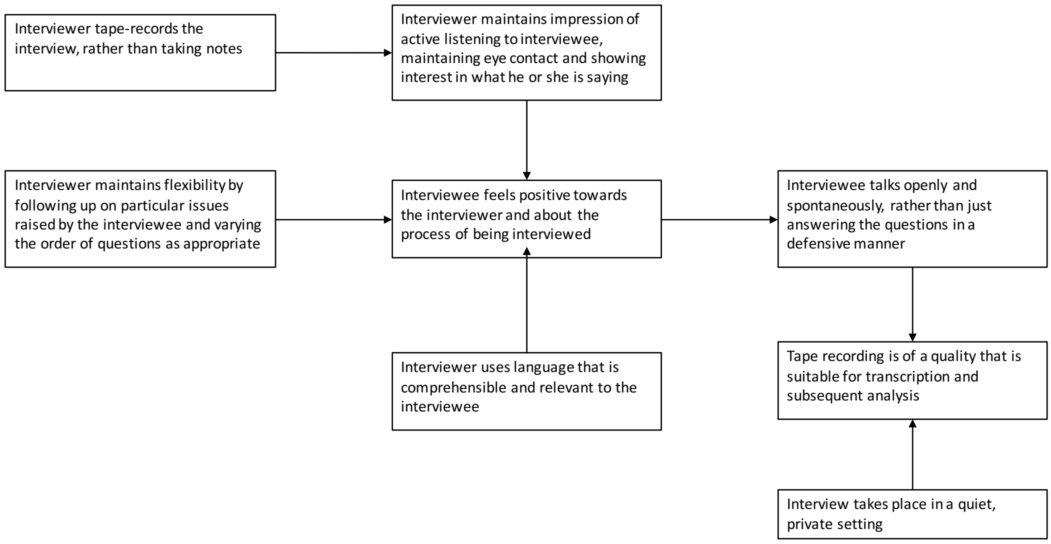


Figure 2 - Directions for conducting effective interviews according to A. Bryman and E. Bell

Since the case study and qualitative analysis methods do not allow to have a stable output, the criteria for assuring the validity of the study cannot be the ones used for quantitative researches. The criteria used in this thesis are the ones suggested by Bryman and Bell for evaluating qualitative researches (Bryman & Bell, 2011):

Credibility

The analysis of the company **depends on the information collected**, different people have different opinions, but, since the interviews were conducted involving different roles from different levels and different departments, the overview of the company issues results complete and corresponding to reality. The interviews were conducted **without biasing** the interviewee with other role's opinions and without giving personal opinions about the topic discuss, furthermore the results of the interviews were discussed with the interviewees themselves at the end of the interview.

Transferability

The data used as a baseline for the research conducted are strongly related to the company analysed, therefore it is not possible to say that the results obtained in this case study will be the same if the same methods would be applied to a different company. Anyway, since the current state of the company, its processes and its issues have been deeply described with a **rich in details analysis**, it would be possible to assume that the same conclusions would be reached if conducting the same research in a company which matches the description given.

Dependability

The findings are based on the **information** collected, all the information is stated in the thesis work and the transcriptions of the interviews are available.

Confirmability

The findings are only based on the **data analysed**, no personal opinions have neither influenced the data gathering process nor driven the author to the conclusions.

Authenticity

This criterion regards different aspects of the research. *Fairness* is reached by interviewing **different roles** and positions in order to get an unbiased description of the situation. *Ontological authenticity* was proven to be achieved when people interviewed said that answering the questions was of **help for themselves** as it allows them to think about their daily working situation and to realise what could have been improved. *Educative authenticity* was confirmed at the end of the AIM session when people told the author that they were **not fully aware** of the impact of their work on other roles involved in the process. *Catalytical authenticity* and *tacital authenticity* were mandatory criteria to fulfil in order to achieve the author goal: the researcher figure must be **outside** the research itself, she had to drive the company people towards the solution, the employees had to feel that they were changing the situation, not the author.

Chapter 3

Theoretical framework

The thesis structure follows the **DMAIC** cycle suggested by the Six Sigma methodology. The first step was to Define the scope of the analysis, then it has been possible to collect data with the interviews in order to Measure the current performances of the company and to Analyse the results looking for causes. Once the causes were identified it was possible to Improve the situation suggesting different visualisation tools and finally to Control that the suggestions were stable.

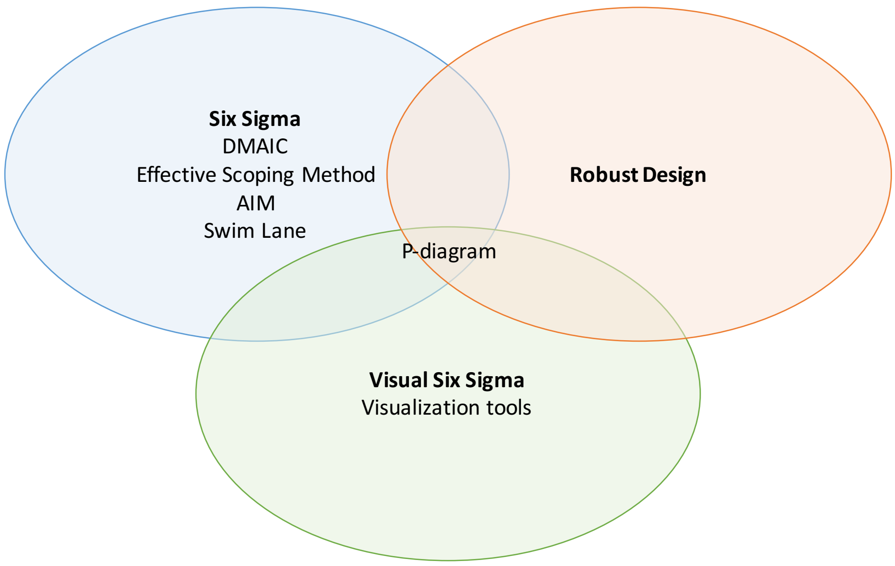


Figure 3 - Theoretical framework summary

Different types of knowledge

There are different types of knowledge that a company should pursue: factual knowledge, causal knowledge, procedural knowledge and positional knowledge. The **factual knowledge**, or know that, is very basic: raw data organised in a report, structured and described are factual knowledge. The **causal knowledge**, or know why, is related to the reasons behind facts that raw data highlights. It requires an analysis of the data. As an example: if a designer analyses the product failures, he will be able to find the reasons behind those and trace them back to the critical part of the product. The **procedural knowledge**, or know how, allows to reach a result, to solve problems. As an example: if a designer realises that a specific part of a product is critical, he will redesign it in a way that removes the criticalities. The **positional knowledge**, or know who, is what allows a company to spread the knowledge: it concerns knowing where the information is stored, or who possesses it (Cantamessa & Montagna, 2016).

Different types of variation: Diachronic and Synchronic

When talking about **Synchronic** variation, the focus is on different conditions compared at the same time; **Diachronic** variation, instead, deals with the same condition monitored over time. With a synchronic approach, measurements are made at a specific point in different time from different location. It is possible to compare, for example, welding robots, welding position, welding order, welding arc stability, but always for the same frame. Without diachronic data, though, it is not possible to estimate the **process capability**, which corresponds to the variation at a specific location on the frame over time and therefore requires data from the same spot from sub-sequent frames over some weeks.

Current use of the visualization tools

Companies use information in order to avoid uncertainty and equivocality: while the former is connected with the lack of data, the latter regards the problems with interpreting those. In order to be innovative, a company needs to enforce its Absorbtive capacity, which means to be able to choose the right information to focus on, assimilate it and apply it correctly to a commercial aim (Cantamessa & Montagna, 2016). It is therefore crucial to be able to process the information effectively and use them correctly in the decision making process in order to reach the business goals (Öberg A. E., Predictability – an enabler of weld production development, 2016).

The currently most common presentation of data is in table format, sometimes using a Pareto or a Bar Chart as a summary tool. Anna Ericson Öberg, during her PhD project, introduced the usage of Control Charts in the Company under analysis, the results were good and the overall impressions were that the tool could be very useful for the management teams, for example: the ability to choose the right actions was improved and there was a shift in language from symptom towards cause.

The tools currently used by most of the companies allows to compare the present value with a target or with a past one: a so-called two-point comparison (Wheeler, 2000). Using this approach, things can suddenly turn from good to bad, and vice versa, very fast preventing the companies to focus on long-term improvements. The focus is on the output itself, not on the system delivering it, therefore the priority cannot be to improve the process. Moreover, the comparison is often made on the mean values, but, as already pointed out, whenever an average is used to represent an uncertain quantity, it ends up distorting the results because it ignores the impact of variations (Danielsson & Holgard, 2010).

Problems with the use and implementation of the visualization tools

When introducing new tools, **training** is essential for the success of the implementation, but it is still not sufficient: according to Öberg's studies, several themes not fully disclosed in the change management literature are important for the implementation success. It is crucial to have a **common language** between the different functions in the Company, to have the same expressions for discussing about the process. In order to have this common language in the Company, it is necessary to reach a critical mass of people being aware of the phenomenon in question and able to spread the knowledge inside their department. This way, the people aware of the improvement path to follow will be able to make it recognizable to other people, who speaks the same common language, involved (Öberg A. E., Predictability – an enabler of weld production development, 2016).

This is why training the whole group together is so important: without a common language, it is impossible to discuss process behaviour charts, variation, and performance measures effectively in the management group. Every member who is not familiar with the language inevitably stops the discussion and will try to drag it back into the old patterns of thinking (Danielsson & Holgard, 2010).

Six sigma: DMAIC cycle

The Six Sigma methodology is useful when the project development involves **multiple stakeholders** and a **cross-functional team** should be used to obtain the best result. The purpose of Six Sigma is to model the process according to the data analysis and in relation to the performance's requirements. The focus of a Six Sigma project is the **variation**: identifying, controlling, reducing and anticipating variation sources. The development of a Six Sigma process follows a specific structure: Define, Measure, Analyse, Improve, Control.

During the **Define** phase both the problem and the team are defined. On the problem side, improvement opportunities, costs, benefits, impact on the customer are described; on the team side, project goals, timeline, process to be improved are described. During the **Measuring** phase real data about the current situation are collected in order to assess and measure the as-is performances: the current variation level is assessed and possible root causes are identified. The goal of the **Analyse** phase is to determine which of the possible root causes are actually root causes according to the data collected. The **Improve** phase focus is on finding the best settings for the factors impacting on the output in order to deliver with the highest performances. The **Control** phase has the role to make the improvements lasting in time and to make sure that the new situation is stable.

Six sigma tools

Effective scoping method

The Effective scoping method (Zanti, 2015) is used in order to **facilitate the problem definition** and avoiding the team to focus on the more immediate to see or easier to solve causes. To correctly apply the tool, it is necessary not only to focus on the right questions, but also to address them in the right order: output, customer, process, input. Starting with the output allows to use a **pull-approach** to analyse the context and therefore to focus on the customers' demands more then on the process itself, which should be a consequence of them.

The first step is to clear what is the **output** of the process. Once the actual output is identified, it is important to understand who is the **user** of the output, the customer, and based on that to define what are the **requirements** for the output, how those can be measured and when they can be considered accomplished. Once the output is defined, it is important to underline who is the **supplier** of it and what requirements, not directly related to the output itself, cannot be lost in the improvement process. The **process** definition takes place after the output definition: defining the **team** jurisdiction and the competencies needed for developing a successful project is the following step. The focus can then move on the **inputs** in a specular way: first the inputs and their suppliers must be identified, then the requirements for the inputs must be set. The identification of output, user and requirements (often called big Y in Quality engineering) is relatively straight forward when it comes to the main flow of products or services. However, when improving the internal supporting processes, such as the information flows addressed in this Thesis, it is not that simple anymore. The recommendation using the Effective Scoping tool is not to frame the underlying system until the small y has been selected. The small y is the metric connected to selected requirements (big Ys) to improve that will drive the exploration of the problem. The major question to answer using the Effective Scoping Method is: does the characteristic measured really reflect the overall improvement initiative initiated by the stakeholder? Typically, new problems might not be very well characterized by old metrics (Hammersberg, 2019).

Affinity and Interrelationship Method – AIM

The affinity and interrelationship method is used when a team needs to identify the **cause-and-effect relationships** among a critical issue. It is a structured way to combine and analyse the opinion and the points of view of different people involved in the same project or affected by the same issue. It is a procedure to apply the first two of the general seven management tools within quality engineering: the affinity diagram and the interrelationship diagraph. The approach was introduced by professor Shiba in 1989 (Bergman & Klefsjö, 2010).

It starts as a brainstorming: a statement related to the situation to analyse in the form of a **question** is used as a conversation starter. The people in the team answer the question privately, writing on post-it one or more statements without sharing opinions or listening to others' responses. The answers are then read out loud and placed to a board so that everyone can understand what the other participants think about the question. The answers are then grouped together by the whole team following an affinity classification: statements that deal with the same theme should end up together, but the grouping can follow different rules. The team gives a title to each group and rates them so that it is possible to understand which aspects are the more significant for the people involved in the analysis. The groups are then connected with arrows according to the influences' direction to associate different groups and visualise the cause-effect relationship. Once the connections are drawn it is possible to identify a final answer to the opening question by taking into consideration only the most significant groups' title and their relationships.

Swim-lane flowchart

The swim-lane flowchart is a visual representation of a process with a particular focus on the **roles** involved in it: the goal is to make clear who does what in the process. The activities are represented in a chronological order and they are placed in different columns, or lines if the flow chart is horizontally organised, based on the owner of the activity itself. This view is very useful when there are a lot of different departments or role involved in the same process and it is important to visualise the **connections** and the **communication** flow between them. It is easier to identify redundancy or inefficiency; in this thesis particular case the loop-structure of the new product development process was represented very clearly (George, Maxey, Rowlands, & Price, 2004).

Visual Six Sigma

Visual Six Sigma is a branch of Six Sigma focusing on the **visualisation tools**: one of the goals of Visual Six Sigma is to make the decision making process data driven with simple and easy to understand and to use tools. It exploits three strategies to support the goal of managing variation in relation to performance requirements: **dynamic visualisation** to see the sources of variation in your data; exploratory data analysis techniques to identify key drivers and models, especially for situations with many variables; confirmatory statistical methods only when the conclusions are not obvious

(Cox, Gaudard, & Stephens, 2009). The most interesting strategy for this thesis development is the first one: using a dynamic visualisation of the data in order to identify what causes the variation in the data under analysis. **Visualisation** is most commonly used to check the data for anomalies, or for exploring them while looking for possible models or for a confirmation of the model assumptions; but, given the importance of **communication** in Six Sigma, it is possible to extend the usefulness of it to the **analysis** of the model results and to the **sharing** of them. Successful companies collect and analyse data on a daily base, but, due to the fact that they are not using the correct visualisation tools, they lose parts of the knowledge they could gain from their data analysis. New insights and a better awareness about the processes performances could be obtained by interacting with their data with the aim to, literally, **see what they represent**.

Visual Six Sigma, as a difference from Six Sigma, does not follow a sequence of actions since it is more of a concept to apply to the Data analysis. It does give, though, a sequence of steps to follow when performing a Data analysis in order to structure it and to be able to suggest effective solutions and decision making tools.

The first step is to **Frame the problem**, the specific failure must be identified and a strategy for improvement should be planned. As for the Define phase of the Six Sigma method, it is important to identify the Y of interest from the start.
The second step is to **Collect data** that relates the output of interest to potential root causes previously identified.
After that, it is possible to **Uncover relationships** between the potential causes and the output of interest so to assess which causes is actually a root cause.
Once they are uncovered it is possible to **Model the relationships** building a statistical model to statistically determine which potential causes explain the variation in the output and represent a causal factor.
The following step is to **Revise the knowledge**; the settings of the inputs can be changed in order to find an optimised effect on the output.
The final step is to **Utilise the knowledge** and to maintain the improvement.

The Visual Six Sigma Data Analysis process has been used in the thesis during the implementation of the graphs. The data used were related to a welding process, which was not the direct object of the thesis work but that has been used as a **means to show the usefulness of the visualisation tools**. Therefore, the purpose was not to build a statistic model in order to predict and set the input of the process. The purpose was to demonstrate that using the correct data analysis point of view and the correct visualisation tool to share it, it is possible to uncover the relationships between inputs and outputs, or, in this thesis case, between processes' updating and variation levels.

Robust design

A Robust Design methodology consists in **considering the noise factors** in a conscious way: environmental variation, manufacturing variation, component deterioration and so on, are all factors that, normally, a company does not try to control, the purpose of Robust Design is to use those factors **to reduce the variation** in the process.

Using the Six Sigma methodology, many companies obtained a positive impact on the cost structure and the customers' satisfaction, but many of them have reached the maximum potential of the approach: Robust Design is the step forward. The strategy of the Robust Design methodology is to optimise the design's choices with the aim of preventing failures during the downstream phases of the process.

The tools of Robust Design are primarily four: **P-diagram**, Ideal function, Quality loss function, signal-to-noise Ratio and Orthogonal Arrays. For the thesis scope the useful tool was the **P-diagram**, the author used it to identify and classify the variables affecting the output of the process.

The Robust design approach suggests a systematic method to reduce the design sensitivity to variation: the **Robust Parameter design**. The first step in the parameter design is to **Formulate the problem**, which means to identify the control and the noise factors and the function representing the process. Then **Data are collected** to check if the concept is correctly captured in the first phase. The following steps have not been developed in the thesis project since they would require a specific and more detailed study: the **effects of the control factors** should be calculated in order to select the optimum settings for the parameters and the final step would be to **Predict the performances** of the product designed if the control factors are optimally set and to check if the prediction corresponds to reality.

Parameter diagram – P-diagram

A parameter diagram is a representation of a process or of a system, it is a tool used for both framing the problem in the **Visual Six Sigma** approach and for defining the development scope in the **Robust design** approach. The system is considered as a function of the inputs factors that combine in order to give one or more outputs. **Outcomes** of interest are denoted as Ys, the inputs are denoted as Xs, the function that describes how the Ys changes with the changes of the Xs is called **signal function**. The Xs, or the causes that influence Ys, could be divided into controlled and not controlled; an X can be not controlled for different reasons: it can be unknown, considered not relevant, impossible or too expensive to control. This not controlled Xs are called **noise factors**, if they are not considered in the design phase, they will come up during the following process' phases causing issues that can be avoided by subjecting the design concept to them using the **parameter design.** The controlled Xs are called, instead, **control factors** as they can be used to control the output: setting the control factors in different ways allows to obtain a, for example, more successful or less expensive output. A design with the appropriate control factors set to have a process as close as possible to the target one at a reasonable cost is called a **robust design**.

Representing a system with a P-diagram leads to focus on some **specific aspects** of the system itself, the ones that are considered to be of high interest; therefore, the model will, intentionally, omit some aspects that might in fact be relevant in order to understand and control the system behaviour. A model will never be a perfect representation of the actual situation, but confronting it with the data and updating it according to it, can make it better and more useful. Having a better understanding of the noise factors means gaining leverage in acting upon the output in order to make it **more favourable**.

Chapter 4

Empirical findings

The focus of the analysis is the first stage of the **New Product Development Process**: the phase which define the drawing and the production process. The focus is on the first stage since it is the one giving the input to all the following and it is, therefore, crucial for reaching high product performances: the sooner actions are taken in the process, the higher the positive impact on the whole process will be.

The Concept Loop is made by a sequence of **iterations** that require a lot of time: both generating and evaluating a concept are **cross-functional** activities based on discussions that are very time consuming since the knowledge in the Company is very department-related. There is a general lack of knowledge about the process performances, which leads to focus on the product performances with a dangerously **reactive** attitude: the product failures are fixed adopting a **fire-fighting** approach that prevent the Company from looking into the causes of the failures and, therefore, from improving its processes.

Focusing on the cross-functional communication flow during the process, leads to understand that the lead time is not closely related to technical issues, but mostly to organisational ones: the feedback loop between the plant and the Design department is not effectively closed. The designers do not receive a useful feedback from the plant, therefore, they need specific meetings and a lot of time to update the drawings. A series of data visualisation tools were presented to the Company in order to analyse how different views could simplify the communication and, especially how they could change the attitude and the focus of the people using them. The final purpose of the graphs presentation was finding a smart and useful way of standardising the communication starting with the New Product Development Process.

DEFINE - Current situation analysis

The New product development process

The process under analysis is the **New Product Development Process**, the reason the author focused in particular on it is that it is more effective to change procedures and working methods starting with the development phase of the production process than acting on the on-going rooted processes in the serial production scenario. The **sooner** the improvements are made, the more they affect the process since they can have a positive impact on all the following steps.

The current situation, as described in E. Zanella’s thesis, is extremely complex (Zanella, 2018). The Product Development Process consists in four loops, the most interesting for the author is the Concept loop since it is the first one and the one that gives the inputs to all the following phases.

The starting point is the customer: based on the customer usage, the **product manager** develops a first version of the product requirements and of the fatigue classes and gives it to the designer.

The **designer** elaborates then the first version of the production instructions on a 3D-CAD model taking also into considerations the budget and cost allocation, historical data, previous version of the product drawing, internal standards and institutional fatigue values. The designer, the calculation engineer and the manufacturing engineer have a close cross-functional communication during planned meetings in order to obtain a 3D CAD model which reflects feasible characteristics.

When they reach an agreement the model is evaluated in a more accurate analysis by the **calculation engineer** whom gives a feedback to the designer that, if necessary, updates the project based on the stress measured in the calculations.

Once the 3D CAD model final version is achieved, the **designer** develops the 2D model whose focus is no more on how the product should look like, but on how it should be: the most critical parameters are set with the aim to realise an outcome that can be produced without incurring in too much production difficulties.

Once the 2D model is approved by manufacturing and calculation, a **Design review** is made involving the **Quality department** and the **Welding engineers and manufacturers** in order to check if the drawing is feasible, in other words, if the welds are possible to realise and to inspect.

When development phase is over and a final version of the drawing is decided, the production phase can start. Two or three prototypes are built in a workshop in order to get ready for the real manufacturing: weld manufacturers and welding engineers checks if the requirements are achievable, they decide the welding sequence to follow and which fixtures, tools and welding methods to use.

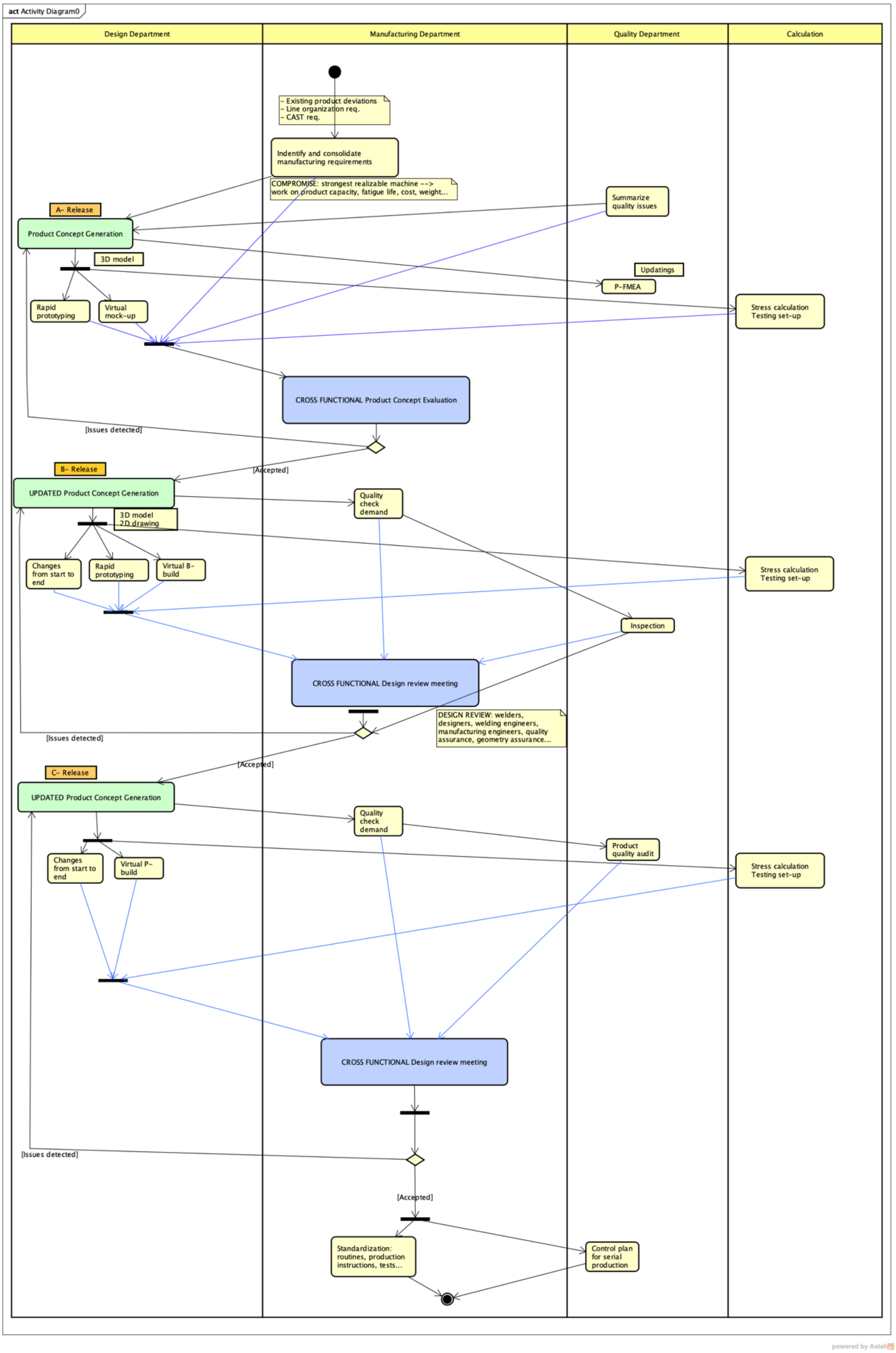


Figure 4 - Swim lane flow chart representing the New Product Development Process' Concept development and evaluation phase as it currently is

The Concept loop is therefore to be considered as made of three smaller internal loops: General concept generation, Concept testing and evaluation and Industrialisation. The first has the aim to give a starting point, the output drawing is based on historical data and previous production choices; in particular, the New product development process used as an example for the analysis had the purpose of updating an existing product, this means that the changes were made on the general product concept level within an existing production system and did not include, for example, the selection of manufacturing principles that might influence the factory lay-out and the flow design. The second one is the **bottleneck** of the whole New product development process: it requires a lot of time and cross-functional communication to get to the final result, which is the drawing used for the first prototypes. The loop requires a lot of iterations not only in order to find the right compromise between customer demands and feasibility, but also in order to make everyone involved in the evaluation understand the results of the testing and identify the improvement solutions. The third loop is related to the production and evaluation of first prototypes and to the final minor adjustments.

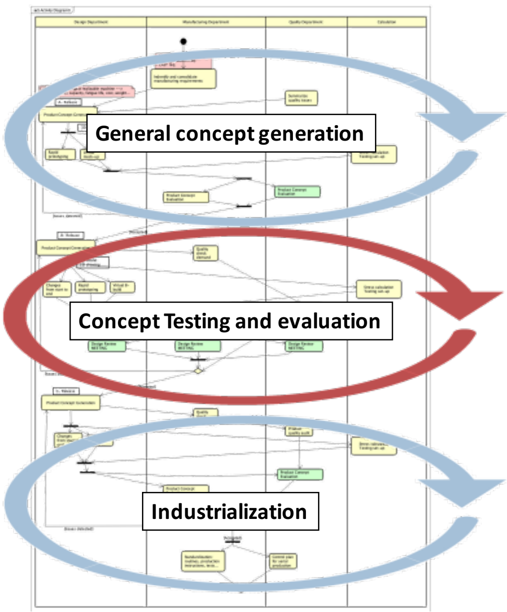


Figure 5 - Disaggregation of the Concept loop into the three smaller loops

Interviews results

The purpose of the interviews was to understand what phase of the process was the **most critical** from the information flow point of view and what **role** was the crucial one in the communication. The reason behind this is that by acting on the most critical information link it is possible to reach the highest positive impact on the rest of the process. The author looked into the data requested by and shared between the different departments in order to find a missing link, or a loop that is not closed, to act on in order to improve the information flow.

Role interviewed: Measuring and Product Quality Manager

The Quality department is responsible for the Non-Destructive testing, the product audit and the measurements gathering. The data collected daily by the department are not shared with the Design department since no designers **ask** for it for their usual working tasks, but they are available on an open software that everyone in the Company can access. When a **significant change** is needed, either because the Manufacturing department cannot produce the frame as it is stated on the drawings, or because serious issues occur on the plant, or because the Company decides to update a product drawing, the Quality department shares the measurements with the Design department so that the designer responsible for the updating knows what the problem is and where it lies. The **reports** the department gives to the Design and Manufacturing departments, most of the times, require a verbal description of the data, since the simple visualisation as Control Chart, or as measuring Protocol is not enough to give the information requested: this means that the responsible for the report needs to spend a lot of time explaining the results. When a defect is detected the department, together with the Production department, needs to find a solution: **time is crucial**, so the problem needs to be solved in the fastest way possible.

Role interviewed: Project Quality Manager Operations

It is important to share the view that all the functions are striving towards a **common goal**: the *green product*. All the departments need to achieve the requirements in order to have a good product at the end of the process: purchasing, materials, subassemblies, machining… every phase, from the start, needs to fulfil the drawing specifications. The product needs to be designed in a way that allows to produce it the same way every time: reference points must be clear, process steps are taken in different order, the product positioning in the fixtures is not a poka-yoke process. It is important to start acting from the start, with a **Robust design** attitude, in order to eliminate as many variation causes as possible with the drawing instructions. Not all the production processes are stable, but the real issue is that when a problem happens there is no interest in looking for the root cause, it is more important to save **time**: the problem is solved with a firefighting attitude and it is built into the process itself.

Role interviewed: Manufacturing Engineering Manager

The Manufacturing department includes both the Fabrication and the Assembly sub-sections. The decisions taken on a daily base concern both the **repair** of the occurred defects and the **process changes to take** in order to avoid those defects to occur again. The biggest problem for the department is the lack of knowledge about the **processes capability**: it is known where the variation is bigger and what processes are the most critical, but the baseline of the knowledge is the employees experience on the plant. It is also not known why the variation happens and therefore it is not possible to reduce it working on the **causes** instead of on the **effects**. It is important that the Design department is aware of the feasibility of the drawing and that the requirements are expressed on the drawings in a way that is **understandable** for the Manufacturing department, since people in production are responsible for choosing the way to produce in order to achieve the requirements.

Role interviewed: Designer

The Design department is not located in the same place as the Quality and the Manufacturing department, therefore most of the communications take place using **Skype**, and face to face meetings occur only in specific occasions, approximately four times a year. The designers are responsible for delivering the **drawings**: they set the tolerances and the points where to check the product. The Design and the Production departments interact in order to obtain effective drawings: the welding positions should be **possible to reach** for the welders on the plant, the tolerance limits should be **achievable** for the Manufacturing department. The most common problem designers face during their activities is the lack of knowledge about the **gap** between what really happens on the plant and the drawings' requirements. The information about failures on the plant during normal production is not available, but it is crucial for them to know what tolerance limits are critical and what part of the product are harder to produce. Due to the **over-processing** on the plant, designers do not know what tolerance limits allow to achieve the customer requirements. When measurements are needed the designer needs to ask for them directly to the other departments, but it is not clear who to ask what to, so most of the time the information needed is not accessed. On the other hand, since there is a lot of work to do, both the designer and the people asked for information have no **time** to look deeply into the detail of the problems: the data available are not of immediate understanding.

Role interviewed: Management Systems and Data Analysis Director

The bigger problem when analysing the data is that on the same platform there are data from every department and it becomes hard to find a **connection** between such a huge amount of data. The view is most of the time **focused**, even if departments are connected: it is confusing when issues are transferred between different function, since there is no way to understand which one was the starting point. The full picture is missing, therefore the focus is **misplaced**: the attention is not directed to what is most important from a customer point of view, but to what is more urgent on the production site. It might happen, for example, that in order to reduce the time to market the Company focus on shorten the production process, even if the bottleneck is the order acquisition. The tools used for data analysis are Control Charts, Bar Charts, Pareto Charts and Pie Charts.

Role interviewed: VariLight project manager

The VariLight project manager is responsible for the **project goal** achievement: she needs to make sure that the work path is followed, that the team is moving according to the initial planned intentions. She checks that the work packages are performed respecting the prevented time and scope and she makes sure that both the Academia and the Industry side are getting the expected deliveries from the project.

Interviews results: Summary

There is a **general lack of knowledge about the processes performances**: engineers know which processes are reliable and which are not, but the capability analyses are not conducted, therefore the information is not based on any quantitative data, but only on experience. Since the processes capabilities are not known, the robustness of the process cannot be acknowledged. A problem on the plant is the **over-processing**: to be sure that the welds are reliable and that the product is robust the welders go beyond the requirements, as a result it is not possible to know **how robust the products actually are** and if the over-processing decreases the products might not be robust enough, therefore it is not possible to update the tolerances in an informed way. This issue is aggravated by a **fire-fighting attitude on the production site**: when a problem occurs, the first thing to do is obviously to solve it, but once it is solved there is no further analysis of the original causes. Solutions are built into the process during the emergency condition, but these solutions do not solve the original problem, they are just palliative actions that, in the long term, can lead to other problems. The fact that **no in-process measurements** are taken makes the identification of the root causes even more difficult since it is not possible to understand in which phase of the process the problem originated. The focus is on the **short time** solutions, but this attitude prevents the processes to improve since the causes of failures are not eliminated. It would take too much time to look into every on-going process and to find and solve the root causes of the variation, but it is critical to change the attitude for the production processes that are being updated and for the issues that will happen in the future.

The interviews also revealed an **exclusion of the Design department**: the department gives the inputs to the other departments, but does not receive feedback from them unless there are serious issues to solve. The Manufacturing and Quality departments work together during the daily operations, they share knowledge about the process' performances and they look for solutions together, but the issues occurring on the plant go back to the Design department only when severe issues happen and there is an urgent need of change of the drawings specifications. The designer should know what Manufacturing can produce in order to develop drawings with achievable tolerances, but this information does not go back to the department neither before the drawings are finalised nor after the delivery to production.

A problem for the people involved in the process is the fact that they often do not know **who to ask what to**. The information is **fragmented** in the different phases and departments and there is no share-point for all the data to be stored and accessed in a more aggregate shape. This lack of positional knowledge is related to the fact that most of the management roles interviewed exposed an unawareness of the processes **guidelines** and company procedures. This means that when a new employer is learning how to do his job, he is advised by his or her manager, but does not rely on the process description for his or her activity since the manager is not used to take those into consideration. If the job activities are not performed in a standardised way, the sources of variation multiply: sources related to the different way of practically doing the job add up to the unavoidable human factor's related ones and to the process' ones. This attitude generates a broad confusion inside the company. Even if the production flow can still be managed in the short term, since managers know what their employers are doing, when a defect is detected it is hard to **trace it back** to the process activity it has originated in. The information flow is also badly affected from this lack of standardisation both because there is no clear definition about the way a process is handled and because different process managers handle the same processes in a different way, **disorienting** the other roles involved in the process development.

With an effective information flow in place, employees should be able to find what they want to find in a shape that allow them to easily use the information to know what they want to know: communication and visualisation of data are both crucial.

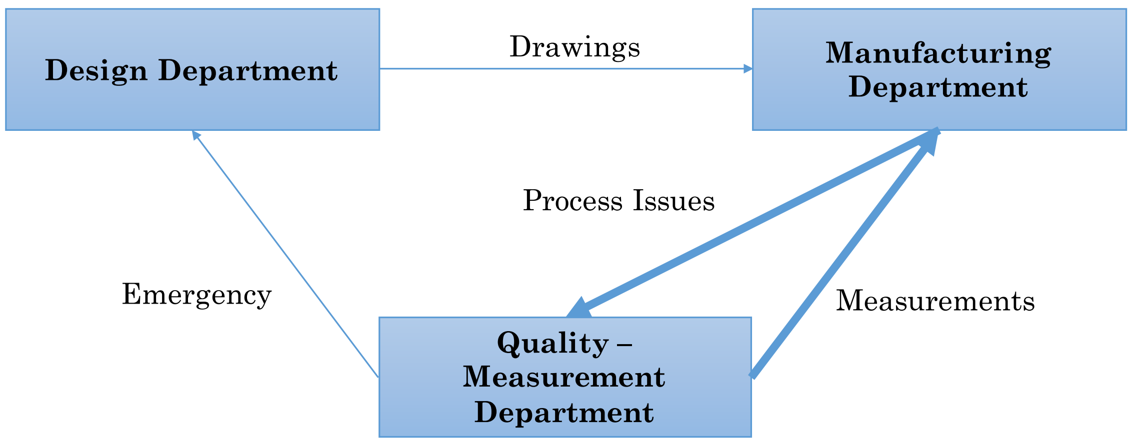


Figure 6 - Simplified representation of the communication between the departments of interest: Design, Manufacturing, Quality

Outcomes from the first design review week

The author took part in the first Design review as an **observer**, the roles involved were: production engineers, tool designer, quality project manager, geometrical assurance manager, designer project leader and designer, welders. The **cross-functional team** went through every requirement on the 2D drawing in order to discuss way to achieve the tolerance limits and, when necessary, way to change them in order to make them achievable. The involvement of different roles allowed a **sharp discussion and knowledge sharing**, every department took part into the discussions and gave interesting inputs to the others. The team was striving towards a common goal: obtaining a drawing that represents an easy to realise product. The discussion helped to understand the different points of view and the different information requirements for the different roles involved: this was the first step towards a **pull-approach** which based the information flow on the customer's, i.e. the user of the information, needs.

The **severity of the requirements** has been a significant point of discussion. Designers decide the first version of the tolerances taking into account the company standards, the customer requirements and the previous drawings. During the design review the Manufacturing department and the welders themselves can give their opinions and suggestions about how to respect the customer's demands with tolerances that are achievable on the plant.

"Do we really need that precision?" (Geometrical Assurance manager)

"It is too much strict; you do not need this much." (Production engineer)

"We should not have demands higher than what we can achieve. It's very hard to have 2mm, we normally don't. We can put 3mm and we are sure that we can achieve it" (Welder)

The different roles have different points of view, but the same goal: achieve the customer demands. In order to do that, the definitions must be understood by all the roles involved in the process, the requirements must be realistic and the production procedure must be effective: respect the customer demands is a cross-functional responsibility, in fact, if the requirements are too high the production will not be able to deliver an acceptable product.

Another important topic is the **lack of knowledge about the other departments situation**: every department is focused on its responsibilities and achievements but there is no information sharing between the different phases of the process, therefore there is no awareness about the influence of one department decisions on the others: different departments do not know how they affect each other.

"*What happens during welding?*" (Tool designer)

"*How are we welding today?*" (Designer project leader)

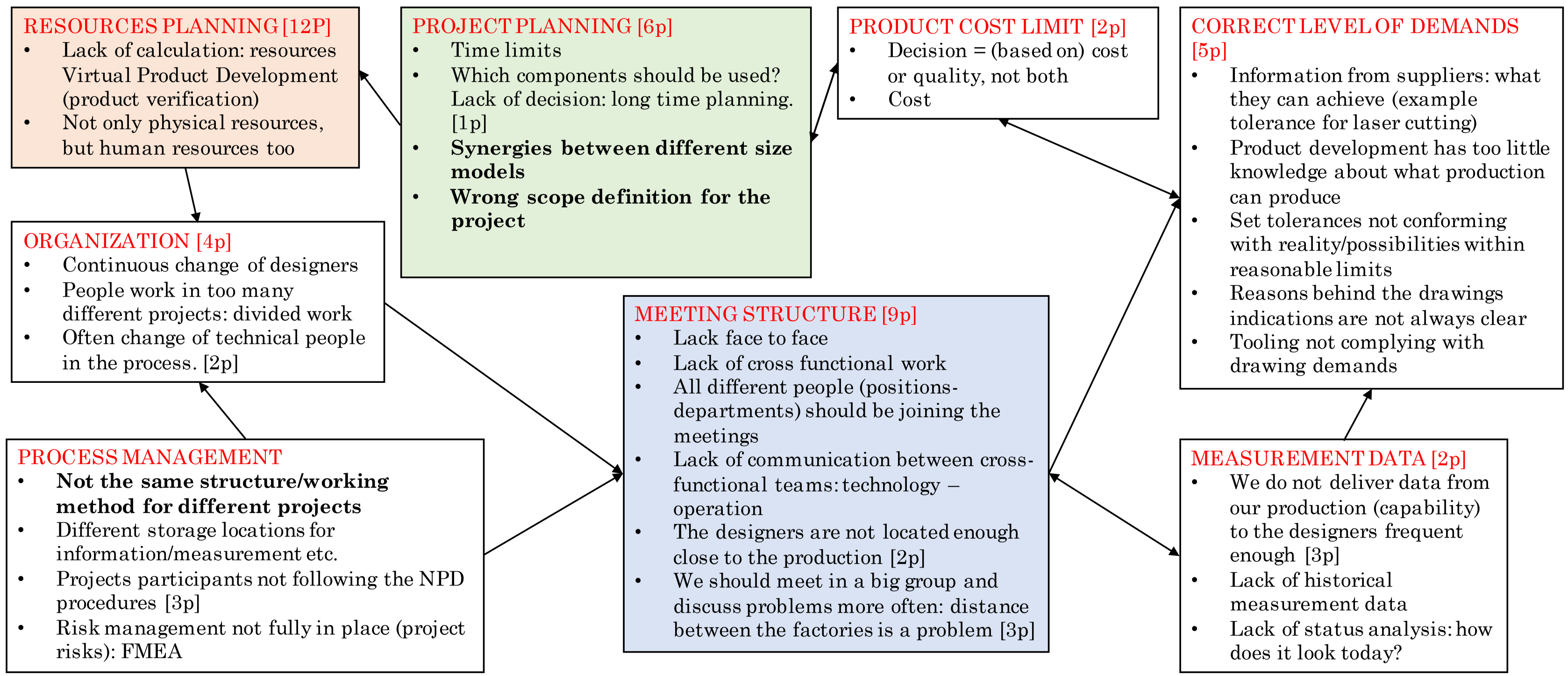
"*We know we have some problems with this, but we don't know why we have these problems*" (Production engineer)

Different roles need to know **different aspects of the process** in order to make the whole process working more smoothly. This face to face meetings were useful to understand **what information every department needs** the most in order to give good outputs to the other departments involved in the process.

AIM results

During the Design review meeting it has been possible to arrange an Affinity and Interrelationship Method session with the roles involved in the New product development process. The question asked for starting the procedure was: *What are the main data related obstacles preventing the NPD process from being effective?* The answer gotten is: *The resource planning does not correspond to the project planning and to the process management, this leads as a result to having difficulties in reaching the organisational demands in the meetings structure.* In order to explain the result is important to look at the statements evaluated as the most critical during the session. The group of issues related to the **Resource planning** is the one with the highest rating: it refers not only to the physical resources available for every project, but mainly to the human resources needed for developing a product with the right characteristics. The focus was put towards the design department which, according to the participants, should spend more time on Virtual Product Development in order to get the most out of it before the prototypes realisation. The second highest rated group of issues is the one titled **Meeting structure**: the problems highlighted are the lack of face to face meetings during the New Product Development Process, the lack of cross-functional work during the daily operations and the need to having all different roles involved in the process joining the meetings. The location of the designer in a different factory is seen as a limitation for the cross-functional communication. The **Project planning** resulted to be another point of interest: the scope of the projects is often too broad, there is a lack of focus on specific aspects of the product to be updated and improved. This, with the time limitations, leads to a problem of priorities' definition when the process is on-going. An interest theme that did not come up during the interviews is the **lack of procedures** in the company. To be more specific, not everyone in the company is aware of the existence of the working procedures and those who are most of the time do not follow them. This is a problem when people are involved in different projects that follow different development strategies and require different way of working. The company procedures exist, they are just not official and explicitly defined and formalised. Routines come up in a specific context as an effective way to do the job, but the performance is strongly connected to the context, which means that if a person involved in the routine development changes position, all the sequence of activity will be affected and, therefore every person involved will have to adapt the way he or she does his or her part of the routine. This leads to continuous little changes of the process that, obviously, are causes of variation in the process performances. The process definition has to be based on the natural existing routines, both when dealing with the production process and when dealing with the information flow: the useful synergies already in place should be exploited and the important one that are not yet in place should be encouraged.

What are the main data related obstacles preventing the NPD process from being effective?



The resource planning does not correspond to the project planning and to the process management, this leads as a result to having difficulties in reaching the organisational demands in the meetings structure.

Figure 7 - Affinity and Interrelationship Method results

Parameter analysis: the communication flow considered as a noise factor

From the information gathered it is possible to understand what are the **causes of variation** in the New product development process. In order to do that, a Parameter diagram (Bergman & Klefsjö, 2010) has been used. The **system** under analysis is the process itself, the **inputs** of the process are the customer demands and the drawing the designer develop based on that information (in Figure 8, a schematic overview of the information system is presented). The **output** is the new product release. The system is affected by other inputs other than the ones stated before: first of all, there are Control factors that can be adjusted in order to determine the quality level of the output; in addiction to them, there are Noise factors, that are not controllable or, at least, not controlled, but contribute to the results anyway. The parameters set by the Company, or the Designer, or the Production engineers are considered **Control factors**: company standards, critical requirements, materials, robot programs, procedures… these parameters contribute to variation, but it is possible to change them in order to reduce it. The parameters that are not controlled, or not controllable, are considered **Noise factors**: environmental condition, human behaviour, information flow… as stated before, it is not possible to act on them to reduce the variation. The interesting point of the analysis, is that the Noise factors are not only uncontrollable, but also uncontrolled: in other words, all the parameters that the Company does not consider, or does not care about, when dealing with the variation are included into the Noise factors. Therefore, if a Noise factor can be **turned into** a Control factor, the control over the system increases and the uncontrolled contribution to the variation decreases. The Noise factors of interested in this thesis are the one related to the **information flow**. Not having a standardised way to communicate between different department makes it hard to gather the information needed when it is needed. This causes variation in the New Product Development Process since the decision making process is not based on solid data. Furthermore, the lack of communication regulation makes it hard to spread the knowledge between the departments, as a result, people in the same department do not have the same information and do not ask for the same data. This causes variation in the New Product Development Process since the decision making process of different person with the same role is based on different data.

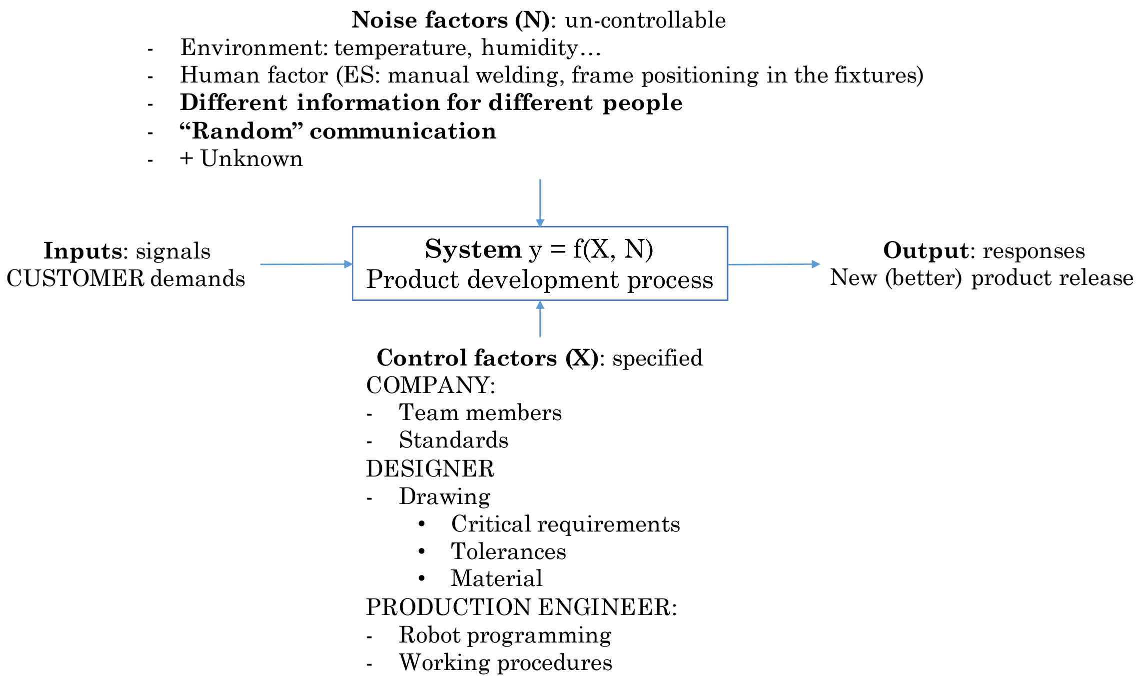


Figure 8 - Simplified Parameter diagram representing the New Product Development Process noise and control factors

Resistance and draw backs

The thesis is based on real information coming from a real company, therefore the author had to **interact** with the people involved in the analysis on different levels even though she was not located directly in, or even close to, the company. Interviews have been made both face to face and using Skype, the company's sites have been visited and, to gather unbiased information, the author participated as a pure **spectator** to some relevant meetings in which the roles of interest were interacting between themselves. Despite of the presence of the author in the company and the close interactions between the author and the employees, some difficulties have arisen during the qualitative data gathering. The thesis purpose is to introduce a new standardised way to share relevant information in order to make the employees' work life easier and their decision making process faster and more reliable. This requires a **change** in the employees' perspective: the as-is attitude is reactive and short-term focused, the attitude expected after the introduction of the new procedures is the exact opposite, proactive and long-term focused. People involved in the process can easily predict the change that will affect their way of working and this have a different effect on different people: it leads someone to sustain the research and someone else to resist it.

It was hard to schedule a meeting with some of the employee and during the meetings some questions were circumvented or the answers were not exactly pertinent to the questions asked. The reasons behind this behaviour are various and different: **habit**, lack of **time**, lack of **knowledge**, lack of **interest**, no **awareness** of the potential gains from the project. First of all, resistance is related to habit: if official procedures are not strictly followed it means that employee are free to do their job in the way most suitable for them, as long as this way is coherent to the company profit. If the company comes up with a new procedure and requires manager to follow it, and make their employees follow it as well, this **freedom** is no longer available and the working way is no longer the most suitable for the single individual but the most effective from a company point of view. Employee were required to dedicate some of their **working time** to the author to help her get the information needed for developing the analysis; moreover, the information asked was related to the way the employee was conducting his job, not to the job itself: since there are no procedure regulating the information sharing in the company, it was the **personal behaviour** of the employee to be explored. Their time was dedicated to perform an activity that is challenging on a personal level for every interviewee and is not a habitual job activity for anyone in the company and as a Design manager said to the author during an interview "*Time is the only thing that we do not have here".* The resources in the company are limited and the workload is huge for everyone, therefore dedicating time and attention to the author's research was not the **priority** of the employee, especially when they did not see how the thesis project could have save their time and made their job activities easier: once again the focus on the short-time negative effects, sabotage the long-time positive ones. The priority of the managers is keeping the daily production on target, standardised procedures does not have the purpose to improve daily operation performances but to keep it stably on target in the longer run. It is important to remember that the company under analysis is a major international firm, its market position is good and there are no urgent reasons to be worry for its future; therefore, the motivation for invest the time in these issues is not easy to get, especially because the positive effect of regulating the information flow are not to be seen in the immediate future, but on a long time basis. The same attitude was not detected when **numerical data** were asked: since in that case the process was being evaluated, not the person executing it, there was no personal pressure on the employee and it was easier to get to the information requested.

Different type of knowledge is shared differently

The **causal knowledge** is not really pursued in the process studied. Most of the time looking into the real causes of the defects requires too much time, therefore the focus is on solving the effect as soon as possible, instead of on finding the root causes of it and eliminate it. It is also hard to share this kind of knowledge in the current situation, as it is not based on quantitative data but mainly on the experts' opinion: experienced employees have a deep knowledge of the processes and of the different way the same requirement can be achieved, so they can predict what are the results of taking a choice instead of another; but, their predictions are not based on facts, therefore sharing them is a risk and not everyone is ready to take that risk.

Enhancing the **procedural knowledge** is the aim of this thesis: regulate the data sharing and make people get the right information is crucial to choose the most effective solution and will facilitate the **positional knowledge** expansion. Employees do not know how to navigate the software where procedures, processes, work description and information about the company are stored; therefore, they do not know which roles have which information, who can give them the right insight about what happens in the company. There is a general lack of awareness about who to ask what to and this slows down the **factual knowledge** spreading: even if there are a lot of data in the company and the processes are measured and evaluated, the information is not shared between the right roles, or is not shared at all outside the department responsible for the measurements.

Define phase summary

Two main entities strongly related one with the other interact in the first stage of the New Product Development Process: the first one is related with the **input** that the Design department gives to the production site, the other is the one related with the **feedback** that the Design department receives from the production site.

It is clear how the **Design department** is the centre of the unclosed loop: the information goes out as a drawing, but does not come in as a useful data analysis. This means that the drawings have to be updated and improved several times before reaching an acceptable feasibility level: the tolerances have to be updated, the fixtures setting has to be revised and the coordinates of the control points have to be adjusted. A **cross-functional** effort is required in order to update the drawing in a way that makes the product easier to produce and closer to the customer requirements. Otherwise, the designer needs to spend a lot of time looking into the product requirements achieved following the currently used drawing to make the changes in a conscious way. What the designer needs to know to **close the gap** between the drawing specification and what is actually achieved in the plant is, simply, what happens on the production site. What **should be** shared is a representation of the performances of the product as it is, but what **is** shared is a measuring protocol with a list of requirements achieved or not achieved for every frame produced.

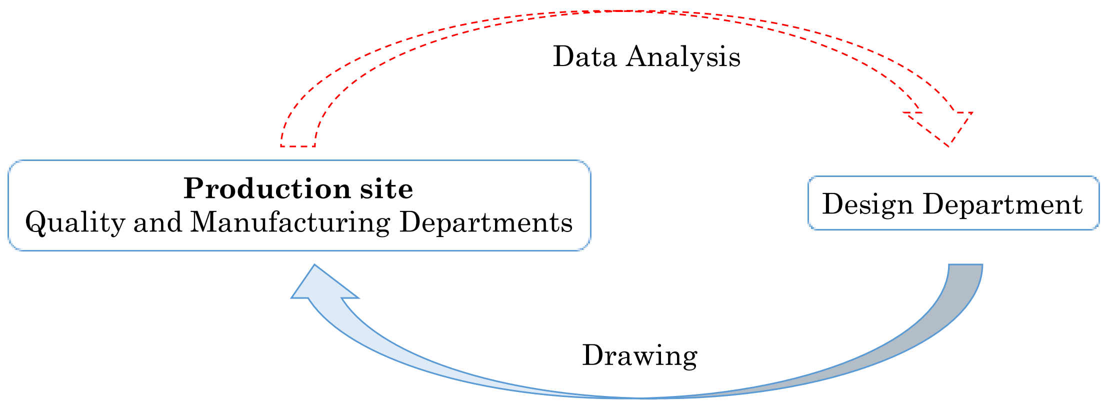


Figure 9 - Summarised view of the Communication flow between the departments of interest

An **Effective Scoping Method** analysis has been developed on both sides in order to have a structured view of the processes. On the input side there is the **drawing**: it incorporates all the information needed on the production site in order to produce and control a frame which corresponds to the customer demands.

The designer decides the **tolerance limits** and the points where to check them, taking into consideration the interactions between different plates during the production process and, in particular, during the assembly phase. The tolerance limits on the drawing must be **achievable** on the plant and the checking points must be **attainable** by the quality auditors. In order to decide what tolerance limits to put on the drawing, the designer needs to consider different parameters, based both on the company and on the feasibility perspective. It is important to accomplish the customer requirements in a way that is achievable from a manufacturing point of view and that respects the company's criteria: it is important to rely on the on the historical data without forgetting about the internal standards. Once the importance of the drawing is explained, the focus can shift from the output to the input: the **data analysis**.

In order to develop a product which is performing at a high level, designers need to have a clear picture of how the product is performing in the current state, therefore historical data are the starting point for the new drawings. Those data need to be easily understood and retrieve, the designer should not need to ask for them and the auditors should not need to explain the meaning of the information included in the reports shared: a **self- propelling** visualisation tool is what is needed to close the loop in the most efficient way.

The level of detail of the tool should be carefully calibrated: the focus, at this point of the project, is not on giving to the Company the most accurate and updated visualisation tool, it is instead on giving it the most suitable for sharing the correct information in an easy and fast way.

Table 2 - Problem definition with the drawing-as-output view developed using the Effective Scoping Method

Process = feedback loop: Design, Manufacturing, Quality						
Supplier	**Input**		**Process**	**Output**		**Customer**
8b. Who supplies the inputs?	*8a. What are the inputs to the system?*	*9. What does the system require of the inputs?*	*7a. Team/project jurisdiction of changes*	*1. What comes out of the flow: OUTPUT*	*3. What is require of the output from this particular user?*	*2. WHO uses the output?*
• Company	• Internal standards, drawing standards	No numerical measurements since the system under analysis is a feedback loop which is based on information sharing and not on numerical	Design department, Quality department, Manufacturing department	**Drawing**	Reasonable tolerances	**Manufacturing and Quality departments**
• Weld manufacturer	• Factory production specifications	The system, though, requires the processes' evaluation measurements to be shared and distributed.	*7b. What competencies needed in the team (WHO)?*		*4. What measure (y) should be understood and improved?*	
• Product manager	• Product specifications		**Designer** : deep personal interest to push the change (time saving, easier way to work, less focus on the everyday plant-		Tolerances need to be informative and precise, which means:	
• Laboratory engineer, calculation engineer	• Test results calculation results		**Quality engineer** : data analysis and visualization competencies with the interest on being able to share information without losing too much		• Achievable by manufacturing → **y: process performances** Accomplished if the process behaviour improves.	
			Manufacturing engineer: data measurement and process changes competencies. The change of behaviour should happen as a consequence of the new procedures (apply what other departments say and		• Measurable by quality → **y: measurements data** Accomplished if the quality control process is more focused and therefor faster.	
			The physical flow of things to be improved can be named:		**Other y: defects; design lead time; control lead time**	
			Information distribution		*5. What is the baseline of the y and can that precisely be measured today (and*	
			6. From where is the physical output shipped?		Reliable **data** about the process behaviour are being collected and analysed by the quality department, but not shared on daily base with other departments.	
			Design department		There are **visualization problems** when sharing: to be understandable for everyone the data need to be presented in a simple enough way, otherwise the department providing the analysis has to spend a lot of time preparing reports with detailed written explanations of the results' meaning.	
					The visualization tool chosen needs to be of immediate understanding for the receiver (designer) so that the giver (quality engineer) does not have to spend too much time in further explanations: **self-propelling visualization tools.**	
					7. What other Y cannot be lost in the process (constraints).	
					Do not get lost in the data and lose the reason why visualization needs to	
					• Shift towards Long term focus	
					• Shift towards a more Proactive attitude	
					• Shift action focus on root causes, not	

Table 3 - Problem definition with the data analysis-as-output view developed using the Effective Scoping Method

Process = feedback loop: Design, Manufacturing, Quality						
Supplier	**Input**		**Process**	**Output**		**Customer**
8b. Who supplies the inputs?	*8a. What are the inputs to the system?*	*9. What does the system require of the inputs?*	*7a. Team/project jurisdiction of changes*	*1. What comes out of the flow: OUTPUT*	*3. What is require of the output from this particular user?*	*2. WHO uses the output?*
• Company	• Internal standards, drawing standards	No numerical measurements since the system under analysis is a feedback loop which is based on information sharing and not on numerical measurements.	Design department, Quality department, Manufacturing department	**Data analysis – report**	Easy to read data analysis reports with the information useful to set reasonable tolerances (critical requirements and parts to be redesigned)	**Designer**
• Weld manufacturer	• Factory production specifications	The system, though, requires the processes' evaluation measurements to be shared and distributed.	*7b. What competencies needed in the team (WHO)?*		*4. What measure (y) should be understood and improved?*	
• Product manager	• Product specifications		**Designer**: deep personal interest to push the change (time saving, easier way to work, less focus on the everyday plant-production problems)		The communication flow and the interactions between different departments need to be understood in order to assess what knowledge designers need to have.	
• Laboratory engineer, calculation engineer	• Test results calculation results		**Quality engineer**: data analysis and visualization competencies with the interest on being able to share information without losing too much time on reports		Different data and information shared are examples of **ys: process performances, process variation, critical requirements**..	
			Manufacturingengineer: data measurement and process changes competencies. The change of behaviour should happen as a consequence of the new procedures (apply what other departments say and change attitude)		**Other y: defects; design lead time; control lead time**	
			The physical flow of things to be improved can be named:		*5. What is the baseline of the y and can that precisely be measured today (and can old data be trusted)?*	
			Information distribution		Reliable **data** about the process behaviour are being collected and analysed by the quality department, but not shared on daily base with other departments.	
			6. From where is the physical output shipped?		There are **visualization problems** when sharing: to be understandable for everyone the data need to be presented in a simple enough way, otherwise the department providing the analysis has to spend a lot of time preparing reports with detailed written explanations of the results' meaning.	
			Quality Department - Calculation		The visualization tool chosen needs to be of immediate understanding for the receiver (designer) so that the giver (quality engineer) does not have to spend too much time in further explanations: **self-propelling visualization tools.**	
					7. What other Y cannot be lost in the process (constraints).	
					Do not get lost in the data and lose the reason why visualization needs to be improved:	
					• Shift towards Long term focus	
					• Shift towards a more Proactive attitude	
					• Shift action focus on root causes, not firefighting	

MEASURE

Data collection: different graphs presentation

During the Measure phase **opinions about different visualisation tools** have been acquired using both Skype meetings and face to face interviews and presentations.

The graphs used for the analysis were made using the data about the frame under investigation during the Design review the author took part in.

The first aim of the data collection and analysis was to understand how to design the fixtures in order to decrease the bending level in the x-direction of the rear frame after welding. The bending is measured using the deviation from the target of the z-direction on a number of frames after each process change.

The performances of five different process layouts have been measured to develop the analysis:

- Process layout **0**: Starting point, first detection of the deviation level;
- Process layout **Changed frame side**: Adjustments to the welding fixtures;
- Process layout **Changed final fixture**: Adjustments to the final fixtures;
- Process layout **B-build**: Prototypes after updating the design of some product parts;
- Process layout **P-build**: Prototypes after updating the design of other product parts;
- Process layout **A-build**: New design for eleven parts of the product.

The author tried different way of visualising the outcome of the process remembering that the final goal is to find a tool which is easily and immediately understandable, even without detailed verbal explanations.

The different possibilities have been shown to different people in the Company in order to understand **which information different graphs could give to the different roles** involved in the analysis and which graph could give more information to the different roles. The graphs have been shown during the second Design review to all the people involved: Designers, Production engineers, Geometrical assurance, Project Quality Manager, Welders and Tool designers.

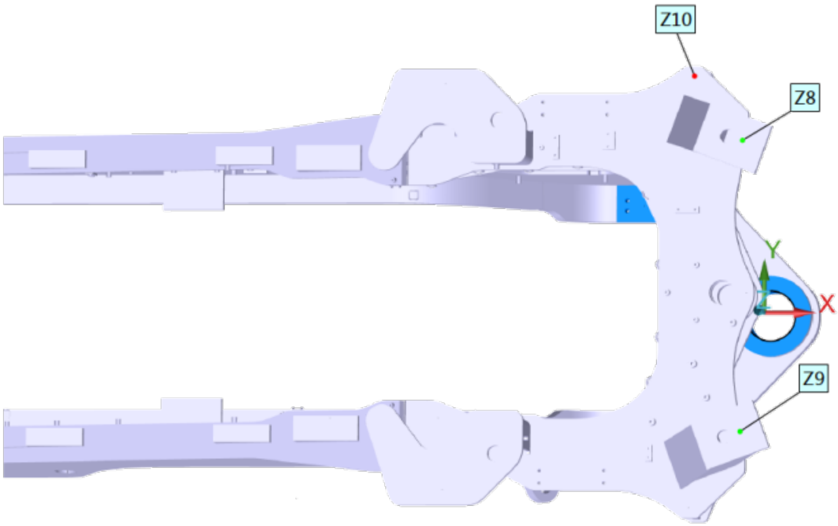
The author is now going to give a brief explanation of the currently used visualization tool; in the following chapter the author will describe the new graphs suggested with a particular focus on the discussion arose towards the people involved in the project while looking at those.

Currently used visualisation tool - Measuring protocol

The company is currently communicating the information about the product status using a measuring protocol. The document shows the checking points on a three-dimensions **picture of the frame** and it contains their **actual value measurements**. To show if the measurements correspond to the tolerances limits a bar with the dimension of the tolerance interval is used: if the measure is inside the limits a green line is represented in the bar respecting the proportions according to the actual value; if the measurements are out of tolerance, the line is red and it goes out of the tolerance interval on the left if the lower specification limit is not respected and on the right if the upper specification limit is not respected.

This visualisation is not immediate, it requires a lot of time to understand the current situation and it does not give information about the history of the measurements and, therefore, it does not allow to find patterns in the behaviour. Moreover, the visualisation is very **product oriented**, it does not use mean values, but actual values of one specific product. The Production engineers need to look deeply into more than just one measuring protocol in order to have a picture of the process and the Designers need to do the same in order to have a picture of the product behaviour.

The discussion on this visualisation is focused on **solving the product issues** with a fire-fighting approach aiming to turn the red measurements into green ones, but it does not cover topics as the reasons why the red measurements are red, or as how the process can be improved in order to avoid having red measurements at all strengthening the watermelon effect.



	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 10 - Currently used tool: The measuring protocol

Chapter 5

Analysis

The graphs were used as **conversation drivers**: the purpose of showing them was analysing how a visualisation tool could trigger the conversation towards different topics and change the point of view of the users. In order to propose a standardised information flow, it was important to understand what information was needed from every role involved at every step of the process, therefore a **pull approach** has been used. Once it was clear which graph was the most suitable in every phase for every role, proposing a **specific** Data analysis report to use in the different stages of the Concept loop for the different roles involved was an immediate consequence. The choice was not only based on the users' demands, but also on the results of the discussion analysis. It was important to suggest visualisation tools that could be useful on a **broader level**, e.g. enhancing the cross-functionality and encouraging a proactive approach and a process focused attitude.

ANALYSE

Different analysis point of view: graph by graph

Different visualisation tools give different information to the user. At the same time, different users look for different information in the same visualisation tool. This means that the same image can have a different meaning based on the role looking at it. The following analysis has the goal of understanding how different visualisation tools affect the company **behaviour**; how the **decision making process** changes based on the different graphs meaning; what is the impact on the **information gathering process** of different data analysis. The author proposed six different graphs and analysed the inputs they gave to the cross-functional discussion with the aim to find out which one is more useful and informative in which phase and for what specific role. While the currently used measurement protocol only allows a diachronic analysis on the frame, the graphs proposed combine both a diachronic and a synchronic point of view.

Looking for patterns in the IDs: values in time – Graph A

The first visualisation tool proposed is an evolution of the measuring protocol: the focus is on the single IDs, but it is possible to visualise the **evolution** of the measurements on a timeline.

The representation resembles a **Control Chart**: the limits on the graph are not the control limits, but the specification limits and the measurement values are plotted based on the process' series, which are used as a proxy of the time sequence. The x-axis represents the time while on the y-axis there are the values of the measurements, the specification limits are represented by the green lines. The dots represent the mean value of the ID measurements in the frames belonging to the same series, the blue line connects the dots in order to see if there is a **trend in the ID measurements** evolution in time.

This view does not allow to have information about the process capability for every point checked, since the control limits and the process stability are not the focus of the analysis: different series correspond to different process settings, therefore in the same graph it is possible to visualise the evolution of the ID measurements in time and in different process changes according to the tolerance limits.

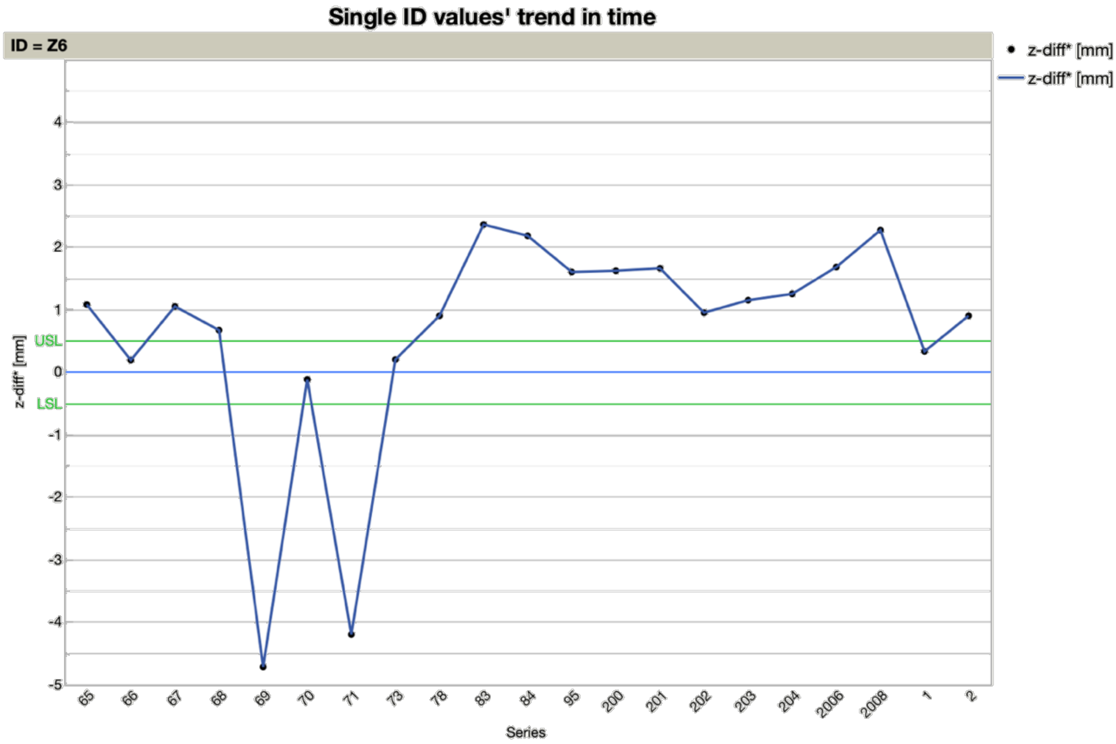


Figure 11 - Graph A

The problem with this kind of visualisation is that it still is time consuming: in order to have a complete view of the product it is required to look at more than fifty graphs, one for every point checked. **Production engineers** look for patterns in the IDs measurements, they want to know the process behaviour and its stability, therefore it is important for them to visualise the evolution of the variation level in time. Anyway, with this tool, their focus remains on the **single IDs** and not on the product as a whole: the discussion they have is about fixing the issues for the critical IDs, but this prevents to have a broader view: the **fire-fighting** approach is not weakened. The

Designers are, on the other hand, interested into the critical areas, they want to know which parts of the frame do not correspond to the requirements and they want to do it fast. This kind of visualisation is, therefore, not helpful for a Designer: he/she would have to look into all the IDs graphs in detail to see where the issues lay and he/she would find it very difficult to gain a complete picture of the frame status and of the correlations between different IDs.

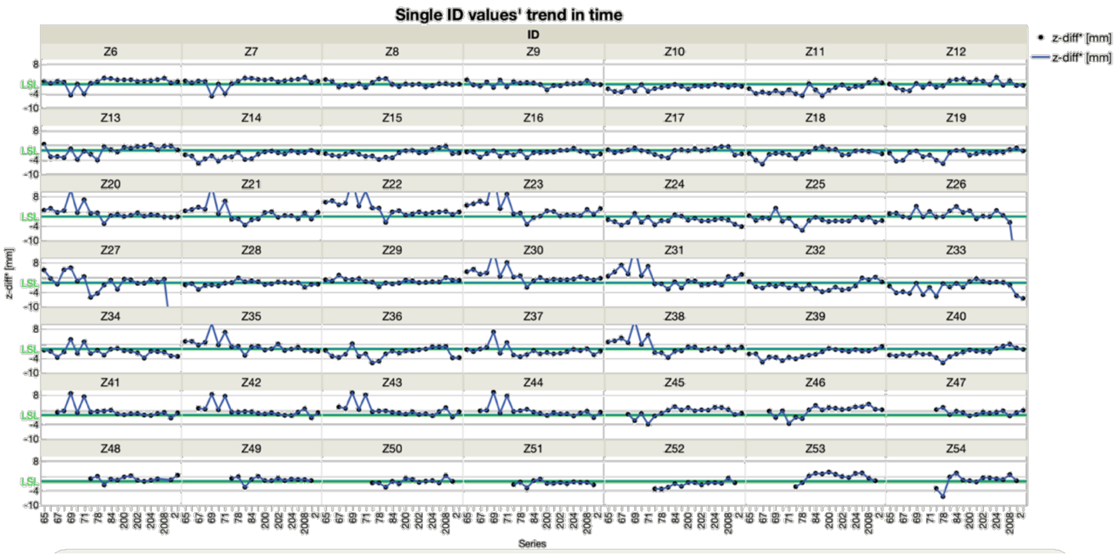


Figure 12 - Graph A extended

Looking for the critical IDs: Mean Bars and Measurement points organised by front to rear position on the frame – Graph B

The second graph presented put together **all the IDs on the different frames**, categorising them based on the position on the frame itself from the **front (1) to the rear (5)**. As in the previous view, the specification limits are represented by the green lines, the bars represent the mean value for the ID measurements on the different frames checked and the dots correspond to the single values.

This view allows to get an impression of the **frame as a whole** and to know where the different IDs are located on it, but it is not of immediate understanding: the IDs variation measurements vary a lot and to get an overview it is required to go through every measure. The added value, though, is that it is possible to visualise both the mean variation and the single measurements on the same graph so that the user can be aware of the significance level of the mean values.

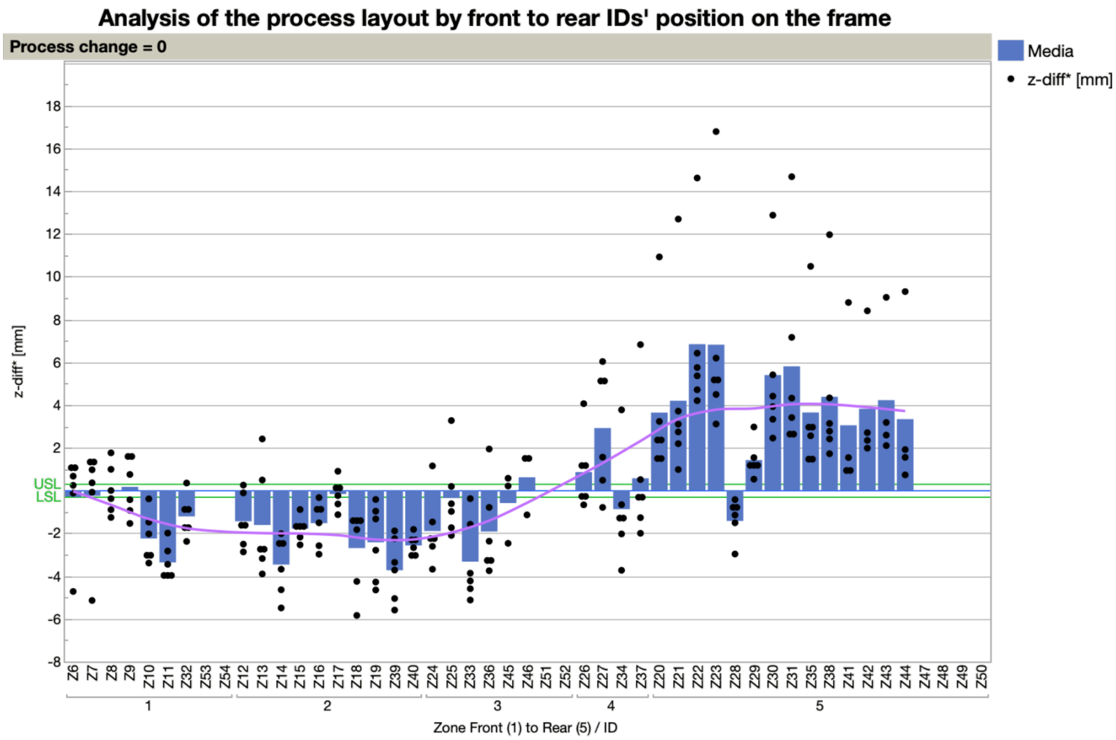


Figure 13 - Graph B

The view is useful for both the **Designers** and the **Production engineers**: it is clear which IDs are **critical** and it is possible to understand if the **mean value** is meaningful or not. The bars give an approximation of the IDs value, but the fact that the points are on the graph is an insurance: it is possible to check if the mean value is a result of measurements that are very distant from one another, or if the values are close to one another and around the mean value. For the Designers a further step is required in order to take action: they still need to check where the IDs are located on the **drawing** to see if there are correlations between the not-compliant checking points. For both the Designers and the Production Engineers it is not easy to imagine the situation on the product as a whole or to find possible causes for the deviations, not even the effects of it are clear on a broader view: it is only possible to understand that some IDs are not capable, but further analysis is needed to look deeper into the reasons behind it and into the consequences of that. It is possible, though, to visualise the product behaviour and how it changes in time. This view is also divided into different process changes, so it can be used to compare different process layouts and visualise the critical IDs for every process version.

When discussing about this graphs, Production engineers are focused on the product areas, the single IDs are not of interest anymore: the discussion was about the frame shape, in this case a **banana shaped function** was recognised.

The **Designers** are more interested into the differences from one Process change to the other, they look at the product as a whole and at what changes had a positive impact on the variation levels.

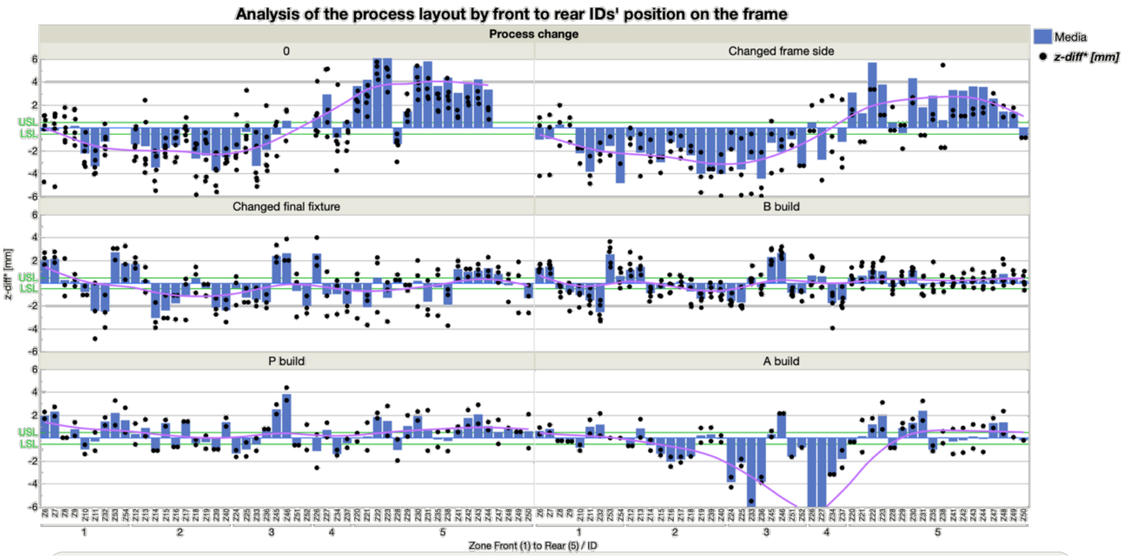


Figure 14 - Graph B extended

Looking for asymmetries: Mean Bars and Measurement points organised by left to right position on the frame – Graph C

The third graph was an update of the second one, instead of organising the variation by position Front to Rear on the frame, the author organised it based on the position **Left to Right**: this different categorisation allows to look for the **asymmetries** in the frame, since the frame sides are fabricated in twin mirrored flows, with the same specification but with different physical equipment. As in the previous view, the specification limits are represented by the green lines, the bars represent the mean value for the ID measurements on the different frames checked and the dots correspond to the single measures.

This graph gives, again, a picture of the **whole frame** and of the **location** of the different IDs on it, looking at the bars it is easy to see if one side is different from the other. The drawback of the view is that the user needs to know the frame to know where the IDs are located on it.

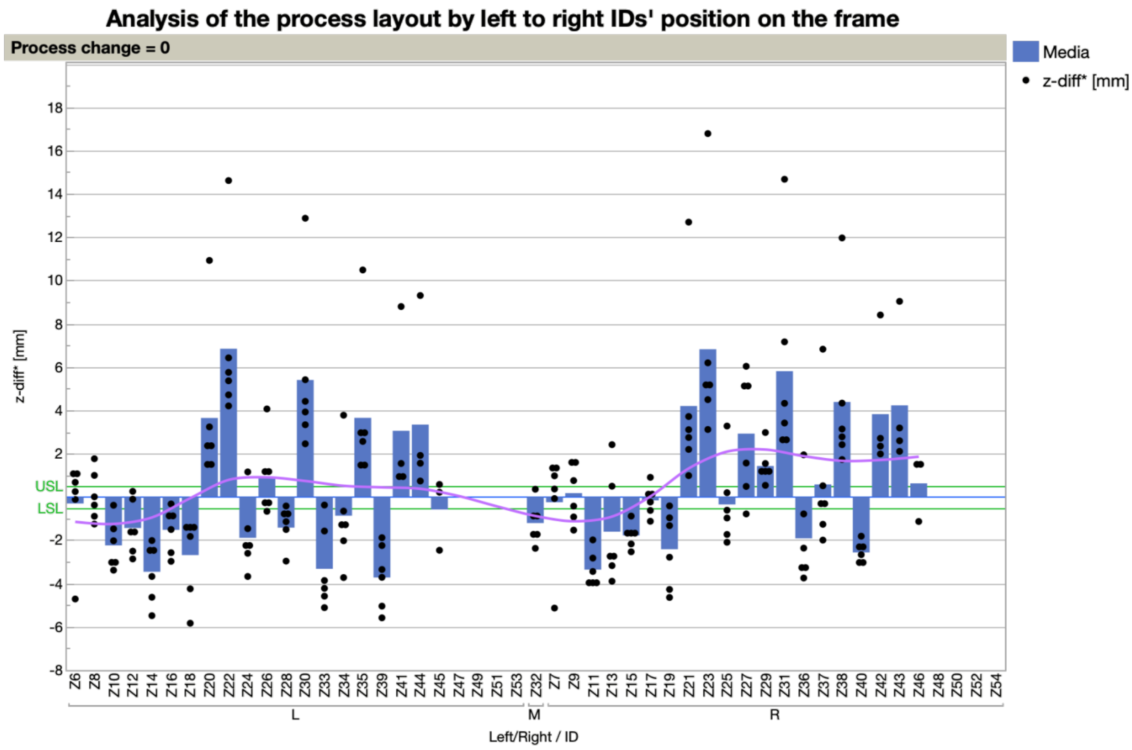


Figure 15 - Graph C

This view is of particular interest for the **Geometrical assurance** since it allows to see if the frame **sides** are significantly different, which is a key feature of the frame since it has to be assembled with other parts. When the sides are different the machining and the assembling phase become longer and more complex. This is an important information, for example, to understand how the **welding order** affects the frame variation, or to check if the **positioning** of the frame in the fixtures is correct, therefore it is an important view for both the **Production engineers** and the **Tool designers** too. It is not possible to look for trends in the variation spread on the frame, but it is possible to visualise trends in the sides behaviour: in other words, it is possible to see if a side faces always positive or always negative variation. It is also possible to compare the material level on the different sides and to check if the variation of both follows the same direction: in other words, whether the sides are **symmetric** or not.

As the previous one, this view is divided into different process changes, so it can be used to compare different process layouts and visualise the asymmetries for every process version. Comparing different Process changes it is possible to go back in time to see the effects of the alterations between one version and the others which is interesting for all the roles involved in the Product development process.

The focus of the discussion was the product as a whole: a broader view on the status of the frame was adopted. Looking at the asymmetries, the point of view shifted from product to **process oriented**: the questions that were discussed are about **why** one side is different to the other and about **how** this variation can be controlled and reduced acting on the welding order, on the process and on the tools currently used.

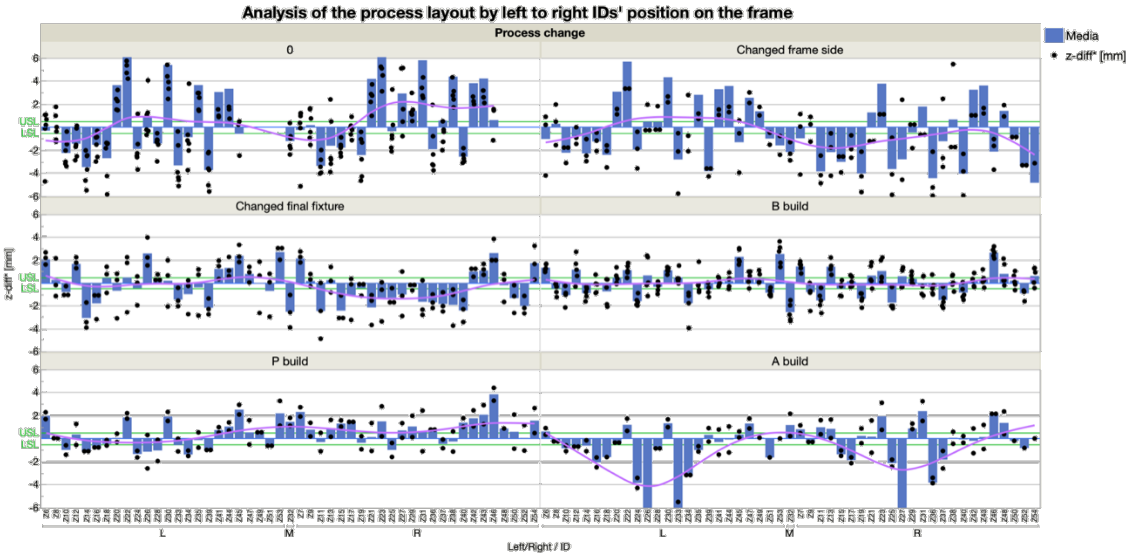


Figure 16 - Graph C extended

Looking for patterns in the measurements distribution on the product: checking points organised by both position on the frame and side – Graph D

The fourth view is a summary of the two previous ones: it allows to visualise the frame from both the **sides** and the **zones** points of view. Different colours represent the different sides: green on the right and blue on the left side. It is possible to see both the checking points variation level in the different zones of the frame and an approximation of the **trend** in the material variation distribution on the frame. This view allows to see if there are **asymmetries** between the different sides and, at the same time, how the lack or excesses of material are dislocated on the frame zones. It does not allow to find patterns in the IDs variation, but it gives an overall view on the **product** and it is a good summary of the previous two graphs. It requires, anyway, a verbal description with a detailed explanation of the meaning of the graph's components in order to be fully understood by the receiver.

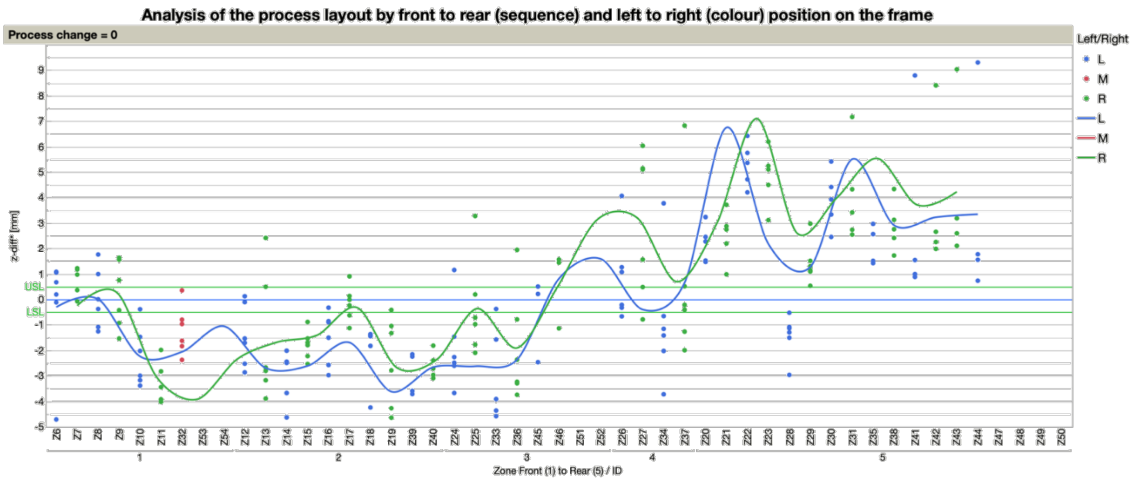


Figure 17 - Graph D

The graph allows to visualise both the checking points **position** on the frame and the different **sides** on the same image: this makes it easier to see the asymmetries just by looking at the lines trend. Comparing the overlapping curves, it is possible to see if the sides evolve in the same direction or not: the more the curves overlap, the more symmetric the sides are. The information given is the same of the previous two graphs, but in an easier way. It can also be used to compare the different process versions to see how the product have developed in time. The **Designers** and the **Geometrical assurance** can immediately visualise asymmetries and critical areas; the **Production engineers** can easily understand which Process change caused the deviations. It becomes harder to find the patterns, though, since a lot of information are enclosed in the same image, but this graph is perceived as a summary of all the previous ones.

As with the previous graph, the discussion is product oriented: the questions concern the frame status, the possible reasons behind the behaviour of the frame itself. There is no focus on the single ID, or on the single frame: the point of view changes from product to **process oriented**.

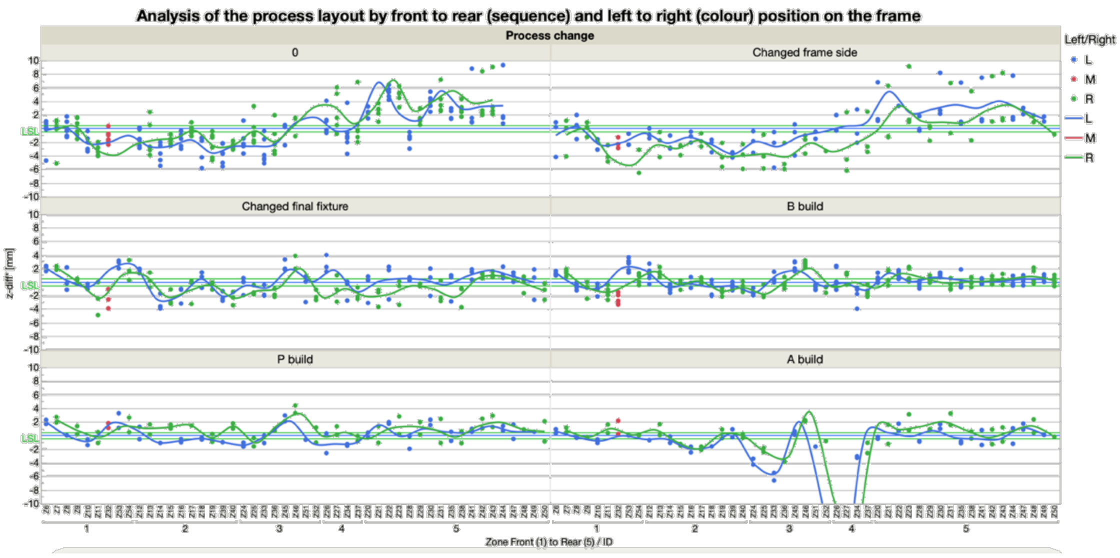


Figure 18 - Graph D extended

Looking for asymmetries and critical IDs: Contour plot – Graph E

The fifth graph is a **bird's eye two-dimension view** of the frame variation. The axes represent the coordinates of the checking points on the frame: from front on the left, to rear on the right; right side above and left side below. Different **colours** correspond to different variation levels: where the area is blue, the variation is negative, therefore the material available is the location of the ID-position is **below** nominal position defined by the drawing; where the area is red, instead, the position is **higher** in the z-direction than nominal, therefore the material available is too much; where the area is green, the variation is closed to zero and the ID-position is on **target** in the z-direction, therefore the material amount is close to the tolerance limits on the drawing. Same reasoning is applied to the dots' colour.

The dots' **dimension**, instead, represents the range of the measurements: the bigger the dot, the bigger the difference between the smallest and the biggest measurement. The black dots' dimension corresponds to the target interval of the different measurements, while the coloured dots' dimension corresponds to the actual interval. As an example: if the requirement is $10 \pm 5\,mm$ then the black dot's dimension will be proportionate to the interval of 10mm; if the actual measurements will range from 82mm to 112mm the coloured dot's dimension will be proportionate to the interval of 30mm.

This representation is easy to understand for the people involved in the production process, since they know the frame shape and they can visualise it under the coloured areas. It is harder for people not directly involved in the production process since the contour plot does not have the frame shape, therefore the role responsible for writing the report would have to explain what the graph represents with a verbal description.

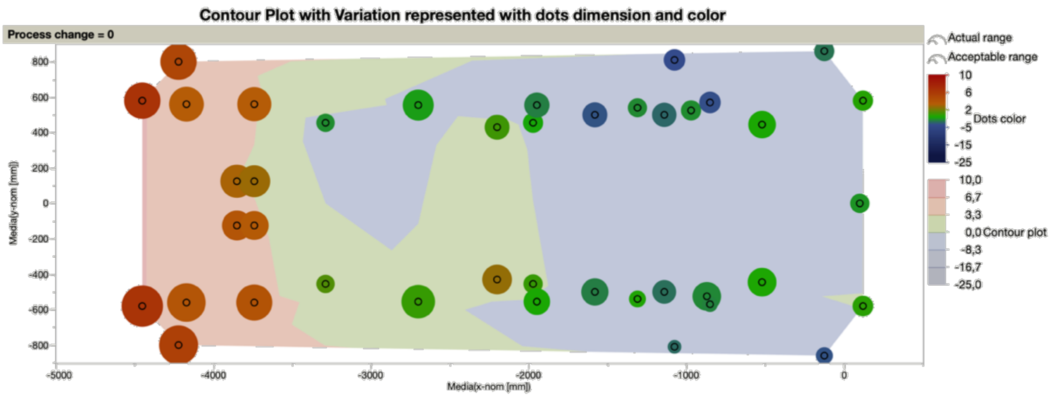


Figure 19 - Graph E

This graph is not only related to numbers and lines, but it is actually **visual**. It is not clear for everyone why the area is fully coloured and not only the frame shape is, this makes it confusing for Production engineers and Designers: the view is immediate only for people who know how to read it and what it means, therefore the report needs a **verbal explanation** of the graph meaning and of the results that the graph is showing. Once explained both the way a Contour plot works and the meaning of the colours, it is easy to visualise **significant colours shapes**: in this case, the **banana function** was easily recognised. It is also clear if the **sides** are behaving differently and which part of the frame is more critical: you see how the variation is distributed on the frame and how the material is spread with just a glance.

In this case, as in the previous ones, the discussion was **process oriented**: the focus was on the frame as a whole, but the issues that arose are related to process changes and tools adjustments that can improve the process behaviour and reduce the variation in the whole frame.

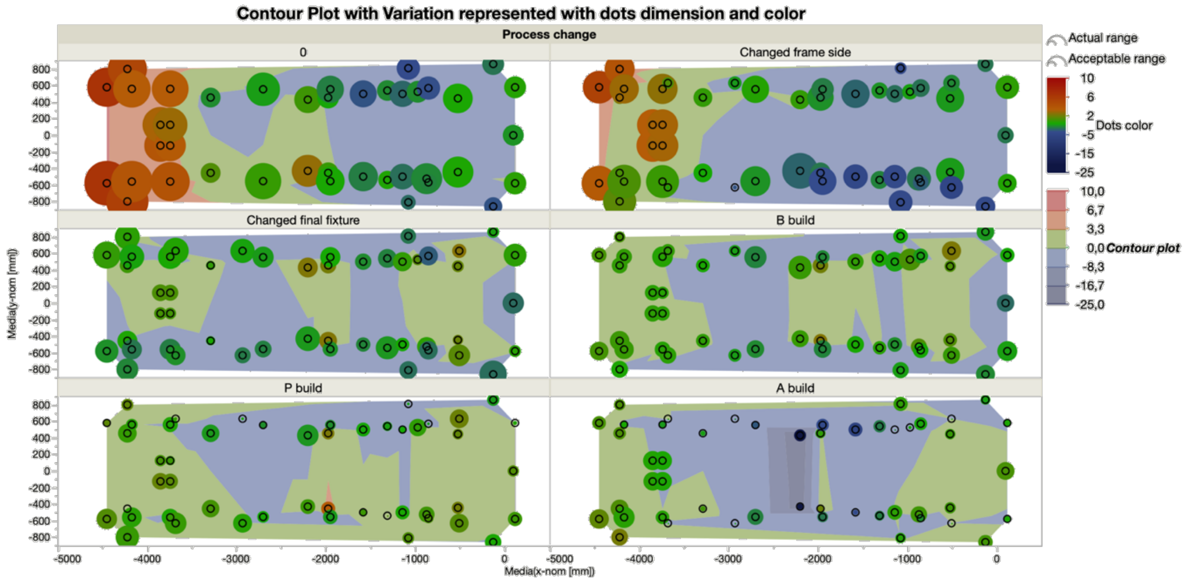


Figure 20 - Graph E extended

Looking for asymmetries and critical IDs: Shaped contour plot – Graph F

The sixth view is an update of the previous one: what does not make the first contour plot of immediate understanding is that it does not follow the **frame shape**, to solve this issue a different contour plot has been used. The coordinates and the colours have the same meaning as in the previous one: positioning on the frame and material amount. In this view the coloured areas representing the material amounts expand around their checking point, which is the centre of them, but where there are no checking points the area stays uncoloured. Different coloured areas overlap and draw the frame shape in a very easy to understand way, moreover the dots colour corresponds to the variation level, therefore it is easier to understand the material level for every point even if the coloured areas overlap. The dots dimension is related to the measurements range as in the previous graph.

This view gives a precise picture of the frame, but not every role in the New product development process can understand it, even if it follows the frame shape: a verbal explanation of the meaning of the graph's components is still needed.

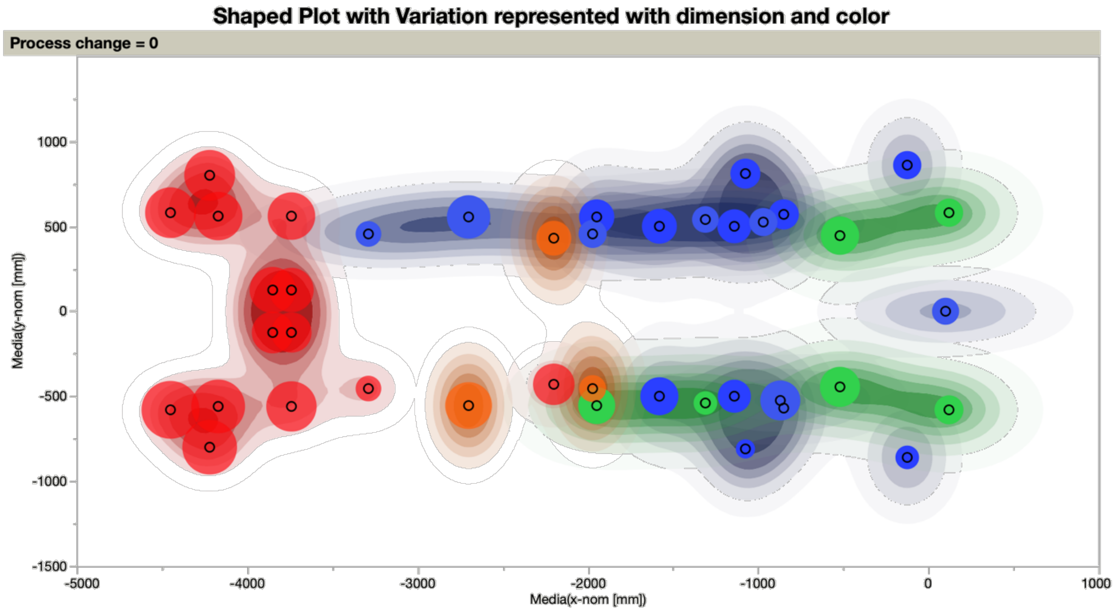


Figure 21 - Graph F

The frame shape is clear, the sides and the checking points position are easily recognised and the colours give an easy to grasp overview of the frame status. It is possible to visualise the **asymmetries** and the **correlations** between different parts of the product without the need of lines or bars. The understanding of the frame state is made easier by the fact that the dots colour corresponds to the variation level, which makes it easier to understand the material spread on the frame with a fast glance. It is also easy to compare different **process changes**, **welding orders** and **positioning** on the fixtures. It was directly understood that the varying dot size represents the variation at each location: the graph gives a clear idea about process capability and directs the discussion to a process point of view. The circles showing the **tolerance** at each location will be very useful in order to facilitate the communication between design, engineering and manufacturing about the process of tolerance setting, fixturing and what is a good enough tolerance. A comment from the Lead data analyst was "*It might be possible to handle a varying tolerance setting based in structural needs.*", the Project leader industrialization commented "*Very easy to see relative the tolerance where the frame is fixed and where it maybe should be fixed. […] This view* *will probably elevate the discussion between functions on how to upgrade the fixture and welding process, when it becomes so obvious how the variation and displacement of different measurement positions are connected. This graph combines both mean, variation and position in a nice way.".*

The view can be used both as an **in-process tool** and as a single frames overview. Even if the graph shows the mean values, it would be easy to compare different frames to see, for example, the variation in the same process change. This visualisation tool is useful for having an **overview**, both on a Designer and on a Production engineer point of view: it can be a starting point for directing the further analysis where it is needed.

The discussion when this graphs are shown is similar to the one about the previous ones: the focus is on the frame as a whole and on how the process should be adjusted in order to reduce the variation and the asymmetries.

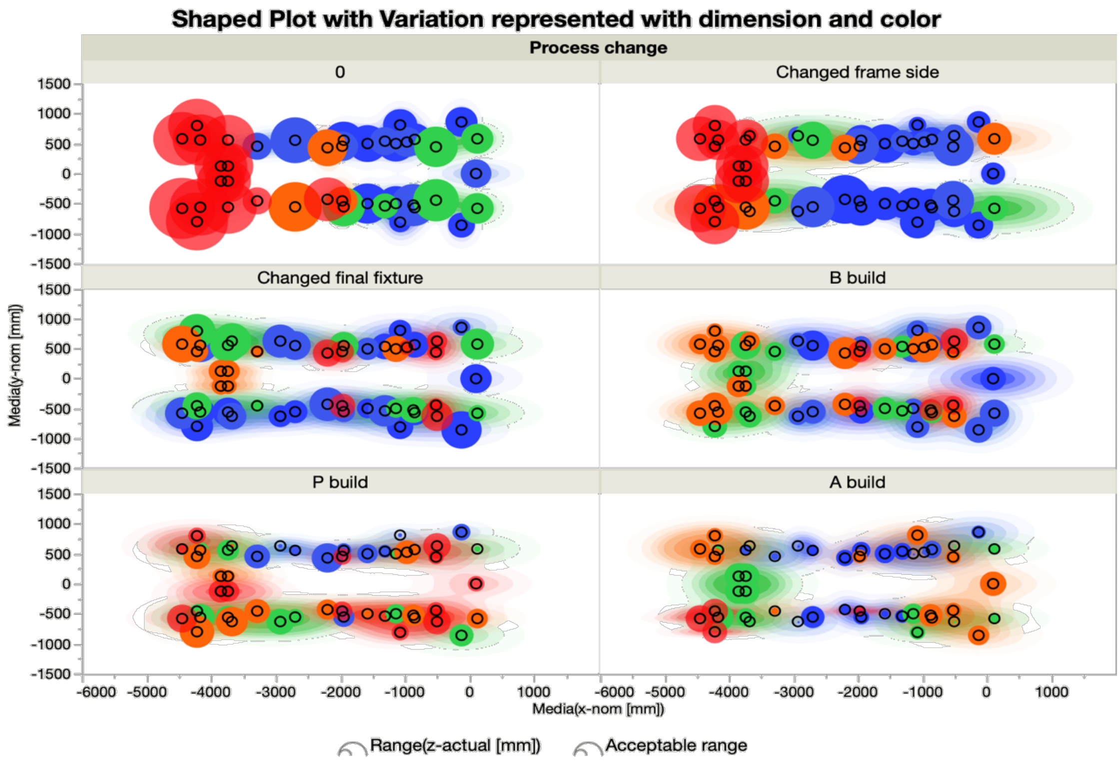


Figure 22 - Graph F extended

Looking for asymmetries and critical IDs in an immediate overview of the product: Overlapping the contour plot to the drawing – Graph G

To make the previous view even more easy to understand the author overlapped it to a two-dimension **model** of the real frame. The result is a virtual picture of the frame with the materials variation levels coloured directly on it. This image makes it possible to visualise the frame criticalities directly on the drawing itself, without the need of knowing how the frame looks like and what every checking point refers to.

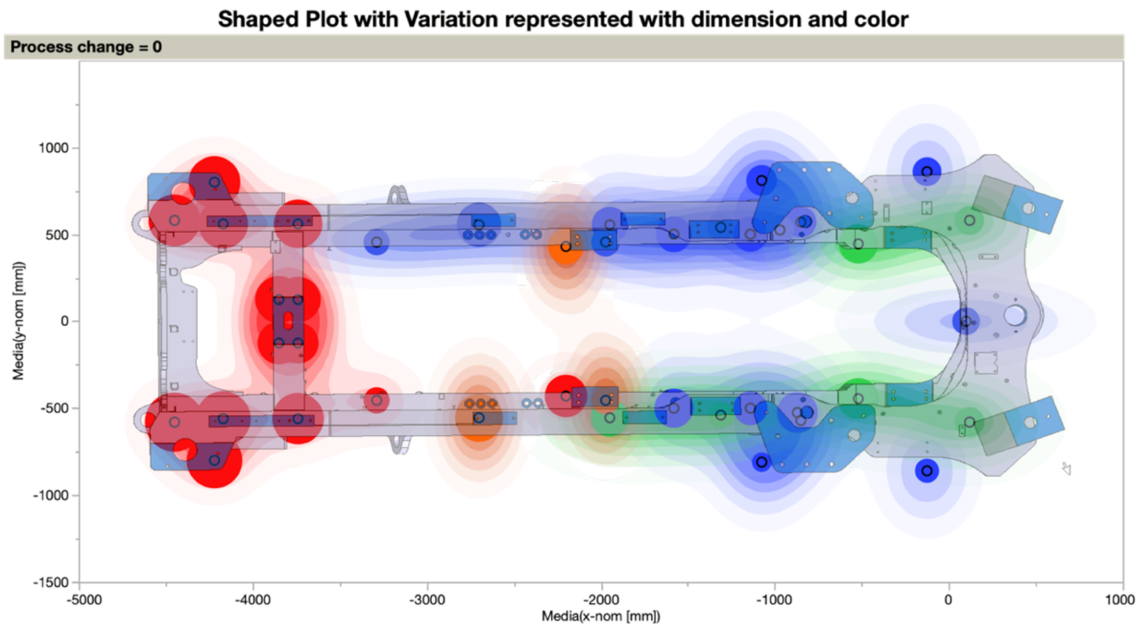


Figure 23 - Graph G

Adding the drawing of the frame to the Contour plot makes understanding it even more **immediate**. It is possible to see the frame itself with the colours and the points on it. For the **Production engineer**, even having only the coloured points on the frame would be useful, but having it coloured gives a more complete and easy to grasp view. If the legend is clear, there is **no need to explain** the meaning of the colours and of the points. The frame performance in the different Process changes is clear and it is also easy to compare them, even if you have to watch different images with the coloured points it is very fast to check the areas of interest. It is also a first step towards finding the **causes** for the changes in the variation levels, instead of focusing only on the effects of the Process changes on the frame: if things did not improve, or even did get worse, from the P build to the A build, it is possible to trace it back to what changes affected the frame parts that became red or blue and that were green before.

For a **Designer** this view saves a lot of time, in the same graph it is possible to visualise both the frame and the variation level in a way which gives the complete view of the frame's areas and of the correlations between them.

The discussion was, again, **process focused**.

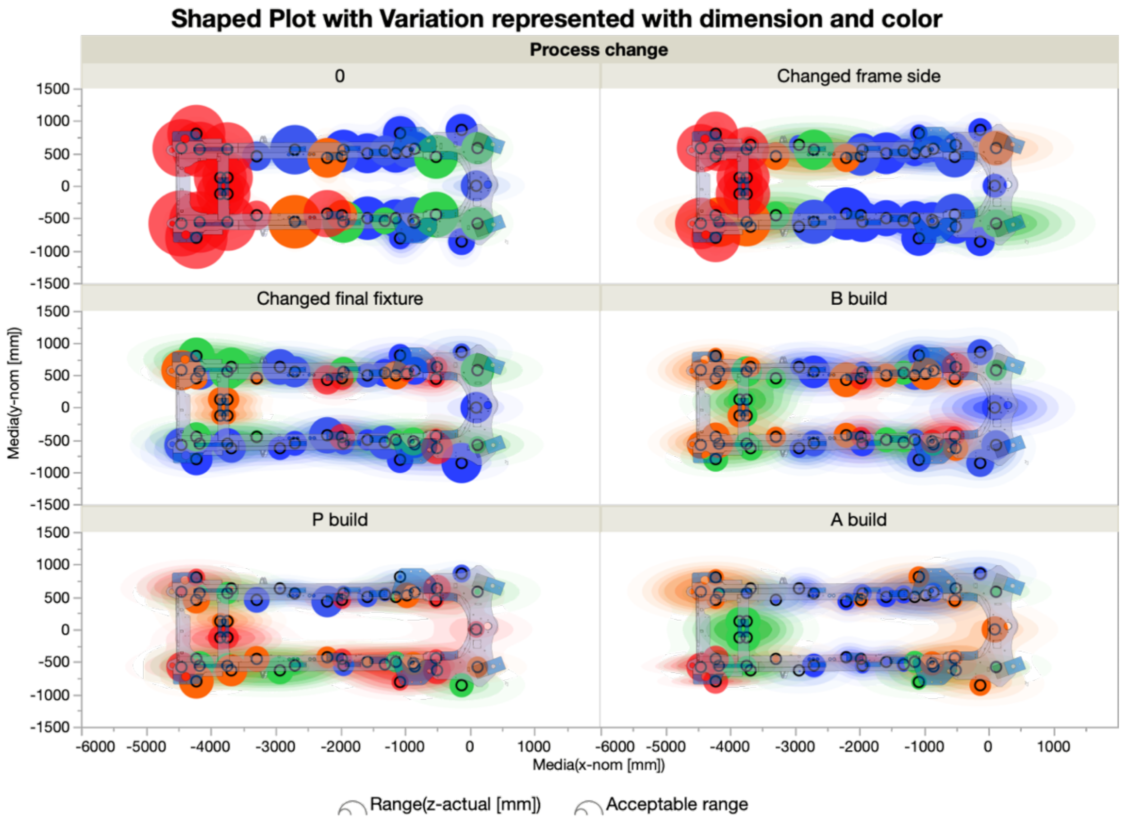


Figure 24 - Graph G extended

When is the Graph G view most informative?

It is important to specify that, even if what is plotted on the graph is the variation level, the picture is based on the **mean value** of the variation level for the different frames measured in the same, e.g., process change. Every point, therefore, represents the mean value of the variation measurements for that ID in the different frames measured. This view does not allow, therefore, to see a pattern in the measurements evolution during time and it is weak when the frame measured are very few and with very different values for the same ID.

On the other hand, when the frames measured are few, it is possible to obtain a contour plot **for each one** to see the differences between one and the other and to understand if a mean value evaluation could be significant or not. If the differences between frames are significant, it would be possible to overlap different contour plots to have a picture of the process behaviour.

Since the data is correlated within each frame, this discussion is important: even though the mean gives an idea of the fixture design, a separated representation of each frame will give an idea if the points are up or down simultaneously. It is **complementary** information to the mean.

The Graph G could also be used during the product life time, with a **longer term** point of view: if the available measurements cover years of production it is possible to review the development of a concept during time in order to check the stability and to connect the changes to specific events, i.e., root causes.

This view is therefore useful especially at the **very beginning** of the New product development process or when the process is mature enough to be considered **stable**. In other words, either when the frames are produced in a very limited number and in order to make the process adjustments before the serial production; or when the variation in the frames is little and the mean values carry a reliable information about the process behaviour.

Example of how the Graph G view can be useful in a real process: the Geometrical Assurance Process

The Graph G can significantly improve the performance of, the **Geometrical Assurance Process**, which is a critical part of the New Product Develop Process. The process taken as an example to explain the usefulness of the visualisation method involves two different sub-assemblies which needs to be assembled in one interface. The **requirements** setting (1) needs to make them meet in the assembled part. Different **concepts** are developed and evaluated in order to find the most effective set of tolerances (2). Once the concept is selected the **Purchasing** function is involved (3) and a series of verification is run to check the procedures for the operation, the geometry of the single parts and the effectiveness of the tools. When the concept gets to the **Production** phase (4) the fulfilment of the requirements is checked and, based on the **feedback**, the project team can decide to improve the concept, to completely change concept or to keep the developed concept. The feedback in the 4th phase is based on real measurements, therefore it is interesting not only for the Operations, but also for the Design department. The purpose of the feedback is to get an **overview of the setup** in order to understand what is not working properly and where to put the further effort. The purpose of **Graph G** is exactly what this phase requires: an overview of the frame that allows to have an immediate picture of the current situation in order to take a **data-driven decision** about which areas and parts are critical and need further work. Once the Graph G is used to identify the areas of interest, other visualisation tools can be used to look **deeper** into the specific IDs related to the identified areas.

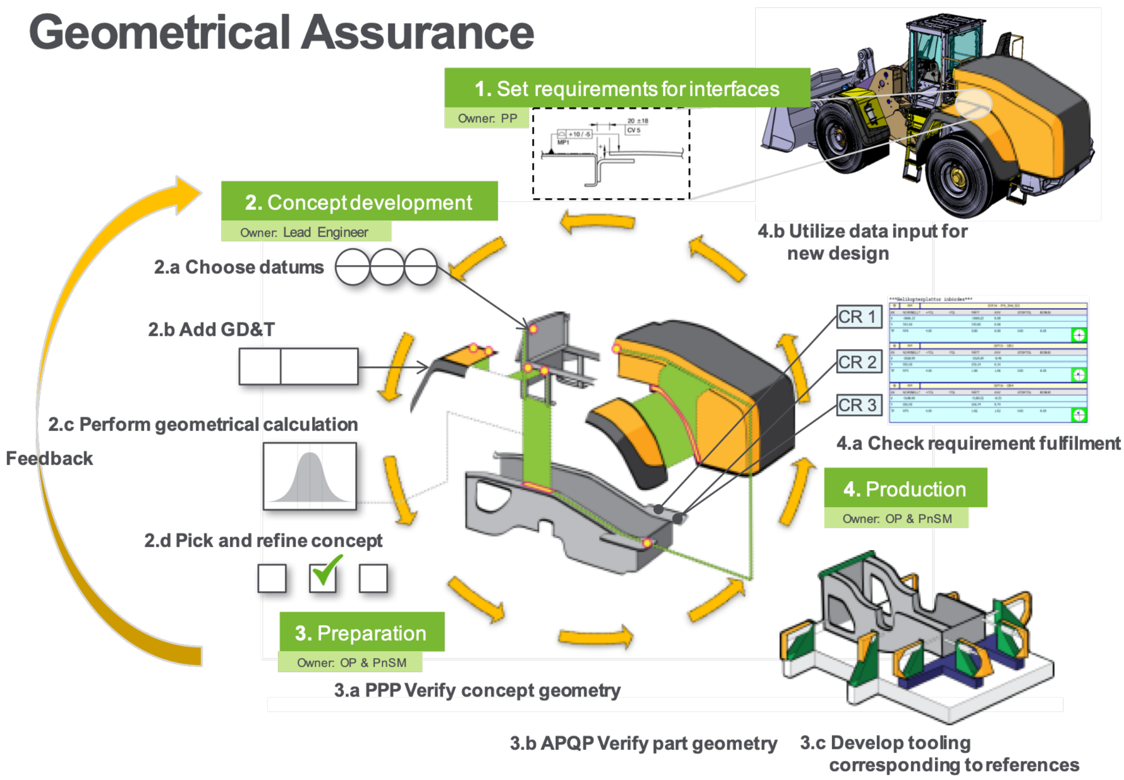


Figure 25 - Geometrical Assurance solutions development process

Different analysis point of view: summary

Different visualisation tools give different input. The graphs were shown during a **cross-functional** meeting; therefore, it was possible to understand how different roles discuss over different graphs. This made it easier to understand the **point of view** of the different departments on the same graph, and, on the other hand, to understand how different graphs can drive the discussion towards different **topics**. It was clear that the discussion got to a very **higher level** when the last visualisation tools was presented: at the beginning the answers were very basic and short, moving towards the more complete graphs the discussions became more broad and open. Also the point of view of the people involved changed with the last graphs presentation: at the beginning most of the attention was given to the critical points, or to the critical areas; whereas, when the more complex graphs were shown, the attention shifted towards the process itself and the possibilities for improvement.

It is interesting to see, again, that the **information needed already exists** in the Company: the barrier that stops it from spreading is that the questions asked are not the correct ones. Production engineers and Quality engineers know what the Designers need to know, they do not know how to tell them, though; the Designers, on the other hand, do not know how to ask for what they need in a way that makes it easier for the Operations departments to understand what it is and how to provide it effectively.

Different focus: Effects or Causes of variation

Looking at the frame as a whole gives different information than looking at the checking points one by one. When looking for trends, if the Production engineers look into the single IDs, they will find a trend that is specific for the ID, but they will lose the information related to how that point is related to the other on the frame. Therefore, when looking for a solution, the **fire-fighting** approach will lead to changes that might worsen the overall behaviour of the process. If the trends are searched in the frame as a whole, instead, what happens is that the solutions are correct for improving the process behaviour, not the ID behaviour. Therefore, affecting the frame and the process itself is a positive move, not a dangerous one. When looking at the process as a whole the engineers tend to find solutions for the **root causes** and not, as it happens when considering the single points, for the effect of the variation on the frame.

Different point of view: Product or Process

Looking at the frame as a whole lead the discussion towards a process point of view, when the focus is on the single IDs, on the other hand, the discussion point of view is the single product. When the focus is on the product behaviour, there is no **time** to compare the different Process changes; therefore, it is not possible, to look for the causes of the variation. This is one of the reason why, so far, the Company has adopted a fire-fighting approach: when the focus is on the effect of variation, the easiest and fastest way to improve is to eliminate those effects. This attitude, though, prevented the Company to understand the causes behind the variation. When the focus is on the process behaviour, it comes naturally to compare the different **Process layouts** in order to understand what adjustment in the settings caused what differences in the variation distribution on the frame. The Company, adopting this point of view, can significantly improve its processes without building the problem into them.

Different information shared: Cross-functional communication vs silos action

When the focus is on the product, the Department involved in the discussion are mainly the Manufacturing and the Quality departments. The reason is that the Design department is responsible for acting on eliminating the root causes, not the effects, of the variation. Therefore, when issues occur on the production site, the Quality and the Manufacturing department act alone to fix it **as soon as possible**. The Design department is involved in the discussion when the effects of the variation are serious and severe and a **substantial change** is required in order to fix the problem. Therefore, the Design department is involved when the process needs to be restructured and updated. The **cross-functionality** is undermined by the current Company approach, but it is possible to change the approach itself in order to enhance the cross-functionality. When the focus shifts from product to process oriented, the Design department **naturally** becomes part of the discussion since its knowledge is required. At the same time, since it is fully involved, it can become fully aware of the current situation in the production site, this means that the knowledge sharing becomes easier.

To summarise: sharing the correct information, with the right visualisation tool allows to shift the Company approach from product to process oriented; this change in the attitude enhance the cross-functionality and the involvement of the Design department in the everyday issues; therefore, the knowledge is shared in an easier way since every department communicates frequently and effectively and is aware of the current situation.

A pull approach to the standardisation

The graphs' analysis purpose was not only to understand how the use of different visualisation tools could impact on the level of communication in the company, the purpose was also to understand the **different demands for the different roles** and departments. The roles analysed are Quality engineer, Manufacturing engineer and Designers.

The first two role belongs to the **plant**, they need precise information about the process behaviour and their knowledge about the frame is very high: they deal with the real product and with the production process in their basic working day. The overview of the product state is already clear to them; therefore, a visualisation like the one proposed with the graphs E, F and G could be useful for them to have a confirmation about what they expect. The visual overview of the product could be useful for them to point the effort in the right direction without having to take decisions based on their experience and opinions, but based on a **data analysis** instead. The graphs that are be more useful for them, though, are the more technical ones. For a **Quality engineer** it is important to know that the overall frame is correct, but if it is not, it is important to know **exactly what** is wrong: the graphs B, C and D can be used for this deeper analysis. Looking at the **graph D**, a Quality engineer can *see* the frame and its behaviour, he/she can identify the critical points and, comparing the different process changes, he/she can understand what caused the criticalities. For a **Manufacturing Engineer** it is important to know that the process is delivering a product that corresponds to the demands, but if it is not, it is important to understand where the demands are not met and what causes the mismatch: looking at **graph D**, a Manufacturing engineer can *see* the frame and its behaviour, he/she can identify the critical tools and, comparing the different process changes, he/she can understand what caused the criticalities. With **graphs B and C** it is then possible for a Quality or for a Manufacturing Engineer to go deeper in the analysis, focusing more on the frame zones or on the asymmetries in the frame depending on the specific situation.

The Designers are **less connected with the plant** operations and with the actual production, therefore their knowledge about the physical frame is not as advanced as in the previous cases. That is the reason why, they need a visualisation tool that allows them to understand what happens on the frame even if they do not have the frame picture already in mind. A visualisation like the one proposed in the graphs E, F and G is useful for them to be able to *see* the frame and the behaviour of it. Those graphs can be used by them to have a **general view** of the frame as it is, compared with how it should be according to the design and also to understand which areas are more critical and which tolerances are not met so that the drawings updating could be data-driven. With a **Geometrical Assurance** point of view, the **graph G** is very useful to understand what specifications are not met in an overall way, it is not important that a specific ID does not meet the specifications. What is really important is to *see* how the out of tolerance IDs are related: where they are positioned, if they are all in the same area or in the same side of the frame, if they are casually spread on it. To *see* the relationships and the correlations between different IDs is what is most important on a geometrical point of view. Once the critical areas are identified, it is possible to dig deeper with other graphs, like the graph D, for example, to have a more numerical awareness of the situation. For a **Designer** it is important to understand which tolerances are not met and how to change them in order to get a product with high quality but that is **feasible** in the plant. Some drawings' tolerances are not **coherent** with the production procedures, therefore it is not possible to meet them in reality and the measurements always show an out of tolerance point. Most of the times, where there is an always non-compliant ID, there are other connected to it that are not compliant or that are affected by that one in some ways. Therefore, a Designer needs to see the **correlations**, the frame as a whole and the little details in it, that is why the **graph G** is the most useful, at least for a first analysis. It is possible then to dig deeper in the areas of interest with other tools.

Chapter 6

Discussion

To change the Company behaviour, the suggestions have to become a standardised procedure to be used in every upcoming project, therefore, it is important to find a way to make the tools usage easy and **spontaneous**: the people involved in this first pilot process need to understand the value of the tools so that they will be the **promoters** of the standardised information flow. It is not possible to standardised the communication for every process in the Company, it would require too much time and the result would probably be too complex to be actually used in the everyday activities. Nevertheless, it is possible to start with a specific process and once the positive impact of the method is proven to spread it and adapt it to the other processes. The crucial part of the standardisation is to identify a figure willing to **prepare** the graphs for the different Product development projects following the suggested procedure so that the other people involved will be driven to **adopt** the tools in a spontaneous way, this way the change would be driven by the employees and not forced to them. If the communication flow is successfully standardised it can be used as a **control factor** for the process, therefore, it will be possible to turn it from noise factor into variation reducer.

IMPROVE

Standardisation of the information flow in the process analysed

In order to become a standardised procedure, the information flow should be **designed** and its effectiveness **tested**. Since the information requesting and delivering cannot be considered exactly as process phases, and since in the Company it is already difficult enough to follow procedures that concern the working processes, it is more pragmatic to act on the **existing processes** and to add the information flow standardisation to those. In other words, since designing an information flow that covers a whole company would result in something too complex to be follow and, consequently, to give an added value to the activities, it is more useful to focus on an existing process and to add the information flow instructions to the production ones.

The first step to standardise the information flow is to understand **what information** is needed by each role involved in the process. The use of a pull approach that starts with the user and not with the information itself, is critical in order to develop an information flow that is easily understood and adopted by all the roles involved: it is important to build the process according to the working procedures already in place and to the people's habits and demands.

The information needed by the studied roles have already been defined in the previous phases of the thesis project. The departments on the plant, i.e. Quality and Manufacturing, need **precise and detailed** information about both the process and the product behaviour and performances, something that can show the process evolution in time and compare the effect on the final product of different production's choices. On the other hand, the design department need a **clear and easy to grasp** overview of the product critical areas in order to know where to put further effort to reduce the variation or the deviation from the target values.

Considering the previously proposed graphs, it is possible to match the needs of the Quality and Manufacturing departments with the graph D and the needs of the Design department with the graph G.

It is possible to update the New product development process concept generation and evaluation phase adding the recommendations about the visualisation tools to use in each step. At the **beginning** of the process the designer needs to have a picture of the **historical** performances of the product he/she is updating, if such an information exists, it should be presented with the **graph G**, so that the designer can **see** where the criticalities were in the previous version of the product. If the product to be developed is completely new, it can still be useful to have some pictures about **similar** products: the graph G representing a product with similar customer's demands, or with similar requirements can be useful to guide the designer in his/her job.

For the **first evaluation** of the drawing, the **graph G** is still the most useful: the data about the first concept will not be enough to give a meaningful view using a more technical graph; moreover, being still at the very beginning of the process, having a clear overview picture is more important than digging deep into the details that are still not definitive. The graph G can be used also for **evaluating different concepts** criticalities in order to come up with a more effective solution.

The drawing will be updated based on the criticalities that the graph G will highlight, critical areas will be managed and fixed, tolerances will be set in a smart way according both to the customer demands and to the product feasibility, and so on. At this point, since the concept is decided and finalised, the **graph D** is more useful: the overview is already common knowledge for the production side, but it is important for the Manufacturing and the Quality departments to have a detailed picture of the results of the testing phase to understand which specific checking points are out of target and which steps of the process might be causing the issues.

For the designers, though, the **graph G** keeps being useful even in the downstream phases: they cannot design based on single points. At first they need to identify the areas that need to be improved, then they can look deeper into the single points to understand if the problems are in the drawing itself or in the tolerances.

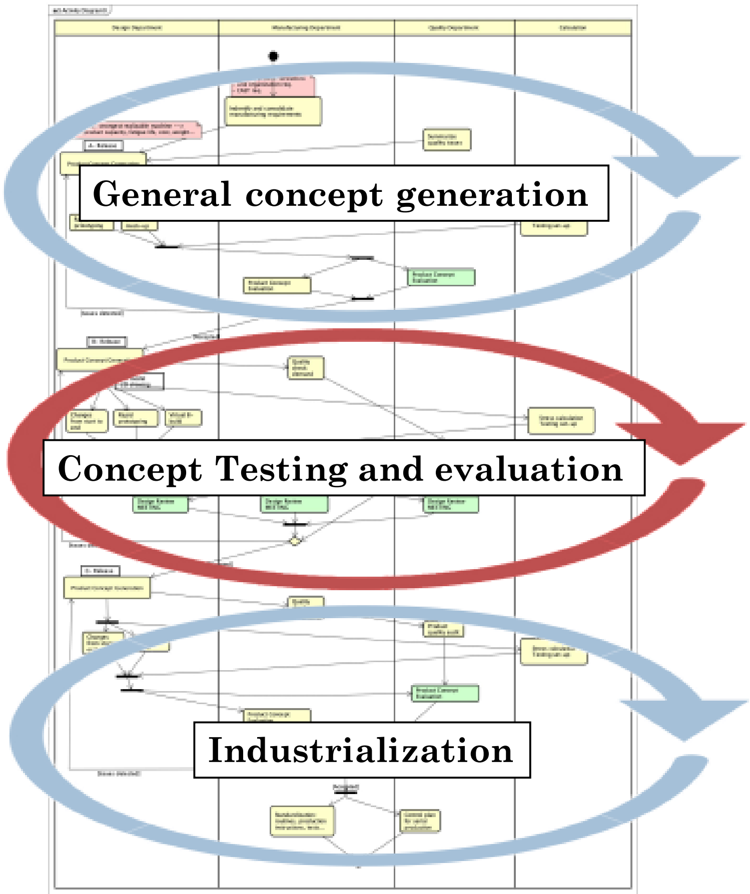


Figure 26 – Simplified example of the Information flow standardisation for the process analysed

During the design reviews, the different departments can share their knowledge: the detailed knowledge of the Quality and Manufacturing engineers can lead the Designers towards a more practical and effective solutions, the broad knowledge of the Designer, on the other hand, can lead the Quality and Manufacturing engineers to more robust and feasible solutions. The cross-functional discussion is crucial to obtain a solution that respects both the customer demands and the plant's competences.

This loop can go on until a satisfying solution is found: the aim of using this specific visualisation tools, though, is to **minimise the iterations**. It is utopian to think that a single iteration could lead to the final solution, but it is obvious that, as long as the information sharing is not based on the actual need of the roles involved in the process and the visualisation tools are not understandable by the users, the iterations needed will always be more than the necessary ones.

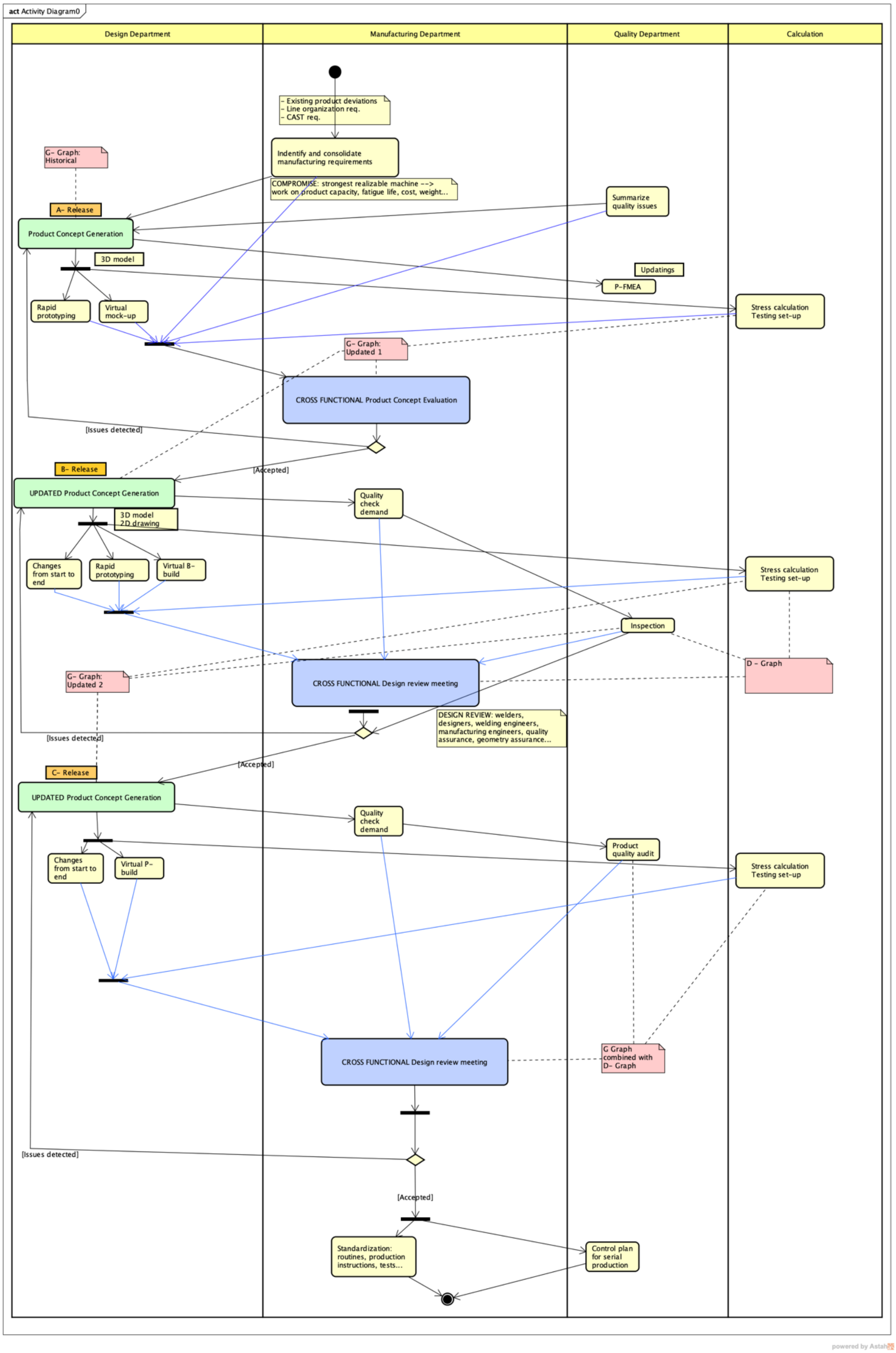


Figure 27 - Swim lane flow chart representing a possible way to standardised the communication flow and the visualisation tool's usage

Parameter analysis: what is the impact of standardising the communication flow

A series of **interviews** has been conducted in order to investigate how the standardisation of the information flow can contribute to the variation reduction in the production phase of the New Product Development Process.

The roles interviewed are the same that have taken part in the study previously, therefore they were already aware of the importance of using the correct visualisation tools when sharing information, even more, they were the ones suggesting the author how to develop a visualisation tool that could be useful for them.

As previously stated, the information needed already exists in the company: data are being collected and analysis are being developed. **The communication issues do not arise from a lack of information, but from a lack of dissemination**: this means that, since the information is not widespread in the company, the knowledge that could come with the data does not evolve. The lack of knowledge concern different aspects of the information flow: it is not clear who owns the information, how to ask for the it, if it is actually available in the company, how to deliver it and who needs what. All this **unclearness** come from the same root cause: the communication flow is not standardised. Since there is not a regulation of the communication and of the information sharing, people just ask other people for what they need without being sure that those people can provide the right answer. Sometimes they are lucky and they find the right person to ask, but it happens that this person does not know how to deliver the information, therefore the person asking for it receive something that is not exactly what he/she needed. The need is consequently dual: first it is important to understand what information is needed by every role, second it is important to find a way to deliver that information in an immediate way.

Standardisation of the information flow as a Robust design enabler

As stated before, a Robust design strategy consists in using the noise factors to the output performances advantage. Controlling the information flow, and frame the settings of it is, according to the definition, a Robust design strategy. Since the information flow is intangible and volatile, it is not easy to define its settings, but on a general level it is possible to say that, if the fact that different people have access to different information and base the same decision on different data causes variation in the decision-making process generating a noise factor, then the reciprocal control factor is a **standardised and defined data analysis report** for every person in the same role; likewise, it is possible to say that if the fact that the communication happens in a random way, with people asking other people the information they need without a structured reasoning, is a noise factor, then the reciprocal control factor is a **standardised and defined information flow**. The settings of the Data analysis are the **information given** and the **visualisation tools** used to show and share it, whilst the settings of the information flow are the **phases** of the process where the communication takes places and the **roles** that mutually exchange information. Therefore, it is possible to use the communication flow, which is a huge variation source, as a control factor which results in both reducing the variation in the process and making the output response more effective according to the customer demands.

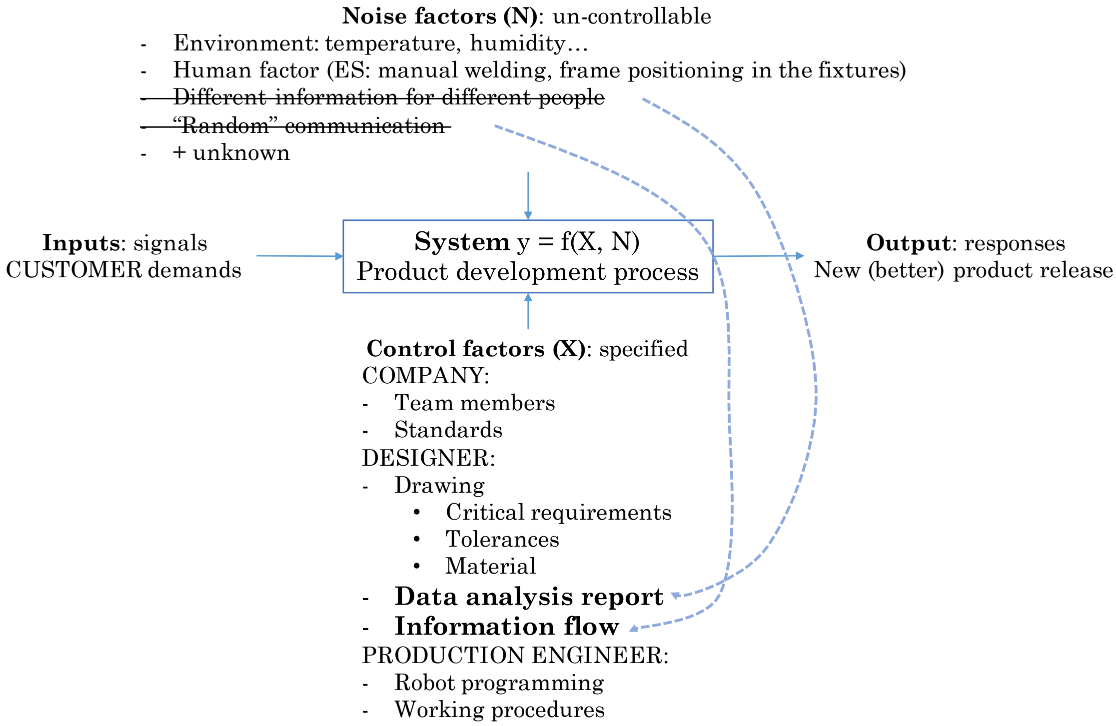


Figure 28 - Simplified Parameter diagram representing the New Product Development Process if the noise factors related to the information flow become control factors

Guidelines to standardise the information flow

It is possible to suggest a general procedure to standardise the information flow in any company following the baseline of the case studied in this thesis.

The first step is to **identify a process to focus on**: in this case the focus was on the **Concept development and evaluation phase of the New product development process**. The Product development process is a good starting point since the communication and the information shared are basically **standard**: historical data to start the concept generation, test results to evaluate the concept. Moreover, the cross-functionality required for gaining a good result is an additional **motivation** to give everyone the right information in order to drive a sharp discussion that leads to a successful concept selection. The information flow in the Product development process is also **easier to control** than the one taking place in a general production process since there are planned meetings and planned reports to share in the team. It also important to state that, based on the analysis the communication in the product development is **crucial**, whilst in a general production process the priorities are different and the advantages might not be so undeniable.

The second step is to identify the **bottleneck** in the process selected, which in the analysed case was the part of the information flow involving the **Production site** and the **Design department** during the Concept evaluation and selection phase. That activity requires more time compared to the other both because it is crucial to define the final product features and because it requires a strong cross-functional communication between the Manufacturing, Quality and Design departments in order to reach a satisfying solution. Identifying the bottleneck is crucial to act on the correct part of the process and to get improvements: implementing a standardised information flow on other phases will not have such an impact on, for example, the total lead time if the bottleneck is not solved. Of course, bottlenecks will move, once the original is solved, another phase of the process will become critical, therefore it is important to keep measuring the whole process and not only at the phases affected by the change to identify the new bottlenecks and solve them as well.

The third step is to identify **key roles** in the process: in this case the **Design** department was the key since a lot of information was getting out of it and very little information was coming in. It is important to understand both the **hub** of the communication and the roles that are instead **excluded**. The hub can be used to gather information about the information needed by the other roles and other information about the process. The excluded roles are most likely the **bottleneck** of the information flow and, as a consequence, of the process: since it does not receive the information that it needs, either it spends a lot of time looking for the data necessary to go on with the job or it is not able to deliver a good output to the other roles and this makes the lead time increasing.

The fourth step is to define **what information is needed** by the key roles in each phase of the process: using a pull approach, which means starting by the customer, i.e. the information user, allows to develop an information flow that meets the requirements of the roles actually using the information and that is easily accepted by the team members. To understand the information needed it is possible to focus on different aspects of the job activities: the point of view, the activity itself, the technical level, the interests of the role… The point of view required can be very detailed, e.g. for the Production site departments in this case, or more of an overview, e.g. for the Design department in this case; the activity itself can be focused on the product features or on the process steps improvement; the technical level of the user can be basic or very high. Different aspects require different information.

Some examples of questions to ask in this part of the analysis are:

- *What decisions do you take to develop your job activities?*
- *What information do you use to take these decisions?*
- *Is the information you use easy to understand?*
- *Is the information you need easy to find in the Company?*
- *What are the questions you ask more frequently to other people or other departments?*
- *What is missing in the information you use?*
- *What decisions do you take based mainly on your experience?*
- *What would you like to know to take these decisions in a more data-driven way?*

The critical part of this phase is to understand the information requirements for the different roles even though they might not know what those requirements are. It is important to understand that it is not easy even for who asks for the information to understand what is actually needed to take the right decisions and to simplify the decision making process.

The fifth step is to decide which **visualisation tool** is more understandable and value giving for each role in each phase of the process. It is not obvious that the most advanced and complex tool is the most useful, it is also possible that an easy but immediate visualisation tool could prove to be the most suitable one. In order to decide which tool is the most effective it is important to consider the technical knowledge of the user, the time the user can give to reading and understanding the graph, the importance of the information shared in the specific phase of the process… If the user has a strong technical

knowledge, probably a detailed and complex visualisation tool will be of his/her interest, on the opposite, if the technical knowledge of the user is basic there is no point in develop a too advanced visualisation tool as it will just frustrate him/her. The same reasoning can be applied to the time of analysis: if the information shared is crucial and the time to analyse and understand it is planned to be long, a complex visualisation tool can be used, otherwise a time-saving choice is the better one.
Some examples of questions to ask in this part of the analysis are:

- *How detailed should the data analysis be?*
- *What are the most important features you need to focus on?*
- *How much time do you spend reading graphs?*
- *How long does it take for you to fully understand the data and to finally proceed with the decision making process?*
- *What are the main issues when you read the currently used graphs?*
- *What would you like to change in the current visualisation tools?*
- *What are the features you appreciate of the current visualisation tools?*

During this phase it is important to focus on the demands of the different roles, the purpose of adopting a pull approach is, in fact, to find a most suitable solution for the specific people, not to use the most advanced and complex visualisation tools.

The sixth step is to **test** the graphs chosen showing them to the people involved in the process and to **update** them based on the feedback. It can be useful to implement an **Information quality report** so that the people involved can give a structured feedback that can be used both for updating the current visualisation tools and for checking the usefulness of the proposed ones.

Role Requesting the data analysis	Designer				
Role Delivering the data analysis	Data analysis project responsible				
Data analysis report code	XXXX				
	Completely False				Completely true
	1	2	3	4	5
Information quality	3,00				
I got the information I was looking for			x		
The information was explained in an easy to understand way		x			
The information was complete and precise			x		
The level of detail was correct			x		
I could use the information as it was without having to work on it		x			
I got the information fast					x
Visualisation tool quality	2,67				
I could easily read and understand the chosen graph			x		
The visualisation tool corresponded to what I needed		x			
The visualisation tool made it easy to grasp what I was looking for			x		
Report quality	2,25				
The Data analysis report helped me taking the decision		x			
I would like to get the same Report when I ask the same question		x			
I did not need further explanation for understanding the graph				x	
I did not need to ask for other information	x				
Overall Quality	2,64				

Figure 29 - Information quality report example

The seventh step is to **integrate** the tools in the process flow. It is important to collocate the information flow in the actual process phases in a smart and effective way which considers the findings of the previous phases. In this phase, having a **swim lane** flow chart is useful to position the graphs under the right user so to be able to verify the logical connection between tool and role.

The final step is to **apply** the new information flow to the existing and on-going process in order to monitor the effectiveness and the usefulness of it. As stated before, once the first identified bottleneck is solved, something else will become critical. That is why, after the procedure is applied it is important to keep focusing on the process in order to identify other possible criticalities in the communication flow.

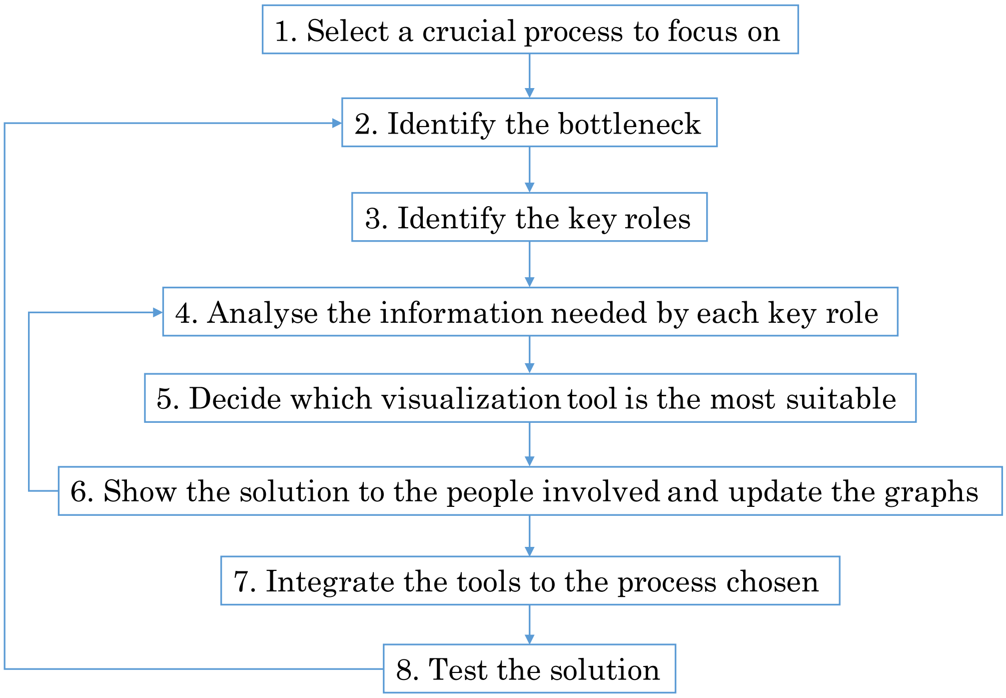


Figure 30 - Proposed procedure to standardise the information flow at any level

CONTROL

Possible metrics to control the effectiveness of the integration of the standardised information flow

The final aim of the communication flow standardisation is to **save time**, which, in the case of the Product Development Process, means reducing the lead time from the first design to the serial production. The lead time reduction can come from different factors. First, sharing the information in a smart way will decrease the number of **iteration** of the concept generation and evaluation loop with the consequent decrease of the number of necessary planned **meetings:** from the start the designers will be aware of the issues and the criticalities occurred during the production of the past version of the product and the quality and manufacturing engineers will be able to guide the designers towards a more feasible concept. The **amount of information** shared, even though it is not easy to measure, is another factor to consider in order to evaluate the success of the standardised flow: if the information shared is more than before, this means that the regulated communication flow works better than the random one. Furthermore, with an increase in the information shared, the design will be more precise and effective and the lead time will decrease since less iteration will be needed to fix the drawing's inconsistencies. It is not only the amount of information that matters, but also the quality of the information shared: sharing more data that are not useful is a waste of time and effort, the information must be precise and punctual according to the needs and guide the user towards an improved result. For example, a good information to share is one that lead to a higher number of **root causes** considered and solved during the first phases of the process, to obtain smoother downstream stages, especially when the production phase will be finally reached, and, as a consequence, a shorter lead time since less time will be spent in finding solution for the issues occurring in the latest part of the process.

As a final result, which is also the most tangible, there should be an improvement in the **process capability**. If it is true that the standardisation of the communication flow can be used as a **Robust design tool**, then the variation in the process should decrease and, consequently, the process capability should improve. Different factors taken into account during the Product Development process can influence the process capability: the tolerances' setting and the tools choices will be updated, the production process itself will be improved based on the previous performances, the materials can change, also the people actually working in the project can make the difference. All those elements will influence the Process capability and all of them have something in common: they need data to be successfully updated. To update the tolerances' settings and the tools choices an analysis of the performances of the previous solution is needed to identify what actually needs to be improved; before acting on the production process the engineers need to gain knowledge about the performances and the criticalities of it; in order to change the material, it is important to understand what it is required from it and what was wrong in the previous one; the people involved in the project will have to communicate and to work together in a cross-functional attitude. This means that the communication flow is crucial in most of the factors that can influence the process capability, even though in an indirect way.

Comparison with another Company in the Automotive industry and involved in the VariLight project

In order to understand if the proposed procedure could have been useful not only for the Company analysed, but also for other ones, the author interviewed a Structural Mechanics Engineer and a Welding Engineer from another company belonging to the same industry and involved in the VariLight project.

The main **differences** between the two cases, are that in the second one the products are assembled in the plant from **supplied components** and the project's **scopes** are narrower. This leads to a different attitude towards the New product development process: since the suppliers have to produce the prototypes and commissioning it requires money and time for the Company that would just go wasted if the prototype is not good, the drawings have to be almost perfect from the first time. This means that the most of the effort is put into the first stage of the product development, with also an **early involvement** of the supplier: as soon as a first drawing is ready, therefore before the actual prototyping phase. The scope of the projects has to be narrow since the supplier involved are responsible for a **single component**, not for a whole product.

As the first Company, the second has issues with both low tolerances that are over-processed and too strict tolerances that are not achievable in production. Given the fact that the supplier are external entities, it is even harder for the second Company to know what is **feasible** on the Production site; anyway, during the prototyping phase, the main focus is on eliminating the root causes. This attitude changes during the serial production though, when there is no time to dedicate to look into the causes of failures.

The concept generation phase of the New product development process of the second Company is not a critical process: the communication is rich because not many people are involved in the same project and this makes it easier to know who to ask what to; furthermore, given the importance of having a prototype that is correct at the first trial, the knowledge about the design is very deep and precise.

The critical phase is therefore not the first one, but the last one: keeping track of the **lessons learnt** is what is missing in the second company. While people are involved in the project, their knowledge is deep and precise, but when the prototype goes to production, people start working on different projects and that knowledge starts to fade; therefore, when a problem occurs in the **serial production** it is not easy to retrieve all the information needed to understand what caused it and the attitude turns into a firefighting one. During the project the measurements are shared as lists of measurements' results, which are understandable during the prototyping phase, but become suddenly unintelligible once the serial production phase is reached: this is when a visualisation tool like the **shaped contour plot** can take the place of the currently used tool. Having a **context** to put the measurements in can make the whole process of retrieve the information easier and faster.

Another issue is worthy to be explored: once the prototype is accepted, the information is spread in the plant to the **Manufacturing and Quality departments**, but the people receiving the data were not involved in the Product Development Process. As a consequence, the production site needs to ask questions to the designers and to the project leaders, risking to get an answer that is not precise or not complete; therefore, there is a problem with **sharing** the information in a way that can help the plant taking its decisions with a **complete knowledge** of the process and of the product. A list of measurements is not of any help in this case, but a **picture** of the frame with the tolerances expressed on the checking points and a classification of critical, functional and basic ones can be a good visualisation tool to make the knowledge more available to whomever was not involved in the project itself.

Based on the interview, the second Company uses an effective communication flow during the Product Development, but the issues identified for the first Company's New Product Development Process can be found in the **serial production** of the second one: over-processing, firefighting attitude, little time to look into the causes of failures and cross-functional issues. Nevertheless, even though the hypothesis used to develop this Thesis project were not applicable to the second case, using the procedure suggested it was possible to identify the **critical process** to focus on: the serial production. Furthermore, adopting the procedure for analysing the New product development process, it was possible to identify the **correct phase** to adjust: the bottleneck was not at the beginning of the process, but at the conclusion of it. The un-closed feedback loop was not the one related to the Concept testing and Evaluation, but the one from prototyping to serial production phase.

To conclude, the comparison allowed the author to confirm that the procedure suggested for the improvement and the standardisation of the Information flow can be successfully applied to different companies, with different criticalities and different supply chains.

Chapter 7

Conclusions

The scope of the thesis analysis was very precise, but even changing a **small phase** of a single process the results were **significant**: the cross-functionality was enhanced, the communication was facilitated, the attitude was turned into a process-oriented one and the approach of the decision making process was shifted towards a more proactive one by simply optimised the way information are shared in the process. It is important to understand that even the most advanced tools and instruments become useless if the organisational context does not allow to exploit them: the communication flow is crucial to spread the knowledge and to create an environment where it can grow. The potential of the standardisation of the information flow is powerful, therefore, following a series of guidelines to standardise the communication in the whole Company could deeply impact the Company's performance both on a customer satisfaction and on an inside growth point of view. In order to apply the guidelines to a whole company, though, the feedback loop needs to be adaptive: the tools chosen and the information flow need to change according to different processes and different information requirements.

Summary of the findings

The **New product development process** as it is in the company is very complex: it is made of different loops, that iterate a number of times before reaching a satisfying solution. The focus of the analysis was the first loop: the **Concept generation and evaluation**. This because it has been recognised to be the loop with the highest number of required iterations: the **bottleneck** of the New product development process. Furthermore, since it is the start of the process, even a little improvement in this stage will have a positive impact on all the following ones. The centre of the loop is the Design department, which is also the excluded department: the outputs for all the roles involved in the process come from the designers' activities, but they do not receive useful feedbacks from the people on the production site, i.e., the Quality and Manufacturing departments.

The most relevant criticalities in the process are the lack of knowledge on an inter-department level, the lack of natural cross-functionality and the fire-fighting approach. The purpose of standardising the communication flow is to solve, or at least to reduce, those criticalities.

The **information** that the different departments need in order to gain a broader knowledge not only about their performances, but also about the performances of the other departments involved in the project and about how their mutual collaboration can improve those performances, already **exists** in the company. It is not used in a smart way, though. There is no need to collect more or different data, but it is important to focus on the **presentation** and on the **sharing** of the existing ones. In order to do so, different graphs have been presented to different roles to understand how the use of those different visualisation tools can influence both the **knowledge** upgrade and the **cross-functionality** enhancement.

The right visualisation tools to use in order to **include** every role in the discussion, are the ones that give to every role the right amount of information about the current situation to both trigger the **suggestions request** to the other roles and the **suggestions proposal** based on the department-related knowledge. The right visualisation tools to use in order to move the discussion from a short-term to a **longer-term** are the ones that focus on the process instead of on the product: graphs that give an **overview** of the product performances in a way that lead the user to focus not on the product itself but on the **process** that makes it realisation possible.

In order to get a real advantage from the usage of the correct visualisation tools, it is important to **standardise** the communication flow in a way that allows to give every role the precise **information** required in order to perform an effective job for the specific **stage** of the process. Different information is required from different roles, and also the same role requires different information according to the process stage.

Managing to standardise the information flow in a smart and useful way enables to **reduce the lead time** in the New product development process and to obtain a solution that is less sensible to **variation**: this because if the information shared is correct it will highlight the variation causes that occurred in the previous products, or versions of the product, and those will be taken into account from the start of the process leading to having few or, at best, no surprises in downstream stages.

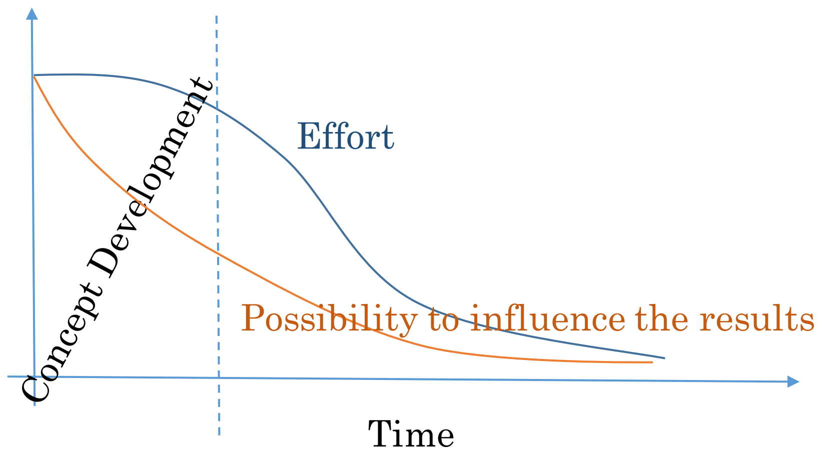


Figure 31 - Graph of the ideal Effort amount in time compared to the possibility to change the final outcome (Project Management Institute, 2017)

Adaptive feedback loop

The thesis project's scope was the Concept generation and evaluation of the Product development process of a specific frame, the goal was to **show the power** of a smart organisational change starting with analysing the impact of improving a small phase of a specific process so that the company would realise the potential of the approach.
If a **small change** in a crucial phase of a specific process was sufficient to change the attitude of the team working in the process, then a significant change in the crucial phases of other processes can lead to a **substantial improvement** in the whole company behaviour.

The final goal is not only to make the single products robust, but to **scale up** until the processes themselves are robust designed: the thesis study should be just the starting point, the eye opener for the company. The potential advantages the company can get from the standardisation of the information flow are significant: most of the problems identified during the analysis can be solved using a more pragmatic communication flow, but applying the guidelines only to one process is not enough.

The feedback loop has been designed for the first stages of the New product development process and its validity and usefulness have been tested in the development of a real product updating, it is possible now, using the guidelines proposed in the thesis, to zoom out and **focus on the process** as a whole. The feedback loop to consider will be the conclusive one: from serial production back to design to check the final effectiveness of the new product release. Once the New product development process is updated it is possible to focus on a frame the company is currently delivering and on the processes related to it, in order to be able to apply the standardisation of the information flow also to the **serial production** flow. Once the production parts' information flows are standardised it is also possible to act on the **assembled** products and to the **platforms** of product. Also the organisational communication can be standardised, for example the report for the department' managers can be updated based on the guidelines. All the information flows related to the processes currently in place in the company could be standardised applying an **adaptive feedback loop** strategy: starting with the crucial phase of a specific process related to a frame and moving up until the whole process is taken into consideration and its communication flow optimised, then focusing on the assembled product and on the platform the product is part of and on the useful information to share within it and, finally, acting on all the organisational processes that allows to evolve from prototypes, to actual frames, to assembled products, to product platforms.

Identifying a role with the responsibility of applying the guidelines and promote the standardisation is mandatory in order to make the change happen: a **catalyst** is required for spreading the usage of the visualisation tools. It has already been proven that the standardisation of the information flow for the New product development process can have a positive impact on the variation in the final product, this can be used as a motivation to standardised the communication in all the upcoming Product development processes. At the beginning of the initiative, it will not be easy to apply the procedure: it will take time to understand the information and visualisation requirements of the different people involved and it will take a serious effort to develop the tools as well. That is why, at least at the beginning, the best way to introduce the change is to give the specific responsibility to **one person involved in the project**. Once the people in the Company are more familiar with the tools and with the standardisation procedure, then it is possible to create a **group** dedicated to the Tools improvement in the Quality department with the responsibility to provide the graphs to the other departments in the Company. Once the standardisation will spread, it will not be required to have a lot of people working on the visualisation tools, so it will be possible to reduce the group dedicated to it until only **one person** will cover the role and the responsibility to check the **already in place** information flow.

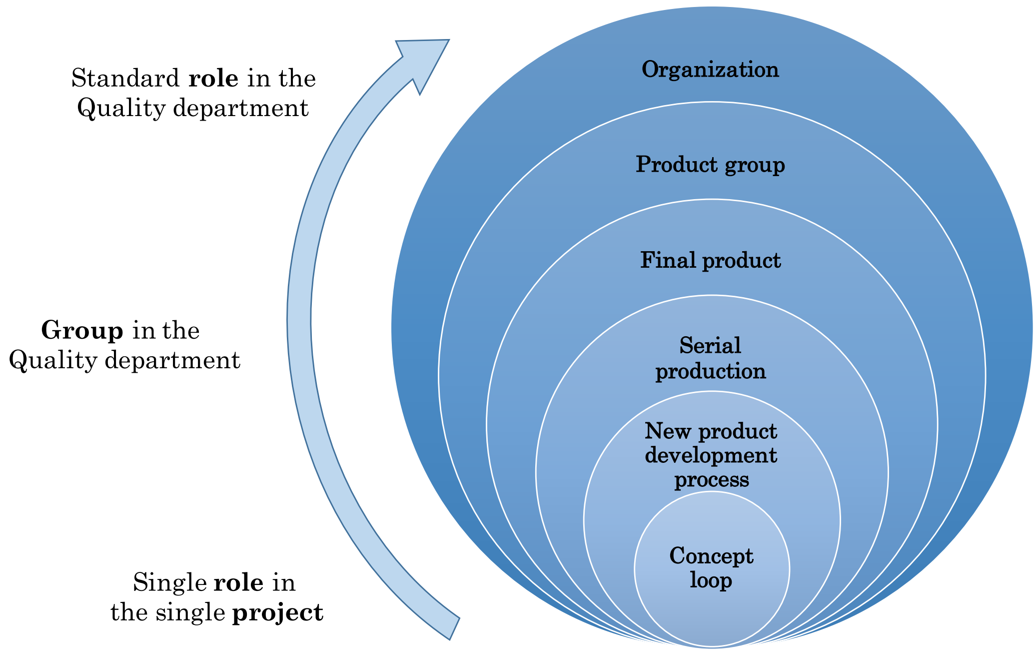


Figure 32 - The Concept loop's information flow standardisation as a starting point to standardise the communication in the whole company

Importance of the organisational issues

It is pointless to spend money on the most innovative equipment if the **support** coming from the organisational functions is not adequate: part of the value of the instruments is lost if the infrastructure of the company does not allow to **fully exploit** them. In order to obtain technical excellence, both **up to date technology** and effective organisational support are required. The case studied proved it clearly: the performances on the market of the company analysed are remarkable and its brand is extremely strong thanks to the robustness of the products delivered, nevertheless, since the cross-functional communication is poor, the **effort** needed to obtain such a result is huge. The reasons behind the difficulties of the company are mainly organisational, in fact, the technical level of the company is high, solving the technical issues is an ordinary working task for all the technical departments and a priority for the management. The accentuated focus on the technical performance prevent the company from considering its **weaknesses on an organisational level**: the time, the attention and the effort of the resources are directed towards the technical excellence, whilst the organisational support is left aside as something that cannot influence the company success on an interest enough level to be considered.

The study proved that, with the **right organisational infrastructure**, even a **simple tool** can make the difference: the graphs proposed to the resources involved in the project are not the most advanced visualisation tools, they do not have a strong statistical base behind, like, for example, the control charts that have been used in previous thesis projects, nevertheless they managed to affect the discussion view and topic and to change the attitude of the team in the intended way.

The technical solutions impact is affected by the **context** they are used into: more value can be given to the instruments simply by improving the organisational support they rely on. The study highlighted the importance of the communication flow for fully exploit the data visualisation tools, but the organisational infrastructure has an impact on the whole company value: a good cross-functional communication leads to the **alignment** of the goals of the different departments' managers with the company's goal, as a consequence, the **priorities** of the separated functions will support the company strategy, allowing the strengthen of the resources' engagement which is crucial for having a working environment where every employee and leader feels valued, and motivated to contribute with his/her strengths, skills and knowledge in powerful ways.

Answers to the Research questions

The thesis research phase was guided by two research questions, the author wanted to analysed the importance of the visualisation tools as conversation driver and mind-set's changers and the impact of the standardisation of the information flow on the whole product development process.

RQ1: How can the visualisation of the data analysis drive the change of focus of a company from product to process oriented?

The choice of different visualisation tools proved to have an impact on the **information flow**. When the graphs used are not informative, or not understandable, the information flow becomes **casual**, random and confused; people look for data in different places and ask the same question to different people that give them different answers making the decision making process ineffective and unreliable. On the other hand, when the graphs used deliver the exact information the users are looking for in a simple and immediate way, the information flow becomes **standard**; people find the data needed exactly when and where they look for it and the decision making process can therefore be data-driven. When the information flow is standardised, it is possible to choose visualisation tools that drive the **discussion topics** towards fixing the **effects** of the tolerances' unfulfillment on the product itself, or towards eliminating the root **causes** of those unfulfillment. In the first case, the short-term focus and the **product point of view** will lead to a reactive approach that will not enhance the company performances; in the second case, instead, the long-term focus and the **focus on the process** are pursued in a way that will lead the team to improve the process instead of fixing the product.

RQ2: How can the standardisation of the information flow be used as a robust design tool?

Turning the casual information delivery process into a standardised data analysis and the random communication into a regulated information flow, essentially means to turn two noise factors into two control factors: what was a noise generator becomes a **noise reducer** through the standardisation process. The variation is therefore reduced both acting on the data usage and on the communication misunderstandings. The data usage is standardised through the data analysis report, this way people with the same role in the company will not receive contradictive or partial information and will be able to work with the correct knowledge level; the communication misunderstandings are eliminated by standardising the information flow, this way people will receive the information they need when they need it, without having to ask the same data to different people many times.

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