POLITECNICO DI TORINO

Corso di Laurea in Ingegneria Gestionale

MASTER’S THESIS

DECREASE THE RISKS OF PRODUCT FAILURE BY MANAGING THE COMPLEX INFORMATION FLOW IN A WELDING FABRICATION INDUSTRY

A qualitative mapping of the information flow between product development and manufacturing follow by a quantitative analysis using a Bayesian network statistical approach

Supervisor

Prof. Maurizio Galetto

Graduand

Elisa Zanella

April 2018

Abstract

The complexity of the information flow between functions in product development and industrialization phases influences lead-time to customer and safety margins that are increased in order to prevent the risk of failure.

The information flows are not the main priority of the organizations because it is easier to focus on something tangible like the main value stream and nobody is responsible directly for it. The information flow is also intangible, hard to identify. It contributes to increment the variation in the welding process resulting in larger safety margins.

In this Master thesis, the author did a qualitative and quantitative analysis. The first one has the purpose of mapping the actual flow in two companies, Volvo CE and HIAB, in order to identify the bottleneck of the information system. The second one has the aim to understand, through a statistical approach represented by the Bayesian network, how the risks of failure affect the manager decisions on budget and resources allocation.

Acknowledgments

I would like to thank everyone that helped me and supported me during these five years at Politecnico of Turin and during my two great Erasmus experiences in Brazil and Sweden.

First of all, I want to say thank you to my Professor Maurizio Galetto for the big opportunity that he gave me, permitting to do my master thesis in Gothenburg, at Chalmers University, in Sweden. It has been a challenge that I faced up also with the help of my co-supervisor Peter Hammersberg. He was always there when it was necessary and he addressed me in the right direction every time I was going off track. Both my professors have been an important and constant point of reference for me: Thank you again.

I want also to express my gratitude to the two organizations, Volvo CE and HIAB, which hosted me several times in their meetings and plants, it has been a big moment of growth and I had the opportunity to touch with hands what happens in a real working environment.

I would like also to thank you, my roommates, Ida, Alejandro and Pantro for the enjoyable days that we spent together in Sweden. They were very kind to me and I will never forget that.

The last, but most important thanksgiving, goes to my family that supported me in this long journey made of obstacles and hard moments and without which would has been impossible to achieve this important goal. If I am an engineer is especially thanks to you mum, dad, my brother Simone and my beloved grandparents Ida and Emo. I love you all.

Elisa Zanella

Turin, April 2018

Ringraziamenti

Vorrei ringraziare tutti coloro che mi hanno aiutato e supportato durante questi cinque anni di studio trascorsi al Politecnico di Torino e durante le mie due meravigliose esperienze Erasmus in Brasile e Svezia.

Innanzitutto voglio dire grazie al mio Professore Maurizio Galetto per la grande opportunità che mi ha dato, consentendomi di elaborare la mia tesi magistrale a Goteborg, nell'Università di Chalmers, in Svezia. E' stata una sfida che ho affrontato anche con l'aiuto del mio co-supervisor Peter Hammersberg. Lui c'è sempre stato quando ne avevo bisogno e mi ha sempre indirizzato nella giusta direzione ogni volta che perdevo la retta via. Entrambi i miei professori sono stati un importante e costante punto di riferimento per me: Grazie ancora.

Voglio anche esprimere la mia gratitudine alle due organizzazioni, Volvo CE e HIAB, che mi hanno ospitato diverse volte nei loro stabilimenti e che mi hanno consentito di partecipare a diversi meetings: è stato un grande momento di crescita, in cui ho avuto l'opportunità di toccare con mano cosa succede realmente in un ambiente lavorativo.

Vorrei anche ringraziare i miei coinquilini Ida, Alejandro e Pantro per i piacevoli giorni che abbiamo trascorso insieme e che hanno allietato il mio soggiorno svedese. Sono stati molto gentili e disponibili e questo non lo dimenticherò mai.

L'ultimo, ma più importante ringraziamento, è per la mia famiglia, che mi ha supportato in questo lungo viaggio fatto di ostacoli e momenti difficili e senza la quale sarebbe stato impossibile raggiungere questo importante traguardo. Se sono un ingegnere è soprattutto grazie a mia madre, mio padre, mio fratello Simone e i miei adorati nonni Ida e Emo. Vi voglio bene.

Elisa Zanella

Torino, Aprile 2018

Table of contents

List of tables

List of figures

Chapter 1

Introduction

1.1 Background

The idea of this study came from a previous PhD thesis, *Predictability – an enabler of weld production development*, realized by Anna Ericson Öberg. According to what she says, the majority of the factories use a push approach for communication instead of a pull approach, based on decision/information need (see Figure 1). In the latter, the starting point is represented by one decision that needs to be made instead of a data push procedure. Typical characteristics of a push versus behaviour to are:

a) Push approach can be synthesized with this sentence "Make all we can just in case". The consequences of this method are represented by a high inventory because the information of production comes from the management and not the customer. The communication between the different functions is poor and the management's purpose is keeping active the production cycle without considering the customer's demand;

b) Pull approach can be synthesized with this sentence "Make what's needed when we need it". It is focused on fulfilling the customer's requirements and allows to realize only the amount of products requested by the customer's demand without having big warehouses that are useless and represent immobilized money. This philosophy agrees with the just in time theory that wants to create flow, reduce production's wastes and improves the cooperation and communication between the different business functions from the value stream perspective.

The second approach also increases the information accuracy because the operation times are decreasing together with the setups between the different working phases. The model is simple, the only disadvantage can be represented by the fact that diverse types of presentation of the same problem are requested because every actor into the production chain needs a different kind of information and because there are many a prioritization between them has to be made in order to customized the data for the most significant ones.

The main benefit of the pull method is that the focus is to give the right information to the right person in order to improve the decision-making process and reduce the sources of variation into the process, which is to identify what information can be standardized. In addition, this technique can adapt to fast changes and for the motivation, it is more difficult for the competitors to copy, in fact, the way of acting of pull approach is similar to agile processes, because the company has to be able to react to the changes quickly to be "on the market".

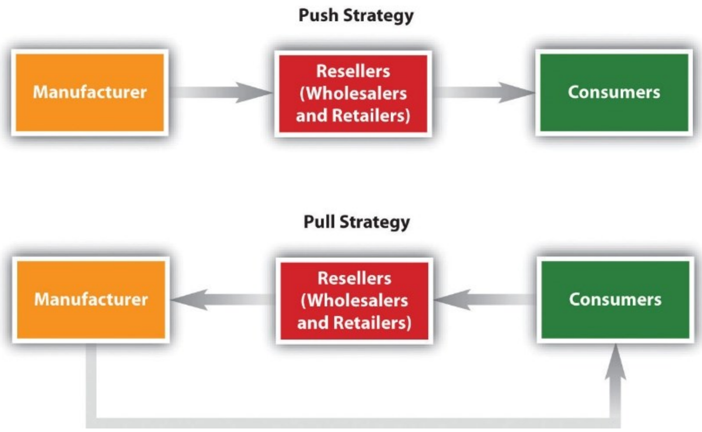


Figure 1 - Push vs pull strategy (diytradenews.co.za)

The information's role in the factory is very important for making a better decision and can lead to many unwanted consequences; for this reason is particularly relevant, the process with the information is acquired and transmitted. It is also essential to understand that not all the actors in the organization need the same type of data. If let think to the manufacturing process it is obvious that the welder and the CEO need two different types of information that have also to be presented in two different ways because they have two kinds of knowledge and needs to take two different kinds of decisions. The first needs to know how he has to weld the component, while the second one needs to know how the production process is going.

The lack of the correct information can also introduce variation into the process that at the end does not realize a product able to satisfy the customer's requirements. If the right data does not reach, the exact person to whom is destined, sources of variation can be introduced into the information flow and the process at the end can produce a product that does not satisfy the customer's requirements. 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 realizing these products is long, many different people are involved and numerous parameters have to be transmitted from one phase to another. If the information flow is handled in the right way, the companies will have certainly a competitive advantage over the rivals. In fact, if the firm is able to control the flow at the same time is capable of perceiving the variations into the process and she can intervene as soon as possible to avoid re-works, a process quality decrease, or a productivity fall.

Nowadays because of the global competition, the firms are rivals and try to reach first the market reducing the time to market and increasing the flexibility focusing on technology's improvement instead removing the organizational issues such as the lack of communication between functions and the absence of a standardized company language. These last ones are the most difficult to eradicate because they lead to structural changes into the factory even though they permit to save a lot of money. The technical issues, on the contrary, can be easily solved with innovative technologies but they demand heavy investments.

Cohen argues that the ability of a firm to recognize the value of the information, assimilate it and apply to commercial ends it is critical to its innovative capabilities. In fact, if the flow is not controlled the consequences are represented by uncertainty and equivocality. The research, *The Influence of Correct Transfer of Weld Information on Production Cost*, made by Anna Ericson Öberg, shows that the information has also a large impact on cost as well as weld quality because in the short term affects the production expenses while in the long term is crucial to enable the process and product development.

Let consider now the factory as a system and the workers like actors of the system, it is easy to understand how everyone acts on it. Each person tries to do his job without fully bearing in mind the influences that the particular operation that they are realizing has on whole systems ability to fulfill the customer's requirements. In this way, everyone attempts to maximize his functions performance and doing this adds "safety margins". Let take the Volvo's wheel loaders in-house fabrication process of wheel loader frames, for example. This procedure can be divided into the following big phases: Kitting, Welding, Painting, and Assembling. If in each one, the worker adds a safety margin to be sure that the component respects the tolerance imposed by every step, there is the risk, at the end, to realize a final product that is over-produced and does not satisfy the features required by the customer, particularly crucial for single sided tolerances. That happens because everyone has a limited vision connected to his job only and tries to optimize that. In many cases, there is lack of cooperation between functions and employees' due to absence of standardized information that makes it difficult to develop a common language connected to the value stream performance. These two aspects, called also soft issues, have to be considered as important as technical ones because they have an impact on factory's costs. Even though managers understand the benefits of creating a common language it is difficult to find the time and prioritize it in the daily flow of events of full operations, preventing the organization to invest the time needed to avoid misunderstandings that lead to reworks and increase industrial costs. This way of thinking is the same that is used in the "firefighting approach". The firefighting is based on trying fixing a problem without understanding the real causes that originate it. A clear evidence of firefighting is this: a machine is broken and loses oil, the worker will clean the floor instead understand why the machine is broken and this happens because the world of every employee is the workstation and not all factory. It is for that reason that it is important having an overview of what happens in the manufacturing process and how every action will influence the final good and that can only be realised through a common language.

The information has to be cross-functional and has to be understood correctly but this is possible only if the language spoken is the same because an incorrect use of data tends to lead to over-production and adding safety margins in every production step. At the moment, the language that everyone into the factory is able to understand is linked to "money" but it is not enough because every department has his own definition of, for example, weld quality, using different nomenclature and uses slightly but different metrics. At the same time, the "money- language" is the general driver that is the starting point for a cross-functional dictionary and a standardized way of working in all different production chain's departments for solving problems together. If managers as follows to their workers: "Do the job in this way because we will reduce the production costs of five percent". In this sentence, it is clear that the manager does not explain anything on the causes that lead to this change.

The unbundled vision between the different functions highlights that the knowledge needs to be shared to develop a common business culture. If some workshops are realized into the factory with the purpose of spread a common knowledge lots of problems for sure would be eluded, and many re-works would have been avoided, saving money that could have been spent in another, more productive way.

Furthermore, it is important the meaning of the word "trust" into a company. If everyone believes in the job that he is doing and what his colleagues are doing, everyone is committed to reaching factory's goals. The top management is the one with the main responsibility in creating that kind of culture because is the one that needs to be the coordinator of the different business functions and it's the only one that can be the link between them. It is easy in fact to transfer the responsibility to another department and so on, but doing this the problems are pushed to a lower level that at the end is represented by the factory's workers. An analyse the information flow is also important for changing the actual behaviour of the production chain that tends to blame someone for the process variation instead of understanding what went wrong into the communicational flow, which results in focusing on handling the symptoms instead understanding and elimination of the problem's causes. This attitude leads the workers to add safety margins because they do not want to feel guilty or responsible for anything. A common guiding principle in Lean Manufacturing is "correct from me", but the result of it can be counter-productive if it not also is firmly connected to the principle of a pulling system.

In conclusion, it is important understanding not only the type of information requested and by whom it is wanted but also present it in the right way, using the correct instruments. The control charts, for example, are very useful for understanding how the process is operating, analysing if the operation or process is stable or not. Many factories use this method on low level for machine monitoring, but not as often for communication and decision support on an elevated level in favour than an immediate, but less informative one represented by the bar charts. The control charts, in fact, are the tool that permits to look at the variation in a standard way between the different functions and that helps improving the decision-making turning the joint focus from consequences towards up-stream causes reinforcing a long-term development of business' goals. Knowing if a process is stable or not is of fundamental importance because the actions that have to be taken in one case or another are different. A standardized process can be considered stable and predictable if the average is constant and the variability can be controlled because it is caused only by noise factors. On the contrary, a process is unstable when both average and variation change and there is the possibility to see on the control charts some visible signs, the outliners, showing those shifts because they are outside the control limits. Categorizing the type of process helps also to understand how to handle it also because the responsible for is on a different level, in an unstable process the shop floor level is involved while in a stable the top management needs to take actions. In addition in an unstable process, the cause of variation is unpredictable and can be identified and removed because is not intrinsic into it, while in a stable to eliminate that the total procedure needs to be changed, using a new equipment or adopting a different technology.

1.2 Purpose

The project in which this thesis wants to contribute is called Varilight (from 2016 to 2019). The participants are both from Industry (Volvo CE, Bromma, SSAB, HIAB, and Svetskommissionen) and Academy (KTH and Chalmers University). Its purpose is reducing the variation in the manufacturing process enabling lightweight welded structures for construction equipment. This project is focused on realizing vehicles with less environmental impact by decreased fuel consumption, material usage, and production resources and by an increased payload. The aim is also diminishing the time production and the cost through the weld reduction. For doing this, I mean dropping the environmental impact and growing productivity decreasing lead-time, the source of variation needs to be mapped and studied in order to control the process' stability and predictability. The mission is developing recommendations and guidelines for the manufacturing process and designing procedures with larger accuracy and reduced scatter. The project was divided into different work packages that are the following:

- WP1_Project Management: plan, follow up and coordinate the project work
- WP2_Production: identify sources of variation in quality and productivity in weld production
- WP3_Cutting: study the influence of variation in cutting on surface roughness and fatigue strength
- WP4_Fatigue Testing: study the scatter in the fatigue results. Identify sources of variation within the different quality levels
- WP5_Residual Stresses: study formation and variation of residual stresses and relaxation. Develop fracture mechanical models or crack growth analysis
- WP6_Load Analysis: map the variation in the load estimation. Identify the sources of variation in order to assess accurate factor of safety for the load
- WP7_Ensamble WP2-WP6: improved understanding of the entire value stream from load estimation to final assessment

The thesis' purpose is to contribute and support the work package seven, particularly focusing on the problems related to the information flow into the phases of developing and manufacturing. The aim is understanding the structure of the information that every actor into the chain needs to receive and deliver, in order to realize at the end a machine that fulfils the customer requirements and see, if something goes wrong into the flow, what are the sources of variation and which are the consequences on the final product.

The machines used as construction equipment object of study are the wheel loaders, produced by Volvo CE (Figure 3), and the loader cranes realised by HIAB (Figure 2).

Figure 2 - Loader crane (HIAB) **Figure 3 - Wheel loader (Volvo CE)**

1.3 Problem definition and research questions

The information flow, together with the physical one, creates many variations in the development and industrialization process of the heavy vehicles but, while the second one is tangible and easier to control, the first one is intangible and subjected to be different each time that something unexpected happens in the system. A material flow is always the same because it is based on machines and standardised working operations, while the information flow varies a lot because it is created by humans that communicate not following always the same procedures and not using the same language each time. As consequence, not having a standardised process in the information stream leads to increase the lead time for the customer, the machines will be delivered later and the production times will be bigger. Before understanding and later managing this flow in the proper way, is fundamental for saving costs, decreasing the presentation on the market of a new product and to diminish the safety margins that the organization introduces not betray the customer timing expectations but that it does not really know where they come from because they are intangible. Acting in this way means not trying to solve the cause of the problem but only focusing on the effects without really paying attention to the information flow process. Going more into detail, this was the author starting point (see Figure 4):

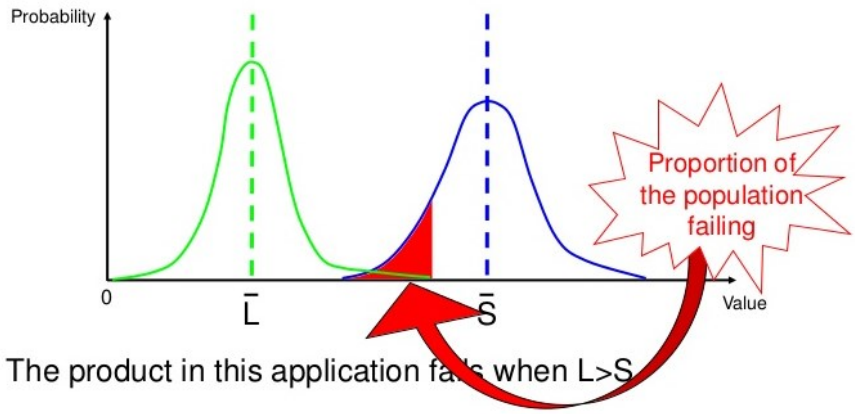


Figure 4 - Load and strength model (slideshare.net)

The curve on the left is under the control of the customer and indicates the load applied to the machine by him, the curve on the right, instead, is the strength of the final product so the load that the machine can carry according to the factory specifications. The last one is the result of the development and industrialization process in the organization and it is the only one on which it can act. Of course, if there is an overlapping between the two curves there is a failure. The variance of the strength distribution is created both by the physical and information variations, this means that, if the information flow is studied, the variance can be reduced.

The author decided so to analyse this stream both from a qualitative and quantitative side. Before used a Lean thinking to figure out how the information flow is actually working, mapping it, and later understood, through a statistical approach represented by the Bayesian network method, how the risk of failure changed if the process is wrong somewhere.

The author wanted to expand the problem through these research questions to which she will answer in the report:

- ***RQ1***: *Is the welding developing and industrialization process influenced by the actual information flow functioning?*
- ***RQ2***: *How can the lead-time to the customer be decreased by a better resource working allocation?*
- ***RQ3***: *How the risks of failure knowledge affects the budget usage in an organization?*

1.4 Restrictions

The author introduced some boundaries and delimitations in her researches. The main restriction adopted is represented by having studied the information flow only in two factories that are Volvo CE and HIAB. This means that the same conclusions, to which the author came up with, cannot be generalised in other similar contexts because maybe, even if the fabrication and assembly process is the same, some significant differences in the information flow can lead to different results. On contrary, the procedure can be reused in similar working processes without problems.

1.5 Structure of the thesis

The thesis will be organized in the following way:

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

The author will present the problem object of analysis in the introduction. Later in the chapter second and third will explain the methodology and the theory used to come up with the findings written in the following section. The shreds of evidence, at that point, will be before analysed, with the help of the theory described before, and later discussed, in order to come up with the conclusions exposed in the last chapter.

Chapter 2

Methodology of research

2.1 Research approach

The research approach is the procedure with the author conducts the research and according to Bryman et al 2014, can be qualitative, quantitative or mixed (qualitative and quantitative approaches are used together). The author chose a qualitative approach for supporting her researches because the purpose is mapping the different sources of variation from an information point of view, so non-numerical data represent the object of analysis.

Gubrium and Holstein (1997) identify four different types of approach to the qualitative research:

- Naturalism tries to understand the reality how 'as it really is';
- Ethnomethodology wants to learn how 'the social order is created through talk and interaction';
- Emotionalism is based on subjectivity and this can mutate the way with the reality is perceived;
- Postmodernism is influenced by 'method of talk' and this changes how the reality is reproduced;

The qualitative approach, used for the thesis, is the first one; in fact, the author, through interviews with the different actors working into system studied, wants to capture the sources of variation that make the welding process not completely stable.

2.2 Research strategy

The qualitative approach usually entails that the strategy adopted is the inductive one, and this is the author's case. According to Bryman et al 2014, the relationship between the theory and the findings can be deductive or inductive. In the first case, the theory leads to the research results, while in the second case the findings and observations are the starting point to build a theory. It is important to underline that this relationship is not so strict and does not go just in one direction, because, in the inductive procedure, the theory is a sort of background always present in the writer's mind. In fact, the lean tools and principles are been used by the author to support her research and analyse the data collected. The concepts of constructionism and interpretivism play so a fundamental role in the inductive process like highlighted by Bryman et al 2014.

2.3 Research process

The research process, adopted for collecting and analysing data, follows the one suggested by Bryman et al 2014 for a qualitative approach to the problem. The scheme, in Figure 5, summaries it.

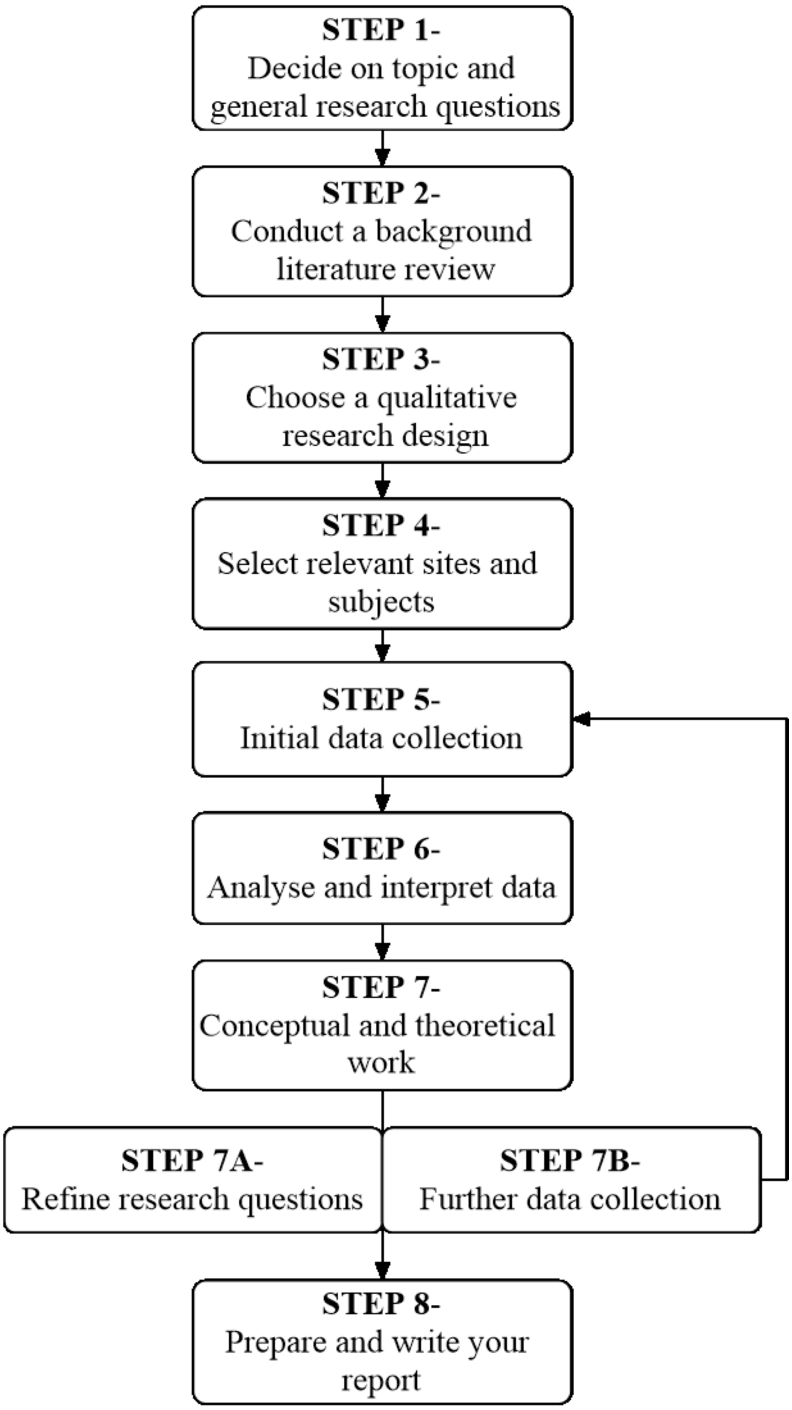


Figure 5 - Research process (Bryman et al 2014)

STEP 1- Decide on topic and general research questions

In author’s case, the main topic, the weld, was given by her supervisor, but the focus of her researches was decided by herself after learning more about the meaning of Varilight project and its goals. Then, thanks also a literature review, she chose the research questions, modified different times according to her findings. During the interviews, in fact, new issues do not even considered before, come up, showing that the source of the problem was elsewhere she though at the beginning.

STEP 2- Conduct a background literature review

The author, before starting her researches, read many books and articles on the welding topic to understand the process along with its problems and make out which themes are already been studied in the literature. Ph.D. thesis, written by people directly involved into the process analysed, books and articles given by writer's supervisor or found in Chalmers library, together with the academic articles searched on Google Scholar and Google Scopus are the materials consulted that contributed to building the author's background on welding. In addition, discussions with her supervisor lead to clarify her doubts on papers read and to amplify the knowledge on the topic thanks his big experience accumulated in numerous projects in which he has been involved.

STEP 3- Choose a qualitative research design

The research design indicates the framework used for collecting and analysing the data. Because the approach is qualitative, according to Bryman et al 2014, there are four different types of framework that can be used and in order are the cross-sectional design, the comparative design, the longitudinal design and the case study design. The one, adopted in this research, is the last one. In fact, as Stake 1995 said, it is the most useful and practical way to work when the topic is very difficult to study and it is necessary to go in depth.

The case study, in this case, concerns the welding into heavy vehicles, in particular, will analyse the developing and manufacturing process that leads to the realization of the final product that is the wheel loader for Volvo's factory and the loader crane for HIAB's factory. Every case study, as in this case, usually starts with some assumptions that define the system's boundaries.

STEP 4- Select relevant sites and subjects

Before starting the data collection, the author discussed with her supervisor from where begin. The interviews were the only method available to learn first how the system works, and later all the sources of variation in it. For this reason, only people directly involved in the process were selected for the interviews.

STEP 5- Initial data collection

The interviews adopted in this study, for gathering the information needed, were unstructured interviews because the author had to know as much as possible by the respondents in order to create, at the same time, a proper background for her researches. The interviewees were chosen with attention from people directly involved in the process. A certain consecutio temporum between each interview was used and every one took place in different weeks so the writer could reflect and had the time to come up with ideas, suggestions, questions, and doubts. They were done into the factories where the people work, so there was the possibility to look at the process, to get a factory tour where the interviewee explained how the process works and the author could ask questions if it was necessary. All the interviews took place vis a vis because in this way possible misunderstandings can be avoided through the use of additional explanations to words: manual drawings and schemes supported the discussions. The direct communication was preferred to Skype or telephone because, even these channels are less expensive and easier because they require less time, have some limits. First of all, there is not the eye contact during the discussion and the interviewer does not have the possibility to analyse the respondents' facial expressions that could demonstrate a sign of uncertainty or confusion or distraction. Thanks to a face to face, there is the chance to get the feeling of interviewee's thoughts but, as stressed before, the vis a vis procedure requires more money. In this study, every discussion was conducted outside Goteborg, that it is the writer living and studying city, and realised into the respondent's working office for making them feel more comfortable and for permitting them to come back to work if something important happens into the factory. The location also allowed more times for the respondents to specify their words with documents that they could not show through Skype because are private contents. Skype was used just one time to clarify some author’s doubts but both she and the respondent already shared a common language and there was not the risk of contaminating the results.

That is the summary of the interviews (Table 1):

NAME INTERVIEWEE	DATE INTERVIEW	LOCATION INTERVIEW	ROLE INTERVIEWEE
Svante Widehammar	02/11/2017-03/11/2017	HIAB	Structural Mechanics Engineer at HIAB
Erik Astrand	14/11/2017	Volvo CE	Weld Engineer at Volvo CE
Hasse Olsson	05/12/2017	Volvo CE	Weld Engineer at Volvo CE
Kim Ranheim	06/12/2017	Volvo CE	Robot Programmer Engineer at Volvo CE
Yang Shin	13/12/2017-19/12/2017	Vaxjo library Skype	Designer Engineer at Volvo CE

Table 1 - Summary of the interviews

The unstructured interviews, as stressed before, were adopted because, respect the structured or semi-structured ones, they give a large freedom to both the author and interviewee, who feels free to talk how much he wants. Thanks to this ‘freedom factor’, the discussion can stimulate curiosities into author’s mind who can decide to do another interview. The discussion topics were before identified and were discussed in detail with the respondent, following an order not decided before starting the interview and different from one interview to another, because the author does not want to stop the natural discussion flow. The ‘questioning style’ (Bryman et al 2014) is informal and the ‘phrasing’ changes from one interview to another but the topics argued are always the same. Sometimes the respondents raised issues not before considered and the interviewer chose, every time was necessary, to dig into them more. In fact, in this kind of gathering data procedure, the researcher is interested in respondents' thoughts and considerations because they are an integrated part of the system studied. The important is that the respondents share a common language for not influencing badly the partial and total results. Each one has to talk the same language for avoiding misunderstandings linked to the meaning of certain terms, but that is interviewer’s responsibility to homogenize and standardize the terms giving them a proper meaning not object of mistake. Before starting a discussion the author explained recurrent terms, in order to prevent communicational errors and at the end of a topic discussion summed up the contents for being sure of understanding correctly. In addition, all the findings were shown to the respondents and explained at the beginning so the interviewee was into the condition to add or point out or correct something. This behaviour was necessary because each respondent talked about the process of developing and manufacturing but he is not involved into each phase of the process and there was the risk that his rough picture of what happens in some points falsify the exact reality. Notes were taken during the discussions through drawings, schemes, diagrams, bulleted lists that were enriched later, as soon as the writer had the time for forgetting nothing of important, according to respondent's words. The questions and topics were shown just on interview's day and not before, except one case, because the respondent felt more comfortable knowing them before for answering in the most detailed and appropriate way as possible.

To sum up, the author tried to follow these ten criteria suggested by Kvale (1996) for being a good interviewer:

- Knowledgeable: the researcher has to know the topic of discussion and study it before, so he can be an active part of discussion;
- Structuring: the researcher has to guide the interview and transmit his final goal; in fact, only if both are on the same boat an empathy might born between them and the respondent is more and more involved into research;
- Clear: the researcher has to talk in a comprehensible way, making sure that the respondent gets the point of discussion. For reaching this goal, he can repeat a concept more times in different ways using the same meaning or adopting easy words which are part of the common language;
- Gentle: the researcher has to be kind, let other people talk, reflect, and he has to speak only when the respondent has finished his speech;
- Sensitive: the researcher has to read the facial expressions and body language to get the respondent's feelings and sensations;
- Open: the researcher has to be 'flexible';
- Steering: the researcher does not have to lose the research focus. It's fundamental listening but not being absorbed by the digressions is still more important;
- Critical: the researcher has to show the inconsistencies of some affirmations given sometimes by the respondents;
- Remembering: the researcher has the role of keeping in mind all the topics treated in order to make the right connections from one to another;
- Interpreting: the researcher has to 'extend the meanings of interviewees' statements' in order to avoid misunderstandings.

STEP 6- Analyse and interpret data

The strategy, used for analysing data, is the analytic induction. The scheme below, Figure 6, explains how this procedure works. First of all, it is an iterative process that starts with a rough definition of the research questions, just to follow a direction in the first data collection. After that, the first analysis checks if the findings confirm the hypotheses previously elaborated. In the negative case, the research will go on until no deviant cases from the hypotheses will be found. In fact, a theory is a truth only if there are not contrary cases.

In order to interpret and studying the data as best as possible, the author followed the Yin's suggestion (Bryman et al 2014) of writing a case study database with:

- Notes written during the interviews, factories visits, discussions with author's supervisor, and books reading;
- Documents shared by the interviewed people to help the author's understanding;
- Tabular materials, shared by the companies involved in the process, such as archival data;
- Narratives written by the author as a commentary on research findings and results. They were used, then, to draw up this report.

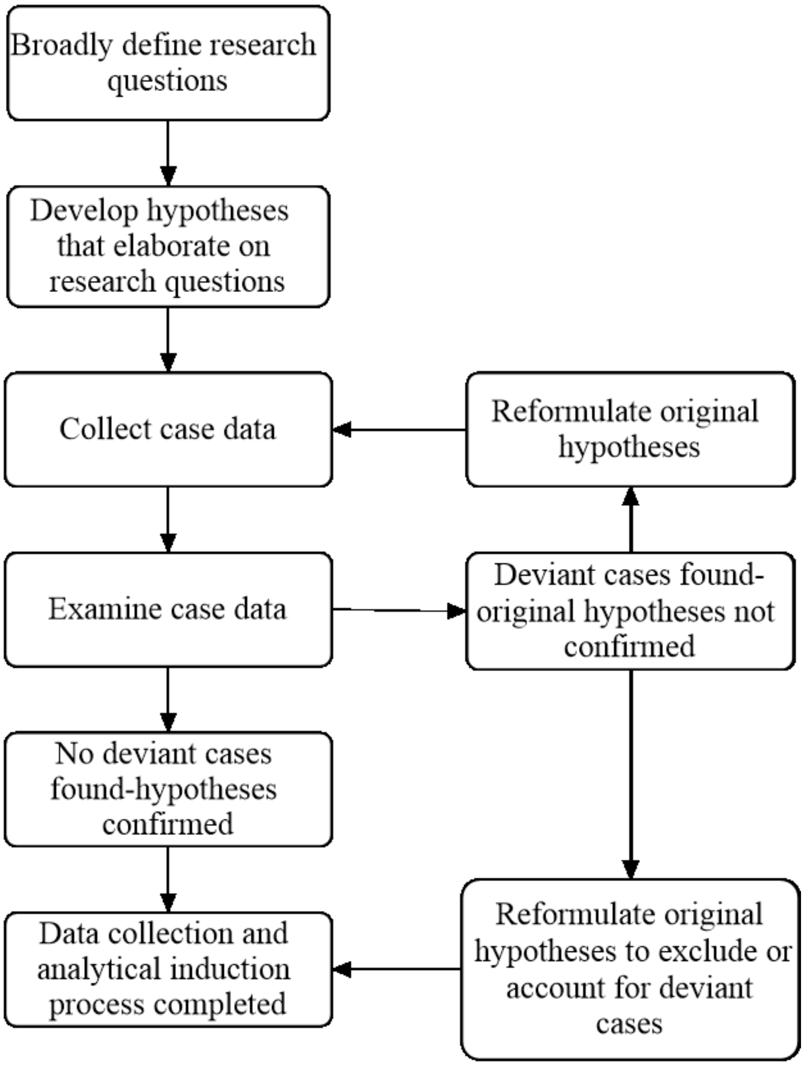


Figure 6 - Procedure for analysing and interpreting data (Bryman et al 2014)

STEP 7- Conceptual and theoretical work

The author, in this phase, has to analyse the data using theory and tools coming from the literature (see Chapter 3_Theoretical Framework).

STEP 7A- Refine research questions

STEP 7B- Further data collection

STEP 8- Prepare and write your report

2.4 Research quality

The research quality of a qualitative approach can be evaluated (Lincoln and Guba 1985, Guba and Lincoln 1994) through two criteria that are the following ones:

- Trustworthiness
- Authenticity

The first one can be divided again into four criteria that are credibility, transferability, dependability, and confirmability. The author, to prove her results, adopted, during her work, all these criteria which are explained more in detail below, according to Lincoln and Guba studies.

Dependability: the researcher should adopt an ‘auditing approach’ in order to witness the truth of his findings. In fact, in each step of the research process, since the problem formulation, the author used notebooks to write her considerations, thoughts of the people involved in the process, results interviews. Doing so, at the end the researcher is able to assess the report quality degree.

Confirmability: because of it is very difficult to be objective in a qualitative research, the writer has to show that the procedure of collecting and analysing data was not been influenced by beliefs and bias present in author’s mind and that another person would have reached the same conclusions.

Transferability: the researchers' description has to be ‘thick' because, in this way, the contents could be applied in another context or to similar working environments by other people.

Credibility: the author’s credibility has to be strong, otherwise his researches will not be accepted. The degree of acceptance can be incremented by ‘canons of good practice’ and by ‘respondent and/or member validations’. The last one happens when, as in author case, the partial and total research results and findings are shown to the people part of the system studied. At the beginning of every interview, the author explained the partial results to each person, who had the role of listening and correcting possible imperfections, adding, at the same time, if necessary relevant information for the studies.

Authenticity: the findings have to be ‘genuine and original’ in order to be used. They do not have to present results that are already part of the business literature. For this reason, the writer, before starting her research, consulted the literature already known.

It is also important adding that, for respect in the best way these criteria, the Sen. Lec. Peter Hammersberg chose for conducting this research, a person who was completely outside the system studied but, at the same time, with a proper school background for understanding the problem and influencing the results as less as possible.

Chapter 3

Theoretical Framework

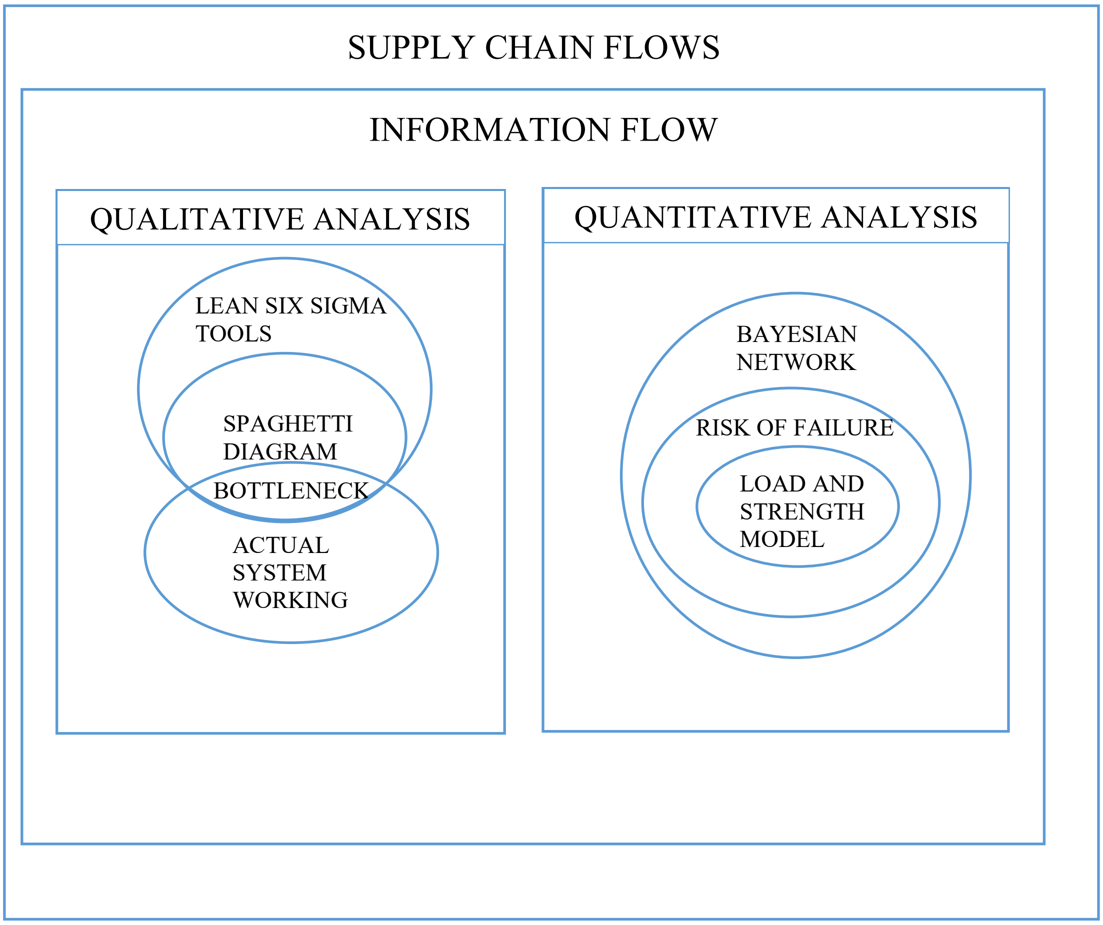


Figure 7 - Summary of the theoretical framework used

3.1 Qualitative Analysis

3.1.1 Bottleneck definition

There are several definitions of the word bottleneck in the literature (Roser, C., Lorentzen, K. and Deuse, J. (2014)). These ones are the most explanatory:

- Krajewski et al. define it as a " function that limits the output"
- Chase and Aquilano identify it with "a resource whose capacity is lower than the demand"
- Roser et al. say that it is "the stage that slows down or stops the entire system"
- Kuo et al. affirm that it is "the machine with the lowest production rate of all system"
- Kuo et al. say that it is "the machine with the largest buffer"

- Kuo et al. define it as "the machine with the highest production rate" because it is always working if it stops all the system will stop as well
- Christoph Roser, Kai Lorentzen and Jochen Deuse joint some definitions before cited and define it "as a process that influences the throughput of the entire system"

The consequences created by a bottleneck in the system can be of two types and both lead to delays, higher lead-time to the final customer and higher costs:

a) Blocking: the process has to stop because the following buffer is full;
b) Starving: the process has to stop because the previous buffer is empty.

When the bottleneck is identified in the system, at that point, is possible to reduce the effects that it creates in the production. Manufacturers usually use these three approaches:

1) Elevate the capacity of the current bottleneck: the factory hires new personal if the work is manual, otherwise buys new equipment or machines. It might also decide to automatize the process. If the bottleneck, instead, is not present always in the system but it occurs only for a limited period during a year, it can choose to subcontract workers, for the temporary over-allocated resource, in the period of highest demand;
2) Sell the extra capacity of the other production steps: align the capacity of all production steps to the capacity of the bottleneck;
3) Cut off the extra capacity: this operation aligns again the capacity of all production steps to the bottleneck.

3.1.2 Flows in the supply chain

The supply chain, for the realization of the final product, is made up of the following four steps, supply, manufacturing, distribution, and consumption.

In the supply chain can be identified five main flows that are the physical or material flow, the information flow, the risk flow, the value flow and the financial flow. Each one has a different direction as the picture below, Figure 8, shows:

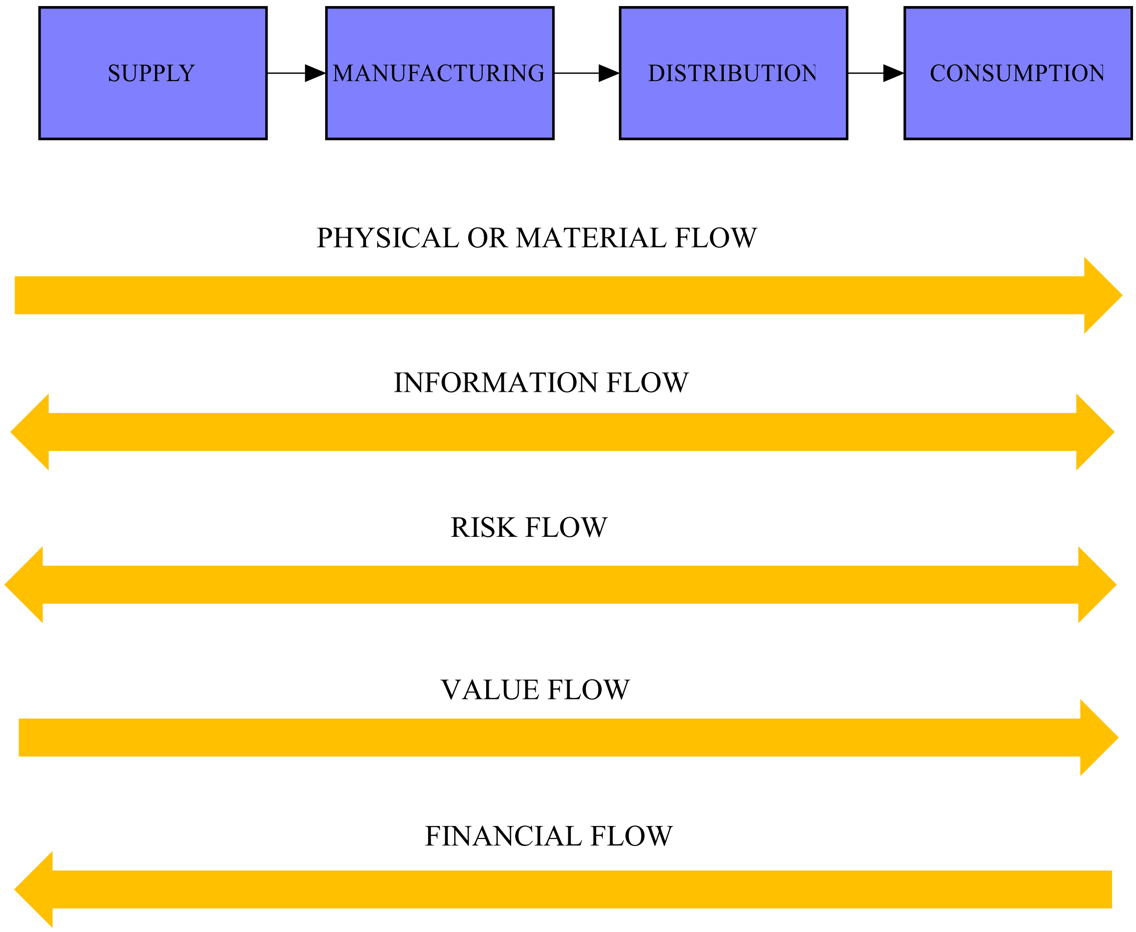


Figure 8 - Several flows in the supply chain (https://kpakpakpa.com/spotlight/the-three-flows-of-supply-chain)

The first one is the most known and easier to think about in the production process. In fact, it is tangible and visible: the raw materials, brought from the suppliers, enter in the factory for being before manufactured and later distributed, by the same factory or another one, to the final customer. This flow is unidirectional and goes always downstream, except in special cases. If some mistakes happen in the supply chain, the product has to be fixed for satisfying the customer requirements and the flow can assume unconventional directions.

The second one is harder to identify first of all because is intangible and secondly because it is not standardised, if the actors of the system change, the flow changes as well even if the role held by the new people is the same of the previous ones. In fact, even if the procedure of transmitting the data is standard and most of the time happens through informatics systems, the human factor influences it considerably through the words used. For this reason, it is very important to implement a vocabulary between the different functions and departments of the production system. This flow goes in both directions and back and forth from the several actors of the chain.

The third one catches all the risks that can affect all process. They are of two types, internal and external. The first ones are under the factory control because it has the possibility to prevent them, and they are for example:

- Manufacturing risks: process interruptions because of machine breakage or human errors;
- Business risks: mistakes created by changes in personnel or working procedures;
- Planning risks: inappropriate planning because of inadequate management;
- Mitigation and contingencies risks: lacking financial coverage because the management did not set the contingency aside.

About the external ones, that are not under the factory control, the most frequent are:

- Demand risks: born from misunderstandings with the customers or from unexpected changes in the demand;
- Supply risks: delays in supply of raw materials;
- Environmental risks: problems created by the weather or natural events like earthquake;
- Business risks: originated from financial inconsistencies of some actors in the process;
- Physical risks: problems with equipment in any steps of the supply chain.

The fourth one follows how the value is created in the different phases of the process. In each step is added value to the product through a physical transformation most of the time or simply adding services, such as marketing.

The fifth and last one flow is again unidirectional from the customer to the supplier but this time is upstream. It follows how the payments are done for covering the costs that, instead, go in the other direction, from the supplier to the final customer. The difference between the incomings and outgoings represents the working capital.

3.1.3 Managing the bottleneck concept in the information flow through lean six sigma tools

The author of this study focused the attention on the information flow from two different perspectives, a quantitative approach, and a qualitative approach. For the last one, she used the Lean Six Sigma tools for identifying the bottleneck into the welding developing and manufacturing process, capturing the different information of the system.

Lean six sigma is a combination of the Six Sigma and Lean visions, the first one based on quality, process variation and defects, the second one on speed and wastes. Both of them contribute to improve the business process and they act together, it is not possible having one without the other if significant positive changes in the factory performances are wanted.

The Six Sigma methodology desires to improve business processes eliminating the mistakes that can create some defects in the final product. The target is having 3.4 defects every one million opportunities and to reach that, the process has to be split up into several parts for trying to improve each one. To grasp that target, before mentioned, the process variation coming out from the manufacturing phase has to be of six sigma. Through an indicator of process performance, called capacity of the process, there is the possibility to check how the process is going. The index is the following one:

$$Cp = \frac{TN}{2} * n * \sigma$$

The expression compares the range of tolerances of the target chosen for a certain process and the deviation standard of the same one already multiplied for the number of times that σ is included in TN, in this case, n is equal to three. If this number is close to one, means that the process is capable, under statistic control because all the variability of the process is included in the limits, otherwise, the process is incapable. Conventionally the limit value is put close to 1.33, meaning that the ex-ante tolerance before settled up is bigger than the ex-post tolerance coming out from the process.

The Lean methodology, instead, is based on reducing the amount of time between activities in order to reduce the total production time and increase the quantities of units realised in a cycle, improving at the same time quality and customer satisfaction. Another fundamental Lean's belief is reducing the wastes in the process, particularly it wants to remove the following ones:

- Waiting: each part of the final product does not have to wait to go to the next production step, the lean is based on the concept of the "just in time theory", the piece arrives only when the next step needs it and not before;
- Overproduction: produce only the amount of products necessary to fulfill the market demand and not more, in order to not build inventory;
- Reworks: try to make them small in time and cost, detecting the defects as soon as possible and setting the machines in the right way to avoid them;
- Motion: reduce the movement of people and products in the factory organizing the layout in the most functional and practical way of avoiding wastes of time;

- Over Processing: select only the data and information useful for the production process, leaving out not important ones;
- Inventory: the level has to be as low as possible because products stocked in warehouses could become obsolescent, could be not sold and they are not liquid cash;
- Intellect: use the factory knowledge when it is necessary and in the right way;
- Unnecessary transports of people, raw materials, parts or total products.

The aim of the Lean Six Sigma is well captured in the following image, Figure 9.

Figure 9 - Lean Six Sigma thinking (www.circle6consulting.com)

The Lean Six Sigma, in order to succeed in its purpose, has different tools; one of them is the spaghetti diagram used for capturing the bottleneck of the welding process from an information point of view.

3.1.3.1 Spaghetti Diagram

The spaghetti diagram, also known as spaghetti chart, usually is used first for catching the distances travelled by humans, parts or final products into a repetitive working environment and later for analysing the results with the aim of deleting wastes of time, energies and unnecessary movements, changing the factory layout for instance. In this way, the current situation is first identified, later it is optimized and finally, it is checked through the

Deming cycle of Plan-Do-Check-Act. The figure below, Figure 10, shows an example of spaghetti chart.

Figure 10 - Example of a spaghetti chart (allaboutlean.com)

In this study, as already said before, the author chose to use the diagram in this way: the spaghetti indicates the incoming and outgoing information from one phase to another one of the welding system and the one with the most density of arrows can be considered the information-bottleneck of the system.

3.2 Quantitative Analysis

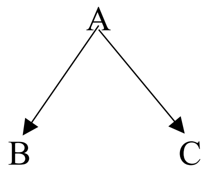
3.2.1 Bayesian network approach

The Bayesian network is a probabilistic model, with no loops, composed of nodes that represent the variables and arrows that indicate the direction of the "conditional dependency" relationship between the nodes. When the edge goes in this way A → B, A is called parent variable while B child variable.

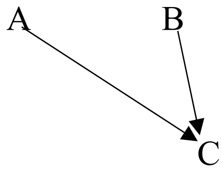
Each variable has a conditional probability distribution that, through a set of parameters, shows the probabilistic relationship with its parents if it has some. The variables can be discrete or continuous: in the first case, a node probability table will catch up all the variables states, mutually exclusive and exhaustive, and their parameters, in the second case a distribution will do that. The probability of each node X can be summed up in the following formula: $\mathbb{P}$ (X | PARENTS (X)) = NUMBER.

There are three types of connection between the parents and children nodes:

- Serial: A → B → C, in this case, there is an intermediate cause, B that makes A and C conditionally independent;
- Diverging: the common cause A permits to B and C to be conditionally independent;



- Converging: if the common effect C is not known, A and B can be considered conditionally independent.



The writer chose this statistical approach to understand better the problem because it permits to perturb the system a little bit and see what happens. In fact, when all the variables and the parameters are defined it is possible to test it later through two types of disturbances:

1) Diagnosis: $\mathbb{P}$ (CAUSE | SYMPTOM) =?
2) Prediction: $\mathbb{P}$ (SYMPTOM | CAUSE) =?

This means that if a variable of the system is observed, all the likelihoods of their children will be affected positively or negatively by the evidence; as well, if a derivative node is observed all their parents will be affected someway.

The problems for which is appropriate using a Bayesian network approach, according to Barbaros Yet, 2013, have these characteristics:

- Uncertainty that has to be analysed with a "thinking fast and slow" approach;
- High complexity for using just the instinct;
- Necessity of computing the joint probability of multiple and interrelated events;
- Domain knowledge together with historical data are requested.

3.2.1.1 Bayesian network example

The graph below shows an example of a Bayesian network, Figure 11.

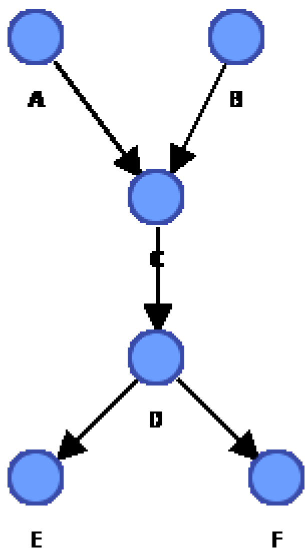


Figure 11 - Example of a Bayesian network

To start working with the Bayesian network, the first thing to do is to define the variables, in this case, they are A, B, C, D, E, F. The node A and B are the parents of the node C, that it is itself the parent of the node D, which has E and F as children. After this step, in order, it is important to understand the states that each variable can assume. To simplify let suppose two values, for each one true or false. Now the direction of the relationship has to be identified to be able to complete after the node probabilities tables. In this case, the variables object of study are discrete so the probability is caught through a number and not a distribution such as for the continuous ones. The probabilities that have to be calculated are the following ones:

- $\mathbb{P}$ (A)?
- $\mathbb{P}$ (B)?
- $\mathbb{P}$ (C | A, B)?
- $\mathbb{P}$ (D | C)?
- $\mathbb{P}$ (E | D)?
- $\mathbb{P}$ (F | D)?

The first two are easy because the variables are “orphans” so the table to fill up looks like this:

False	True
100.000	0.000

Figure 12 - Node probability table of an orphan node

There are two states for each variable and the sum of the two values for each one must be one because they represent a probability. The other ones, instead, are conditional probabilities that can be computed through the Bayes' theorem:

$$\mathbb{P}(D|C) = \frac{\mathbb{P}(C|D) * \mathbb{P}(D)}{\mathbb{P}(C)}$$

- $\mathbb{P}$ (D | C) is the conditional probability of D when C is known. It is also called posterior probability because it depends on the value of C;
- $\mathbb{P}$ (C | D) is the conditional probability of C when D is known;
- $\mathbb{P}$ (D) is the marginal probability of D.

In this case, the node probability table to fill looks like this:

C	False	True
False	50.000	50.000
True	50.000	50.000

Figure 13 - Node probability table of a child node with parents

The table shows that if the number of parents increases the difficulty of the problem is higher. The procedure described until now is called modelling and it is the first step of the Bayesian approach. After that, the network is set up and can be tested in the validation phase. The figures 14 manifests how the probabilities change before and after an observation. On the left, there are the likelihoods assuming that the system is completely unknown, on the right the probabilities after the observation of the node A. The results highlight that the state false of the variable C decreases dramatically its probability when was clear that the value of the variable A was true.

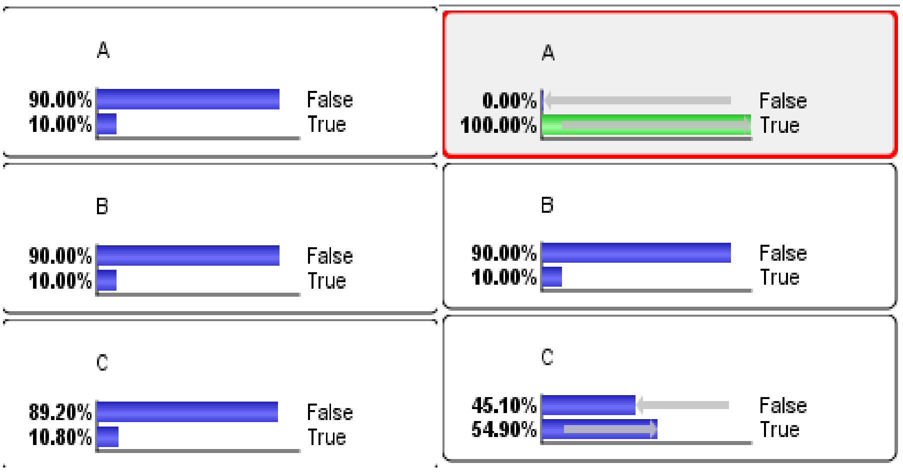


Figure 14 - Probabilities variation before and after an observation

3.2.2 Load and strength model and the risk of failure

The curve on the left (see Figure 15) is the distribution coming from the customers, the customers' usage, and indicates how much the consumers have used the final good, how much they loaded the product regardless of specifications given by the factory. The curve on the right, instead, is the distribution of the final products' strength (or load resistance), the delivered products' resistance, realized into the factory, by manufacturing phase, and shows how long a good will last during fatigue loading, according to factory's specifications. When the customer decides to load the product more than how much he should do, there will be a failure. Because of his behaviour is completely unpredictable, the factory will try to produce a product with a better fatigue resistance than the fatigue load in order to avoid the failure leading to the creation of safety margins like shows the Figure 16.

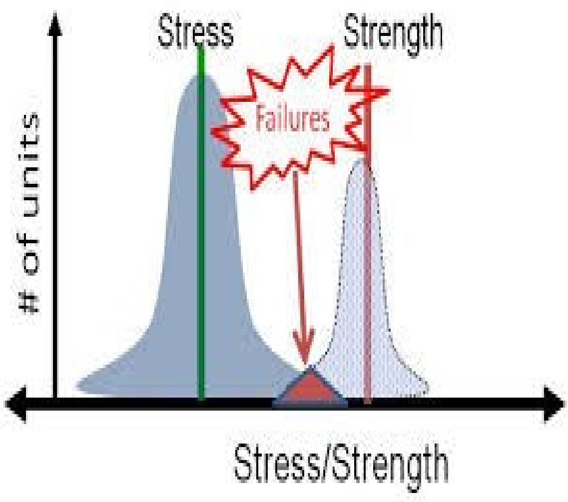


Figure 15 - Load and strength model with risk of failure (accendoreliability.com)

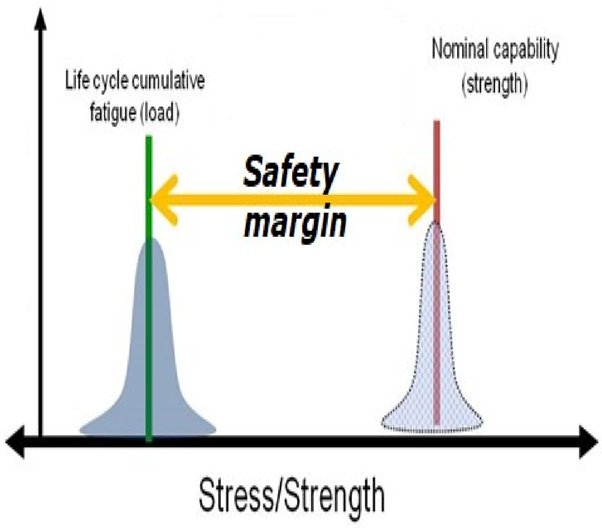


Figure 16 - Load and strength model with safety margins (accendoreliability.com)

While the load distribution is very difficult to know because the customer's behaviour affects it when overloads the machine, the capability distribution is more under the factory's control. The strength variation is the sum of manufacturing variation, designing variation and all the variation coming from the different phases of the process together with the variation coming from the communications and information flow side. The thesis' aim is digging more into the information flow to understand more the strength distribution, mapping the different sources of variation into the process. In fact, if the curve is more robust thanks to the "variation understanding" could be possible, later, to move the strength curve closer to the load one and reducing in this way the safety margins, but this is not an aspect that will be analysed into the report.

Chapter 4

Empirical Findings

4.1 Qualitative Analysis

4.1.1 Development and industrialization of the welding process

In this section, the author will explain how the system object of analysis works. The picture below, Figure 17, shows the process with all the main and secondary actors together with the phases that are meaningful for the final product realization.

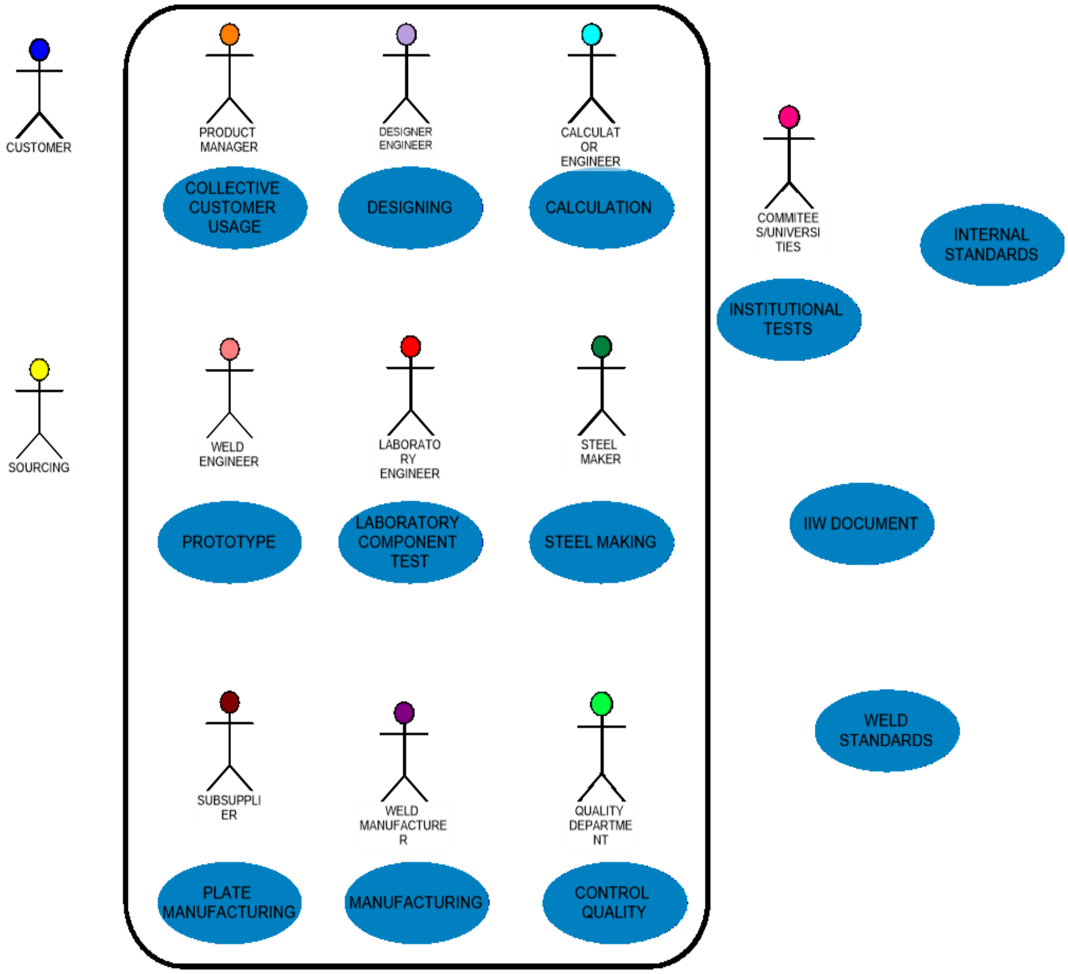


Figure 17 - Main actors and phases of the welding process analysed

The actors and the phases, that are present inside the black track, are the ones directly responsible for the realization of the final product, while the ones outside support some parts of the process. Each actor inside is the "owner" of a particular phase, this means that he is the one responsible for transforming the inputs into an output to deliver to the next phase.

The process is divided into two main steps: the development and the manufacturing. The first one is still split up into four steps that are A, B, C more the first serial manufacturing, also called step P that means 'start of production' (see Table 2). Each developing step works in the same way, the only difference is the number of feedbacks, related to things that have to be changed, that will come from the different phases of the process. Hopefully, they should decrease from the step A to P:

- STEP A, also called concept study, is a physical mook up based on machines' functionalities and usually lasts at least three or four years for a new product;
- STEP B, also called detailed development, it is the first step in which starts the real development;
- STEP C, also called final development or pre-series phase, it is the moment where three or four machines, as more realistic as possible, are built but maybe all the procedures, that will be used later into the production, are not yet updated;
- STEP P, also called industrialization and commercialization or production build, starts when the ¾ of machines are realized with all the features, fixtures, tooling and instructions that will be adopted into the serial production, also called manufacturing;

When step A is finished, the updates in the other steps last less time, usually one year or one and a half year, depending on the numbers of feedbacks. The process in these steps is going faster, because, through the product maintenance system, there is the possibility to update the machines building small packages that will be assembled at the end.

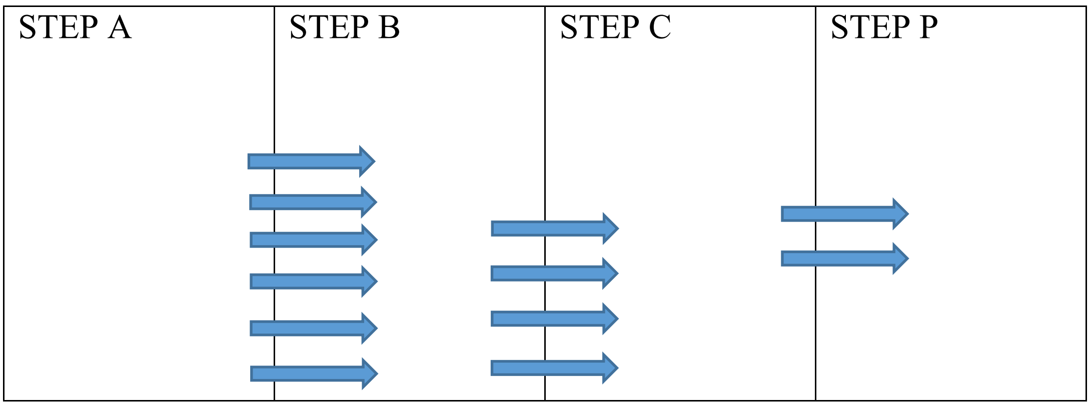


Table 2 - Steps of the development phase

4.1.1.1 Development phase

The process starts with the customer that wants a particular product and ends with the customer that receives what he wants. He contacts the factory's marketing department that has the role of understanding the customer's needs and specifying them. All these requests will be given to the design engineer who knows if they can be implemented; in fact, while the marketing always wants the cheapest and the strongest machine, the designer is more linked to the reality and perfectly knows what can be realised. The communication happens in both ways between the designer engineer and the marketing department, represented by the product manager, and it is based on machine optimization: in this step, they negotiate on product capacity, fatigue life, costs, weight and other features requested. At that point, the designer engineer references to the existing machines and competitors for coming up with a new idea that will test later: he realises the 3D CAD model first and then on it, he will run some strength analyses. The model is done physically by the design engineer, but he is talking at the same time with the calculator engineer and manufacturing engineer also about possibilities of weld, weld access, in order to design a 'weld friendly' for who will have the duty of manufacturing it. Yang Shin affirmed that this communication, represented in Figure 18, is crucial for speeding up the process and avoiding many unnecessary loops that only take money and time. The shared knowledge, in this phase, is fundamental in order to catch up the right direction during the different discussions that they have.

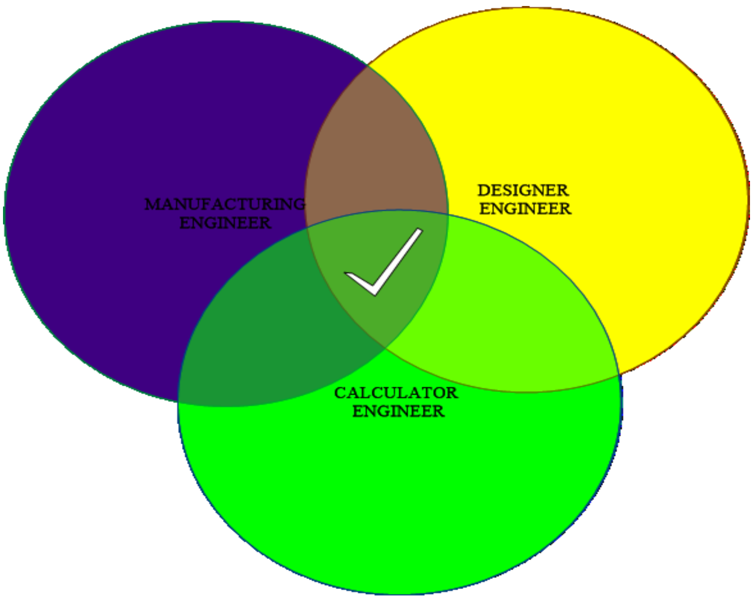


Figure 18 - Sharing knowledge process in the concept loop

This efficient communication before, during the realization of the 3D CAD model, and after the strength analyses performed by the designer, is necessary to make all three agree on the model that will be then delivered to the calculator engineer, who will do more appropriate and accurate analyses. Every discussion between them, in this phase, happens through a meeting and they do not communicate with papers, except the calculation department that has the duty of writing a report, in which documents all the strength tests done. The report has to be detailed, formal, for this reason, it takes a lot of being realised in a proper way. From that document, then, the most significant data will be extracted in a power point that shows more briefly the results; in fact, because it is a summary, it is used for the speeding the communication in these early steps.

After this phase, in which the aim is seeing if the concept works, the discussion between the three actors goes on another level based on the 2D model; now the question is not anymore how the weld should look like, but how should be. In that phase, the most critical weld parameters like weld size, weld penetration depth, toe radius, dimension area are set up and later an analysis will be done for confirming the drawing or changing some parameters, according to strength results. This is a more delicate step and, for that, more people than one of the three area s of knowledge previously involved will have an active part. While the 3D CAD model wants to see if an idea works, the 2D model wants to realize something that will be implemented without numerous problems. When all from these areas agree, a design review on the drawing is done, calling into welding guys from the factory and the quality and assurance (Q&A) department that, if necessary, will write some reports on things that have to be changed before the drawing releasing.

All the process described until now is the one related 'in-house weld ', but there is also another one similar to the subassembly parts, the casted parts, bought by the factory. The procedure until the drawing releasing is the same but another important actor, the supplier, is part of the process since the beginning. In fact, after the realisation of the 3D CAD model, this is delivered to the calculator engineer from one side and to the supplier from the other side. He has to verify if there is the possibility to cast a certain weld and to run some tests, like the solidification simulation, that is very important because sometimes it is critical and causes inside defects. When both are satisfied with a sort kind of shape, the designer engineer does the drawing and sent it to the supplier again who, at the end, will write a document, called RTS, that stands for review technical specifications. In RTS, maybe the supplier affirms that certain tolerances are tough to reach and the defect level is too stringent. The defect level is another critical aspect because, when the design engineer designs cast parts, there is the risk that occurs a defect like porosity that will affect the product's fatigue life. At that point, when also the supplier gives his approval and feedback through the RTS, as before, there is the Q&A check control to see that every weld realised can be inspected without problems. The Q&A, in fact, has to be able to access every weld because, in the developing process, every actor has to understand the critical parts and if one is inside a box, for example , that is impossible. The philosophy, used from step A to P, is "learn by doing" through "trials and errors", as shown in Figure 19. That is the reason because is very important to involve in the all steps A, B, C, P the same factories, suppliers and all the other actors for not losing this big opportunity.

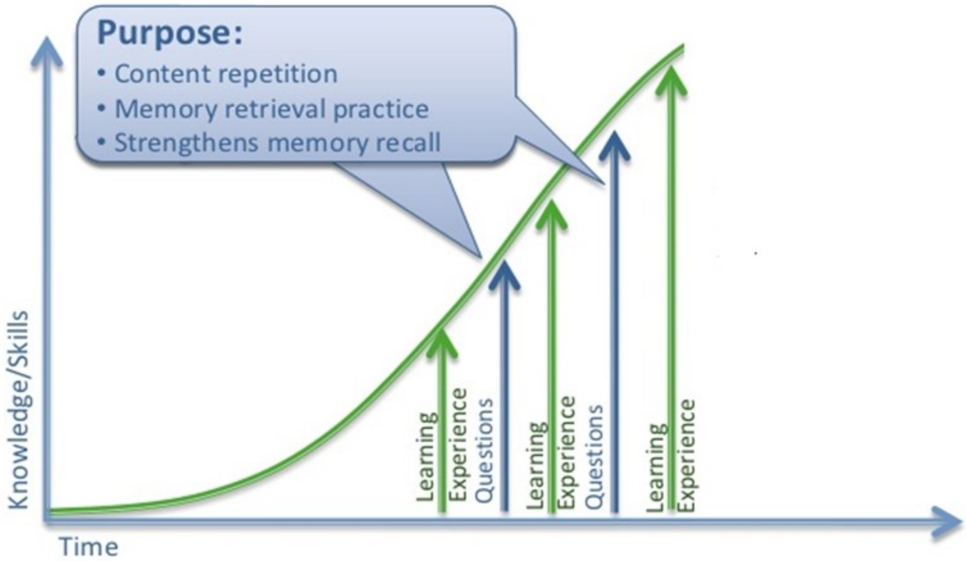


Figure 19 - Learn by doing philosophy (slideshare.net)

At this point, all the actors previously involve approved the drawing and the production can start. The first prototype machines are built in a workshop. The schemes in Figure 20 show both the physical and information flows that take place in the prototype production; while the first one is linear, the second one is more articulated as underline the numerous arrows.

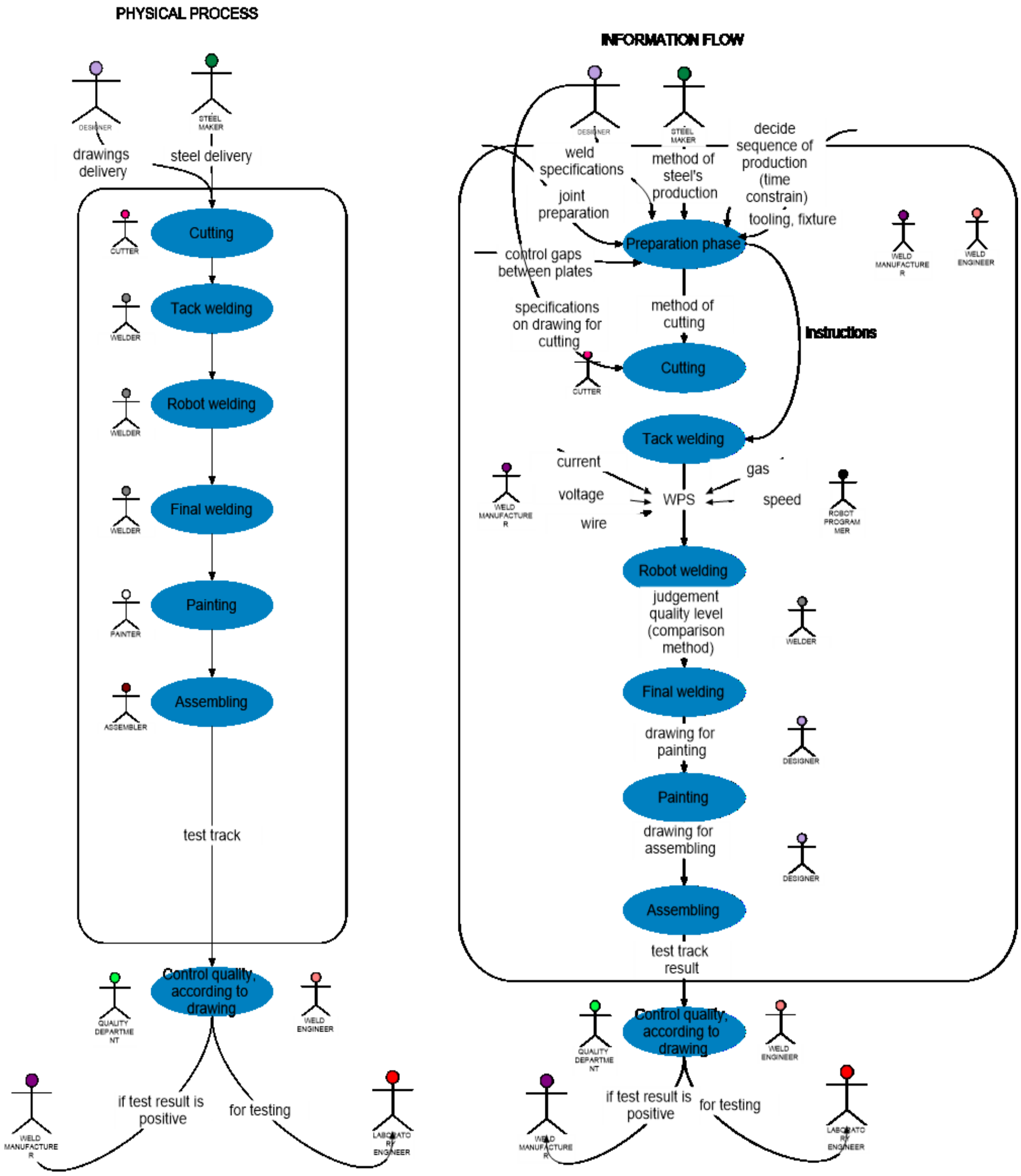


Figure 20 - Physical and information flows in the prototype industrialization loop

Before starting the real manufacturing, a preparation phase is needed in order to set up the production. Both the weld manufacturer and the welding engineer check critical things like the gap between plates before welding because that could affect badly the weld geometry, the geometry of plates and the characteristics of ongoing materials. They see if they are able to fulfil the drawing's requirements and they decide the sequence of production and which tools, fixtures and improvement welding method to use. There are two types of sequence, between which they have to choose:

- First one: Tack welding, Robot welding, Final welding used for the majority of welds

- Second one: Tack welding, Robot welding, Tack welding, Robot welding, Final welding used for the welds that have to go into the robot two times.

The choice is linked to the dimensional quality in fact, during the welding, the material shrinks in several ways so it is better to put some welds into the robot more than once.

Now the physical process can start: the steel plates coming from the supplier first are cut, and later, through the tack welding, robot welding and final welding are definitely welded together. The tack welding is an operation done manually by the workers, who follow the instructions coming from the weld manufacturer and weld engineer. The papers explain how they have to work, where they have to weld and which equipment they should use.

Into the robot welding phase, big machines that are programmed by the robot programmer do the work and are controlled during the operations through a system that permits of making changes if necessary. The robot programmer receives the drawing with all the technical requirements and then starts doing the WPS, that stands for welding procedure specifications, following his knowledge, experience and the old history of the factory. He decides, case by case, the values and its relative tolerances for the welding speed, voltage, current. The programming can be done directly into the working station or offline and then imported into the robot machines. The second option permits to save a lot of time because, while the machines are welding, the robot programmer can start to program another frame. It is important to remember that the robot programmer has been involved in the first phases of the designing for trying to see if the concept works into the robots. In fact, after the realization of the 3D CAD model, he does some offline programs to test and verify it. He runs some simulations to see the angles and where and how the additional features should be placed.

Coming back to the developing phase, the weld that comes out from the robots is, later, checked and analysed, in order to see the quality and efficiency of the WPS. It is a destructive test made in a laboratory, the weld is cut to measure with the microscope all the relevant parameters affecting the fatigue life, first the penetration depth, the toe radius and the throat. That is the only test trusted in order to value the WPS. From this control will be elaborated a document that will report all the test results and findings.

Another report is written by the Q&A that during the production, first or later the robot operation, checks through a visual inspection and the ultrasonic method if there are some problems with the weld. In that case, they compile a document for the robot programmer division, in which they specify the defect position, the kind of defect and the degree of danger. The prioritization is made according to the safety; the scale used has the following values:

- "1": stands for minor defects on the product, there is a small deviance from the weld standards and not work is needed;
- "5": means that there is a deviance greater than the one allowed by the standards and, for this reason, there is the necessity of acting;
- "25": indicates dangerous for someone's life because something can go really wrong. This major fault has to be fixed as soon as possible;
- "100": is the value used when there is a safety fault.

This just described, is only one way for the robot programmer of getting a feedback on the welds, there is, in fact, another one more direct, but less standardized, represented by the communication "talk to talk" that happens into the factory through the welders and the robot division. Kim Ranheim affirmed that the robot programmer's figure is different from the technicians that are always seated in the office, he is out into the field and the reality.

The final welding is the last step of the welding procedure and it is done manually; it is necessary for two reasons:

1) Adding features that are small or in difficult places to reach for the robots, such as holes, and so would require a lot of time;
2) Repairing welds when they do not look good because maybe they could affect the final product's quality. The "reparation decision" is taken by the welder himself, and most of the time happens through the comparison rule; this means that the welder usually looks at two consecutive welds and if one is worse than the previous one it will be repaired.

When the fabrication phase, that includes all the welding steps, is finished the product frames will be before painted and later assembled, in both cases according to drawings. At that point, the Q&A will check, control the product and later will write documents and papers that catch all the modifications that have to be implemented before the serial production. The test track represents the last developing moment in which the machine is driven very hard, to simulate its behaviour in these conditions and for seeing that the transmission, the engine work well together. This is not a fatigue test on welded structures because for doing this, the machine has to be driven longer and longer in time and there is not enough time for this quite expensive operation. In replacement, an FEA analysis realised through a computer simulation will predict the product's fatigue life.

4.1.1.2 Fatigue strength tests in the welding process

After that, the prototype phase is ended with the quality check control and the test track, the following phase is different into the two factories studied. While, as said before, Volvo CE does not realise a complete destructive test on the machine or components to see how many numbers of cycles the machine can handle before a crack happens, HIAB does. It has a laboratory where a component is subjected to different loads until it breaks. This kind of test is called product testing and it is a very expensive test, done just on three or four types of the same product for costs reasons but the information coming from it is very important for the overall process. The test results are three and are shared between the calculation, designing, manufacturing and developing division in order to learn as much as possible from this test:

- Ok or not ok
- Number of cycles to crack
- Crack position

The product test is not the only one fatigue strength test done into the process. In fact, tests on joints, and base material are done.

The tests on joints are not made in the factories but by institutional committees like the universities. In this system, KTH and Chalmers are the ones taking care of it. They are not main actors because they are not necessary to realise the final product, they are secondary actors because support the process. The institutional test results will be then used to update the international and internal standards. The results report the number of cycles that the joint holds before it breaks. The crack is later analysed, the position will be studied together with the weld that is cut in order to be able to see inside. Weld parameters like throat, penetration depth, toe radius are measured.

Both laboratory people and the supplier of the steel are the ones who test the base material. They run an ultrasonic test and some destructive tests as well, such as the hardness test, through which they specify the material hardness. This procedure is necessary because, while for the steel plates international rules standardise how they should be realised, for the steel plates that have to be cast more information are needed. The laboratory people and the steelmaker document each batch, indicating the chemical properties and the kind of composition, ex. Manganese. They do not work alone in this phase because also the designer engineer is involved; in fact, he is the one that at the end, has to specify, according to them, the hardness level right enough for the process.

The one, just described, is not the only involvement of the material laboratory people. They work a lot into product maintenance when problems on the field occur. In that case, they do analyses of material composition close to the crack: maybe a wrong composition or a bad weld parameter leads to the crack.

Into the test list is also important to include the cut surfaces because they are a source of variation for the overall process and they can influence badly the following phases. The way in which is cut the steel plate leads to different thickness and surface properties that then give variation to weld dimensions.

4.1.1.3 Industrialization phase

After manufacturing the prototype, the serial production can start. The machines will be produced exactly in the same way done previously for the prototype. During this phase, the products are first realised and later tested by the quality department. If something goes wrong, the problem usually involves just the manufacturing people because, after the step P, the drawing and the way in which the machine will be realised, are accepted by the manufacturing department, so it is the one that has to fix the problem. Just in exceptional cases, the issue is raised up again to the designing department and this happens when the designer engineer does not think of something before and it emerges only into the serial production. In the last case, the product maintenance designing section into the designing department will take care of it and the solution will be directly implemented. When the Q&A approves the machine through a quality check control, it can be delivered to the final customer and the process ends.

4.1.2 Interviews outputs

4.1.2.1 Interviews evidences

The process description shows that the system is very complicated and can be simplified, dividing it into four big feedback loops (see Figure 21) that capture the information flow:

- The first one can be called concept loop, starts with the 3D CAD model realization and ends up with the drawing review; different actors are involved, the design engineer, the calculator engineer, the robot programmer, the weld manufacturer, the welding engineer, the quality department, the steelmaker and the supplier. That is the most frequent loop;
- The second one can be defined prototype industrialization, starts with the 3D CAD model realization and finishes with the quality

check control made by the quality department. It includes the industrialization of the drawing through the manufacturing process. Hopefully, this loop should be less and less frequent from step A to P;

- The third one can be named test component validation, begins with the 3D CAD model realization and ends up with the test results. The frequency is very low because of the high costs of the test component;
- The fourth one can be called product industrialization, is related only to the serial production. The factory produces machines equal to both the prototype and the drawing. The loop so starts with the production and finishes with the quality check control realised by the quality department. If everything is ok, the machine will be delivered to the final customer, otherwise will go in revision into manufacturing. Just in exceptional cases, the designing department is involved in this phase.

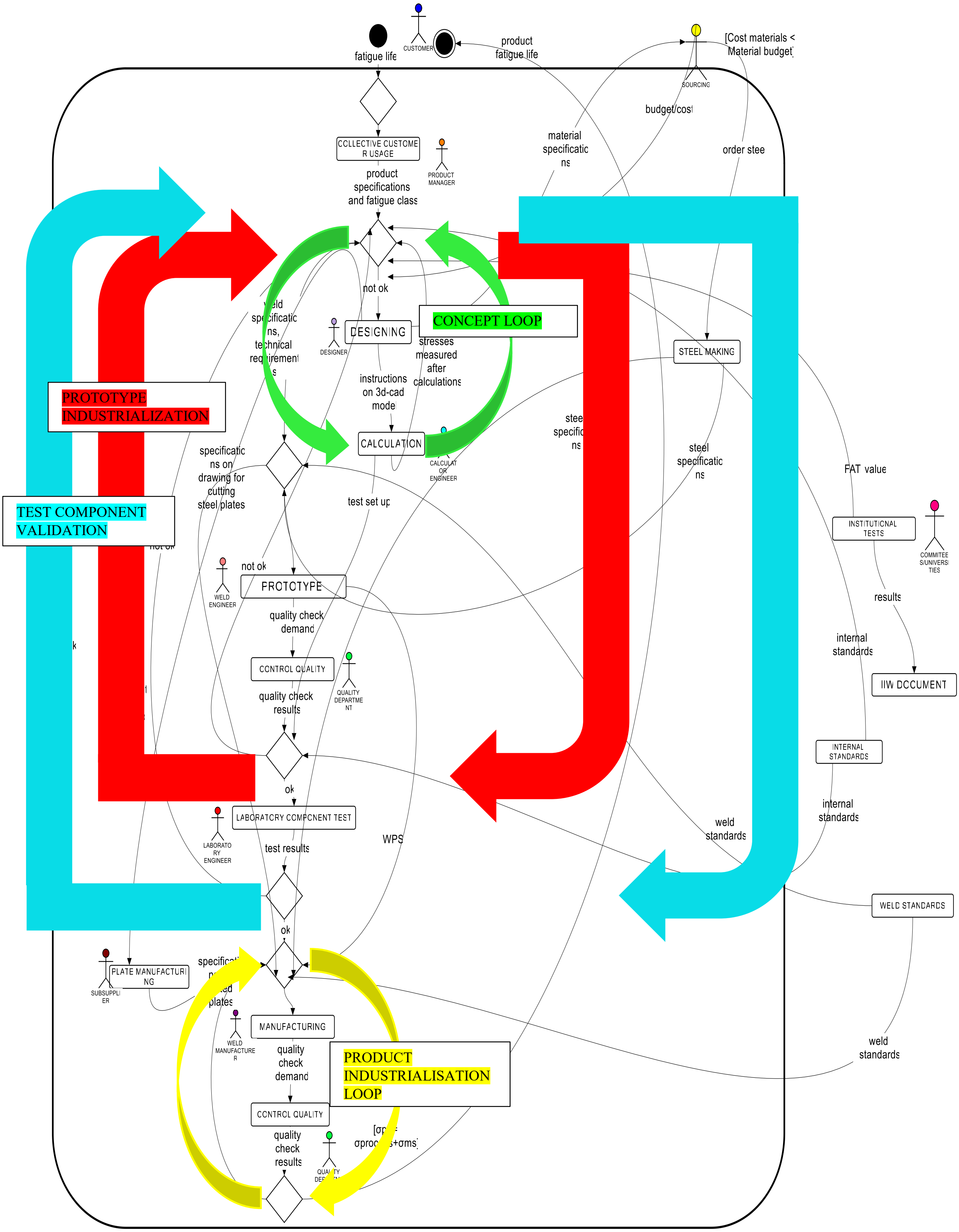


Figure 21 - Four loops of the welding process

4.1.2.2 Interviews results

In order to map the sources of variation into the process from an information point of view, the interviews were focused on catching the variation from three different perspectives: the inputs, the outputs, and the noise factors. Each phase can be represented like a box and the variation coming out from it, is a sum of variation in what enters (inputs), in uncontrollable factors (noise factors), in controllable factors (control factors) and an internal process steps (what happens into the box). The control factors and internal process steps were not taken into account because the author wants to be at a high level and not go too much into detail.

The following one is the frame used, Figure 22:

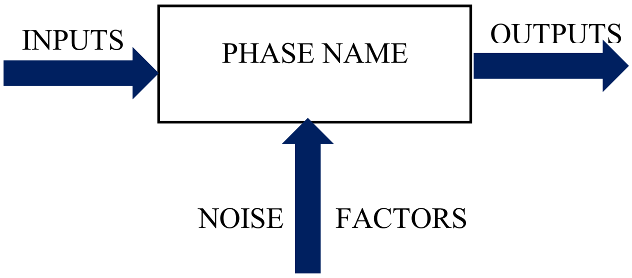


Figure 22 - P-diagram frame used

These are the results of the most critical phases of the process:

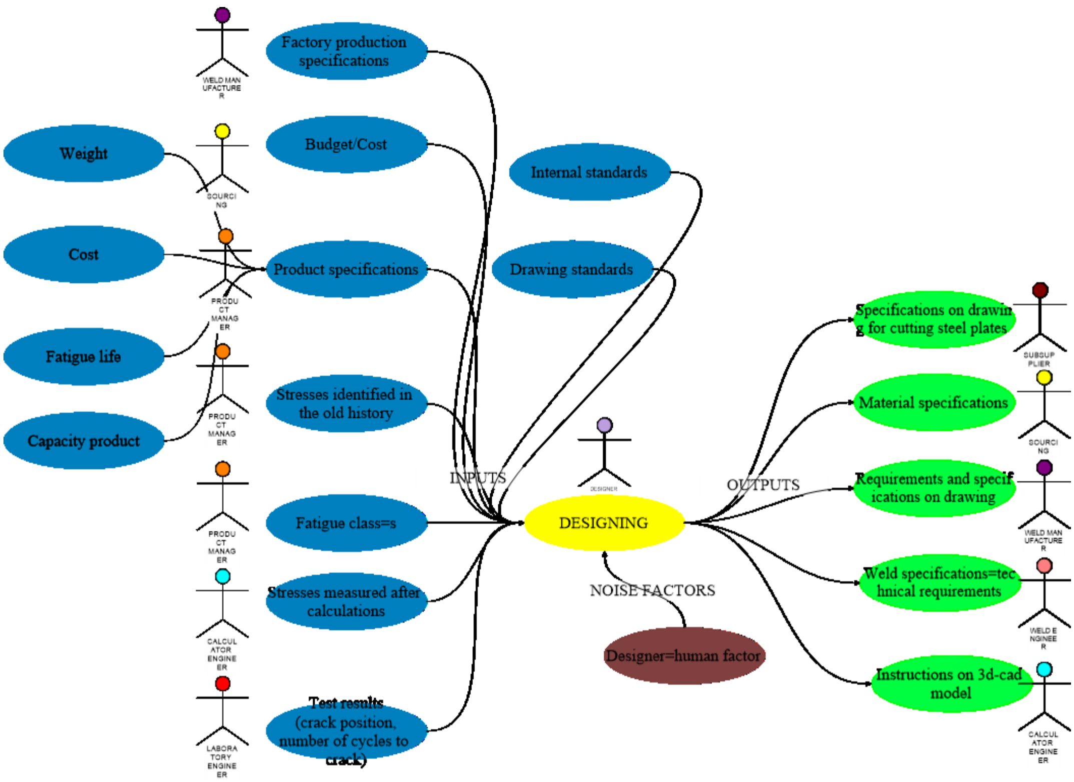


Figure 23 - P-diagram of the designing phase coming out from the interviews

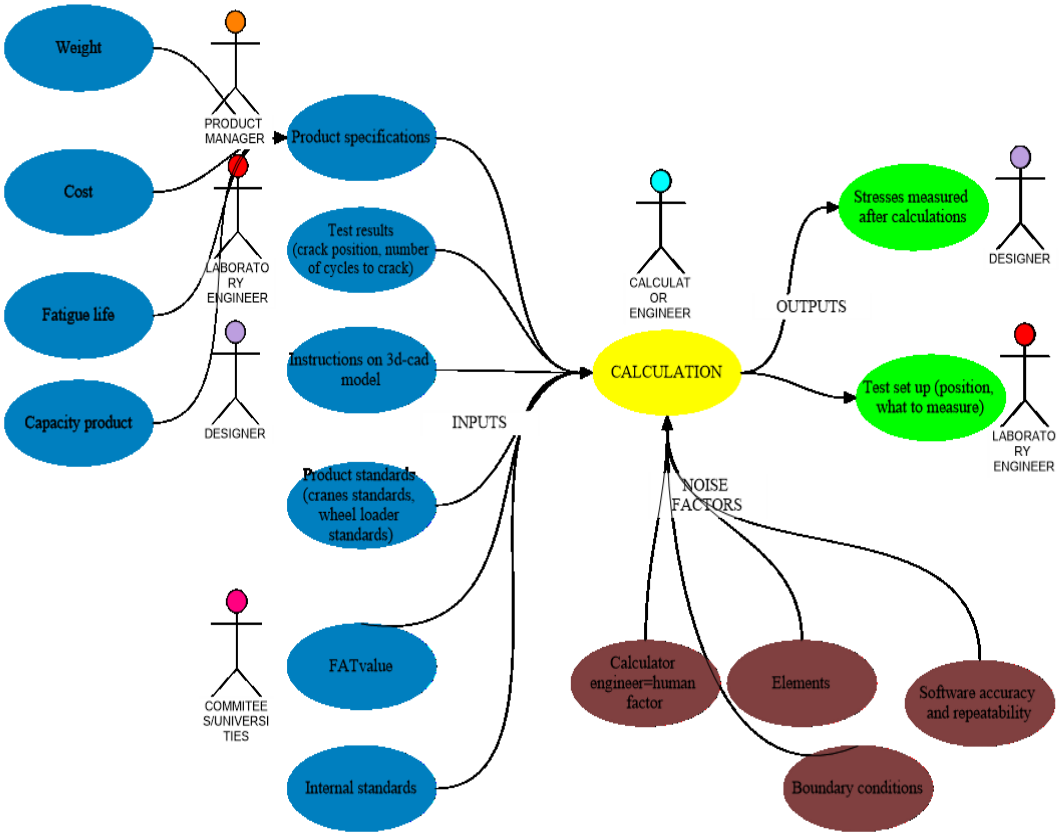


Figure 24 - P-diagram of the calculation phase coming out from the interviews

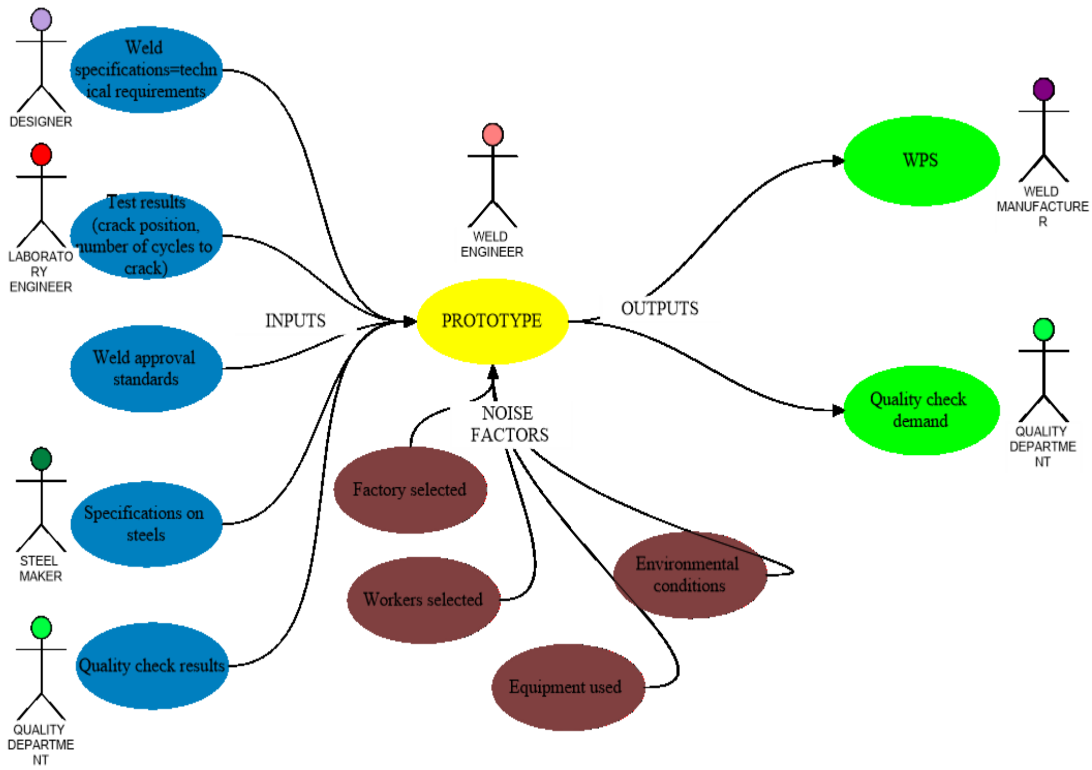


Figure 25 - P-diagram of the prototype phase coming out from the interviews

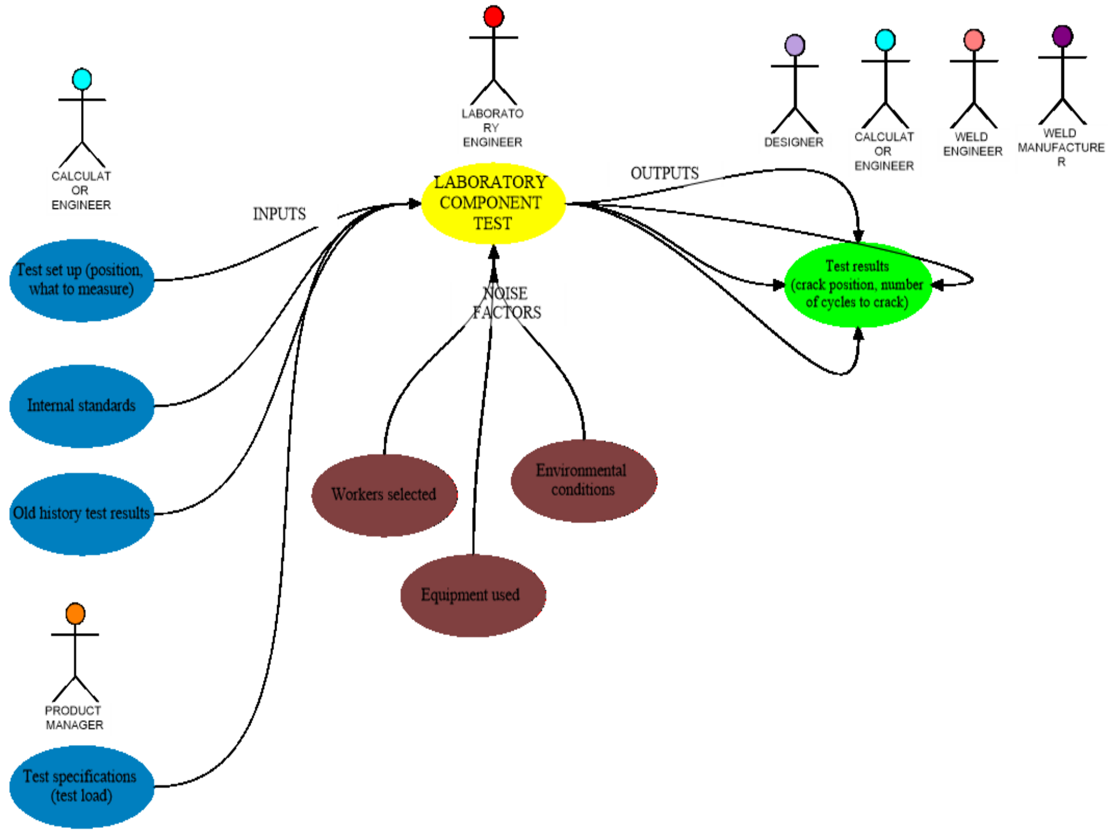


Figure 26 - P-diagram of the laboratory component test phase coming out from the interviews

Figure 27 - P-diagram of the manufacturing phase coming out from the interviews

4.2 Quantitative Analysis

4.2.1 Bayesian network: model definition

In order to build the Bayesian network of this system, the author proceeded in the following way. First identified all the variables object of analysis, the states that these variables could assume and the direction of the relationship between them, later defined the strength of the link between parents and children. According to Barbaros Yet (2013), the first step can be called structure and the second one parameters. Both of them can be discovered with the help of the people working into the system or using real data or a mix of these two.

The structure was derived from the actual system: each phase was transformed into a variable with a correct or incorrect state and the arrow's direction was defined logically thanks the information got during the interviews and author's background built thanks to the literature reading. Acting in this way, the author had a causal map that transformed into a Bayesian network assuming that represents the dependency map of the probability distributions (Nadkarni and Shenoy, 2004). These are the variables of the network, Table 3.

VARIABLES	STATES
BAD_ASSESSMENT	Correct/Incorrect
CALCULATION_STRESS	Correct/Incorrect
EQUIPMENT_VARIATIONS	Correct/Incorrect
FAILURE	Present/Absent
FAT_VALUE	Correct/Incorrect
FATIGUE_LIFE	Correct/Incorrect
LOAD	Correct/Incorrect
MATERIAL_SELECTION	Correct/Incorrect
MISSING_DEFECTS	Correct/Incorrect
NUMBER_OF_CYCLES_TO_CRACK	Correct/Incorrect
QUALITY_LEVEL_CHOICE	Correct/Incorrect
STRENGTH	Correct/Incorrect
STRENGTH_MATERIAL	Correct/Incorrect
STRESS_DEFORMATION	Correct/Incorrect
SURFACE_PROPERTIES	Correct/Incorrect
TEST_RESULTS_ON_WPS	Correct/Incorrect
WELD_GEOMETRY	Correct/Incorrect
WELD_PARAMETERS	Correct/Incorrect
WELD_PRODUCTION_SET_UP	Correct/Incorrect
WELD_SIZE	Correct/Incorrect

Table 3 - Variables of the Bayesian network

The graph below, Figure 28, represents the output of the modelling step, the Bayesian network object of study. The aim of the diagram is to calculate the probability of a failure when something goes wrong into the system and see how this changes under different assumptions. The type of failure consequence taken in the exam is the downtime machine. It is considered that the machine cannot be used for a certain amount of time and the severity of the failure does not permit to hold the load that would fall down.

The failure happens when the load is bigger than the strength and the two curves overlap. This can occur if the customer overloads the machine respect the factory's specifications or if the realization machine process goes wrong somewhere. The author will analyse this last possibility because is the only aspect that the factory can control, the other one is not predictable. The fatigue life, which is the number of cycles that a machine can hold under a certain stress, influences the machine's strength and it is influenced itself by:

- Controlling defect: the possibility that the quality department misses, during the inspection, a defect such as cold laps, transition radius, lack of fusion, undercuts, throat size, misalignment or pores, that could cause a crack initiation;
- Strength material: could be higher or lower respect the specifications;
- Surfaces properties: the way in which the steel plates are cut can influence the properties of the plates in a bad way reducing the expected fatigue life, but this is itself influenced by the weld parameters that drive, through a drawing, the cutting phase;

The fatigue life is also linked to the weld geometry that is the result of how the process produces the machine, if the equipment of the factory changes or the test results on WPS are not so accurate, this could lead to a wrong weld production set up that is the cause of a bad geometry. In fact, the weld geometry should respect the weld parameters decided by the designer and the weld size coming out from the calculation stress but this not always happens: the weld size gives the static stress level, the target or the nominal strength, while the real strength depends on the real geometry realized into the factory.

The weld toe is the most probable cause of a failure and its geometry is the responsible for it, so, in this model, the weld geometry considered is the weld toe one. As shown in the network, the assessment is also an influencer for the weld geometry, means that during the quality inspection some quality variations could be missed. For instance, each weld has a radius and the quality assessment has to pick up the smallest one because it is the responsible for the fatigue life and if this does not happen the failure risk increases.

Relating the concept phase, the model shows that the decision of the designer on how to put the values on the drawing is affected by the quality level choice that is linked to the standards used into the factory. In this case, the Volvo's standards are adopted, they include four different weld classes for fatigue strength that are VE, VD, VC, VB, respectively from the lowest to the highest requirements. About the calculation stress instead, the calculator engineer has to keep in consideration the FAT value that is the stress range in MPa allowed for a certain number of cycles.

The old history, captured by the stress deformation variable, is important such as a beginning point for both the designer engineer and the calculator engineer because is a reference for starting to think to a new machine or to update an old one. The field data, at the same time, are relevant also for the laboratory department that has to conduct the destructive tests on a component part: the laboratory engineer follows the instructions given by the calculator on how to set the test and uses the real data as a reference. The test results, in fact, at the end will influence the weld size, already affected by the material selection: if the material has a high strength or a normal one, this has a consequence not only on the size but also in the all process.

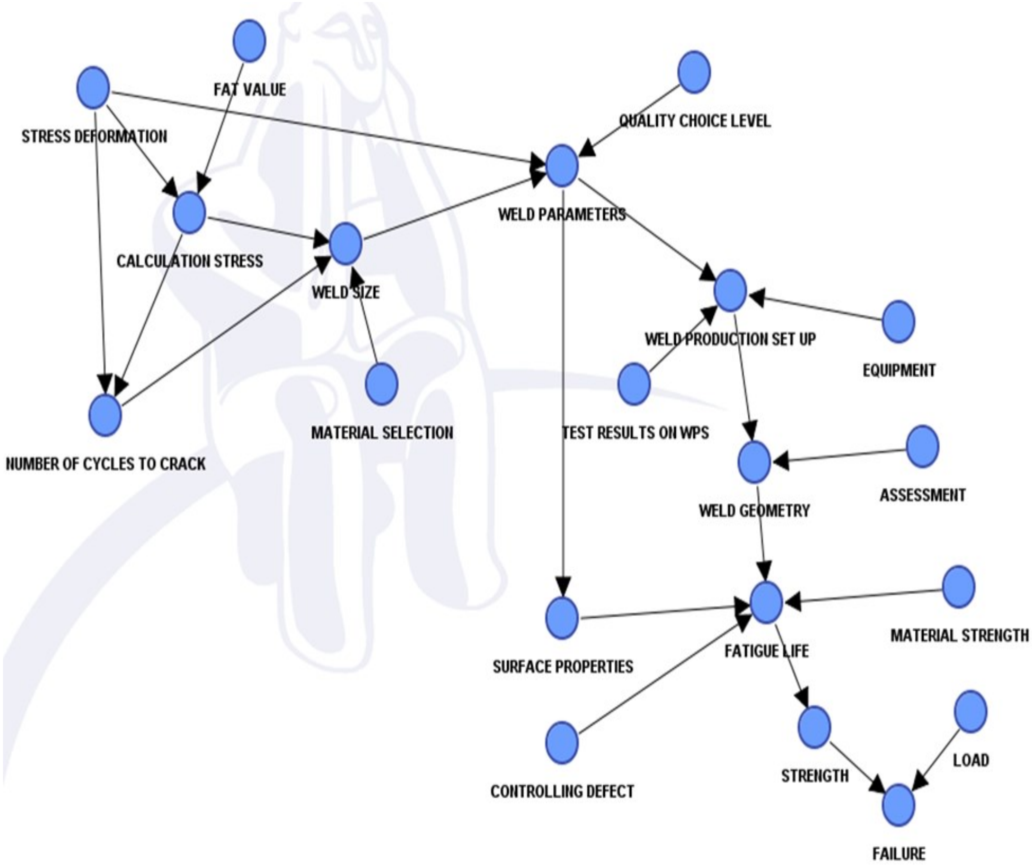


Figure 28 - Bayesian network of the welding process studied

The parameters setting step will be considered in the next chapter.

Chapter 5

Analysis

5.1 Qualitative Analysis

5.1.1 The spaghetti diagram and the bottleneck of the system

Picking up all the data collected and putting them together, the author, at that point, was able to map through a spaghetti diagram, Figure 29, all the different sources of variation from an information point of view. The graph highlights all the incoming and outgoing information for each phase and, if it is analysed using a lean approach, shows which is the most critical phase, called also bottleneck of the process.

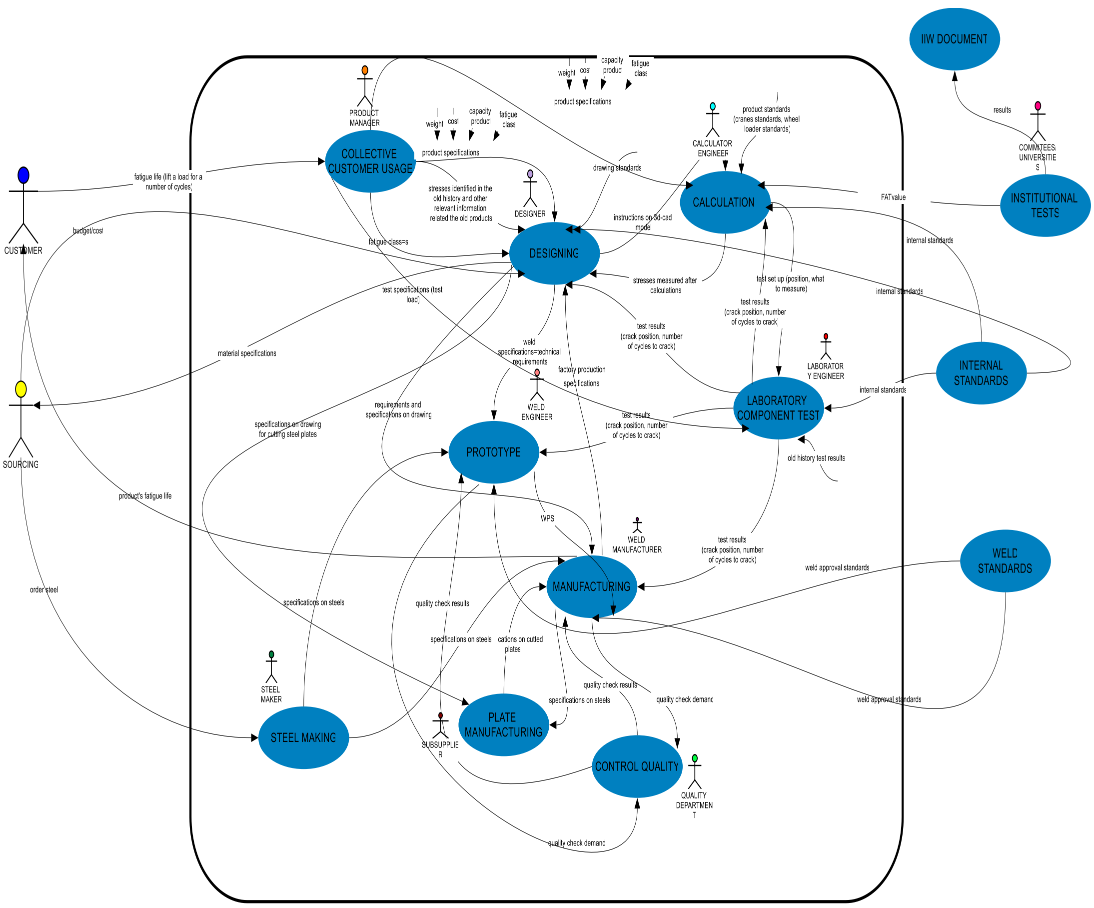


Figure 29 - The spaghetti diagram of the information flow in the welding process studied

The author decided to identify the bottleneck looking at the information density of each phase. The diagram shows that the phases most critical are the ones linked to the physical machine realization, so the designing, the manufacturing, the prototype, the laboratory component test and the calculation. In particular, the designing is the bottleneck with nine incoming arrows and four outgoing. This means that almost all the other phases need the designing department support directly or indirectly to work and this slows down the communication process and increases the production time.

5.2 Quantitative Analysis

5.2.1 Parameters setting

The approach, for defining the parameters of the Bayesian network, instead, was different from the previous one adopted for the model definition, so the experts were not consulted in this step. The purpose, in fact, was avoiding possible bias originated by the people into the system that sometimes do not have a clear picture of what happens in some moments. As consequence, it was chosen to put a casual number in each node probability table to overcome also the problem that the factories do not want to share these values. The author, in this way, created a general structure that logically works for each weld system with the same characteristic of this one taken in the exam. These casual numbers were chosen keeping in mind the information coming from the interviews and trying to produce realistic and believable numbers for not coming up with strange results. The procedure in this step was the following: depending by the number of parents, was adopted the same probability table for all the variables with this same characteristic, except for the nodes without parents where the values were set one by one.

In order to avoid strange and unrealistic results, as said before, the author chose to create three different scenarios, the pessimistic, the optimistic and the most likely one and to assign, in each one, a different node probability table for each variable.

Nodes with no parents (orphan nodes)

VARIABLE	STATE	OPTIMISTIC	MOST LIKELY	PESSIMISTIC
STRESS DEFORMATION	Correct	0.999	0.998	0.995
STRESS DEFORMATION	Incorrect	0.001	0.002	0.005
FAT VALUE	Correct	0.99	0.95	0.85
FAT VALUE	Incorrect	0.01	0.05	0.15
MATERIAL SELECTION	Correct	0.99	0.95	0.90
MATERIAL SELECTION	Incorrect	0.01	0.05	0.10
QUALITY LEVEL CHOICE	Correct	0.90	0.85	0.70
QUALITY LEVEL CHOICE	Incorrect	0.10	0.15	0.30
TEST RESULTS ON WPS	Correct	0.99	0.98	0.97
TEST RESULTS ON WPS	Incorrect	0.01	0.02	0.03
EQUIPMENT	Correct	0.999	0.998	0.995
EQUIPMENT	Incorrect	0.001	0.002	0.005
ASSESSMENT	Correct	0.90	0.80	0.70
ASSESSMENT	Incorrect	0.10	0.20	0.30
CONTROLLING DEFECT	Correct	0.95	0.90	0.80
CONTROLLING DEFECT	Incorrect	0.05	0.10	0.20
MATERIAL STRENGTH	Correct	0.92	0.85	0.65
MATERIAL STRENGTH	Incorrect	0.08	0.15	0.35
LOAD	Correct	0.90	0.80	0.70
LOAD	Incorrect	0.10	0.20	0.30

Table 4 - Nodes with no parents (orphan nodes)

Nodes with one parent (surface properties, strength)

MOST LIKELY SCENARIO	VARIABLE X	VARIABLE Y	
		Incorrect	Correct
	Incorrect	0.95	0.05
	Correct	0.05	0.95

Table 5 - Nodes with one parent (most likely scenario)

OPTIMISTIC SCENARIO	VARIABLE X	VARIABLE Y	
		Incorrect	Correct
	Incorrect	0.90	0.10
	Correct	0.01	0.99

Table 6 - Nodes with one parent (optimistic scenario)

PESSIMISTIC SCENARIO	VARIABLE X	VARIABLE Y	
		Incorrect	Correct
	Incorrect	0.99	0.01
	Correct	0.10	0.90

Table 7 - Nodes with one parent (pessimistic scenario)

Nodes with two parents (calculation stress, weld geometry, number of cycles to crack)

MOST LIKELY SCENARIO	VARIABLE X	VARIABLE Z	VARIABLE Y	
			Incorrect	Correct
	Incorrect	Incorrect	0.95	0.05
	Incorrect	Correct	0.50	0.50
	Correct	Incorrect	0.50	0.50
	Correct	Correct	0.05	0.95

Table 8 - Nodes with two parents (most likely scenario)

OPTIMISTIC SCENARIO	VARIABLE X	VARIABLE Z	VARIABLE Y	
			Incorrect	Correct
	Incorrect	Incorrect	0.90	0.10
	Incorrect	Correct	0.40	0.60
	Correct	Incorrect	0.40	0.60
	Correct	Correct	0.01	0.99

Table 9 - Nodes with two parents (optimistic scenario)

PESSIMISTIC SCENARIO	VARIABLE X	VARIABLE Z	VARIABLE Y	
			Incorrect	Correct
	Incorrect	Incorrect	0.99	0.01
	Incorrect	Correct	0.60	0.40
	Correct	Incorrect	0.60	0.40
	Correct	Correct	0.10	0.90

Table 10 - Nodes with two parents (pessimistic scenario)

Nodes with two parents (failure)

MOST LIKELY SCENARIO	VARIABLE X	VARIABLE Z	VARIABLE Y	
			Absent	Correct
	Incorrect	Incorrect	0.05	0.95
	Incorrect	Correct	0.50	0.50
	Correct	Incorrect	0.50	0.50
	Correct	Correct	0.95	0.05

Table 11 - Nodes with two parents, failure (most likely scenario)

OPTIMISTIC SCENARIO	VARIABLE X	VARIABLE Z	VARIABLE Y	
			Absent	Present
	Incorrect	Incorrect	0.10	0.90
	Incorrect	Correct	0.60	0.40
	Correct	Incorrect	0.60	0.40
	Correct	Correct	0.99	0.01

Table 12 - Nodes with two parents, failure (optimistic scenario)

PESSIMISTIC SCENARIO	VARIABLE X	VARIABLE Z	VARIABLE Y	
			Absent	Present
	Incorrect	Incorrect	0.01	0.99
	Incorrect	Correct	0.40	0.60
	Correct	Incorrect	0.40	0.60
	Correct	Correct	0.90	0.10

Table 13 - Nodes with two parents, failure (pessimistic scenario)

Nodes with three parents (weld size, weld parameters, weld production set-up)

	VARIABLE X	VARIABLE V	VARIABLE Z	VARIABLE Y	
MOST LIKELY SCENARIO				Incorrect	Correct
	Incorrect	Incorrect	Incorrect	0.95	0.05
	Incorrect	Incorrect	Correct	0.70	0.30
	Incorrect	Correct	Incorrect	0.70	0.30
	Incorrect	Correct	Correct	0.40	0.60
	Correct	Incorrect	Incorrect	0.70	0.30
	Correct	Incorrect	Correct	0.40	0.60
	Correct	Correct	Incorrect	0.40	0.60
	Correct	Correct	Correct	0.05	0.95

Table 14 - Nodes with three parents (most likely scenario)

	VARIABLE X	VARIABLE V	VARIABLE Z	VARIABLE Y	
OPTIMISTIC SCENARIO				Incorrect	Correct
	Incorrect	Incorrect	Incorrect	0.90	0.10
	Incorrect	Incorrect	Correct	0.60	0.40
	Incorrect	Correct	Incorrect	0.60	0.40
	Incorrect	Correct	Correct	0.30	0.70
	Correct	Incorrect	Incorrect	0.60	0.40
	Correct	Incorrect	Correct	0.30	0.70
	Correct	Correct	Incorrect	0.30	0.70
	Correct	Correct	Correct	0.01	0.99

Table 15 - Nodes with three parents (optimistic scenario)

	VARIABLE X	VARIABLE V	VARIABLE Z	VARIABLE Y	
PESSIMISTC SCENARIO				Incorrect	Correct
	Incorrect	Incorrect	Incorrect	0.99	0.01
	Incorrect	Incorrect	Correct	0.80	0.20
	Incorrect	Correct	Incorrect	0.80	0.20
	Incorrect	Correct	Correct	0.50	0.50
	Correct	Incorrect	Incorrect	0.80	0.20
	Correct	Incorrect	Correct	0.50	0.50
	Correct	Correct	Incorrect	0.50	0.50
	Correct	Correct	Correct	0.10	0.90

Table 16 - Nodes with three parents (pessimistic scenario)

Nodes with four parents (fatigue life)

MOST LIKELY SCENARIO	VARIABLE X	VARIABLE V	VARIABLE W	VARIABLE Z	VARIABLE Y	
					Incorrect	Correct
	Incorrect	Incorrect	Incorrect	Incorrect	0.95	0.05
	Incorrect	Incorrect	Incorrect	Correct	0.75	0.25
	Incorrect	Incorrect	Correct	Incorrect	0.75	0.25
	Incorrect	Incorrect	Correct	Correct	0.50	0.50
	Incorrect	Correct	Incorrect	Incorrect	0.75	0.25
	Incorrect	Correct	Incorrect	Correct	0.50	0.50
	Incorrect	Correct	Correct	Incorrect	0.50	0.50
	Incorrect	Correct	Correct	Correct	0.25	0.75
	Correct	Incorrect	Incorrect	Incorrect	0.75	0.25
	Correct	Incorrect	Incorrect	Correct	0.50	0.50
	Correct	Incorrect	Correct	Incorrect	0.50	0.50
	Correct	Incorrect	Correct	Correct	0.25	0.75
	Correct	Correct	Incorrect	Incorrect	0.50	0.50
	Correct	Correct	Incorrect	Correct	0.25	0.75
	Correct	Correct	Correct	Incorrect	0.25	0.75
	Correct	Correct	Correct	Correct	0.05	0.90

Table 17 - Nodes with four parents (most likely scenario)

OPTIMISTIC SCENARIO	VARIABLE X	VARIABLE V	VARIABLE W	VARIABLE Z	VARIABLE Y	
					Incorrect	Correct
	Incorrect	Incorrect	Incorrect	Incorrect	0.90	0.10
	Incorrect	Incorrect	Incorrect	Correct	0.65	0.35
	Incorrect	Incorrect	Correct	Incorrect	0.65	0.35
	Incorrect	Incorrect	Correct	Correct	0.40	0.60
	Incorrect	Correct	Incorrect	Incorrect	0.65	0.35
	Incorrect	Correct	Incorrect	Correct	0.40	0.60
	Incorrect	Correct	Correct	Incorrect	0.40	0.60
	Incorrect	Correct	Correct	Correct	0.15	0.85
	Correct	Incorrect	Incorrect	Incorrect	0.65	0.35
	Correct	Incorrect	Incorrect	Correct	0.40	0.60
	Correct	Incorrect	Correct	Incorrect	0.40	0.60
	Correct	Incorrect	Correct	Correct	0.15	0.85
	Correct	Correct	Incorrect	Incorrect	0.40	0.60
	Correct	Correct	Incorrect	Correct	0.15	0.85
	Correct	Correct	Correct	Incorrect	0.15	0.85
	Correct	Correct	Correct	Correct	0.01	0.99

Table 18 - Nodes with four parents (optimistic scenario)

	VARIABLE X	VARIABLE V	VARIABLE W	VARIABLE Z	VARIABLE Y	
					Incorrect	Correct
PESSIMISTIC SCENARIO	Incorrect	Incorrect	Incorrect	Incorrect	0.99	0.01
	Incorrect	Incorrect	Incorrect	Correct	0.85	0.15
	Incorrect	Incorrect	Correct	Incorrect	0.85	0.15
	Incorrect	Incorrect	Correct	Correct	0.60	0.40
	Incorrect	Correct	Incorrect	Incorrect	0.85	0.15
	Incorrect	Correct	Incorrect	Correct	0.60	0.40
	Incorrect	Correct	Correct	Incorrect	0.60	0.40
	Incorrect	Correct	Correct	Correct	0.35	0.65
	Correct	Incorrect	Incorrect	Incorrect	0.85	0.15
	Correct	Incorrect	Incorrect	Correct	0.60	0.40
	Correct	Incorrect	Correct	Incorrect	0.60	0.40
	Correct	Incorrect	Correct	Correct	0.35	0.65
	Correct	Correct	Incorrect	Incorrect	0.60	0.40
	Correct	Correct	Incorrect	Correct	0.35	0.65
	Correct	Correct	Correct	Incorrect	0.35	0.65
	Correct	Correct	Correct	Correct	0.10	0.90

Table 19 - Nodes with four parents (pessimistic scenario)

5.2.2 Model running

Before running the model for testing it under different assumptions and conditions, the author decided to validate it, sharing the structure and the parameters just described to people part of the system. In order, it was shown before to Peter Hammersberg, Sen. Lec. at Chalmers University and part of the Varilight project, and later to Svante Widehammar, Senior Structural Mechanics Engineer at HIAB Loader Crane and Anna Ericson Öberg, Management Systems & Data Analysis Director at Volvo CE, both responsible for managing the project Varilight.

When both the structure and the parameters are set, at that point, it is possible to start understanding the system reactions under the information propagation that updates automatically the probabilities. Barbaros Yet (2013) defines the Bayesian network inference through these words: "*When you observe some variables in a Bayesian network, it computes the posterior probability distribution of all other variables, in other words, updates the probability of all variables in a mathematically correct way when you observe some variables*".

According to Barbaros Yet (2013), there are three ways with the Bayesian network inference acts:

1) Causal reasoning (from cause to effect): a cause node is observed, its state and its parameters are known so the effect nodes probabilities are automatically updated;
2) Diagnostic reasoning (from effect to cause): an effect node is observed, its state and its parameters are known so the cause nodes probabilities are automatically updated;
3) Explaining away from causes (abductive): some effect nodes are observed together with a cause node so the other cause nodes probabilities can be easily updated.

The author chose to run the model with the help of a software, *BayesiaLab*, for computing the results coming from Bayesian network inference. She wanted to answer these two questions:

a) Question_1: Which orphan node has the major influence on the probability of failure? Removing the uncertainty about this node, what happens in all system and on the other variables?
b) Question_2: Which child node has the major influence on the probability of failure? Removing the uncertainty about this node, what happens in all system and on the other variables?

In both cases, a sensitivity analysis between the three scenarios will be done for checking if the results are affected by the values previously settled up, even it is not realistic a scenario where all the variables assume pessimistic values or optimistic values.

5.2.2.1 Question_1

The orphan nodes can be considered such as starting points of the model because they are not influenced by anything else before. In order to understand on which one it is more important to put efforts in terms of workforce and money, the procedure adopted was the following. Only one orphan node per time was observed (correct or incorrect state equal to one hundred percent of probability) and all the other orphan nodes were not touched into the simulation, as well as for all the values of the other variables of the process, in order to capture the effects on them and how their states' probability change.

The scheme below, Table 20, was used to run the model several times.

VARIABLE Y INFLUENCED	STATE VARIABLE Y ANALYZED	DEFAULT VALUE VARIABLE Y BEFORE OBSERVATION VARIABLE X	UPDATE VALUE VARIABLE Y AFTER OBSERVATION VARIABLE X	CONDITION = OBSERVATION VARIABLE ORPHAN X	DELTA % ABSOLUTE	DELTA % INCREASE/ DECREASE (RELATIVE)
Failure	Absent			If Variable X is incorrect/ correct		
Strength	Incorrect			If Variable X is incorrect/ correct		
Fatigue life	Incorrect			If Variable X is incorrect/ correct		
Calculation stress	Incorrect			If Variable X is incorrect/ correct		
Weld geometry	Incorrect			If Variable X is incorrect/ correct		
Number of cycles to crack	Incorrect			If Variable X is incorrect/ correct		
Weld size	Incorrect			If Variable X is incorrect/ correct		
Weld parameters	Incorrect			If Variable X is incorrect/ correct		
Weld production set up	Incorrect			If Variable X is incorrect/ correct		
Surface properties	Incorrect			If Variable X is incorrect/ correct		

Table 20 - Scheme used for question_1

As shown in the table, the variables touched are only the ones that have parents, because the other ones are like a starting point that influences and is not influenced itself by observations. The author chose every time to analyse the state incorrect for all the variables affected because the percentage of the other state is complementary to one hundred percent. The observation, instead, was done both in the correct and incorrect statements. With the outputs of the model at that point, was possible doing some considerations through two different formulas:

a) $delta\ \%\ absolute =$
$update\ value\ variable\ y\ (after\ observation\ variable\ x) -$
$default\ value\ variable\ y\ (before\ observation\ variable\ x)$

b) $delta\ \%\ \frac{increase}{decrease} = \frac{delta\ \%\ absolute}{default\ value\ variable\ y\ (before\ observation\ variable\ x)}$

The second formula is the one more truthful and more suitable for analysing the data because takes into account also the initial value in the denominator. Maybe one absolute variation is small and is considered not significant, but the default value is small and this means that the relative variation could be relevant. The equation b) deletes so this possibility of error.

5.2.2.2 Question_2

In order to answer the second question, the author adopted the same procedure of the first one. One variable per time was observed for seeing the variations of the other ones. In this case, the orphan nodes were not taken into consideration and only the child ones were observed. The following scheme, Table 21, was adopted several times to run the model.

VARIABLE Y INFLUENCED	STATE VARIABLE Y ANALYZED	DEFAULT VALUE VARIABLE Y BEFORE OBSERVATION VARIABLE X	UPDATE VALUE VARIABLE Y AFTER OBSERVATION VARIABLE X	CONDITION= OBSERVATION VARIABLE CHILD X	DELTA % ABSOLUTE	DELTA % INCREASE / DECREASE (RELATIVE)
Failure	Absent			If Variable X is incorrect/ correct		
Strength	Incorrect			If Variable X is incorrect/ correct		
Fatigue life	Incorrect			If Variable X is incorrect/ correct		
Calculation stress	Incorrect			If Variable X is incorrect/ correct		
Weld geometry	Incorrect			If Variable X is incorrect/ correct		
Number of cycles to crack	Incorrect			If Variable X is incorrect/ correct		
Weld size	Incorrect			If Variable X is incorrect/ correct		
Weld parameters	Incorrect			If Variable X is incorrect/ correct		
Weld production set up	Incorrect			If Variable X is incorrect/ correct		
Surface properties	Incorrect			If Variable X is incorrect/ correct		

Table 21 - Scheme used for question_2

The equations for analysing the data are the same described before.

Chapter 6

Discussion

6.1 Qualitative Analysis

The first evidence coming out from the spaghetti diagram is that the welding process is very complex. There are four loops in the development and industrialization steps that can repeat several times, depending on the difficulty of the weld at the moment realized. The second one is that the actors, in almost every phase of the process, cannot act alone but they have to communicate and swap information back and forth until they agree on the action plan. The cooperation and interaction so it is very important and this aspect slows down the speed of the physical flow that needs several sets up moments. As consequence, the top management, responsible for the work schedule and allocation resources, has to know very well the process but also the tasks of each actor not only from a physical perspective but also informative. In fact, the information exchange takes a lot of time that can be seen as the setup time for the next operation. If this time, that is fundamental, is not considered during the planning, at the end, the actors will be full of work like in this system object of analysis. The design engineer is almost involved in each phase of the process and has a key role in the all chain but, because he is over-allocated, he is the critical resource that stops the natural working stream. He is the bottleneck and this means that, while the others have both working time and idle time in a different percentage in a day, he has only a working time equal to one hundred percent.

All these interruptions increase the lead time to customer and delete the delivery of the final product to him but, if they are captured before in the scheduling phase, this would not happen anymore. It is so fundamental understanding the involvement of each actor from an information flow perspective. Clarify the confusion around the communication process and information transmission is also important because the organization usually to overcome this problem, that leads to not respect the lead time to the customer, adds somewhere safety margins without trying to focus on where the lack of time comes from.

The author chose to go more in deep in this issue using the swimlane, a Six Sigma Lean tool, which permits to identify all the information delivered and sent by everyone in the system. These below, Figure 30, are the results.

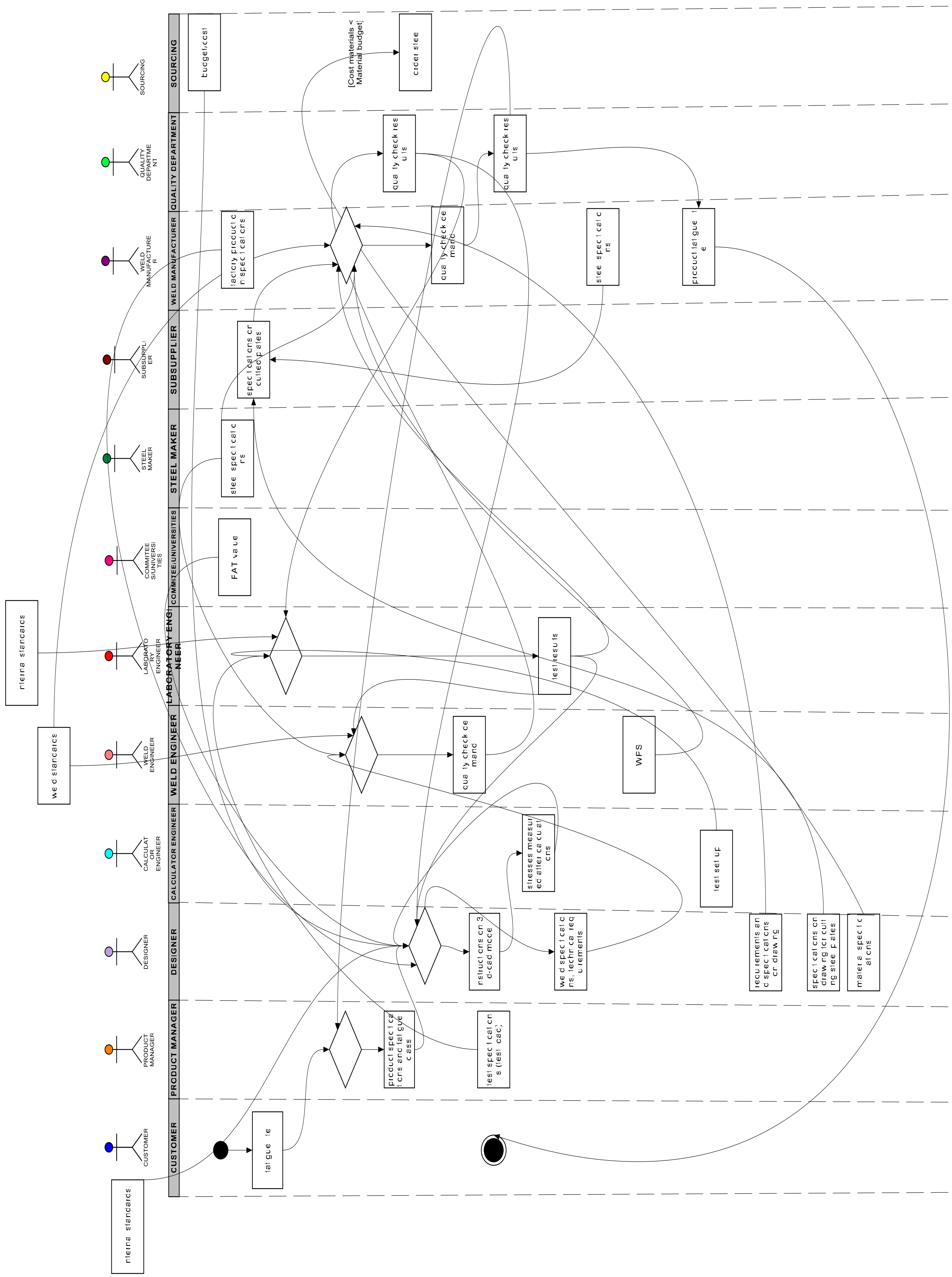


Figure 30 - Swimlane of the welding process studied

This diagram shows, another time, how much the information flow is complex and permits to look more in detail when each actor is needed. In order to linearize the process and simplify it, could be interesting quantify before the frequency of the different arrows and later remove some connections or the number of cycles of someone but this is very difficult because they change from one weld to another one.

Capture the correct system functioning it is, in conclusion, fundamental for avoiding to have a bottleneck that stops the working flow. Having a bottleneck, in fact, it is not necessarily bad because in each process there is a critical resource with more work than others, the important it is that it does not block or slow down in some way the natural system behaviour. If the top management has a clear picture of the process, it does not matter anymore, for the planning step, which one is the bottleneck because, in an information flow, it is not static but dynamic. In fact, in a physical flow the machine that is the bottleneck will be always the same if no significant improvements are adopted but, in an informative process, it moves very quickly. It is true that the designer, looking in general, is the bottleneck of the system but, if the perspective is a specific weld, the problem maybe could be elsewhere, considering that the weld is an unstable process difficult to keep under control.

6.2 Quantitative Analysis

6.2.1 Question_1

Which orphan node has the major influence on the probability of failure? Removing the uncertainty about this node, what happens in all system and on the other variables?

MOST LIKELY SCENARIO						
VARIABLE	STATE	DEFAULT VALUE	UPDATE VALUE	CONDITION	DELTA % ABSOLUTE	DELTA % INCREASE/ DECREASE (RELATIVE)
Failure	Absent	76,43%	40,43%	If load is incorrect	-36%	-47,10%
Failure	Absent	76,43%	75,76%	If FAT value is incorrect	-0,67%	-0,88%
Failure	Absent	76,43%	72,23%	If stress deformation is incorrect	-4,20%	-5,50%
Failure	Absent	76,43%	75,37%	If material selection is incorrect	-1.06%	-1,39%
Failure	Absent	76,43%	73,65%	If quality choice level is incorrect	-2,78%	-3,64%
Failure	Absent	76,43%	75,10%	If test results on WPS are incorrect	-1,33%	-1,74%
Failure	Absent	76,43%	75,08%	If equipment is incorrect	-1,35%	-1,77%
Failure	Absent	76,43%	73,25%	If assessment is incorrect	-3,18%	-4,16%
Failure	Absent	76,43%	68,39%	If controlling defect is incorrect	-8,04%	-10,52%
Failure	Absent	76,43%	68,89%	If material strength is incorrect	-7,54%	-9,87%

Table 22 - Results question_1

The results (see Table 22) show that the most influencing orphan node on the probability of failure is the controlling defect. In the second place, there is the material strength variable. The outcomes are logically truthful because they say that, if the quality department does not detect a defect or if the material strength is different by the nominal target needed, the machine can have a fatigue life different by the one requested by the customer. Consequently, the strength curve is closer to the load one and the risk of failure increases considerably. It is important to underline that the states correct and incorrect for the variables strength and fatigue life indicate that they are under the nominal target demanded and for the variable load over the factory specifications, otherwise the curve strength is farther by the load one, safety margins are created and the probability of failure decreases. Further confirmations can be found into studies made on welded structures and published in these two books: *2nd Swedish conference on design and fabrication of welded structures* and *Proceedings of the Swedish Conference on Lightweight Optimised Welded Structures*.

The author decided to analyse just one parameter of the weld that is the weld toe radius (see Figure 31) because this one is the major cause of machine breakage following a crack initialization originated by over stresses concentration given by geometrical discontinuities.

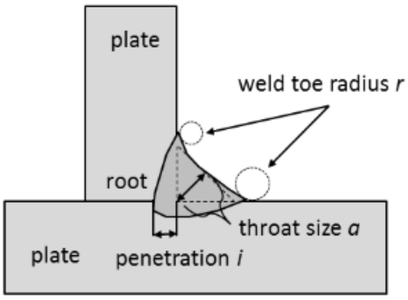


Figure 31 – Weld toe radius (Öberg, A. E. (2016))

The fabrication mistakes that usually the quality department could miss at the weld toe and have a bad consequence of machine functionalities are the following ones:

- Cold laps: small lack of fusion at the weld toe. They occur when the melt material does not merge with the cold plate surface at the weld toe. The blasting operation after welding, for example, introduces residual stresses that could lead to this defect. Bigger is the size of the cold lap, worse are the consequences on the fatigue life, also because of they are very difficult to detect with no destructive methods. For this reason, a light optical microscopy is used for evaluating the weld;
- Transition radius: the transition area between the weld toe and the plate surface could affect the fatigue life if not realised according to the specifications. In the old standards, there was the "even transition condition" such as requirement on the transition area, but it was controlled visually and it was a too subjective method, as consequence this condition was deleted in favour of an objective approach based on checking the stress concentration factors that can be translated into geometric measures;
- Throat size: a too small throat has a negative impact both on toe side and root side of the weld;
- Undercuts: the material is thinner close to the weld toe because during the solidification phase it skinks more than the expectations.

Investigations made in the last years, point out that some defects play a significant role on the fatigue life affecting it considerably and they are more important than the quality level choice, as the outputs show: the fatigue life can vary until two magnitudes because of an error. Anyway, it is important to underline that the defects might be not detected not only because of mistakes in the control check phase but also because of a bad measurement system, which maybe is not settled correctly or is based on the usage of inappropriate instruments.

A recent study highlights that gauges do not give the right accuracy needed in the measure of the weld toe because the way in which they are used, even if the procedure is standard, it is influenced by the human factor and how the people handle the instruments.

On the other nodes, the load has the biggest influence on increasing the probability of failure looking at the results, but this variable is not under the factory control and depends on how the customer wants to behave, so if he respects the factory specifications that say how to use the machine in a correct way. Instead, it is important to analyse the role of the node stress deformation. In fact, this one is the real starting point, both for calculation and designing department, and affects considerably the concept phase and how the final machine will be realised in the manufacturing phase. If at this point is made a mistake, it will flow inevitably until the end of the process.

6.2.1.1 Sensitivity Analysis

Definition: *"The sensitivity analysis tries to determine how the change of input parameters would affect the change of the output"*.

The author chose to do later a sensitivity analysis on the results. In fact, because they depend by the way in which the values are settled into the node probability tables, her purpose was to see if in three different scenarios they were different. As the table 23 below shows, the results are not sensitive to the data put before. This means that if other numbers are introduced the outputs are the same and are robust.

SENSITIVITY ANALYSIS					
VARIABLE	STATE	CONDITION	DELTA % INCREASE/ DECREASE PESSIMISTIC SCENARIO	DELTA % INCREASE/ DECREASE MOST LIKELY SCENARIO	DELTA % INCREASE/ DECREASE OPTIMISTIC SCENARIO
Failure	Absent	If load is incorrect	-59,41%	-47,10%	-38,27%
Failure	Absent	If FAT value is incorrect	-1,71%	-0,88%	-0,30%
Failure	Absent	If stress deformation is incorrect	-9,31%	-5,50%	-2,46%
Failure	Absent	If material selection is incorrect	-2,50%	-1,39%	-0,55%
Failure	Absent	If quality choice level is incorrect	-5,44%	-3,64%	-1,70%
Failure	Absent	If test results on WPS are incorrect	-3,24%	-1,74%	-0,71%
Failure	Absent	If equipment is incorrect	-3,30%	-1,77%	-0,71%
Failure	Absent	If assessment is incorrect	-6,45%	-4,16%	-2,16%
Failure	Absent	If controlling defect is incorrect	-15,33%	-10,52%	-5,80%
Failure	Absent	If material strength is incorrect	-12,61%	-9,87%	-5,51%

Table 23 - Sensitivity analysis question_1

6.2.2 Question_2

Which child node has the major influence on the probability of failure? Removing the uncertainty about this node, what happens in all system and on the other variables?

MOST LIKELY SCENARIO						
VARIABLE	STATE	DEFAULT VALUE	UPDATE VALUE	CONDITION	DELTA % ABSOLUTE	DELTA % INCREASE/ DECREASE (RELATIVE)
Failure	Absent	76,43%	74,94%	If calculation stress is incorrect	-1,49%	-1,95%
Failure	Absent	76,43%	68,34%	If weld geometry is incorrect	-8,09%	-10,58%
Failure	Absent	76,43%	74,99%	If number of cycles to crack are incorrect	-1,44%	-1,88%
Failure	Absent	76,43%	73,55%	If weld size is incorrect	-2,88%	-3,77%
Failure	Absent	76,43%	68,29%	If weld parameters are incorrect	-8,14%	-10,65%
Failure	Absent	76,43%	69,51%	If weld production set up is incorrect	-6,92%	-9,05%
Failure	Absent	76,43%	68,21%	If surface properties are incorrect	-8,22%	-10,75%
Failure	Absent	76,43%	41%	If strength is incorrect	-35,43%	-46,36%
Failure	Absent	76,43%	43,25%	If fatigue life is incorrect	-33,18%	-43,41%

Table 24 - Results question_2

The results (see table 24) show that, if the mistake is made later in the fabrication production chain, the consequences are worse because to solve it, the organization has to spend more money; in fact, at that point, the machine is almost finished. The probability of failure increases considerably with the variables fatigue life and strength. Going more through these pieces of evidence, it is clear that both these two nodes are a direct consequence of the weld geometry, more specifically of a good or bad weld geometry.

The local geometry of a weld, if it is not correctly realised according to specifications, can be the starting point for fatigue cracks. In fact, the influence of the residual stresses on the fatigue strength does not depend only on the magnitude of the residual stresses itself, but even more by the weld geometry at the weld toe and the material properties in this area. The geometry features that affect more the fatigue strength are weld angles, weld toe radius, throat thickness and weld penetration. Except the last one, the others can be measured easily without destructive techniques.

Post-treatment improvement methods that have the role of decreasing the stresses at the weld toe and introducing compressive stresses for balancing the previous ones have been studied and developed during the last years. They want to improve the fatigue strength where necessary, anyway it is important to use them not for covering a bad weld process. One of them is the ultrasonic peening that has the purpose of refining better the fatigue resistance of the weld joints. Fatigue test out comings show that the fatigue life is improved until four times more for high ranges thanks, this method because it reduces the geometrical stresses concentration at the weld toe and redistributes the residual stresses caused by welding.

Other variables that are very important to mention for their consequences are the surface properties and the weld parameters.

The peak stress and the fatigue cracking is affected also by the surface properties and, in detail, by the competition between the throat thickness and surface toe radius together with the surface roughness. Not cutting properly the plates according to the drawing can have a bad effect from a manufacturing variation point of view because, for example, if there are small variations in thickness these give different dimensions. The properties can change even more if the sub-supplier is not always the same because there is the possibility to have different quality levels.

About weld parameters, instead, of course, if they are chosen wrongly in the concept phase the possibility of having something different from customer requests is more probable, but maybe there is not necessarily a failure for that error because the designer took conservative decisions that lead to an upper-quality level. At the end, the output is a more expensive machine that lasts more than necessary because the organization decided to invest more money in quality rather than decreasing costs, reaching the targets and not adding safety margins paying attention to delicate steps involving, for example, more people from different departments.

6.2.2.1 Sensitivity Analysis

The author did also for this question a sensitivity analysis on the results in order to see if they are again robust and do not depend on the initial values chosen. As shown in the table 25 below, they are still not sensible to previous assumptions.

SENSITIVITY ANALYSIS					
VARIABLE	STATE	CONDITION	DELTA % INCREASE/ DECREASE PESSIMISTIC SCENARIO	DELTA % INCREASE/ DECREASE MOST LIKELY SCENARIO	DELTA % INCREASE/ DECREASE OPTIMISTIC SCENARIO
Failure	Absent	If calculation stress is incorrect	-3,41%	-1,95%	-0,83%
Failure	Absent	If weld geometry is incorrect	-14,32%	-10,58%	-6,44%
Failure	Absent	If number of cycles to crack are incorrect	-3,36%	-1,88%	-0,82%
Failure	Absent	If weld size is incorrect	-5,65%	-3,77%	-1,88%
Failure	Absent	If weld parameters are incorrect	-14,17%	-10,65%	-6,21%
Failure	Absent	If weld production set up is incorrect	-13,05%	-9,05%	-5,58%
Failure	Absent	If surface properties are incorrect	-13,73%	-10,75%	-6,65%
Failure	Absent	If strength is incorrect	-46,32%	-46,36%	-40,89%
Failure	Absent	If fatigue life is incorrect	-45,43%	-43,41%	-36,58%

Table 25 - Sensitivity analysis question_2

6.3 Future work

The procedure explained in the thesis, for analysing the information flow in a factory, can be adopted in other working environments, not only welding related, both from a qualitative and quantitative side.

About the system object of analysis, instead, could be interesting using real data for doing realistic simulations with the Bayesian model built. At the same time, the spaghetti diagram realised can be studied in deeper in order to remove some arrows, simplifying and linearizing the process. Even if the process is complex itself, in fact, can be done a re-allocation of tasks and responsibilities in order to delete some unnecessary connections that increase the difficulty of the communication. Some tasks also could be clustered more for avoiding the necessity sometimes to contact other workers.

Chapter 7

Conclusions

The purpose of this master's thesis was to analyse the information flow in a developing and product industrialization welding process adopting two different approaches, a qualitative and a quantitative one. The author's goal, in fact, was trying to optimize the planning of the working resources and improve the allocation of the budget, in order to not over allocate of work the actors of the system and not to spend money for activities not critical for the heavy vehicles' life following how the risks of failure changed under different hypothesis. The table 26 below sums up all the main author's findings.

TYPE OF ANALYSIS DONE	INSTRUMENTS USED TO SUPPORT THE AUTHOR'S RESEARCHES	PEOPLE OUTSIDE THE SYSTEM ANALYSED THAT CAN SOLVE PRACTICALLY THE PROBLEMS TAKING SERIOUS ACTIONS	CAUSES OF PROBLEMS IN THE SYSTEM ANALYSED	EFFECTS CAUSED FROM THE PROBLEMS	ACTIONS TO TAKE
Qualitative analysis	Lean six sigma tools (swim lane and spaghetti diagram)	Top management department that has the task of scheduling the human resources work	Wrong system understanding	- Bad workers allocation - Lead-time to customer increased	Catching the right involvement moments for each actor through for example swim lane tool
Quantitative analysis	Bayesian network	Top management department responsible for allocating the budget	Wrong understanding of the sources of failure critical for machine breakage	- Spending money on activities not critical for the machine breakage and	- Hiring skilled people in the quality department - Buying the adapt equipment

				brand image - Increasing safety margins	for doing measurements - Incrementing the number of checks before setting up the robots through meetings with several actors

Table 26 - Summary of thesis' findings

Furthermore, these following research questions were used for supporting the author in her investigations and reaching the goals previously mentioned.

RQ1*: Is the welding developing and industrialization process influenced by the actual information flow functioning?*

The information flow is very complex and influences both the welding developing and industrialization process. It is composed by four different loops, the concept loop, the prototype industrialization loop, the test component validation loop, the product industrialization loop and each one is characterized by a frequency that can vary depending on the difficulty of the weld realised. As consequence, the process is not linear and to improve it, it is very important understanding the role of the actors in the system, how they communicate together and the different types of information that they swap because each one is a potential source of variation. The author chose the Lean approach to identify the bottleneck in the process, in order to have a starting point to look at. The spaghetti diagram shows that the design engineer is the most critical actor in the system because it is involved in each step of the developing and industrialization process and without his involvement, the flow is blocked and cannot go on. In fact, if something goes wrong in all the four loops the one that has to handle the problem is always the designer engineer. Analysing later each information sent and delivered by the design engineer, the author discovered that the frequency of each one is high and this means that each time a new weld is produced he has to manage always new and different information from the previous ones.

RQ2: *How can the lead-time to the customer be decreased by a better resource working allocation?*

If the management that has the task of allocating the working force in the process does not understand correctly the role of the different actors in the system, the result is an over-allocation of some resources, as it is currently happening. The consequences are represented by a bigger lead-time to the customer created by the numerous interruptions in the process: if the designer engineer, who is the critical resource, for example, is needed in a certain point but he is occupied doing another job, there is a suspension in the normal working flow until he is available. In order to avoid this inconvenient situation for the organization, it is important that who plans the working schedule had a clear picture of what happens in the system. As result, a correct allocation leads to respect deadlines and have a better project programming. The swim lane tool helps to identify all the moments in which each actor is involved, captures the actual situation and it is the starting point for improving the working resources allocation.

RQ3: *How the risks of failure knowledge affect the budget usage in an organization?*

The outputs, coming from the Bayesian network approach, are relevant for managing the budget and controlling the costs in a better way in an organization, allocating the money correctly. The results show that the two critical steps in the welding process are represented by the control defects phase, realized by the quality department, and the weld geometry of the toe radius coming out from the robots. As consequence, the top management department has to devolve a bigger part of the budget for the actors responsible for these activities. In fact, if there is a defect or the weld geometry is different from the theoretical one decided before, the probability of a failure increases and if this happens, in reality, the brand image is affected negatively and the factory does not want bad advertising. Nowadays the organizations for saving their image from bad advertisements produce machines characterized by big safety margins that means that they have a fatigue life bigger than the one declared to the customer. Acting in this way, factories spend money for avoiding a problem and not trying to solve it: they attempt to cure the effects without looking in deep at the cause, adopting the principles of the firefighting theory, characterized for not dealing with the sources of a problem but with the consequences of it.

The out comings of the Bayesian network give two important suggestions and starting points for allocating the money where it is really needed and not putting economic efforts somewhere else not relevant for machines breakage. The first one says that the quality department has to be skilled enough to catch the defects but at the same time has to have the right equipment in order to succeed in his goal. Having skilled and well-prepared people is useless if the microscope gives them bad and inaccurate results to analyse. The second result, instead, highlights that, in order to reach the target geometry, is important to set up the welding robots in the most appropriate way as possible. As consequence, before doing that practically, a setup meeting with all the actors previously involved could be used as double checking moment and for supporting the robot programmer in his decisions because nowadays is the only actor practically involved in the programming step implementing drawings approved before.

References

A Brief Introduction To Lean, Six Sigma And Lean Six Sigma | Quality Management - https://www.greycampus.com/blog/quality-management/a-brief-introduction-to-lean-and-six-sigma-and-lean-six-sigma.

'Advances in fatigue assessment methods for welded structures', *Proceedings of the Swedish Conference on Lightweight Optimised Welded Structures: Borlänge, March 24-25, 2009*.

'An experimental study of cold lap formation in gas metal arc welding (GMAW)', *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

'A new world class system', *Proceedings of the Swedish Conference on Lightweight Optimised Welded Structures: Borlänge, March 24-25, 2009*.

Åstrand, E. (2013) 'Innovative welding procedures for efficient fabrication of fatigue loaded structures', *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

Barsoum, Z. (2010) 'Local weld geometry and the influence on fatigue strength', *Proceedings of the Swedish Conference on Lightweight Optimised Welded Structures: Borlänge, March 24-25, 2009*, p.26-38.

Barsoum, Z. (2010) 'Prediction of welding residual stresses by simplified approaches', *Proceedings of the Swedish Conference on Lightweight Optimised Welded Structures: Borlänge, March 24-25, 2009*, p.39-50.

Bryman & Bell (2015) 'Business Research Methods - Alan Bryman, Emma Bell - Google Books', in *Business Research Method* , p. 777.

Ericson Öberg, A., Hammersberg, P. and Fundin, A. (2017) 'Factors influencing control charts usage of operational measures', *Measuring Business Excellence*, 21(3), pp. 225–238.

Hammersberg, P., Technology, M. and Olsson, H. (2010) 'Statistical evaluation of welding quality in production', *Proceedings of the Swedish Conference on Lightweight Optimised Welded Structures: Borlänge, March 24-25, 2009,* pp. 148–162.

How to Avoid Bottlenecks in Production with Lean Methods and Tools - http://www.cmc-consultants.com/blog/how-to-avoid-bottlenecks-in-production-with-lean-methods-and-tools.

Jonsson, B. (2013) ‘Design and weld for purpose shown in a demonstrator: A Boggi Beam’, *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

Jonsson, B. (2013) ‘Updates of newly implemented weld quality system within Volvo CE’, *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

Karlsson, L. (2013) ‘Increasing fatigue life using Low Transformation Temperature (LTT) welding consumables’, *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

Lean vs Six Sigma: What’s the Difference? - http://www.ultimus.com/blog/bid/33875/lean-vs-six-sigma-what-s-the-difference.

Li, P. *et al.* (2013) ‘Characterization of cold lap defects in tandem arc MAG welding’, *Rivista Italiana della Saldatura*, 65(5), pp. 761–769.

Lu, J., Jain, L. C. and Zhang, G. (2012) ‘Risk Management and Decision Making’, *Handbook on Decision Making*.

Öberg, A. (2012) ‘The Influence of Correct Transfer of Weld Information on Production Cost’, *Proceedings of The 5th International Swedish Production Symposium. Vol. 2012, p. 295-302*.

Öberg, A. (2013) ‘A Different View of Quality Assurance for Fatigue Loaded Structures’, *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

Öberg, A. E. and Hammersberg, P. (2016) ‘Facilitating decision-making by choosing an NDT method based on information need’, *Welding in the World*, 60(5), pp. 979–985.

Öberg, A. E. (2016) Predictability – an enabler of weld production development, PhDThesis.

Öberg, A. *et al.* (2016) ‘The absence of variation in key performance indicators’, *PMA, Performance Measurement and Management: New Theories for New Practices 26-29 June 2016, Edinburgh, Scotland*.

Öberg, A. E. and Sikström, F. (2017) ‘Barriers for industrial implementation of in-process monitoring of weld penetration for quality control’, *The International Journal of Advanced Manufacturing Technology*, 91(5–8), pp. 2427–2434.

Öberg, A. E. and Åstrand, E. (2017) 'Improved productivity by reduced variation in gas metal arc welding (GMAW)', *The International Journal of Advanced Manufacturing Technology*, 92(1–4), pp. 1027–1038.

'Quality systems and algorithms for assessing weld surface geometry in welded joints', *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

Roser, C., Lorentzen, K. and Deuse, J. (2014) 'Reliable shop floor Bottleneck detection for flow lines through process and inventory observations', *Procedia CIRP*. Springer Berlin Heidelberg, 19(C), pp. 63–68.

Samuelsson, J. (2013) 'The development of fatigue Loaded welded steel structures', *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

'Static behaviour of fillet welded cruciform joints in S600MC high strength steel', *2nd Swedish conference on design and fabrication of welded structures, October 9-10 2013, Borlänge*.

Stenberg, T. (2016) Fatigue properties of cut and welded high strength steels - quality aspects in design and production, PhDThesis.

'Stress analysis of laser weld geometries for light-weight design joints', *Proceedings of the Swedish Conference on Lightweight Optimised Welded Structures: Borlänge, March 24-25, 2009*.

The Five Major Flows in Supply Chain – https://brandalyzer.blog/2016/03/23/the-five-major-flows-in-supply-chain.

The three flows of supply chain - https://kpakpakpa.com/spotlight/the-three-flows-of-supply-chain.

Yet, B. *et al.* (2013) 'Decision support system for Warfarin therapy management using Bayesian networks', *Decision Support Systems*. Elsevier B.V., 55(2), pp. 488–498.

Yet, B. (2014) 'Bayesian Networks for Evidence Based Clinical Decision Support', pp. 1–219, PhDThesis.