UNIVERSITY OF AGDER

Waste in Design and Engineering

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I. Preface

This thesis is part of our Master of Science in Industrial Economics and Technology Management at the University of Agder (UiA). In addition, it is part of the Integrated Methodology for Project Management (INPRO) project, which aims to create more efficient and predictable planning through comparing project management in the construction industry with other industries. INPRO has support from The Research Council of Norway (RCN) and consists of the Norwegian University of Science and Technology (NTNU), UiA, Veidekke ASA, Cowi, Ulstein Group and AS Nymo. Our study attempts to contribute to the INPRO-project by examining the design and engineering phase in particular. A case study at AS Nymo was conducted as part of our research. There were several other students at the case company which we collaborated with, this was helpful and interesting.

The topic of this thesis "*Waste in Design and Engineering*" is based on the courses: Quality Management and Lean Six Sigma at the Carlson School of Management, University of Minnesota and Supply Chain Management and Quality Management at California State University Northridge.

The process of writing this thesis has been very rewarding, but also extremely challenging. Concurrently, we wrote a paper for the 23rd annual conference of the International Group for Lean Construction. The feedback from the conference committee has been invaluable.

Grimstad, 26.05.2015

Knut Erik Bonnier

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II. Summary

Issues and Purpose

Predictability in design and engineering processes is a significant challenge. It is important to improve predictability since design and engineering processes affects the entire product life-cycle. Increased predictability can render these processes more effective, thus, it is vital to understand the mechanisms that might impact value-creation. This study is part of the Integrated Methodology for Project Management (INPRO) project, which aims to improve planning processes in the construction industry. Consequently, the objective of our study is to identify the mechanisms that may potentially lead to waste in design and engineering. Due to the negative implications that waste in design and engineering might have on down-stream processes this is considered an important area for improvement.

Scope and Limitations

The scope of this study is limited to the conceptualization of waste in design and engineering, with an emphasis on the mechanisms that have the potential to lead to waste. This includes waste which is realized in the design and engineering processes and waste these mechanisms might generate in processes further down-stream. However, elements such as measuring waste and methods for waste reduction are discussed to some extent, but are not the main purpose of this study.

Methods

A constructive research approach was used for this study, which is a method for developing constructions that can contribute to theory in the field of research. This included gathering data from multiple sources, such as literature and a case study. The majority of the source material consisted of literature on topics such as lean, engineering, design, management, and learning. The findings from literature were supplemented with the collected data from the case study. The case company is a supplier for the oil and gas industry. The findings were used to present a general representation of the waste mechanisms in design and engineering, thus, they are meant to be applicable to design and engineering in different industries and organizations.

Discussion

In order to conceptualize waste we had to gain some insights into design and engineering. It became apparent that characteristics such as creativity and learning are essential parts of design and engineering, where the process is iterative and explorative, and solutions evolve over time. Simply put, design and engineering can be seen as problem-solving and puzzle-making where the product is information. This is in contrast to conventional production and construction where the product is a physical object. Thus, conceptualizing waste in this context requires a somewhat different approach.

The basis for the conceptualization of waste in this study is the lean philosophy, which has its origins from the Toyota Production System (TPS). Lean facilitates increased value while eliminating waste at the same time. However, previous attempts at conceptualizing waste in design and engineering, to a large extent, involve transposing the seven manufacturing wastes to the area of design and engineering, and often supplementing with additional categories. While several of the wastes from design and engineering can be applied to the manufacturing waste categories, they are often ambiguous. In addition, the manufacturing wastes only consist of seven categories and do not describe the mechanisms that might lead to waste. Thus, it is difficult to identify measures of improvement in relation to mitigating or eliminating waste. Based on these limitations it was decided to approach the problem in a different manner. In order to achieve more predictable and efficient design and engineering processes we created a list of waste drivers. A waste driver in this context is defined as a mechanism that has capacity to create waste and to be hindrances for workflow. Managers, and favorably employees, could benefit from such a list, knowing what contributes to waste will enable people to eliminate it.

The final list was comprised of 18 waste drivers:

Ineffective Verifications	• Include ineffective testing, prototyping, approvals, and transactions • Example: tests that are more costly than the risk they are trying to mitigate
Poor Coordination	• Poor planning, scheduling, prioritizations, unsynchronized processes • Example: Tasks completed in a sequential order, when they can be performed concurrently
Task Switching	• Interruptions that forces a person to reorient themselves • Example: meetings can often interrupt other tasks
Capacity Constraints and Overburdening	• Interruptions of workflow as due to unavailable resources or exceeding the capacity of an entity • Example: too many projects going on at once, which might lead to burnout of employees
Lack of Required Competence	• Not possessing the skill or knowledge required to conduct the task in question • Example: ineffective use of IT tools, due to limited skill
Unclear, Goals, Objectives, and Visions	• Misaligned goals, objectives, and visions in relation to, e.g., customer requirements • Example: employees pulling in different directions, reducing the efficiency
Information Overload	• Large batch sizes, and distributing and storing information that is not needed • Example: excessive information can make the relevant information harder to access
Unclear Authority and Responsibility	• Unclear expectations in relation to performance and organizational roles • Example: overlapping competencies and responsibilities
Insufficient Communication	• Communication demanding excessive time and effort, without adding additional value • Example: miscommunication leading to rework

Interpretability of Information	• Information represented in an ambiguous manner, resulting in misinterpretations • Example: Lack of standardization of documentation
Accessibility of Information	• Information cannot be accessed when needed • Example: missing input
Underutilization of Resources	• Allocating resources in a less effective way than possible • Example: inappropriate use of competence
Over-engineering	• Adding features that do not add value for the customer • Example: increased development and production costs as a result of exceeding requirements
Unnecessary Data Conversions	• Avoidable data conversions occurring due to, e.g., use of inappropriate tools or a lack of standardization • Example: re-formatting and re-entering data
Lack of Knowledge Sharing	• Not exchanging information, expertise, or skills among entities • Example: New projects starting below the potential starting point by not reusing previous solutions
Processing Defective Information	• Processing information that is based on a valid need for information, but the need is not sufficiently fulfilled • Example: defective information processed is not discovered and affects other processes
Changing Targets	• Internal or external changes of requirements • Example: changes can lead to rework, especially when the changes occur late in the process
Cooperation Barriers	• Unwillingness to cooperate • Example: lack of ownership negatively affecting motivation

Evaluation

By creating awareness, the waste drivers enable managers and employees to identify waste related to design and engineering in their organization. Thus, this will contribute to a higher level of predictability and efficiency, which might result in a more profitable operation. However, it is very challenging, or even impossible, to be able to create a list that accounts for all the waste drivers. This is particularly caused by the contextual dependency of the waste drivers. However, all the findings from the case study were compatible with the list of drivers. This suggests that the list of drivers might be applicable for identification of the mechanisms that lead to waste in design and engineering. Consequently, we believe that the waste drivers presented, or a similar system, is currently the most appropriate representation of waste mechanisms in design and engineering. However, there is potential in making the waste drivers more user-friendly.

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1 Introduction

Design and engineering (DE) processes play an important part throughout the product life-cycle. Typically, the design phase accounts for a small portion of the total product cost, however, it can impact the life-cycle costs significantly (Verma & Dhayagude, 2009). This emphasizes the significance of good design. The increased market competition as a result of globalization and the higher level of complexity in projects calls for more efficient and predictable DE processes. Consequently, it becomes important to ensure that time is spent on value-added activities, providing value to the customer within budget and in a timely manner. In this context it is necessary to identify the mechanisms that lead to waste in DE, e.g. unnecessary non-value adding activities.

Several studies have been conducted in an effort to conceptualize waste in DE. An extensive amount of literature and research has been written on the topic of waste in manufacturing and construction. However, it appears to be limited focus on the mechanisms that lead to waste in DE. It seems like previous literature and research has been stuck in a loop trying to relate the wastes of DE to the seven conventional manufacturing wastes described by Womack and Jones (2003). More often than not, researchers end up adding their own categories in an effort to cover the waste drivers of DE. To some extent, previous research fails to consider distinctive elements of DE, such as creative processes, motivation, and social relations. Furthermore, DE is a learning process (Kalsaas, 2011), which adds an additional layer of complexity when trying to define, identify, and eliminate waste. These elements need to be addressed in the aforementioned context. Based on this background the following research question was explored:

W*hat are the mechanisms that might lead to waste in design and engineering?*

The purpose of the study is to increase predictability and efficiency in projects, particularly in DE processes, by identifying the mechanisms that lead to waste. This is important in order to implement methods that can reduce or eliminate waste.

Data has been collected from existing research and through a case study at AS Nymo, which is a company in the oil and gas industry. In particular, the research of Bauch (2004), Oehmen and Rebentisch (2010), Morgan and Liker (2006), and Oppenheim (2011) has been used as a basis in the effort to identify and define the waste drivers. We considered elements from several other theories in an attempt to complement existing research.

The selected approach was constructive research design, which is a procedure for developing constructions that can contribute to theory in the field of research (Lukka, 2003). Furthermore, an action research approach was applied since we worked in close collaboration with the case company. Three months were spent at the case company. This enabled us to gain access to internal information which was valuable for the research. Data was collected from multiple sources during the case study, e.g., meetings, interviews, archival records, and documentation. The collected data was used to examine if the waste drivers from previous research were present at the case company, and vice versa.

The findings from this thesis are also presented in a paper, which has been accepted in the proceedings of the 23rd annual conference of the International Group of Lean Construction (IGLC), and will be presented at the conference set in Perth, Australia during the summer of 2015. Thus, the author's research will have the potential to reach a broader audience and may contribute to the research conducted by the IGLC community and others.

The contents of the different sections are described in Figure 1:

Methodology	• Describes the methodological approaches used, and the reason for choosing these approaches. • Assessment of the quality of our research
The Case Company - AS Nymo	• This section provides an overview of the design and engineering processes at the case company • Describes which processes are influenced by design and engineering
Lean	• Provides a basic overview of the background and principles of lean
Design and Engineering	• This section provides the theoretical foundation for which our construct is built on • Describes the distinctiveness of design and engineering . Includes topics such as information, learning, value, and waste
The Construct - Waste Drivers	• Provides a description of how the waste drivers were created • Descriptions of the waste drivers, with examples
Survey	• Includes a survey of two parts conducted at the case company • Part one is a comparison between previous measurements and more recent measurements at the case company • Part two is a measurement of the perceived waste drivers at the case company
Evaluation	• Our construct is evaluated in this section, based on practical relevance, completeness, usability, and generality
Conclusion	• A conclusion of our research is provided • Suggestions for future research

Figure 1: Descriptions of the Contents of the Different Sections

2 Methodology

This section describes the methodological approaches used, and the reason for choosing these approaches. The section includes presentation and discussion of our research design and methods, description of the research process, data collection procedures and methods, and assessment of the quality of our research design.

2.1 Research Design and Methods

Selecting a proper research methodology is important (Kothari, 2011). Researchers should pay attention to the research design and methodology, as this can improve the research, and enable the research to be systematic, logical, empirical and replicable. Jacobsen (2005) explains that methodology describes a way to collect empirical data representing the real world. The social context and the respective research questions that are analyzed will determine which methodology are most applicable (Grønmo, 2004). Yin (1988, p. 27) defines research design as: *"the logic that links the data to be collected (and the conclusion to be drawn) to the initial question of study"*. Simply put, the research design will guide the researcher through the process of getting from a question to a conclusion. It also provides an analytical model of the findings that enables the researcher to make conclusions about the causal relations among the researched variables (Yin, 1988). The research design should, according to Yin (1988), contain the following five elements: research questions, the propositions, the units of analysis, the guidance on how to logically link the data to the propositions, and the criteria for interpreting the findings. The case study and the research process are described in section 2.1.1 and 2.2.

The selected approach was constructive research design, due to the abstract and explorative nature of the area of study. In addition, the case study was used as a supplement to the findings from theory. Lukka (2000) describes the constructive research approach as a method for creating innovative constructions, where the problems analyzed are based on the real world, thus, enabling the research to be a contribution to the discipline in which it is applied. The key elements of constructive research, as described by Lukka (2000), are shown in Figure 2.

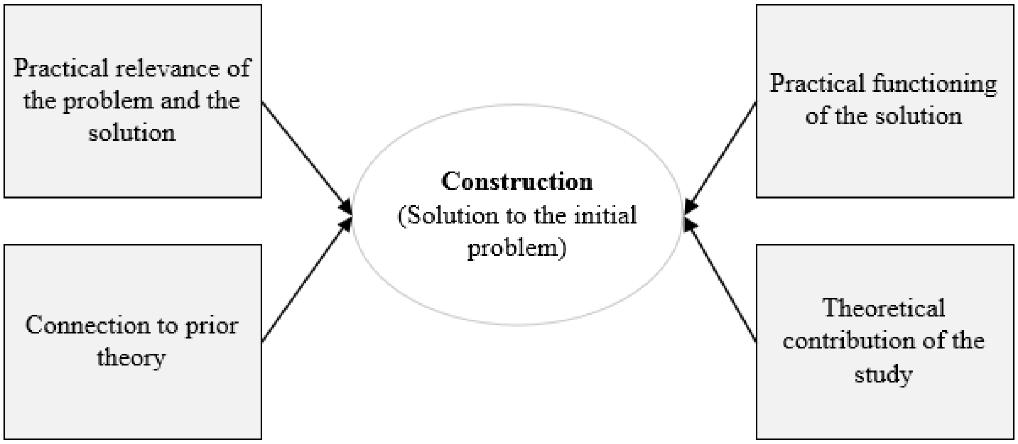

Figure 2: The Key Elements of Constructive Research Design, derived from (Lukka, 2003)

Lukka (2000) provides seven steps that describe a typical constructive research process, shown in Figure 3. Our approach to the constructive research process is described in section 2.2.

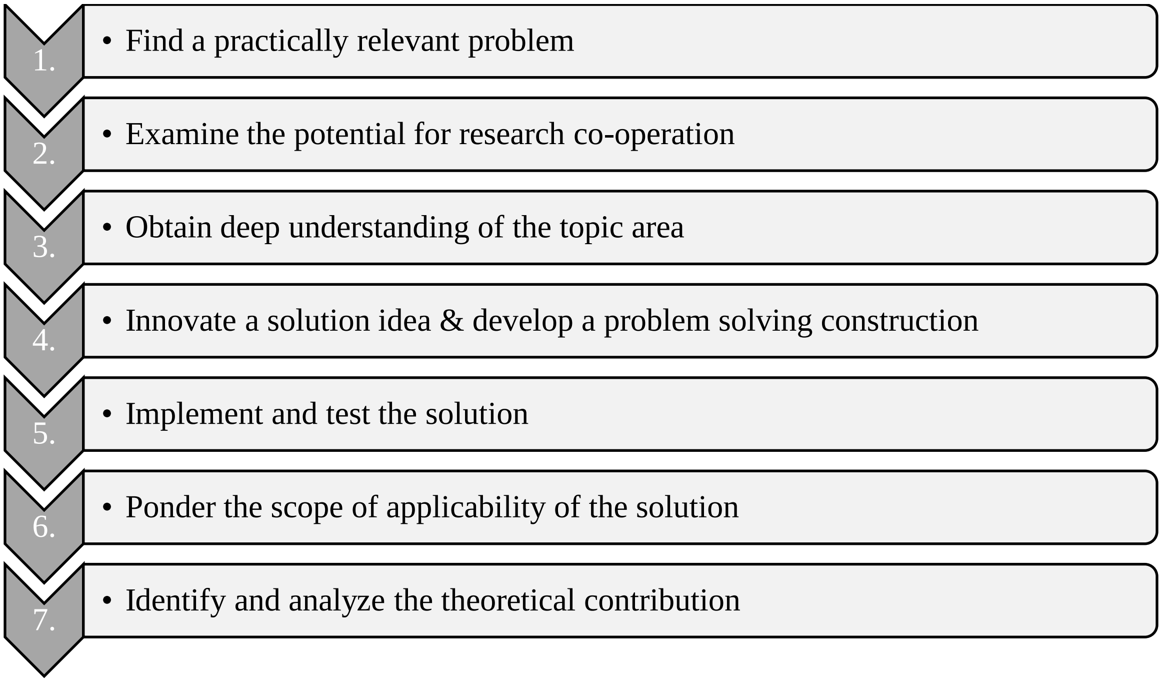

Figure 3: The Process of Constructive Research Design, derived from (Lukka, 2000)

We were present at the case company during the majority of the study, and conducted or participated in activities such as, meetings, interviews, and informal conversations. Part of the research approach can be considered as action research due to the high degree of participation. In the words of Reason and Bradbury (2001, p. 1) action research is: *"a participatory, democratic* *process concerned with developing practical knowledge knowing in the pursuit of worthwhile human purpose, grounded in participatory worldview"*.

Generally, qualitative research methods were used, such as qualitative interviews, and analyzing prior theory. The methodological process was not linear, it could rather be perceived as emergent and iterative, which is typical for qualitative research (Rossman & Rallis, 2011). A quantitative survey was also conducted. Thus, the research process can be considered to use mixed methods of research design (Leech & Onwuegbuzie, 2009). Qualitative and quantitative methods are explained in section 2.3.1.

2.1.1 Case Study

Yin (1988, p. 23) defines a case study as: *"[…] an empirical inquiry that: […] investigates a contemporary phenomenon within its real-life context; when […] the boundaries between phenomenon and context are not clearly evident; and in which […] multiple sources of evidence are used"*. The use of multiple sources of evidence within case studies is also supported by other authors, e.g. Denzin and Lincoln (2000). Furthermore, Yin (1988) explains that the convergence of multiple sources of evidence enables the conclusion to emerge from several sources. Thus, the case study will benefit from existing research within the relevant research disciplines (Yin, 1988).

An embedded single-case study was used for this thesis (Yin, 1988). Since the thesis is supplemented with personal experience, such as the process of writing this thesis, it can also be perceived as an embedded, multiple case-study (Yin, 1988). Single case studies are fitting when the case is divergent in the applied field, in order to explore the divergence (Tjora, 2013; Yin, 1988). However, this is not why a single case company was used; as the company is not perceived to be divergent from other companies. Rather, the case company serves as a general example within the context of the research. A list of similar companies in the region was created, which was used to contact them, in an attempt to gain additional collaborators. However, due to time limitations, this process was not completed.

An additional aspect regarding case studies is that they can be useful when researching areas where the existing theory is considered inadequate (Eisenhardt, 1989). While there is plenty written material about DE, we perceived the literature to be limited regarding the mechanisms that lead to waste.

Yin (1988) suggests that case studies are a preferred method when dealing with “how” and “why” questions. Prior theory was the main source material when trying to answer the “how” and “why” aspects of the research questions. The case was rather used as a supplement, often in order to exemplify the presented theory. However, the insight and knowledge gained by studying the case company arguably gave us a new layer of knowledge. This was useful when interpreting the applicability and relevance of existing theory, thus improving the credibility. We assume that similar results could be made if a different company was studied, i.e. the construct is arguably not case-specific.

2.2 The Research Process

The research process is structured in accordance to the framework presented by Lukka (2003) in section 2.1. Figure 4 summarizes our research process.

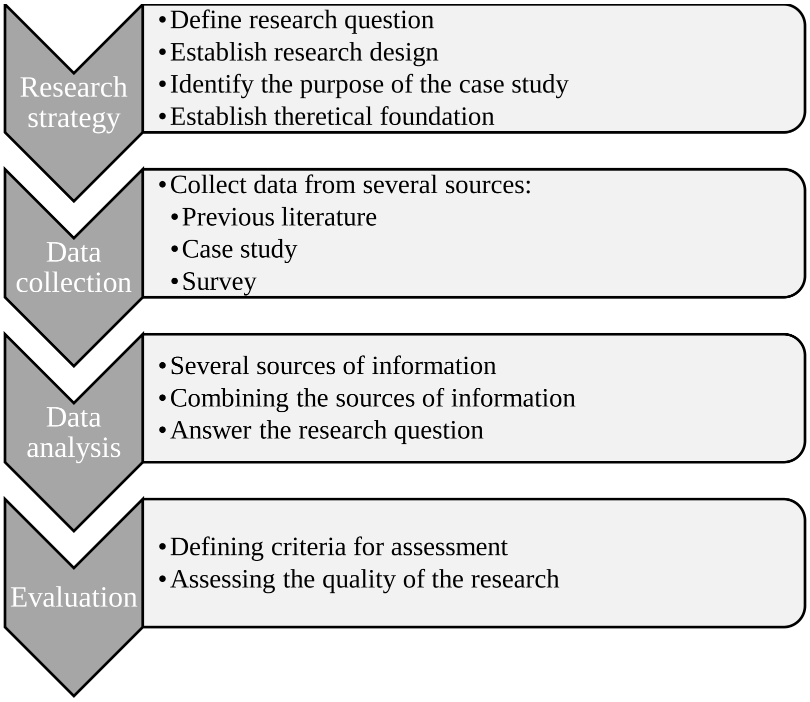

Figure 4: Overview of the Research Process

In order to decide a research design, the research question had to be determined. The research design started out in an explorative manner, where we tried to get an overview of the current situation in the field of research. When we gained a sufficient overview of the existing theory, we attempted to define the research question. However, some changes still occurred as our horizon on the field of research was further broadened. Through findings from literature and the case study it became apparent that the area of study was more complex than previously anticipated.

A substantial amount of material were produced, however, a significant portion are not included in this thesis. This is because the research question changed over time, which led to information becoming excessive or irrelevant. An example of this was the investigation of the implementation of agile methods, such as scrum, into Nymo’s Integrated Project Delivery (IPD) program[1]. This led us to implement elements from scrum and extreme programming into the planning and development process of this thesis. The findings from this experiment were used in combination with literature to decide if the implementation of such methods could be advisable regarding Nymo’s IPD program. From a research perspective, this experiment brings value since it examines if agile methods can be used for non-software development projects. However, this was excluded from the final report, due to the change in scope.

2.2.1 Practical Relevance

In the beginning there were several potential research questions. One of these aimed to present means to reduce waste in DE for the case company. In order to accomplish this, the mechanisms leading to waste had to be identified. This turned out to be a behemoth of a task because of the complexity emerging from the broad range of topics relevant to explain these mechanisms. Thus, we shifted focus from reducing waste in DE to exploring the aforementioned mechanisms. In order to accomplish this, we had to understand DE as a phenomenon (section 5). The knowledge acquired through this process led us to believe that there were limitations in the existing literature on waste in DE. Previous research on the topic seemed to have taken a somewhat reductionist approach. We believe there has been a limited emphasis on incorporating human, cultural and social aspects, such as learning, creativity, and motivation, in the context of waste in DE. These are important aspects since they directly influence how waste is perceived and identified. Failing to identify waste might lead to sub-optimized solutions that are incapable of

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[1] Nymo terms this as Involverende Prosjekt Gjennomføring (IPG)
[2] A batch size of one is the “ultimate goal” (Evans & Lindsay, 2008)

improving the system as a whole. Integrating these perspectives makes it possible to create awareness about what drives waste to happen. In addition, it might be beneficial for future studies to incorporate these perspectives when creating new tools and methods that can help reduce waste in DE.

Previous measurements of waste at the case company showed significant anomalies in comparison to the results from the Lean Advancement Initiative (LAI). In order to investigate this anomaly we conducted a survey based on the method used by LAI. In addition, the survey was used to investigate the potential of measuring waste in DE.

2.2.2 Connection to Prior Theory

During the process of investigating the characteristics of DE, several topics and theories were considered relevant to the research question. The emphasis on the elimination of waste is a central element in lean (Womack & Jones, 2003), which led us to investigate the concepts of lean, including lean manufacturing and lean construction, and the Toyota Production System (TPS). A lot of research on waste in DE has been conducted by LAI at MIT. These studies were used as a starting point for this thesis. Several hundreds of papers, articles and books were read, especially papers from the International Conference on Engineering Design (ICED) and the International Group of Lean Construction (IGLC) were investigated.

Since DE processes depend heavily on communication, creativity, and innovation, it was considered important to explore these topics. The exploration led us to other topics, such as learning and motivation. Thus, learning theories, motivation theories, and communication theories, became subject for study. Other theories such as, design theory, queuing theory, leadership theory, and organization theory, were also explored. Agile methods, the design structure matrix (DSM), value stream mapping (VSM), project management, system dynamics, concurrent engineering, set-based design, and Last Planner System (LPS), among several others, were also investigated. However, the inclusion of these theories and concepts varies, based on their relevance to the research question.

2.2.3 The Construct

The waste drivers, presented in section 6, are the construct of this research. The drivers are derived from existing literature on the topic of waste in DE. Perspectives such as learning, motivation, and creativity, have been added based on literature from the respective topics. Results from the case study and personal experiences from software development and similar have been used to verify and supplement the drivers.

2.2.4 Practical Functioning of the Solution

We were not able to test the solution. Instead an evaluation of the solution was conducted through a critical discussion in terms of a set of criteria (March & Smith, 1995). The discussion and criteria is presented in section 8. By identifying the mechanisms that lead to waste, the understanding of DE processes should increase. Thus, we believe that the presented solution can contribute to more predictable and efficient DE processes.

2.2.5 Theoretical Contribution of the Study

The construct particularly incorporate elements from lean product development, communication theory, organization theory, learning theory, motivation theory and design theory. We have written a paper in collaboration with one of our supervisor: *"Waste in Design and Engineering"* for the 23rd annual conference of the International Group for Lean Construction, which have been accepted for submission. We believe the paper might contribute to future IGLC research, especially on the topic of waste in DE. In addition, the construct could contribute to LAI's research at MIT.

2.3 Data Collection

Several different methods were used to gather data. Wacker (1998) argues that no single research category should be considered as superior to another. Thus, we used several different methods of qualitative data collection, as well as quantitative, in an attempt to utilize the advantages of the different methods.

Yin (1988, p. 84) states that case evidence can come from six different sources of evidence: *"documentation, archival records, interviews, direct observation, participant-observation, and physical artifacts"*. Since the case study was used as a supplementing layer to the construct, we changed "sources of evidence" to "sources of information", and added "literature" as an additional source. Literature concerns all the existing theory we reviewed. The sources of information used in this thesis are shown in Figure 5, where the sources of information used are shown in grey.

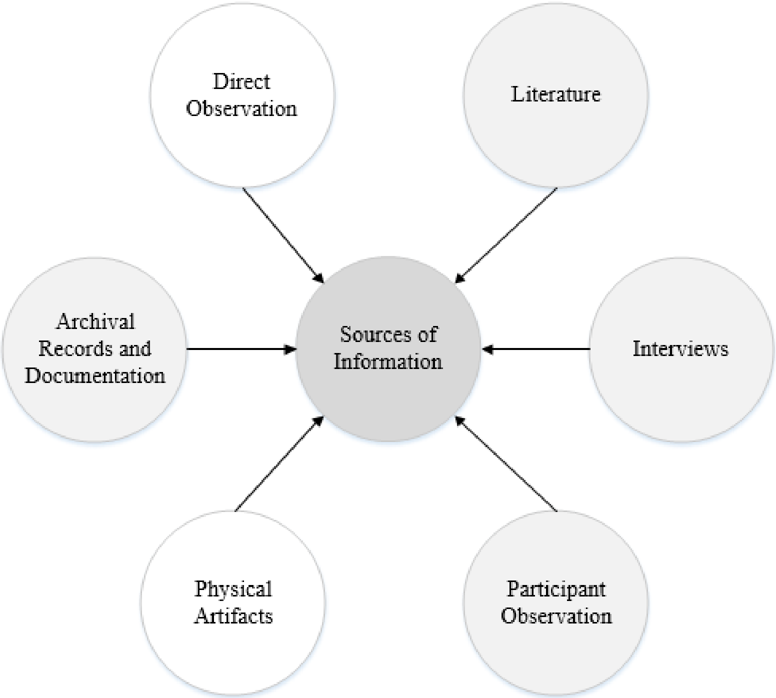

Figure 5: The Six Sources of Information and their Usage in this Thesis, adapted from (Yin, 1988)

Documentation consists of elements such as, minutes of meetings, administrative documents, and media coverage of the case company (Yin, 1988). Archival records include elements such as, organizational records, list of names, and personal records (Yin, 1988). Interviews as a source of information were also used. Direct observation is when the observer does not participate during the observation (Yin, 1988). While we were present at the case company during the majority of the writing process, we do not consider the mere presence as direct observation. However, we used participant observations as a source of information, such as the process mapping meetings (section 2.3.2).

Information was gathered from several different sources, and analyzed using triangulation. Yin (1988) suggests using several sources in order to strengthen the material derived from them. The processing of several sources can be done by triangulation (Berg, 2004). The triangulation technique in research is essentially the same as the technique that are used to find an unknown location on a map, where three known points are used to draw lines toward the unknown location (Berg, 2004). Berg (2004) also states that two observations can be used together, but using a third observation permits the estimation to be more accurate. Yin (1988) explains that the use of multiple sources enable researchers to measure the same phenomenon multiple times. Thus, this technique allowed us to make suggestions and assumptions on a stronger foundation.

2.3.1 Qualitative & Quantitative Sources of Information

Qualitative research as a method can be defined as research where the results do not come from statistical procedures or other quantitative methods (Corbin & Strauss, 2014). Bryman (2012) emphasize that qualitative and quantitative research should be evaluated differently. Qualitative research enables different sources of empirical material to be collected and used (Denzin & Lincoln, 2000). Rossman and Rallis (2011) describe the process of qualitative research as non-linear and flexible, which is in accordance with how we experienced the process. Based on Van Maanen, Dabbs, and Faulkner (1982), Yin (1988) explains that the essence of qualitative research consists of two conditions. Firstly, the researcher uses close-up detailed observations of the natural world. Secondly, the researcher should attempt to not be bound to any theoretical model before the research, i.e., is objective. During the research process, we did not specify a proposition before the research started. The foundation was rather the research question, and by using an explorative approach we could stay objective throughout the research process. The majority of material used is of a qualitative nature. Guba and Lincoln (1994) suggest that qualitative data can provide rich insights in human behavior, thus, this approach appears suitable in the context of DE.

According to Yilmaz (2013) quantitative research is useful to make predictions and generalizations. This is supported by Borrego, Douglas, and Amelink (2009), they state that quantitative studies make it easier to apply the research onto larger populations, thus, enabling the possibility of making generalizations. The quantitative part of the research was a survey, and it was analyzed with the help of computer software. The survey conducted in the context of this thesis was compared with findings from other sources of information. The survey is further explained in section 7.

2.3.2 Meetings

We participated in a series of weekly meetings at the case company. The majority of the meetings involved process mapping of the flow of materials-to-order (MTO) documents. A participant observational approach was used during these meetings, which meant that we were active participants. Several authors have argued that such a viewpoint is priceless in producing a precise portrayal of the case study phenomenon (Yin, 1988). This approach made it possible to perceive reality from the viewpoint of someone inside the company, and ask clarifying questions during the meetings. The meetings gave us valuable information for our research. Several disciplines were represented during these meetings: procurement, engineering, fabrication, quality control, and project management. This provided information from different perspectives, which revealed that the participants had different perceptions of how the process was conducted, which led to some interesting discussions.

One of the main challenges related to participant observation is the potential bias that is produced during the process. The researcher might be less able to act as an external observer, and may assume roles that are contrary to the interests of scientific practice. The researcher is likely to follow a common phenomenon and become a follower of the organization being studied. In addition, the participant role may require too much attention in relation to the observer role. This might result in that the researcher has less time to take notes or to ask questions about events from different perspectives (Yin, 1988). We believe that the benefit from conducting a participant observational study overshadows the challenges. We collaborated with another student at the case company, and shared notes and other collected data. This enabled us to be engaged in the meetings since we spent less time on writing minutes. The collected data from these meetings were just one source of information, and by gathering information from additional sources it is believed that our bias was mitigated substantially.

INPRO Board Meeting

We attended an INPRO board meeting, which took place at Cowi’s headquarters in Oslo. Here we gave a presentation about Scrum and the experiences associated to its usage. The purpose of the presentation was to give an overview of the main concepts of the Scrum method to the participants. The information gained by the participants could then be used to determine if elements from Scrum were applicable to the concept and design phase in construction projects.

The meeting was useful since the participants provided examples of waste drivers on an organizational level, e.g. unclear responsibilities (section 6.3.8). The challenges associated with the building of a new hospital were one of the main topics, and gave valuable insight in relation to such a complex project.

IGLC Waste Workshop

In relation to the thesis and the paper for the IGLC conference, we participated in the opening of the innovation lab at the University of Huddersfield. We also participated in a meeting about teaching lean, and an IGLC waste workshop. At the waste workshop we held an extensive presentation on the topic of waste in DE. This included discussions with the panel of experts present at the workshop. The discussion gave us valuable feedback on our construct. Potentially, the feedback strengthens the validity of our construct.

2.3.3 Interviews

Interviews are one of the most important sources of information (Yin, 1988). Jacobsen (2005) points out that an interview may have different levels of openness. Spanning from open conversations without the use of an interview-guide, to a closed conversation with fixed pre-determined alternatives of answers presented in a specific order.

We participated in interview sessions conducted by another group of students at the case company. The interviews were semi-structured, but somewhat open-ended, since they were constructed in a way that enabled the respondent to discuss aspects that was important to them in relation to the context presented. The 5 Whys technique was applied in order to get to the root causes of why a previous project at the case company had suffered significant delays at the end of the project. The respondents represented all involved disciplines in the project, which provided data from a multitude of perspectives. The majority of the interviews were conducted without our presence. However, notes and voice recordings were made available for study. While the other students were investigating a different topic, the results from the interviews were invaluable for us, since they gathered a substantial amount of data that was directly linked to our research.

In addition to the interviews, we participated in several informal conversations, e.g. during lunch. These conversations involved employees from engineering, fabrication, construction, procurement and other students. This provided constructive feedback regarding our effort to get a holistic view of the company. These conversations were unstructured and explorative, and were primarily used to guide us to new sources of information.

2.3.4 Archival Records & Documentation

We were given access to documentation and archival records at the case company, which is typically reserved for internal use, such as IPD documentation, flow-charts, and punch lists. Information of a general nature was obtained through, e.g. presentations at the case company. We reviewed the information, and it gave us insight about projects, processes, and responsibilities within the company. A previous study at the case company was made available, which included a survey that aimed to measure waste in the engineering department.

2.3.5 Survey

A survey provides a quantitative or numeric description of trends, attitudes, or opinions of a population by investigating and examining a sample of that population. The results are used by the researcher to generalize or make claims about the population (Creswell, 2013).

According to Ackroyd (1992), some of the benefits of questionnaires are that they can be used to collect large amounts of data with little effort, and the results are rather easy to quantify for the researcher. When data has been quantified, it can be compared and contrasted with other studies and may be used to measure change.

Some of the disadvantages of questionnaires are that there is no way to tell how honest and truthful the respondents are, and there is no way of telling how much thought and effort the respondents have put into it. Furthermore, the respondents might misinterpret the context of the situation or be unable to understand the "big picture". In addition, it is possible for respondents to make their own interpretations of the questions asked, which adds a layer of subjectivity. The researcher might also limit the benefits of the questionnaire, since he makes his own decision and assumption regarding what is important or not, which means that critical information may be missing. Further, the process of interpreting open ended questions presents a substantial possibility of subjectivity by the researcher (Ackroyd, 1992).

Survey methods are useful when the research objective is to investigate an incident or the commonness of the phenomenon in question, according to Yin (1988). Thus, a survey was conducted with two purposes. Firstly, the survey was used to compare results from a previous survey. Secondly, it was used to measure what employees from engineering perceived as waste. As a result, the survey included two parts, where both were questionnaires. The first part was derived from a LAI survey at MIT (Appendix 1). The survey was distributed to the entire population of the engineering department through e-mail, and the results are discussed in section 7.

2.4 The Quality of the Research Design

According to Yin (1988), the quality of the research design is evaluated by construct validity, internal validity, external validity and reliability. Thus, this section is divided into subsections that conform to the criteria presented by Yin (1988). Furthermore, the level of validity and reliability is discussed.

2.4.1 Construct Validity

When evaluating construct validity, a central aspect to consider is measurement error. This can be separated into random errors or systematic errors. Method variance, which is a type of systematic errors, might be encountered through informant limitations, social prestige, and through documentation and archival biases, among others. There might also be anomalies regarding the intentional purpose of the data collected, and the context the researchers are using it for (Bagozzi, Yi, & Phillips, 1991). Since we were conscious of these implications, it was decided at an early stage to collect data from multiple sources (section 2.3). This enabled a comprehensive and holistic comparison of different aspects. Triangulation was used to further maintain validity. In addition, feedback was provided from our supervisors, the review committee at IGLC, and a panel of experts at the waste workshop at the University of Huddersfield. Methodological integrity was achieved since several qualitative methods were applied during the research. Furthermore, a chain of evidence is demonstrated by connecting our findings with existing theoretical knowledge. Thus, we believe the construct has strong validity.

2.4.2 Internal Validity

Internal validity concerns casual relationships, and is according to Yin (1988), most relevant in causal or explorative studies. As this thesis was conducted in an explorative manner, especially in the beginning, and causal relationships were made, internal validity is relevant. To some extent, the waste drivers presented are arguably causations themselves. Yin (1988, p. 43) explains the threat to internal validity: *“the investigator incorrectly concludes that there is a causal relationship between x and y without knowing that some third factor – z – may actually* *have caused y"*. Too what extent all the "z" factors have been identified is debatable. The concept of waste in engineering is rather complex, and several factors can be included in the causations. However, most of the casual relationships are based on previous literature, and supplemented with data from several sources (section 2.4.1). This should be sufficient in order to avoid the most obvious errors in respect to causal relationships. Still, as the thesis covers a range of different research subjects, the time constraint makes it impossible to consider all factors within each subject. Thus, it can be assumed that important factors might be overlooked. In addition, the challenges with measuring waste make it difficult to verify the proposed causations.

2.4.3 External Validity

External validity concerns whether generalizations based on causal relationships would still be true, if elements the extrapolation is based on is changed (Shadish, Cook, & Campbell, 2002). In case studies external validity is described as *"knowing whether a study's findings are generalizable beyond the immediate case study"* (Yin, 1988, p. 43). In this thesis the case study is mostly used to exemplify, hence, the question of external validity would be if similar examples could be found in another company. Several findings from the case shared similarities with findings from theory. Thus, it can be assumed that the findings are not case specific. However, even if the provided examples were case specific, no generalizations were made based on the case findings. Thus, there should not be any issues with the external validity in this regard.

Any generalizations made are based on existing theory. The external validity of these generalizations depends on the reliability and the internal validity. Because of the vast amount of information available, different generalizations could be made due to different perceptions and interpretations of existing literature.

2.4.4 Reliability

High level of reliability is accomplished by demonstrating that the operations of the study can be repeated with the same results (Yin, 1988). When determining reliability it is important to consider potential negligence and the effect the data collection methods have on the results (Jacobsen, 2005). We believe that negligence was not an issue since notes were made frequently through the process. In addition, any uncertainties regarding the collected data were dealt with immediately, e.g. asking clarifying questions to the informants. Data was primarily gathered using qualitative methods, which makes it implausible to believe that the exact same results could be obtained. Even if other researchers were to interact with the same individuals, it is likely that they would provide different input. Furthermore, the acquired information is to some extent subject to interpretation, which adds an additional layer of possible variation. However, we believe that if other researchers were to perform the same study they would be able to connect similar findings to existing literature. Although, it is possible that other researches would focus on different aspects of the construct.

The quantitative data collection at the case company should yield similar results if conducted by others. However, we have limited faith in using quantitative data collection for measuring waste in DE.

3 The Case Company - AS Nymo

This section should provide the necessary knowledge to understand the dynamics of the case company, and provide the reader with an overview of the engineering process and the processes it affects. This section is derived from internal documentation provided by the case company.

AS Nymo is an Engineering, Procurement, Construction, and Installation (EPCI) supplier for the oil and gas market, and is situated in southern Norway (AS Nymo, 2010). The company has several facilities, where the majority of the engineers are located at the main fabrication yard. This was the location used for the case study. AS Nymo is one of the participants in the INPRO-project.

3.1 The Engineering Process

In the value chain, AS Nymo positions engineering after marketing and sale, and before procurement, as seen in Figure 6.

Figure 6: Value Chain of AS Nymo

Engineering at AS Nymo is divided into four phases, as seen in Figure 7. The engineering process begins during the preparation of the tender.

Figure 7: Engineering Phases at AS Nymo

Basic Engineering includes elements, such as concept-layout drawings, and it is typically what the customer provides as basis for design. Design Engineering transforms the information from Basic Engineering into completed design drawings; this includes elements such as, CAD-models and analysis. Procurement Engineering includes the work processes that create the foundation for the procurement process. This includes elements such as, technical requisitions and creating

Material-to-Order (MTO) documents. The last engineering process, Fabrication Engineering, involves transforming the information from Design Engineering and Procurement Engineering into the work foundation for fabrication, and involves elements such as, creating work packages and work drawings.

3.2 The Design Process

The design phase, which is a part of the engineering process, is divided into four sub-processes, referred to as project phases. These phases are: layout, design, detailing, and drawing. The company wants to perform the phases sequentially, where layout is completed before the next phase, as seen in Figure 8. Unfortunately, this is in reality quite difficult to achieve in most projects.

Figure 8: The Wanted Design Flow at AS Nymo

The more realistic design flow is shown in Figure 9, where the overlap will vary from project to project. The company tries to minimize the overlap to the extent possible.

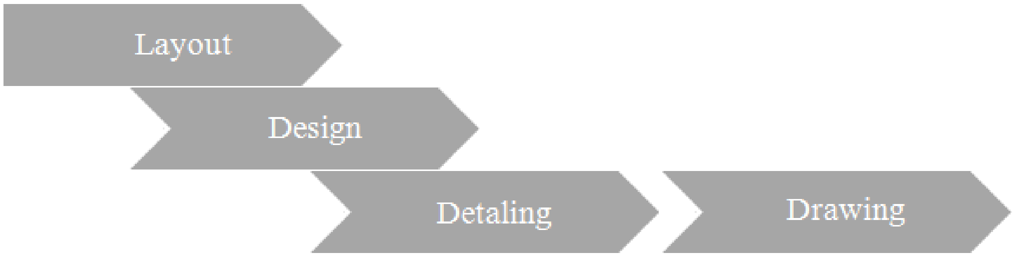

Figure 9: Realistic Design Flow at AS Nymo

The discipline leader for layout is responsible for coordination of all disciplines during the Layout phase. Ideally, all the multidiscipline decisions should be determined when layout is frozen. This enables all the disciplines to work independently without further multidiscipline coordination, until changes that affects the layout occurs. During the design phase the concept established in the layout phase is further developed by design engineers with core competence in different areas. All the relevant calculations are also done during this phase. CAD-models are also developed to an extent that provides sufficient information regarding, e.g. specifications from customers and the project standards. CAD-models are further developed in the Detailing phase in order to fulfill both internal and external requirements. The level of detail should be sufficient in order to prepare the 2D design drawings after the completion of the Detailing phase. The Drawing phase, which is the last phase in engineering, involves the creation of drawings and other documents that have not been created. The maturity and relevance of the documentation is controlled in this phase. DE is further explored in section 5.

4 Lean

The purpose of this section is to provide the reader with the background and basics of lean in order to better understand the principles and framework for which the construct is based on.

4.1 Lean History and Origins

Scientific management principles were introduced by Frederick Taylor at the end of the 19th Century. The main objective was to enhance the productivity and efficiency regarding economics and labor. The emphasis was on continuous learning and improvement of the system and processes by labor work division. Employees would work on the same task constantly, based on the idea that this would enable the workers to gain knowledge and skill through learning. The belief is that this would result in the improvement of efficiency and productivity for the task at hand (Sathe, 2012). However, in contrast to Tayloristic approaches, later research suggest that employee empowerment and involvement increase job satisfaction, which supposedly improve efficiency and productivity (Herzberg, Mausner, & Snyderman, 2011). Employee focus has since become one of the main attentions of several methodologies, such as lean (Womack & Jones, 2003). The term lean was first coined in the book *The Machine That Changed The World* by Womack, Jones, and Roos (1990). The book explores the differences between conventional manufacturing systems and those of the Toyota Production System (TPS), where the latter is commonly seen as the origin of lean production. The essence of the TPS philosophy is the focus on streamlining value-adding activities and the relentless elimination of waste within the system, where the goal is to continuously improve in order to increase customer satisfaction. Furthermore, employee empowerment is a critical aspect of TPS, and in many ways it can be seen as the heart of the system. According to TPS philosophy, improvement efforts should be conducted at the lowest possible level of the organization, using scientific methods. Employees at Toyota are explicitly taught how to improve, and by doing so they are given a learning environment which enables them to develop their problem solving abilities. Thus, one can argue that TPS is comprised of a community of scientists, and that the heart and soul of the Toyota culture is change and continuous improvement through learning (Spear & Bowen, 1999).

4.2 The Basic Principles of Lean

Lean provides the means to do more with less, e.g., less time, space, and resources, while at the same time producing what the customer wants. Lean facilitates increased value while eliminating waste. In this context, waste is defined as any activity which absorbs resources without adding value. The five principles of lean are designed to ensure customer satisfaction by converting waste to value through instant feedback (Womack & Jones, 2003). The following sections describe these principles.

Value

In the words of Womack and Jones: *"The critical starting point for lean thinking is value"* (Womack & Jones, 2003, p. 16). Value must be defined through dialog with the specific customer. It is only the customer that can define value, and it must be expressed in relation to a specific product in order to be meaningful. The producer is the one that creates value, and in the eyes of the customer, this is the reason for the producer's existence. Spite the importance of value; it is hard for producers to accurately define it. If value is not accurately defined, waste will be generated, since the producers will provide the wrong goods or services (Womack & Jones, 2003). According to Womack and Jones (2003) the most critical task in specifying value is to determine a target cost. This is based on the amount of resources and effort necessary to make a product of given requirements, if all the visible waste was removed from the process. Doing this is essential to eliminate waste, as this becomes the target cost for the development, order-taking, and production activities required for the product. Once the target cost is determined it is used to identify potential waste in every step of the value stream.

Identify the Value Stream

The value stream is defined by Womack and Jones (2003, p. 353) as: *"The specific activities required to design, order, and provide a specific product, from concept to launch, order to delivery, and raw materials into the hands of the customer".*

Womack and Jones (2003) explain that there are three critical management tasks of any business: problem-solving, information management, and physical transformation. The value stream is a set of actions that enables a product to move through these tasks. Identifying the entire value stream for each product will typically expose large amounts of waste. Usually, the value stream analysis will show three types of occurring actions. Firstly, several steps will unambiguously be identified to generate value. Secondly, other steps will be found to create no value, but to be inevitable with present technologies and production assets. This type of non-value added waste is termed Type One muda. Lastly, additional steps will be found to create no value and to be instantly needless (Type Two muda) (Womack & Jones, 2003).

Flow

After waste has been identified and removed, one should make the remaining value-creating steps flow. Flow, in the context of lean, concerns how entities or information move through a process or system as fast as possible, e.g. without unnecessary interruptions. Simply put, flow is about reducing throughput time while improving customer satisfaction. Small batch sizes[2] are typically an essential component in order to achieve flow (Womack & Jones, 2003).

Pull

Pull production, often referred to as Just-in-Time production (Evans & Lindsay, 2008), is about making exactly what the customer wants, when the customer wants it (Womack & Jones, 2003). Customer demand dictates production level, in contrast with conventional push production, where forecasts of market demands are used to determine the production level (Evans & Lindsay, 2008).

Perfection

The fifth principle of lean deals with the endless quest for perfection through continuous incremental improvement efforts, usually referred to as kaizen (Womack & Jones, 2003).

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[2] A batch size of one is the “ultimate goal” (Evans & Lindsay, 2008)

5 Design and Engineering

In order to enable the identification of the mechanisms leading to waste in DE, it was deemed necessary to provide a basic understanding of some elements and characteristics of this discipline. DE can be considered as an activity that creates value for customers and consumers. In essence, this means that the product specifies the required values. Additional value may be created in the form of user friendliness and enhanced value creation for the customer. The design values are realized through the fabrication and construction process (Bonnier, Kalsaas, & Ose, 2015). In the researched literature there were several different definitions of design, engineering, and product development. However, in the context of this thesis, we chose to disregard any differences as they seemed to be subtle or ambiguous.

5.1 Distinctiveness of Design and Engineering

The phenomenon of DE is characterized by a balance of creativity and rationality (Bonnier et al., 2015), and involves a systematic and intelligent generation of design concepts in conformance to specifications needed to realize these concepts (Dym, Agogino, Eris, Frey, & Leifer, 2005; Lia & Ringerike, 2014). The design process plays a crucial role throughout the product life-cycle. It is essential that the product design is precise at the earliest stages of development. The design phase typically accounts for a fraction of a product's total costs, but it affects the total manufacturing cost significantly. This indicates the importance of good design (Verma & Dhayagude, 2009).

According to Koskela, Huovila, and Leinonen (2002) it is possible to conceptualize the design process in at least three different ways: transformation, flow, and value generation. The transformation aspect cover transforming requirements, and other input, into the product design. Increased transparency among the actors of the organization is achieved through a Work Breakdown Structure (WBS), which is a hierarchical decomposition of activities. However, important aspects like time constraints and customer requirements are not part of this conceptualization, i.e., the concepts of flow and value generation is neglected. The flow concept views design as a flow of information (section 5.3.5). Central principles include the elimination of waste, time reductions and diminution of uncertainties (Koskela et al., 2002; Lia & Ringerike, 2014).

Human beings are central actors in DE. Thus, one can argue that it is important to consider additional aspects, when compared to manufacturing or conventional production processes. The product of DE is information (section 5.3), which is in contrast to conventional production, where the products are physical objects. Simon (1996, p. 138) goes as far as to suggest that *"The proper study of mankind is the science of design, not only as the professional component of a technical education but as a core discipline for every liberally educated man."* Even though one does not need to agree with this statement, it is plausible the knowledge of technical systems and analysis does not suffice in order to understand what leads to successful and efficient design. The design process is a complex cognitive endeavor, and it is critical to understand these cognitive processes in order to improve existing design methodologies (Dym et al., 2005; Pahl, 1997). Creativity and innovation are important in order to generate good solutions, this is often accomplished through experimentation (Ulrich & Eppinger, 1995). In this context, creativity can be seen as the process of coming up with novel ideas that have value. Innovation can be seen as the process of realizing these ideas. Without creativity in design it is impossible to have innovation, and it is mandatory to have innovation in order to improve quality, create new markets, and extend the range of existing products (Verma, Das, & Erandre, 2011).

Problem-solving is a paradigm used to describe creativity in the context of design. The process can be decomposed into four phases (Takala, 1993; Wallas, 1926):

1. Preparation – The gathering of information relevant to the problem, and analysis seen from different perspectives in order to solve the problem
2. Incubation – The subconscious processing of the problem while the subject is not concentrating on it, e.g. while sleeping or working out
3. Illumination – The sudden manifestation and acknowledgement of the solution
4. Verification – The detailing of the solution by comparing and contrasting it against the given constraints and requirements of the problem

It is important to emphasize that creativity is not only the solving of a given problem. In order to even start a creative process, it is required to have a significant level of internal motivation (Takala, 1993). This indicates that to come up with good design, it is important that the designers possess a significant level of motivation. Encouragement of creativity, in the form of tangible and socio-emotional rewards, has a positive effect on creative motivational orientation, according to Eisenberger and Shanock (2003).

The process of engineering design typically consist of the following five steps (Verma et al., 2011):

1. Formulation – Transformation of design specifications and requirements into possible solutions
2. Synthesis – Select the best solution, based on the ability to conform to requirements within the given constraints
3. Analysis – Analyze the performance and expected results of the solution
4. Evaluation – Compare and evaluate result of tests with the desired results
5. Documentation – Document the process for future purpose

Creativity is especially important in the first two steps of the process, since new thinking or rearrangement of existing data is required (Verma et al., 2011). The process typically begins with the analysis of the product’s intended usage and context. The analysis leads to a heterogeneous set of loosely related details, and possibly some insight to potential solutions. The design problem is initially structured and its solution defined through its implicit properties. The solution is further elaborated in relation to additional requirements, and if the context and requirements determines a distinctive solution, it may be derived algorithmically. Then designing is basically just the problem’s transformation from its intentional to its extensional form (Takala, 1993). However, it is common that the algorithmic rules are unknown, or that the problem lacks specifications. This typically leads to an explorative approach of trial and error, which is usually not a random effort. The paradigmatic solution is compared against an increasingly maturing set of requirements, and modified as needed. In this aspect, design is described as the convergent evolution of solutions (Takala, 1993; Yoshikawa, 1981). Its progressive evolution may branch, and lead to detours and backtracking, which eventually will result in a path to the solution (Takala, 1993). Simon (1996) suggests that detours are a natural part of the design process. Even though a general notion of the goal is known, barriers that are encountered along the way call for a continuous adaptation in accordance to these obstacles. Ballard (1999) argues that design requirements and their respective solutions evolve as the process progresses. This is what

Thompson (1967) depicts as reciprocal dependencies: relationships where output from one activity establish the next (Kalsaas & Sacks, 2011).

The design phase comes to a halt when the engineers run out of time (Reinertsen, 1997). This might indicate that the ideal solution cannot be achieved, and that decisions must be made in accordance to what is perceived as good enough (Bølviken, Gullbrekken, & Nyseth, 2010; Bonnier et al., 2015). Typically, this is the solution that is most consistent with the original requirements.

Male et al. (2007) point out three challenges that are distinctive to design:

- Requirements are often subject to interpretation, since they tend to be vaguely formulated
- Problems become increasingly clearer as solutions evolve over time
- The design process is an interactive, multidimensional effort that represents the interests of several stakeholders

Kalsaas (2013a) suggests that these challenges are caused by the need for design to mature. Kalsaas (2011) conceives design as a learning process, where one develops and optimizes a solution. Thus, the aspect of learning can be seen as particularly relevant in the context of DE. The topic of learning is further explored in section 5.5.

5.2 Lean Design and Engineering

The potential to strengthen the competitive advantage is higher in DE compared to other parts of a company. This is somewhat caused by that most companies have improved their production process, and the gap between companies are not that large, reducing the possibility for improvement (Karlsson & Ahlström, 1996). Implementing Lean Design and Engineering (LDE) can contribute to the likelihood of market success by getting products out in the market faster, as they spend less hours on engineering and achieve a higher degree of manufacturability and quality (Ćatić & Vielhaber, 2011; Karlsson & Ahlström, 1996). McManus (2005) identifies three goals in lean engineering that represent different areas of process improvement. The first goal is to create the right products. This includes creating product architectures and designs that increase the value for the stakeholders. The second goal is to create value by effective lifecycles and enterprise integration. Thirdly, there is the goal of eliminating waste and improving cycle time and quality in engineering, thus creating an efficient engineering process.

Ko and Chung (2014) state that improper design is one of the biggest causes of waste, in large due to the negative implications further down-stream. Major decisions taken early in the development process could potentially have a significant impact on the end results, e.g. reduced manufacturability (Morgan & Liker, 2006; Sehested & Sonnenberg, 2011). One of the main differences between conventional DE and LDE is when decisions are made. In conventional DE, concepts are chosen at an early stage in the process, resulting in decisions based on limited information. Usually, the subsequent steps of the DE process will focus on iterations and optimization of the chosen preferences. In LDE it is seen as advantageous to postpone decisions to a later stage in the process (Holmdahl, 2010). The uncertainties regarding the final solution are highest in the early stages; the concept of front loading can help mitigate this. Front loading adds more resources to the early stages of DE and delays decisions until the necessary information is acquired, thus reducing the uncertainty, and potentially reducing the development time (Sehested & Sonnenberg, 2011).

Set-based design is an approach that enables decisions to be made at a later stage. It is a method where different alternatives are considered instead of focusing in on a single solution. The emphasis is on taking time to reflect over solutions, and not rush into something which might cause defects downstream. The engineering work often begins before the design is frozen[3]. This provides an opportunity to study different alternatives (Liker, 2004). Set-based design is often considered as a contrast to iterative point-based design. The use of iterative point-based design might consume large parts of the budget and the schedule, due to the risk of unknown iteration loops, which can lead to changes in requirements (Oppenheim, 2011). Ballard (2000) introduced the terms negative and positive iterations, where positive iterations are the processes that create value. Negative iterations are connected to what is perceived as waste in the design process, and what iterations that can be removed without decreasing the level of value creation. However, it can be a challenging effort to separate these since the path to the desired result is commonly unknown.

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[3] In automotive jargon the final vehicle design is called “clay-model freeze” (Morgan & Liker, 2006)

There are some caveats to be aware of when implementing lean engineering. McManus (2005) states that the process is often experimental, where the participants learn what works throughout the process, since the techniques of applying lean to DE are not that well established. The process can be both risky and difficult. Karlsson and Ahlström (1996) state that there is a risk to no longer work efficiently in cross-functional teams, since there can be too much focus on research and development, and the technical aspects of the product. Also, the process of defining waste and value is quite difficult to articulate (Siyam, Kirner, Wynn, Lindemann, & Clarkson, 2013). The implications of LDE are not necessarily positive either. An example from Japan in the 1990s is that LDE led to too much product variety. This led to an expensive production process. The problem was later mitigated by reducing the product variety by keeping 20 percent of the products that generated 80 percent of the profits (David & Göransson, 2012).

5.3 Information - The Product of Design and Engineering

"Information is the 'product flow' or work objects which is to be made to flow through an uninterrupted product development value stream" (Slack, 1998, p. 30).

Several authors suggest that the product in DE is information (Bauch, 2004; Chase, 2001; Graebsch, 2005; Zhao, Tang, Darlington, Austin, & Culley, 2007). This was also supported by the panel of experts at the waste workshop at the University of Huddersfield. Bauch (2004, p. 1) states that *"Product development […] can be understood as some kind of information creation factory"*. Due to the relevance of information in DE, the aim of analyzing and improving the processes in DE can be considered an analysis of the generation of different information types, as well as their respective qualities (Vosgien, Jankovic, Eynard, Van, & Bocquet, 2011).

5.3.1 Creating Information

Several attempts have been made to describe the creation of information (Vosgien et al., 2011). However, only a limited selection is provided within this thesis. Bauch (2004) provides a model (Figure 10) based on the work of Schwankl (2002), that tries to explain how information is generated, and how it eventually will contribute to value. The model shows that there is a mutual dependency between the different states of information, where the transition from one state to another is not distinctly described, implying that the transition can happen in a number of different ways. The model also implies that knowledge is not directly transferable from one entity to another; it has to be converted into information first (Graebsch, 2005). Furthermore, it illustrates that the value of information increases as it is converted closer and closer to what Bauch (2004) calls know how. Know how includes both the explicit and tacit knowledge (section 6.3.15), which will affect the abilities of employees, rendering them more effective.

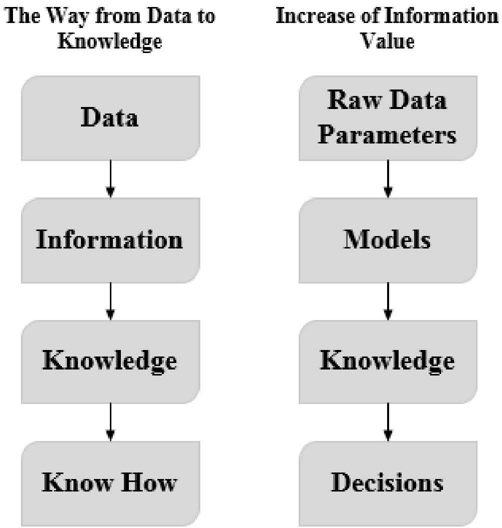

Figure 10: The Process from Data to Knowledge, and the Value Generated in the Process, adapted from (Bauch, 2004)

The model derived from Bauch (2004) provides a rather linear perspective of information. Ahmed, Blessing, and Wallace (1999) propose two stages with different outcomes. In the first stage, the context of the data must be understood in order to transform it into information. If the context is not understood it remains as data. In the second stage, information must be interpretable in order to transfer it into knowledge; if it is not interpretable it remains as information (Graebsch, 2005). Consequently, waste can be expected to occur if the recipient is not aware of the context, and is unable to interpret the information (section 6.3.10) (Graebsch, Seering, & Lindemann, 2007).

5.3.2 Types of Information

There are several ways to differentiate between different types of information within a DE setting. Graebsch (2005) points out that it is important to keep the types of information and their interfaces in mind, when, e.g. reducing waste.

Graebsch (2005) defines three views on information in DE:

- Information in tools - takes the terminology used in the tools into account
- Information in products - takes base in the physical information, often represented through structure analysis
- Information in processes - is applied in the context of organizations and people based on social science

The types of information in DE are not exclusive, i.e. they will interact with each other in the interfaces in DE, and can be defined differently depending on the user. Graebsch (2005) uses the example of sending an electronic document through email, where it can be perceived as information in a process since it is sent from one entity to another, information in a tool, which in this example is the email client, and information in a product as the data sent are transformed into a product.

Slack (1998) categorizes information into four different areas in DE:

- Product information - in essence this is the information required to create the product, and it includes the transformation of customer requirements into parts requirements which is then transferred into design parameters
- Project information - the information directly related to management, such as schedule and cost management information
- Process information - the information that describes how processes should be executed, i.e. it describes how employees should accomplish tasks. Slack (1998) mentions that this information includes the procedures in order to satisfy ISO9000[4] requirements regarding documentation of work processes
- Business information - this is the information related to the business processes of marketing, sales and finance. It involves elements such as ledgers, orders and accounts

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[4] ”The ISO 9000 family addresses various aspects of quality management and contains some of ISO’s best known standards. The standards provide guidance and tools for companies and organizations who want to ensure that their products and services consistently meet customer’s requirements, and that quality is consistently improved” (ISO, 2015a).

Each of the four information types are present in the value stream, where product information is the most important (Slack, 1998). According to Graebsch (2005) the information types by Slack (1998) have too sharp borders, while in reality these borders are hard to detect and might in some cases even not exist, e.g. project information can become product information (Vosgien et al., 2011).

While keeping the different types of information in mind, Graebsch (2005) suggests a higher level of categorization in order to conduct activities such as reducing waste. He refers to this view as a non-exclusive, high-level categorization. This view should be sufficient in the context of this thesis. Graebsch's (2005) basic differentiation consists of the following elements:

- Content type information - this information is used to provide participants in the process information about the product to be developed, and includes elements such as specifications, drawings, and CAD-models
- Process type information - the purpose of this type of information is to inform about the context of the development, e.g. schedules and organizational charts
- Noise type information - this is the information that serves no developmental purpose, such as spam and personal mail

In this differentiation a piece of information can be produced in order to serve either, both of the developmental purposes, or just one of them. Furthermore, Graebsch (2005) suggests that it is likely that when information extends its intended purpose, there will be a reduction in the value of the information, increasing the chances of waste occurring. Noise type information is according to Graebsch (2005) almost always waste. However, it cannot be removed completely, due to people's understandable interests aside from the actual product and its development. We somewhat disagree with this perspective, since personal interests and social interactions are important elements in a healthy organization, i.e. the social learning environment (section 5.5), and should thus not be considered waste. Graebsch (2005) somewhat touches upon this, as he suggests that personal networks can be an effective way to distribute and gather information, which opens the possibility to partially foster this type of "waste", instead of eliminating it.

5.3.3 Information Carrier

An information carrier is a combination of a physical structure, function and representation of information, i.e. it describes how information can be represented. The carrier is a theoretical description of the structure of information. In essence, a carrier is needed in order to display, transfer and store information (Bauch, 2004; Graebsch, 2005).

There are two types of physical structures of information, durable and non-durable. The durable information is storable, such as written documents, while non-durable information is not directly storable, such as conversations. The information goes through plenty of transformations between these two physical forms. For example speech, which is non-durable, can be transformed into a design drawing, which is durable. The physical structures of information go through the technical functions of storage, transformation and display. These functions do not usually add any value, the exception being when customers pay for displayed information, e.g. in consulting (Graebsch, 2005).

Before information can be represented in a physical structure it must be encoded. Encoding takes a mental image, also called an internal representation, of the information and transforms it into a physical representation, through mental and manual processes. From a physical representation the receiver decodes the information back into an internal representation. During the process of encoding and decoding the content of information is subconsciously altered (Graebsch, 2005). Arguably, this process makes it possible for information to be lost, i.e. information can be wasted.

Graebsch (2005) provides a list of what he recognizes as the most common ways to represent information in DE:

- Non-verbal - this is typically a way of communication that occurs unintentionally, e.g. through gesticulations. Different entities, e.g. different cultures, can have different perceptions of non-verbal representations of information, which consequently can lead to misunderstandings
- Verbal - communicating verbally is both fast and simple. However, verbal representations should not be used for everything, e.g. a design drawing is close to impossible to describe accurately with a verbal representation, and in this regard verbal

comments would be more useful. Furthermore, verbal communication is dependent on the availability of the sender and receiver

- Alpha-numerical - this includes texts, calculations, tables, etc. It is easy to distribute through, e.g. email. The encoding of this information can be a timely effort, while the decoding can be done faster. In part due to the time it takes to encode, there can be time lag in this form of representing information, often occurring in feedback loops
- Graphical - this representation is conveyed through, e.g., sketches, illustrations and drawings. It can vary in cost and detail, e.g. a simple sketch or a highly detailed CAD-model. It is similar to the alpha-numerical representation in the way it is encoded and decoded. Furthermore, it is often combined together with this information representation
- Artifact - this is a physical object such as a prototype, sketch model or the actual product itself. Artifacts can transport any type of representation of information, which then can be transformed into a physical structure, such as in the case of a prototype. This will however depend on the resolution of the artifact, e.g. a scaled model of a structure should come together with other representations to show the real dimensions. Some limitations of the artifact representation of information are the difficulties with transferring it, e.g. it is hard to send a prototype through email, and both encoding and decoding can be very time consuming, such as when dimensions have to be measured from a physical model

All the different types of representing information can be used simultaneously. The way the information is represented can affect the quality of information, as well as how efficiently the information can be transferred. In essence, information should be represented in the way that is most similar to the internal (mental) representation, and it should be able to be encoded and decoded easily and without errors (Graebsch, 2005).

5.3.4 Information Quality

Information can be considered the product of a DE process, and several aspects can be used in order to describe its quality, in a similar fashion to when describing physical products. Consequently, Juran's term *"fitness for use"* (Juran & Godfrey, 1998, p. 223) should be applicable when describing information quality. Strong, Lee, and Wang (1997, p. 39) modify Juarn's term and describe information quality as *"fit for use by information consumers"*. The quality of information is defined by the consumer of the information, which includes its usefulness and usability (Bauch, 2004; Graebsch, 2005).

Strong et al. (1997) created several terms to describe the quality of information. Bauch (2004) summarize the terms introduced in a graphical representation, which Graebsch (2005) further improved, shown in Figure 11.

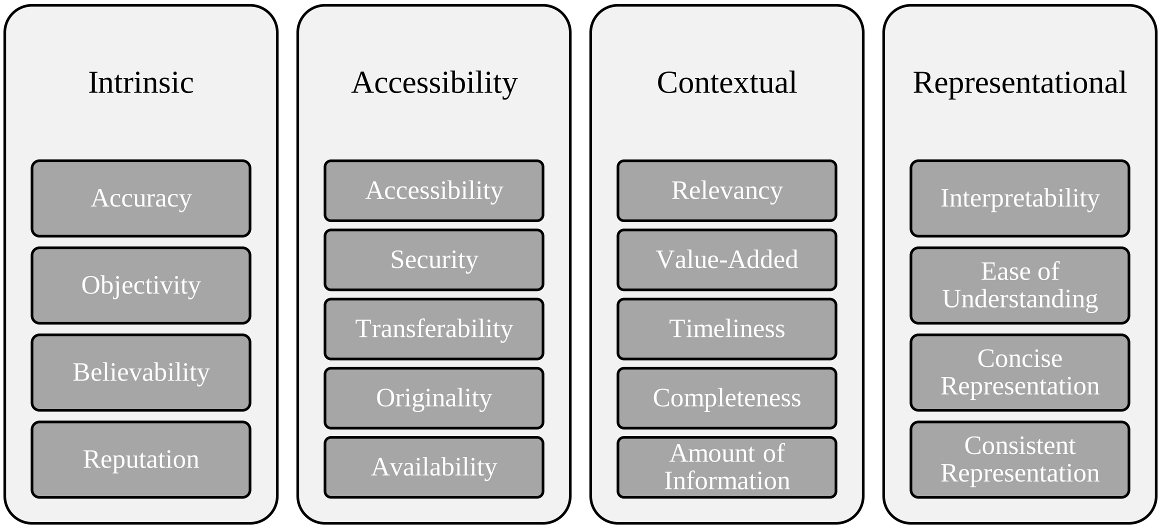

Figure 11: The Different Attributes of Information Quality, derived from (Graebsch, 2005)

Graebsch (2005) criticizes the use of this representation of information quality, as the representation provided by Strong et al. (1997) do not target DE specifically, and it is not created with the perspective of lean thinking. While there is possible to provide more specific attributes of quality, Bauch (2004) implies that this representation is useful in order to describe information quality in DE. With the improvements done by Graebsch (2005) it can be assumed that this representation of information quality should prove sufficient within the scope of this thesis. Information quality is central in several of the waste drivers found in section 6.3.

5.3.5 Flow of Information

Information flow is explained by Graebsch (2005, p. 58) as *“the transfer of information, without considering its content at all”*. Thus, the flow of information do not concern issues related to the interpretability of the information, as this rather is defined as a communication issue. Regarding the flow of information the goal is to make it flow seamlessly in the different dimensions. The dimensions of information flow include spatial distances, and time. Spatial distances are, e.g.

when information is passed from one person to another, where the information has to be transported. Graebsch (2005) suggests that the distance between the sender and the receiver should be reduced in order to make information flow more seamlessly in the spatial dimension. In the time dimension, Graebsch (2005) explains that using carriers that do not require acceleration enables information to flow seamlessly. Acceleration refers to that some carriers will require several resources to be transferred at the required speed, e.g. air mail is faster, but more expensive than normal mail. Electronic transfers are usually so fast that they do not require any additional acceleration. An additional non-physical dimension is the functional steps required to facilitate the transfer. For example, in order to sign a document it might be necessary to print it out, scan it, and then send it, requiring more steps than, e.g. an electronic signature. Doing more steps than necessary, consumes more resources than required, and can be deemed as waste. Graebsch (2005) concludes that seamless information flows travel fast directly from the sender to the receiver, in short distances. Since information is the product of DE, improving the flow of information could prove as a valuable approach in order to eliminate waste.

5.4 Communication

The DE processes rely heavily on communication. Millard (2001) explains that in an ideal world it would be better if one person had all the knowledge he needed in order to complete a task. Unfortunately, persons have limited knowledge, leading to handoffs. People have to communicate in order to facilitate handoffs and information transfers. Graebsch (2005, p. 78) defines communication as: *"an interpersonal connection across tasks, with a limited time frame, for the purpose to define, conduct and control the transfer of information generated in one task to another"*. Graebsch (2005) further explains that his definition does not include the communication within a task, since this is in essence what happens when generating information, i.e., communication do not create information, it only transfers it. Graebsch et al. (2007) also state that information transfers are a volitional act, where one or several pieces of information are sent from one entity to another. Thus, information transfers do not cover the receiving, since it can be sent without reaching its potential recipient. Crowston (1991) explains that a task that does not require assignments of subordinates will not require communication. This is similar to the ideas of Millard (2001). Graebsch (2005) provides a model which explains the process of communication (Figure 12).

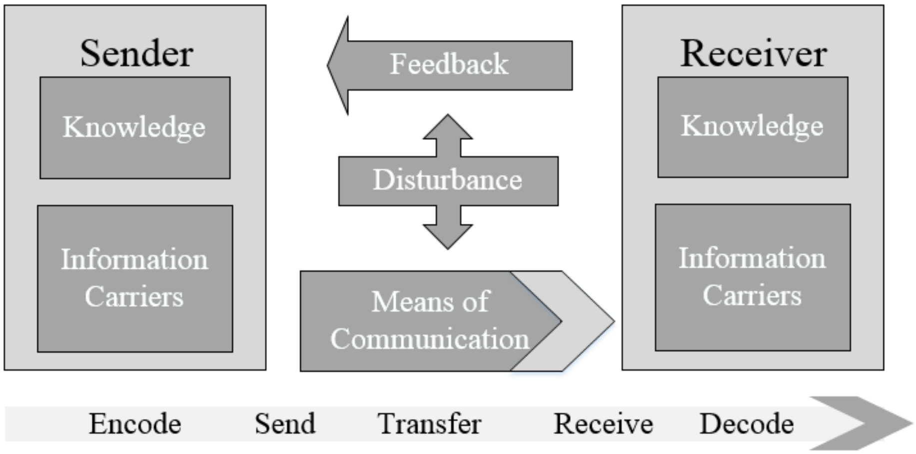

Figure 12: The Process of Communication, adapted from (Graebsch, 2005)

The model includes several activities that occur during communication. First, the information is encoded and put into an information carrier (section 5.3.3). The information carrier is then sent through different means of communication, which is selected by the sender. Then it is received and decoded. It should be noted that the recipient have to be aware that the information is sent. Eventually, feedback of the received information can occur. During the transfer of information there can be disturbances. This can influence the time, the content, and the cost of the transfer (Graebsch, 2005). In order to send information, the carrier must be represented in a media. The main difference between carriers and media is that several carriers can be represented in a media. A commonly used media in DE is documents. In a document there can be both alpha-numerical and graphical information carriers (Graebsch, 2005). In order to transfer media different tools are used, Graebsch (2005) refers to this as means of communication. Means of communication in DE are, e.g., emails, meetings and phone calls.

Graebsch et al. (2007) studied information transfers in relation to value. Out of 663 observed information transfers only 11.8 percent contributed to the value of the end product. Consequently, there is great potential in reducing and eliminating information waste, especially when considering all the time needed to create the information. Graebsch et al. (2007) found that the waste drivers by Bauch (2004) were present in all the information transfers that did not add value. Several of the waste drivers we present in this thesis (section 6.3.) are adapted from Bauch's (2004) waste drivers.

5.5 Learning

DE can be seen as a learning process (section 5.1). Furthermore, problem-solving and continuous improvement through learning is also a central principle of lean thinking (section 4.1). Thus, learning theory is included in order to provide a basic notion.

Kolb’s (1984) model for experiential learning depicts the process of learning as a four-stage cycle: concrete experience, reflective observation, abstract conceptualization, and active experimentation. The learning cycle can be portrayed as an iterative process, where the cycles of adaptive learning are repeated to allow further learning. Kolb (1984) divides the cycles into two dimensions, representing dialectically opposing pairs of adaptive orientations: concrete experience versus abstract conceptualization, and active experimentation versus reflective observation. Kolb (1984) terms the abstract-concrete dialectic as prehension. This is a concept that describes the representation of two opposing processes of grasping or taking hold of experience by relying on conceptual interpretation and symbolic representation, or by relying on the immediate experience, which he terms as apprehension. The active-reflective dialectic is seen by Kolb (1984) as two opposing ways of transforming what has been grasped through the prehension of experience, through internal reflection or active manipulation of the external world. Thus, one can say that the two dimensions of learning are divided into the capturing and grasping of experience, and the process of ensuring what is captured is translated into internal understanding and external action (Kalsaas & Moen, 2015).

Kolb’s model primarily deals with learning on the individual level. Illeris’ (2007) model incorporates individual learning into an understanding of learning in the workplace. In this model, learning is perceived to be taking place in the intersection between the learning environment of the workplace, and the learning progress of the individual. The learning environment is seen from the technical-organizational and the social perspective. The technical-organizational aspect relates to how work is organized and how it impacts the possibilities for learning. The social learning environment is comprised of the work community and social interactions. The progress of learning is tied to the individual’s experiences and their ability to assimilate knowledge. Learning is the product of the dynamic interactions between the learning environment and the individual’s learning progress (Kalsaas & Moen, 2015).

Illeris (2007) splits the technical-organizational learning environment into six categories: division of labor, work content, scope for decision-making, scope for using one's qualifications, scope for social interaction, and work strain. A strict division of work can negatively affect the individual's perception of work as meaningful (section 6.3.18). Work content relates to the social importance of the activity and its significance to the individual. The scope for deciding over one's work relates to elements such as organizational structure and leadership style. Work strain, such as performance demands, can have a negative influence on the learning process, since it can be seen as interference regarding the time and energy needed to learn.

Illeris (2007) divides learning into three dimensions: the cognitive dimension, the psychodynamic dimension, and the environment. The process of acquiring knowledge takes place in the intersection of the cognitive and psychodynamic dimensions, which subsequently interacts with the environment. According to Illeris (2007), there are different variants of learning in the cognitive dimension: assimilative, accommodative, and transformative. The general form of learning, which is termed assimilative, is the kind of learning that evolve progressively through encounters with new impressions and impulses, in everyday life. In DE, this learning can be in the form of acquiring additional knowledge and competence in how to use CAD software efficiently. Accommodative learning is described as the process of relating what is already known into situations that one cannot understand, e.g. applying knowledge to a different context than where it was originally used. Such learning requires creative efforts and is very important when attempting to improve existing work practices, e.g. continuous improvement (kaizen). This can be seen in relation to the waste driver lack of knowledge sharing (section 6.3.15). Accommodative learning in DE can be the knowledge of dealing with uncertainties and how to apply it to different projects, even though the objectives and specifications may differ. Transformative learning is described as developing new mental models, and can be related to a state of crisis on the personal level.

The psychodynamic dimension involves motivational, emotional and intentional patterns. These are influenced by the cognitive dimension, in the form of knowledge and skills. Illeris (2007) argues that mental defense mechanisms, such as defending identity, are critical in the context of resistance to learning. Identity in a work environment can be tied to something one excels at, and resistance may flourish when someone attempts to threaten this identity (section 6.3.18). Illeris

(2007) points out that the psychodynamic barriers, in the form of resistance, are amplified in relation to the increased level of complexity and difficulty of the learning requirements. The optimal conditions for workplace learning are found in the intersection where work practice and identity intertwine (Kalsaas & Moen, 2015).

According to Kalsaas and Moen (2015), there are limitations related to experiential learning. It might negatively affect the will to experiment, since an existing pattern, for which one is rewarded, may interfere with the willingness to reach for the best performance.

5.6 Value in Design and Engineering

In essence, a value-adding activity is an activity that alter the form or function of a product or service in a positive way (Stauffer, 2006). In order to implement LDE and remove waste, it is important to precisely define value. Value is likely to be defined and measured differently in DE when compared to manufacturing. DEs value stream consists of flows of information and knowledge, which are harder to track than the material flows in manufacturing (McManus, 2005). Defining value in DE is difficult and complex as value has several different dimensions, with conflicting values among stakeholders. Organizations often focus on waste and its causes, instead of focusing on value. While lean principles can help identify and eliminate some of the more evident wastes found in DE, a firmer definition of value is needed in order to truly optimize the process of DE (Chase, 2000; Siyam et al., 2013).

Within DE there are many different perspectives on value. Value will be perceived differently depending on who perceives it, e.g., customers, end users, and employees. The emphasis is often on customer value, but once it is identified there are a variety of entities that can contain value or waste (Chase, 2000). The value definition should encompass the components of value and its related attributes (Vosgien et al., 2011). This suggests decomposing value into several layers, based on the different perspectives of value. First, there is the decomposition into basic attributes such as cost, performance, and timeliness. Furthermore, value can be assessed in relation to activities, where the value from activities include the created information, products, the smooth flow of combined activities, or a combination of the values generated through these entities. In addition, these entities can have several attributes that can be considered valuable, such as performance, risk, schedule, and cost of the design in development, are characteristics of value.

Lastly, there is the aspect of quantitative metrics, which can be critical when attempting to improve or optimize value generation, i.e. the attributes need to be measurable in order to be quantified (Chase, 2000). An overview of this decomposition of value is illustrated in Figure 13.

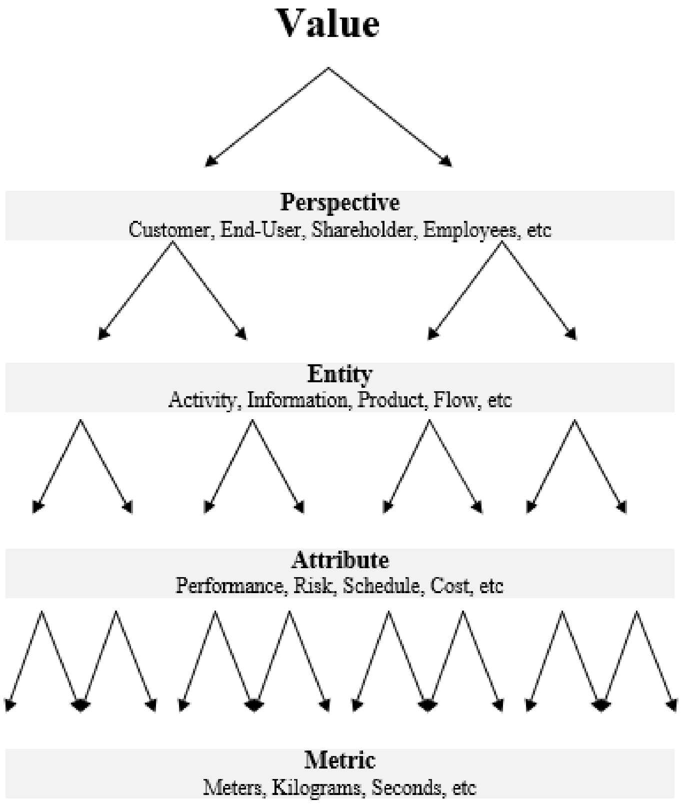

Figure 13: Overview of the Dimensions of Value, adapted from (Chase, 2000)

Defining value is likely to be a never-ending task. Thus, the emphasis should be to gain a working definition, in order to guide continuous improvement efforts. A simple approach is to first consider if the overall processes are value adding, where value is considered in two different contexts. Firstly, the value processes have in relation to the organization. Secondly, the value these processes have for the key stakeholders, while considering how that value is created through the individual tasks inside a process. This means taking downstream processes into consideration, both internal and external (McManus, 2005).

5.7 Waste in Design and Engineering

According to Morgan and Liker (2006), eliminating waste is the heart of TPS. Activities can be divided into value adding, non-value adding, but necessary, and non-value adding. True lean thinking does not focus on one-dimensional elimination of waste. It is necessary to understand that it is required to eliminate all the three types of interrelated waste, known as the three Ms, in order to achieve waste elimination.

The three Ms are categorized as follows (Morgan & Liker, 2006):

- Non-value-added waste (Muda) – The seven wastes of TPS is included in this category. Non-value-added waste is comprised of any activity that lengthens lead times or adds additional costs to the product, which the customer is unwilling to pay for
- Overburden (Muri) – Pushing people, processes or machines beyond their natural limits are considered as muri since this can lead to potential safety risks, defects and rework (section 6.3.4)
- Unevenness (Mura) – In normal production systems it may happen that the workflow is uneven. Sometimes there is not a lot happening while other times there is more work to do than what the employees, processes and machines can handle. The uneven levels of production result in non-value-added waste. Furthermore, an uneven production level requires the organization to always have the resources available that is required for the highest level of production, even though the average requirements are much lower

Several authors have provided definitions of waste, such as the one by Womack and Jones (2003), shown in section 4.2, where waste is defined as any activity which absorbs resources without adding value. Ōno (1988, p. 54), who is considered the father of TPS, explains that *"waste refers to all elements of production that only increase cost without adding value"*. Macomber and Howell (2004) state that waste is commonly understood as anything that is not value. They elucidate that waste is the expenditure of effort or resources that do not generate value. Similarly, Koskela (1992) explains that waste is activities that takes time, resources or space, while not adding value. Additionally, during a presentation in Huddersfield, Koskela defined waste as the gap between the intended and the achieved. Formoso, Isatto, and Hirota (1999) explain that waste is the loss created by activities that generate direct or indirect costs, while not adding what the client perceives as value. Several of the authors refer to waste as something that consumes resources without adding value, thus the resources that can be wasted in DE should be identified. The seven conventional waste categories describe waste through, e.g., rework, waiting, and overprocessing (Morgan & Liker, 2006). However, these categories do not explicitly describe what is actually wasted. Sugimori, Kusunoki, Cho, and Uchikawa (1977, p. 554) state that TPS works on the assumption that *"anything other than the minimum amount of equipment, materials, parts, and workers (working time) which are absolutely essential to production are merely surplus that only raises the cost"*. Thus, the unnecessary use of resources can describe what is wasted. Bauch (2004) identifies and describes the factors that are wasted in DE. He divides the waste into primary and secondary waste types, where the underlying causes are the waste drivers (section 6). The primary waste types affect the flexibility, and impacts: quality, time, and cost to market.

Bauch (2004) identifies resources as one of several secondary waste types. Due to the generality of the word resources, we would rather identify this as a general term. Thus, we rename Bauch's (2004) secondary waste types to resources. Some types of resources that can be wasted are:

- Manpower **-** Lack of proper care and attention during task performance, as well as individuals defying the established standards (section 6.3.18), typically result in rework. Some rework requires little manpower, but it can also consume capacity from a whole team or group, e.g. when rework results in the repetition of entire sub processes (Bauch, 2004).
- Machine power – Tools can also be wasted. For example, rework can render machines, such as computers, unavailable. This could potentially delay other projects as well (Bauch, 2004).
- Time **-** The waste of time is closely related to the waste of manpower. Unproductive meetings, caused by poor communication discipline, bad preparation, and aimless procedures, can also be considered to waste time (Bauch, 2004; Oehmen & Rebentisch, 2010). In addition, unproductive meetings often lead to more meetings. Waste of time can also be caused by, e.g. waiting for software applications to load (Bauch, 2004).

- Information/Knowledge **-** Since creating information and knowledge can be considered the core task of DE, loss of knowledge, and deficiencies in information quality means waste (Bauch, 2004).
- Potential **-** Not managing the available resources in a manner that enables project targets to be achieved with less effort, due to oversight of people, tool and technology potential, can also be considered waste (Bauch, 2004).
- Money **-** The resources used in a project, such as man-hours and materials, are assessed in money. Thus, if money are used on, e.g., ineffective testing equipment, unnecessary software tools, and prototypes based on insufficient analysis, money is wasted (Bauch, 2004).
- Motivation **-** Motivation (section 6.3.18) should be nourished since motivated employees will get a sense of responsibility regarding their tasks, as well as the output of the entire process. In addition, motivated employees exhibit a more dynamic performance, where control loops are done automatically and independently. Thus, decreasing the motivation of the employees is considered as waste (Bauch, 2004).

While these resources are separated here, in reality they will be inseparable in most contexts. For example, a waste of manpower will often lead to a waste of time, as the employees are not efficiently utilized. Furthermore, the wasted manpower will typically mean the money spent on maintaining the manpower is also wasted.

The hierarchy of the primary waste types and resources and the waste drivers are shown in Figure 14.

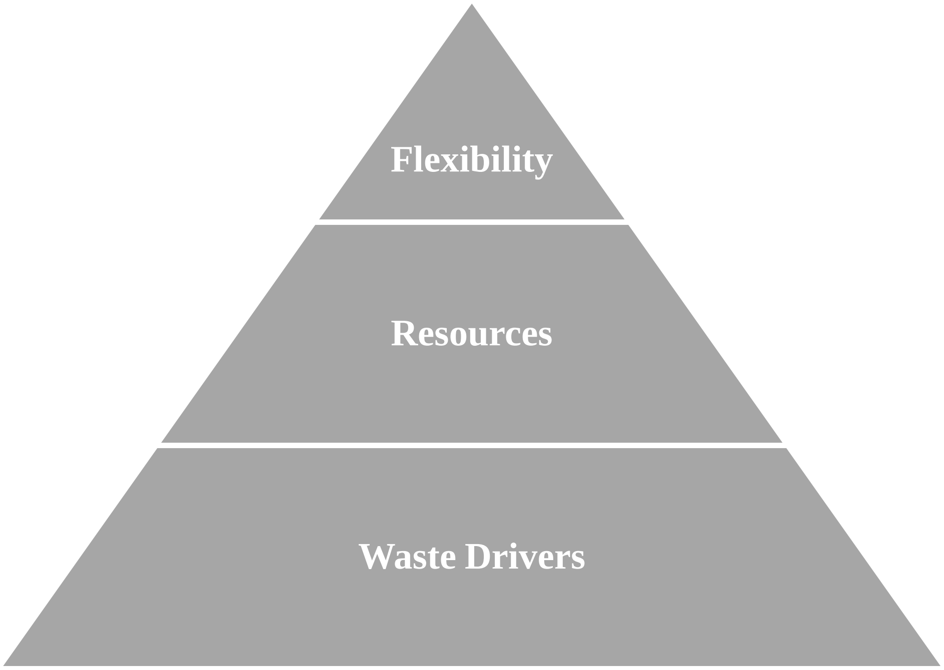

Figure 14: Waste Pyramid, adapted from (Bauch, 2004)

In addition to the resources that can be waste in DE, it is important to emphasize that DE processes can generate waste in processes down-stream as well. Thus, we can differ between what is wasted in DE, and what is wasted due to DE. The wastes that occur due to DE will be context dependent. For example, the downstream process can be a construction process, which arguably can have different waste than a manufacturing process. However, the waste in downstream processes is likely to impact the time, cost and quality to market of the product. Thus, the downstream waste is included in the waste pyramid.

Based on the provided definitions of waste, and the suggestions to what is wasted in DE, a proposed definition can be made. We propose that waste in DE might be defined as resources spent on activities that negatively impact the cost, time or quality to market of the designed element. The market includes both internal and external customers, in accordance with the description of value in section 5.6.

5.7.1 Categorizing Waste in Design and Engineering

Ćatić and Vielhaber (2011) state that two categories of waste can be identified. They label the categories operational and strategic waste. The operational waste is tied to the seven manufacturing waste categories.

The seven manufacturing wastes have been adapted into DE by several authors, a suggestion based on some of the attempts is shown in Figure 14, where the categories have been renamed, and an additional category has been added.

Overproduction of Information	• Producing more information than needed • Two different groups creating the same deliverable • Delivering information too early • Unsynchronized concurrent tasks
Overprocessing of Information	• Processing information beyond the requirements, i.e. over-engineering • Converting data back and forth between e.g. IT systems • Working on redundant tasks • Process variation
Miscommunication of Information	• Large and long meetings, excessive email distribution lists • Unnecessary hand-offs instead of continuous responsibility
Stockpiling of Information	• Saving information due to frequent interruptions • Creating large information repositories due to large batch sizes
Generating Defective Information	• Making errors in component and architecture design • Delivering obsolete information to following tasks
Correcting Information	• Optimization iterations • Reworking deliverables due to changing targets • External quality enforcement
Waiting	• Waiting for long lead time activities to finish • Waiting due to unrealistic schedules • Waiting for decisions and information
Unnecessary Movement of People	• Obtaining information by walking up and down the hallway • Travelling to redundant meetings • Superficial reviews

Figure 15: The Seven Manufacturing Wastes in the Perspective of Design and Engineering, derived from (Ćatić & Vielhaber, 2011; McManus, 2005; Morgan & Liker, 2006; Oehmen & Rebentisch, 2010)

Ćatić and Vielhaber (2011) define strategic waste as waste of knowledge, which in essence affects all the operational wastes. DE is considered a learning process (section 5.1), where the product is not only designs and information (section 5.3), but also knowledge. The idea of waste of knowledge can be divided into waste of product knowledge and waste of process knowledge. The consequences of knowledge waste are elaborated in section 6.3.15.

According to Vosgien et al. (2011), defining waste is essential to increase process efficiency. Slack (1998) concluded that the primary manufacturing wastes could be applied to DE. However, due to the complexity associated with DE, the set of categories was not considered all inclusive. Furthermore, several other publications (Bauch, 2004; Morgan & Liker, 2006; Oehmen & Rebentisch, 2010; Slack, 1998; Womack & Jones, 2003) have addressed this issue, and it typically involves transposing the seven manufacturing wastes to the area of DE, often supplementing with additional categories (Vosgien et al., 2011). Macomber and Howell (2004) discuss the force-fitting of the seven manufacturing wastes, and based on observation they introduce what they call the two great wastes: not listening and not speaking.

The fact that previous publications deem it necessary to add more categories can be interpreted to be an indicator that the seven manufacturing wastes are of limited use to define waste in DE. Bauch (2004), and Oehmen and Rebentisch (2010), demonstrate that a waste driver might belong to several of the seven manufacturing waste categories. This indicates that the process of categorizing waste in DE, to some extent, is open to interpretation.

It is also worth pointing out that several of the manufacturing waste categories will be a natural part of the engineering process, and it may depend entirely on the situation if these activities should be defined as waste or not. As an example, if information is stored deliberately to enable reuse in later assemblies, then it might be considered value adding (Oehmen & Rebentisch, 2010). In manufacturing, overproduction is considered the most important waste, this cannot be defended regarding projects that are one-of-a-kind, like a design project often is (Koskela, Bølviken, & Rooke, 2013). Information that is presented might not always be a waste since, in some instances, it can be beneficial in terms of creating a buffer along the critical path as well as alleviating resources (Oehmen & Rebentisch, 2010). Overproduction might actually be a value-added activity in some contexts, such as set-based design (section 5.2).

Oehmen and Rebentisch (2010) interpret the relationship of the different types of waste in a system dynamics model. The model (Figure 16) indicates that all types of waste in engineering, indirectly or directly, lead to waiting. Slack (1998, p. 33) states that *"waste time muda is the difference between the total processing time and the time necessary to complete the value creating activities. Therefore, any process which has non-value added steps theoretically could fit within this waste category"*. This further indicates that the manufacturing waste categories might be too ambiguous to identify waste in DE. However, it is worth pointing out that not all waiting in DE should be considered waste. DE processes are dependent on creativity (section 5.1), and it might be beneficial to create some leeway for reflection.

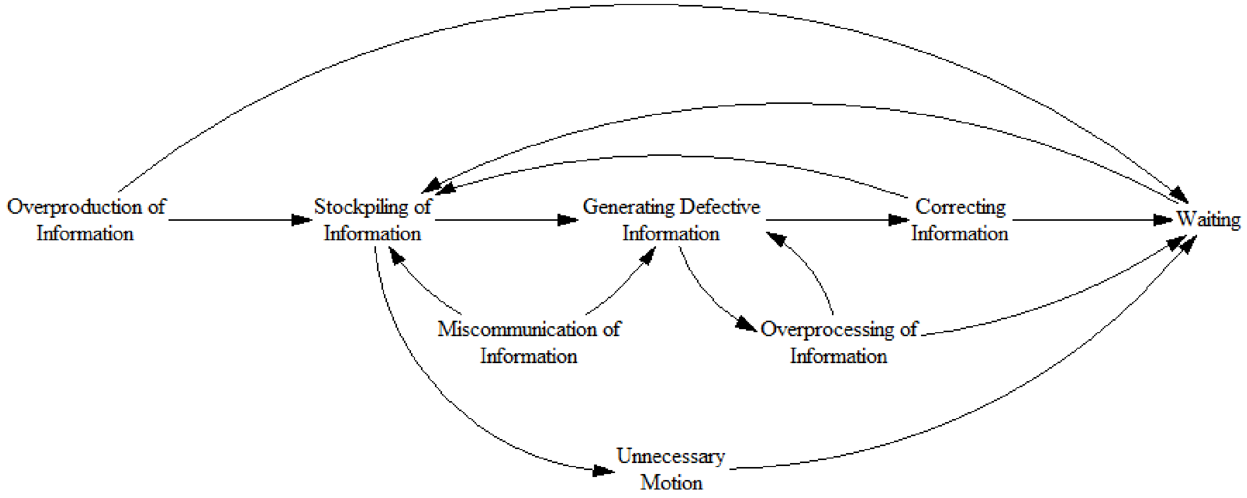

Figure 16: Relationship among Waste Types in Design and Engineering, adapted from (Oehmen & Rebentisch, 2010)

The original categories can, however, be helpful in relation to brainstorming activities in an effort to identify waste. Based on the literature reviewed, it appears that the majority of authors on the subject spend time and effort categorizing waste in DE into the manufacturing wastes.

6 The Construct - Waste Drivers

Based on the discussion in section 5.7.1, we believe that a new perspective could be beneficial. One of the authors from the researched literature, Bauch (2004), tries a different approach. Bauch (2004) uses the seven manufacturing waste categories. He also builds on these by adding three additional categories[5]. Bauch (2004) refers to the categories as drivers, since they describe why waste is happening, and not what waste is or what is wasted. In addition, he divides the categories into sub-drivers. We found this interesting, and wanted to explore these ideas further.

Bauch's (2004) idea of sub-drivers might have the potential to create a less ambiguous representation of waste in DE, and will perhaps even make waste easier to identify. Based on the sub-drivers created by Bauch (2004), and other literature, such as Oehmen and Rebentisch (2010) and Oppenheim (2011), we created a list of waste drivers. This was supplemented with findings from the case study and personal experience. The usefulness of creating a list of waste drivers is considered to be supported by Koskela et al. (2013), who tries to conceptualize waste in construction processes. They explain that the seven wastes stem from a manufacturing context. Hence, it does not cover the design aspect. They explore the potential of creating a list of waste drivers in construction. Koskela et al. (2013, p. 3) explain the benefit and purpose of such a list: *"Such a list would be instrumental in creating awareness on the major waste types occurring in construction, as well as mobilizing action towards stemming, reducing and eliminating them.".* DE is part of the construction process, and as a consequence, the statement by Koskela et al. (2013) should be relevant in this context as well. The purpose of waste drivers in DE could be to create awareness about the mechanisms that potentially contribute to waste. Managers and employees could benefit from such a list. Knowing what contributes to waste could enable people to eliminate it. Terms like rework and overproduction are too ambiguous in a DE setting (section 5.7) to provide a sufficient image of waste in this context. The waste drivers are an attempt to provide a better image of waste in DE.

A table was created in order to evaluate if the waste drivers should be sorted into the conventional seven waste categories. The purpose was to categorize the drives in accordance to the seven manufacturing wastes. However, the process of categorizing the drivers was time

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[5] Limited IT-resources, Lack of System Discipline and Re-invention

consuming and challenging. The relationships are complex, context specific and thus, very much open to interpretation. It became apparent that many of the waste drivers could be tied to multiple of the conventional categories. Thus, sorting waste in this manner was perceived to not serve any significant purpose. This was much due to the aforementioned issues. It should be noted that the waste drivers could be related to each other. Still, they should be more distinguishable in the context of DE, compared to the conventional seven categories. Furthermore, the waste drivers are more specific, which makes it easier to identify measures that can mitigate or eliminate waste.

6.1 Definition of Waste Drivers

Based on Bauch (2004) and Kalsaas (2013b) waste drivers is defined as a mechanism that has capacity to create waste and to be hindrances of workflow. Our definition of waste drivers is similar to Bauch’s (2004) definition of sub-drivers. Furthermore, the seven manufacturing waste categories are not defined as drivers like Bauch (2004) does. This is since we do not perceive the manufacturing wastes as drivers in the context of DE. For example, rework is a value-adding activity, and not a mechanism that generate waste. Rather, rework is a result of such mechanisms.

6.2 Selecting Waste Drivers

In order to expand on the ideas of Bauch (2004), other authors that provide similar ideas were identified. However, while several calls for a different approach, few provide ideas similar to waste drivers. Oehmen and Rebentisch (2010) provide detailed descriptions of waste drivers in DE. Oppenheim (2011), bases his description of waste on Morgan and Liker (2006), provides examples of waste drivers. The ideas from these authors were summarized in a table (Appendix 2). From the table we tried to adapt the ideas of these authors into a new list of waste drivers, which should cover all the aspects they mentioned. In order to create these drivers, some criteria and definitions had to be made.

During the process of creating the drivers, we attempted to create names in accordance with the definition (section 6.1). A resolution was also suggested, as there might be several layers of mechanisms (section 6.2.1). When the criteria for creating the drivers were determined, the ideas from the different authors were first adapted into 26 drivers. Further, the drivers were crossreferenced with other literature from different subjects. This was done to strengthen the validity of the drivers, in accordance to Yin (1988), who suggests using several sources of evidence. Findings from the case study were also included in the drivers. This was done afterwards to ensure objectivity when creating the drivers. In addition, it is important to mention that the drivers are not intended to cover all the waste generated in DE, but the majority. The waste drivers were made to cover waste related to DE. This includes, to some extent, processes that are influenced by DE, and vice versa.

The task of defining the waste drivers has been an iterative process. In some instances, drivers were merged while others were separated. The final list of waste drivers is comprised of 18 drivers, which are described in detail in section 6.3.

6.2.1 Resolution of Waste Drivers

We perceive that the three aforementioned authors (Bauch, 2004; Oehmen & Rebentisch, 2010; Oppenheim, 2011) use different resolutions when describing the waste drivers. Thus, we tried to determine a fitting resolution, in order to adapt the previous concepts. The main objective was to make the waste drivers identifiable and manageable, in the context of eliminating or reducing waste in organizations. In order to accomplish this we had to choose a fitting resolution.

We tried to find somewhat a golden path between high and low resolutions. While many of the drivers are connected, one of the main criteria when creating the list was to avoid overlapping, to the extent possible. However, this was not completely achieved, since the waste drivers are highly context dependent. Also, no drivers should be effects; the drivers should be the mechanisms that might lead to waste. This interface is a bit ambiguous, as several drivers can be effects of others, depending on the context. Even though many of the drivers can be effects, all of them are mechanisms that lead to waste. In relation to DE, we believe this is an improvement compared to using the manufacturing waste categories. An expansion of the list might include sub-drivers of each driver, and categorizing the drivers in a sensible manner.

6.3 Descriptions of the Waste Drivers

In this section the selected waste drivers are described. Examples are included where possible and suitable. Several of the examples are derived from interviews done in the context of analyzing a recent project at the case company. This analysis was done by Bang and Stykket

(2015), where we participated in some of the interviews. In addition, we received comprehensive minutes of the interviews. Other examples are derived from process mapping meetings, as well as the survey we conducted at the case company (section 7). Furthermore, some examples are extracted from researched literature or media.

6.3.1 Ineffective Verification

Verification is defined as testing the truth or accuracy of, e.g. a report (Hornby, 1974). In the context of this waste driver we perceive verification to deal with tests, prototypes, approvals and transactions.

Testing & Prototyping

Testing and verification procedures are activities that are performed to ensure that a product conforms to requirements. If the same tests are performed on the same component during different stages of development, it is likely to be unnecessary non-value-adding activities. Bauch (2004) claims that the reason for conducting the same tests multiple times may be based on ignorance by participants. An example is when the supplier have already conducted a series of tests, but the contractor is unaware of this, and as a consequence conducts the same series of tests again (Slack, 1998). Since the procedure has no influence on the result, it can be interpreted as waste. Different testing standards and scales in testing is another example. Clausing (1994) discusses what he terms the “hardware swamp”, which are the prototyping efforts that do not contribute to the goal of the project. Thus, building and debugging such prototypes are considered as waste (Ulrich & Eppinger, 1995).

Poor tests, validations and interpretation might cause defects, and the longer these defects remain hidden and undiscovered, the worse. Bauch (2004) differentiates these defects as engineering escapes and validation escapes. Engineering escapes are usually detected during the process by conducting tests and analysis, while validation escapes are commonly not detected until they reach the customer. Validation escapes can to some extent be measured based on data acquired from warranty issues, and this data will reveal information regarding the frequency of such defects. It is obvious that companies will try to minimize the amount of defects, and as a result testing and analysis become important means in this context. Unfortunately, it is quite common, especially regarding DE, to experience a great deal of changes in specifications and requirements at a late stage of development. The consequence of these changes might be significant if the process has been subject to poor testing and verification, since this could have a negative impact on the scope of necessary changes, e.g. rework (Bauch, 2004).

An example on ineffective verification was discovered during the case study. Employees working on assembling modules, which were created by the engineering department, encountered several critical problems during assembly. They claimed that the engineers had designed the module in such a way that it was lacking the necessary space required for the tools needed for assembly. This resulted in a serious amount of rework, and could probably have been avoided if representatives from disciplines, such as fabrication and construction, were involved at an earlier stage. Bauch (2004) suggests that it is possible to mitigate the risk of conducting poor tests and analysis by integrating employees from relevant disciplines in the process. This will probably create an environment of increased awareness of the requirements of adjacent processes, i.e. a learning environment. This could enhance the probability of avoiding potential problems. However, it is important to specify and plan in advance how the testing and analysis should be conducted and what should be achieved.

Ulrich and Eppinger (1995) point out that the outcome of a test may determine if a task should be repeated. If testing a prototype significantly enhances the likelihood that the succeeding activities will be accomplished without iteration, the prototype and testing phase may be warranted. The estimated advantage of a prototype in reducing risk must be weighed against the resources required to build and evaluate the prototype. Products that are tied to a high level of risk or uncertainty due to, e.g., costs, failures, or new technology, will benefit from prototypes. However, products that are associated with limited failure costs and well known technologies do not derive as much risk-diminution benefit from prototyping. The addition of a short prototyping phase may allow a following activity to be finished faster, than if the prototype were not built. In addition, it might be possible to complete sequential tasks concurrently by building a prototype, which saves time and, thus, adds value.

Transactions & Approvals

Excessive transactions is defined by Bauch (2004) as excessive time and effort spent on necessary non-value-added steps. This includes activities, such as, contract negotiation, resource scheduling, and quote meetings.

Excessive approvals might be multiple authorizing signatures or extensive approvals of engineering change documents, e.g. an employee has the authority to decide if an invoice should be paid. However, even though the individual has the required authority to make the decision, the process of authorizing the invoice to be paid have to go through several additional channels, without adding further value or change the results for that matter. This can be considered as waste, since the extra steps of authorization in essence only makes the process take longer (Slack, 1998), i.e. time is wasted. During a series of process mapping meetings at the case company it was discovered that the quality control (QC) department was involved with the authorization of MTO change documents. This step did in reality not add any value since the decision was already made further upstream. Thus, QC's involvement can be seen as an unnecessary non-value adding step. Luthans (1997) suggests that excessive approvals are a source of stress on organizations and that it has a negative impact on the performance of employees. According to Bauch (2004), excessive approvals can be caused by an organization's hierarchical structure. Especially structures lacking the presence of cross-functional teams. As a rule of thumb, one can say that the number of non-value-adding handoffs can be used to partly determine the level of waste present (Bauch, 2004).

6.3.2 Poor Coordination

When multiple people work together towards a common goal there is a need to organize in a manner that an individual pursuing the same goals would not have to do. These extra organizing activities are defined by (Malone, 1988) as coordination.

It seems to be an emergent understanding of the significance of effective design management required to smooth the progress of coordinating design processes within its constraints (Austin, Baldwin, Li, & Waskett, 1999). In addition, Koskela (2000) points out that the design phase is characterized by uncertainty, which is a challenge regarding predictability in and between activities. Usually, DE processes consist of several reciprocal dependencies, which means there are numerous interactions (Thompson, 1967). Consequently, we perceive planning to be of utmost significance, and believe there is great potential to reduce waste through improved planning.

Communication planning is a crucial part of the project planning process, since it is the framework for how communication processes should be conducted among the different stakeholders. *"Communications planning determines the information and communications needs for the stakeholders: Who needs what information, when they will need it, and how it will be given to them"* (PMI Standards Committee, 1996, p. 103). Globerson and Zwikael (2002) argue that communication planning is probably the most difficult for the project manager to plan, since it necessitates getting current and future information needs from all stakeholders. In addition, there are very limited tools and techniques available to the project manager for supporting the communications area. The only tool offered by the Project Management Body of Knowledge Guide (PMBOK), is the stakeholder analysis (PMI Standards Committee, 1996). This further exacerbates the difficulties related to communication planning. Poor communication planning can lead to miscommunication (section 6.3.9), unclear goals (section 6.3.6), and other issues that might result in waste, such as rework.

Other coordination issues are poorly planned and scheduled milestone and data release events, which are among the underlying reasons for waste, in the form of waiting for information (Bauch, 2004). Morgan (2002) claims that stable data are often held back until a pre-planned release event. This disables the possibility for the downstream operations to start or continue work that is depending on the data, which means that time is wasted. In addition, release events and check points within the process may cause conglomeration of information, i.e. large batch sizes (section 6.3.7), which could increase processing time of information, rendering it obsolete.

Oehmen & Rebentisch (2010) suggest that unbalanced processes and too tight schedules may lead to confusion during execution. This might result in that employees ignore the schedule (section 6.3.18), which in turn can lead to waste. Furthermore, if estimates are overly optimistic it is likely that performance will be lower than expected. During the case study it was revealed that employees from the mechanical construction department were subject to unrealistic expectations through scheduling. The mechanics argued that they needed drawings at least two weeks prior to construction, in order to create work packages. The schedule did not account for this, which made it difficult to follow (Bang & Stykket, 2015). While waste occurring here, per se, influences the construction phase, it indicates that planning and scheduling in DE affects downstream processes. If employees are trying to conform to excessive performance requirements over a prolonged period of time it may lead to burnout, which increases the probability of errors and defects. On the other hand, if excessive buffer time is added, it might result in that personnel further downstream will have to wait. However, if the planner manages to create a work breakdown structure that consists of optional activities, then this risk can be avoided or at least mitigated (Oehmen & Rebentisch, 2010).

Poor synchronization of tasks, processes, and running too many projects in parallel, might result in unwanted interruptions, which might result in longer mental setup times (Bauch, 2004). Too many projects going on at once will increase queues and cycle times, according to Morgan (2002), since it overburdens the system (section 6.3.4). The situation will probably become even worse if combined with unnecessary deliverables, which Oehmen and Rebentisch (2010) believe might be the result of poor planning. Bauch (2004) states that overproduction is a direct result of inferior quality regarding synchronization. Even producing information too early might lead to waste, since the information runs the risk of becoming obsolete. If information becomes obsolete then the possibility for rework will increase. In addition, delivering information too early can overload adjacent processes down-stream, which in turn can result in the conglomeration of information and thereby longer processing time (Oehmen & Rebentisch, 2010). However, delivering information early is not necessarily waste since it depends on the situation, e.g. if information is delivered early to create buffers on the critical path. In this case it might even be considered as value adding. Bauch (2004) believes that some of the main drivers for problems with synchronization is related to unrealistic planning by project managers.

A mentioned issue at the case company, regarding synchronization of processes, was the layout drawings, where design started before the layout was completed. This was done consciously, according to the interviewee, even though it would lead to potential rework. Another mentioned synchronization issue, was the cooperation between engineering and fabrication. Engineering considered the project complete when the design was completed, whereas the interviewee implied that in reality they are not done until fabrication is finished (Bang & Stykket, 2015). Furthermore, the IT department starts working 30 minutes later than the engineering department. Thus, if engineers encounter IT related issues before the IT department arrives, they will get nothing done. This demonstrates a challenge associated with synchronization.

6.3.3 Task switching

Task switching such as multitasking, are interruptions that forces a person to reorient themselves. From this perspective, one can say it has a switch cost (Bauch, 2004; Monsell, 2003; Morgan, 2002). The level of switch cost is determined by the frequency of interruptions, and the time that passes until the tasks are continued. Bauch (2004) states that poor synchronized tasks (section 6.3.2), and too many projects, are the root causes for these interruptions. This is despite the strong indicators that suggest that task switching can lead to a 50 percent reduction of productivity (Bauch, 2004). Such interruptions might require an employee to communicate with himself by storing information to enable him to continue work. Also, the process of transferring the task to someone else has the potential to interrupt work, since this involves additional communication (Oehmen & Rebentisch, 2010). Task switching typically occurs more in a matrix organization since people will have tasks associated with one or more projects, in addition to the daily chores. With this perspective in mind it seems plausible that dedicated project teams are less prone to such interruptions (Larson & Gray, 2011). The justification for using such organizational constructs should be assessed in relation to the amount of waste they create (Oehmen & Rebentisch, 2010). Furthermore, the magnitude of switch costs should be considered in the design of human-machine interfaces that require personnel to monitor several information sources and switch between different tasks under time pressure (Monsell, 2003). An example of a typical activity that is associated with task switching is meetings. Although they are often considered as necessary, it will likely interrupt some other task or activity. It becomes pure waste whenever meetings involve participants that do not require the information that is distributed during the meeting.

Task switching also include change of ownership and unnecessary hand-offs. The change of responsibility for a particular piece of information can provide an environment of miscommunication. Change of ownership is typically caused by unclear responsibility and authority (section 6.3.8), or a lack of required competence (section 6.3.5). It might also act as a mechanism that enables people to avoid being blamed for failures and mistakes, by sending the work to someone else (Oehmen & Rebentisch, 2010). This might in turn result in an environment that acts as a breeding ground for disagreement, distrust, and hostility, which might reduce productivity (section 6.3.18).

6.3.4 Capacity Constraints and Overburdening

In this context, capacity constraints are defined as interruptions of workflow as a result of, e.g. unavailable resources. Overburdening is defined as exceeding the capacity of an entity.

According to the *Theory of Constraints* (Goldratt, 1990), every process has a constraint, and total throughput can only be improved by elevating the constraint. Ulrich and Eppinger (1995) and Oehmen and Rebentisch (2010) state that development tasks are typically hampered by the lack of available staff, tools, and equipment. Activities that could have been performed in parallel have to be performed serially because of unavailable resources, which in turn might result in that projects take longer time to complete (Oehmen & Rebentisch, 2010). Constraints in the form of machines include bottlenecks associated with computer hardware and software, e.g. is the hardware capable to process the data reliably and with sufficient speed? Are there enough workstations to get the job done? Do the engineers have the required software licenses? Bauch (2004) points out that if the engineers have to spend time waiting for processing of data, or for a workstation to become available, or having to use inferior software, then this is all considered waste in the form of waiting. Bauch (2004) also points out constraints in the form of busy schedules, which influences the available time window to conduct activities such as meetings.

Oppenheim (2011) suggests that too many contractual obligations are a common constraint that might cause overburdening. Many projects proceed at a slow pace as a consequence of lack of staff and other resources. This is in many cases caused by that companies are working on more development projects than they can fully staff, which in turn increases the odds of overburdening employees (P. G. Smith, 2004). This claim is in line with the findings made during the case study, where several employees stated that they felt that there were too many projects going on at once, and that it was taking its toll on them. This further led to a decrease of motivation and productivity. Battling over resources was another consequence of having too many projects, which had a negative impact on the social relations among the employees at the company.

Time constraints were identified as an issue at the case company. This resulted in late inputs and less time for the designs to mature, according to employees. The time constraints were perceived by the employees to be overburdening them, since they felt that they had insufficient time to complete necessary tasks. This led to turnovers, and the absence of key personnel, for which there were no replacements. In turn, this resulted in communication issues, which had a further negative impact on productivity. Some mentioned unrealistic planning as the cause for the time constraints, more specifically, they did not take indirect engineering work hours accurately into account (Bang & Stykket, 2015). Thus, this example can be interpreted to also be related to poor coordination (section 6.3.2). Oehmen and Rebentisch (2010) argue that time constraints can lead to defects in several ways: It lures employees to take short cuts, and thus ignore best practices, which leads to defects. Furthermore, time constraints are often combined with stockpiling of information (section 6.3.7), as processes go out of sync, and thereby increasing the probability of working on defective or obsolete data.

Tahir, Yusoff, Azam, Khan, and Kaleem (2012) performed a study to uncover the relation between employee work load and performance. Their findings suggest that there is a significant negative relation between the two. Employees that suffer burnout become part of the “working wounded”, according to Izzo and Withers (2001). The burnout causes these employees to lose their motivation, which in turn reduces productivity, innovation, and creates inertia in the workplace. Ronald Downey, which is a psychology professor at Kansas State University, claims that burnout makes people feel disconnected from the workplace and their colleagues, and that turnover is a typical indicator of burnout (Stern, 2012). Wheelwright and Clark (1992) claim that many individuals involved in DE suffer burnout, and as a result may quit their job. Morgan (2002) points out that capacity utilization rates exceeding 100 percent is not rare in DE projects, and that the consequences of doing so can be increased queuing times, and thus, longer cycle times (Bauch, 2004). This indicates that employees in DE are more prone to burnout. If talented people leave an organization because the projects are overburdening them, it can be considered as waste, even though the project is considered a success. Furthermore, Illeris (2007)states that work strain can have a negative effect on the learning process (section 5.5), which means that knowledge is potentially wasted.

6.3.5 Lack of Required Competence

If employees are lacking the required competence to conduct the tasks they are assigned, then this can lead to waste. Oehmen and Rebentisch (2010) state that this leads to additional communication in order to acquire the necessary knowledge to perform the task. However, if the additional communication should be considered waste depends on the circumstances. If the goal is learning, then it creates value for the organization, by expanding the capability of the employee and thus enabling him or her to execute more value creation for the stakeholders. If the newly acquired knowledge already exist in the company, but are not available due to capacity constraints or for other reasons, then it is still necessary, but it is no longer value adding. If the capability already existed in a sufficient quantity or was not used, then it is considered waste.

A process such as quantitative risk analysis, which must be done for each work package in a project, requires a high level of participation of those who are responsible for executing the work package. Thus, all involved personnel should possess knowledge of risk management methods in order to perform the process properly. If this is absent, risk management or any other relevant processes can't be handled effectively on the work package level or on the integrated level. The combination of employees working on a work package without the necessary competence and knowledge of risk management processes, and a project manager without the ability to provide them with this knowledge, makes it improbable to expect successful implementation of project management processes (Globerson & Zwikael, 2002).

Since DE is a cross-functional endeavor comprised of people with complementary skills, it is important to have all the abilities represented by the members of the team. Without the right mix of skills problems may arise. Some managers tend to pay too much attention to interpersonal skills, and in the process they neglect skills needed by the development team to perform successfully (Katzenbach & Smith, 1993). However, Bauch (2004) suggests that deficiencies related to soft skills are critical, since they have a significant impact regarding how people get along, and thus, influence the efficiency of their activities, coordination, and cooperation.

Another aspect that Bauch (2004) emphasizes is people's lack of computer skills, which he states can considerably reduce productivity. Information technology is commonly used in most industries (Census and Statistics Department, 2014). This suggests that a proficiency in software and hardware are becoming increasingly important and employees need to be qualified in this regard. Oehmen and Rebentisch (2010) point out that information management tools can be very complex, and especially the ones used in DE, such as CAD software. If used improperly, they will not perform as intended and will not introduce the expected benefits, and might even lead to waste. Furthermore, software and hardware need to be optimized in relation to the activities and processes they are assigned to support by not being too complex, but also to ensure seamless integration. Bauch (2004) claims that incompatibility and insufficient interoperability of software and hardware systems make it difficult to create seamless integrated solutions. In addition, a lack of employee knowledge and training in conversion and linking systems is another major problem. Even though employees possess the required knowledge it might not be applied or communicated due to a lack of motivation (section 6.3.18). The potential of available IT resources are wasted if people do not know how to use it.

During a software development project, we experienced how the lack of knowledge regarding information technology led to waste, in the form of rework. We joined a project that had been going on for more than a year, and was supposed to expand on the functionality already implemented. However, since the work made prior to joining was done by personnel lacking programming skills, massive amounts of rework were necessary. The code produced did not support the new functionality, thus it had to be redone, which took several months. The project got cancelled as a consequence.

The competence related to leadership may become an obstacle, according to Katzenbach and Smith (1993), particularly if the leader misjudges his role. Bauch (2004) and McManus (2005) point out that a missing understanding of the essential things in development is a potential waste driver, since it may lead to over-engineering by producing just-in-case data and information. DE is often associated with a high level of uncertainty, and might influence the employee to over-engineer solutions. Bauch (2004) suggests that poor insights and feedback in business economics and life-cycle costs, is part of the mechanism that drives the over-engineering.

Bauch (2004) argues that a lack of insight in time management and prioritizing might potentially lead to waste, e.g. engineers spending a lot of time on status reports, updating databases and making presentations, when the core tasks consists of problem solving and the creation of design solutions. However, it is important to emphasize that these activities is not necessarily pure waste, since it depends on the circumstances. The point is that the engineers’ competence are being used inappropriately when forced to focus on tasks that they are not trained for, and thus, having the potential to produce inadequate results and longer processing time. However, this is closely tied to underutilization of resources (section 6.3.12).

Lack of competence can affect continuous improvement efforts. These efforts should not only be tied to the process itself, but also to the employees involved in the execution of the process, by providing training and support (Deming, 1986; Liker, 2004). In order to enable this, it is important that employers are willing to offer such training, and that employees are willing to learn (Bauch, 2004). *"If I see a person as having high potential, I give him special attention. When he flowers, I feel that my original assessment was correct and I help him still further. Conversely, those I regard as having lower potential languish in disregard and inattention, perform in a disinterested manner, and further justify, in my mind, the lack of attention I give them"* (Senge, 1999, p. 80). What Senge (1999) is saying is that people's perceived competence might be influenced by their surroundings, particularly management. When someone is perceived to be lacking competence, management may pay less attention to them, and give them less support. This creates a reinforcing spiral that diminishes the empowerment of the individual in question. This becomes a self-fulfilling prophecy, which is termed the *Pygmalion Effect* after the character in Greek and Roman mythology.

6.3.6 Unclear Goals, Objectives and Visions

According to Deming's (1986) first management obligation, an organization needs to clearly define a constancy of purpose, and management must demonstrate their commitment to this purpose. The most important factor for a team to be successful is clear consistent performance criteria and goals (Katzenbach & Smith, 1993). This claim was also, to a large extent, supported by the panel of experts at the waste workshop in Huddersfield. They stated that a lack of common ground in design processes is a major issue. Senge (1999) explains that the most efficient people are those who are able to stay true to their vision, while remaining committed to perceive current reality clearly. *"Few, if any, forces in human affairs are as powerful as shared visions. At its simplest level, a shared vision is the answer to the question, what do we want to create? […] Shared vision is vital for the learning organization because it provides the focus and energy for learning"* (Senge, 1999, p. 206). This statement suggests that it is important that all participants pull toward a common objective to enable efficient collective learning. The knowledge potentially lost by failing to do so can be considered waste. Senge (1999) suggests that the gap between vision and reality is the catalyst of creative energy, and terms it creative tension. The creative tension increases relative to the gap between reality and vision. In other words, the larger the gap, the more potential for creativity exists. This was also mentioned during the waste workshop in Huddersfield, where it was pointed out, that unclear goals could create value in the form of increased creativity. However, if the gap is constant, then the benefits might increase by having a common goal.

P. G. Smith (2004) and Katzenbach and Smith (1993) point out that an unambiguous project objective is a crucial success factor. The objective must be ambitious, but should also be perceived as attainable and compelling by the project team. Compelling in this context means all participants appreciate it to be critical to business. Senge (1999) adds to this, and states that commitment require freedom of choice. However, even if clear and compelling goals, objectives, and visions exist, it might be hampered by organizational culture, especially if it tolerates failure (Katzenbach & Smith, 1993).

Another important aspect, although obvious, is that the goals, objectives and visions must be aligned with customer requirements. According to Bauch (2004), unclear goals and objectives can be aggravated by a lack of strategic alignment between the different levels in the organization. A lack of strategic alignment might result in incompatible and inconsistent goals, which in turn might result in employees pulling in different directions. Senge (1999) supports this claim, and adds that empowering people that lack a shared vision or goal will result in increased organizational stress, and burden management to retain consistency and a common course. Shared visions and goals are needed to guide local decision makers. If the projects undertaken are firmly linked to the strategy and objectives of the organization, Wheelwright and Clark (1992) explain that the project managers will have a clearer sense of mission and purpose. With clarity the project will become simpler, and enables focus on the actual work of development. Especially with a complete development strategy, elements such as efficient linkage with the aggregate project plan will become more approachable for the project managers (Wheelwright & Clark, 1992). The goals of the organization can be changed (Katz & Kahn, 1978). Perhaps these changes should be done before starting projects outside the original scope of the organization.

In addition, unclear goals and objectives might have a negative impact regarding disagreements among personnel (section 6.3.18). Furthermore, outsourcing might result in an increased risk of employees perceiving goals and objectives as unclear. This might be due to communication issues such as language barriers. Sometimes, goals and objectives might be unclear because of the project sponsor’s inability to explain what is really required (Fichter, 2003). Katzenbach and Smith (1993) suggest that goals should be team-specific, which they argue will keep the team focused on results, as well as enhancing communication quality. Further, they suggest that goals should be split into smaller ones, making them more manageable and faster to accomplish, which in turn might build team unity and accountability. However, by splitting goals into smaller ones, more goals are created. According to the Jensen Group Study (2000), this is the main reason why goals were perceived to be unclear, i.e. it was too many of them. Unclear goals and objectives might also be caused by insufficient communication (section 6.3.9) and poor coordination (section 6.3.2).

6.3.7 Information Overload

Information overload includes excessive distribution of information, stockpiling of information, and large batch sizes. Excessive information distribution is defined as distribution of information that is not needed by the recipient, which is termed by Graebsch (2005) as noise type information (section 5.3). Bauch (2004) points out that increased data traffic, as a result of new IT technologies and tools, reinforces the excessive distribution of information. The situation might become increasingly dire if there are additional issues, such as overproduction and unsynchronized processes, since this might require additional communication efforts. The excessive distribution of information might lead to waste by overloading the system with information (Goldhaber, 1993; Oppenheim, 2011). Sending information to everyone has the potential to reinforce stockpiling of information and increase processing time. It might also lead to important information being lost, since people are more likely to have trouble finding it and are less likely to read it if everything is shared with everyone (Bauch, 2004; Slack, 1998; Xie, Culley, & Weber, 2011). It was mentioned during the case study that several of the employees were unaware of issues shared with them through e-mail. It seemed to be consensus that the underlying reason for this was too much information being shared. The result was “lost” information.

A variant of excessive information distribution is meetings, where disciplines or personnel are represented when they do not need the information to conduct their activities. This might lead to waste, since employees are pulled from their core tasks, which can increase processing time.

Furthermore, if people attend many meetings it might influence mental set-up time, by increasing the switch cost. The same is possibly true for other types of excessive information distribution, since it might lead to task switching (section 6.3.3).

Excessive data storage, or the stockpiling of information, could be considered inventories in lean manufacturing. In DE inventory is essentially stored information (Bauch, 2004). According to Slack (1998), queues in DE are comparable to the ones in manufacturing, with similar issues regarding capacity versus queue size. However, due to the high variability in DE processes, managing and eliminating queues might pose a greater challenge than in manufacturing (Slack, 1998). Storing information leads to the buildup of unused information (Oehmen & Rebentisch, 2010; Oppenheim, 2011). For example, during the early stages of writing this thesis, we found articles by using push techniques. This led to a large inventory of stored information, where we did not have full knowledge of the contents. Later in the project articles were mostly found by using pull principles, and immediately being read and categorized. Since several articles were found during the push phase, the database contained numerous documents that were not used. This excessive storage made the process of finding articles more time consuming.

Information inventories are not expensive, per se, the expenses rather come from the ineffective administration of inventories (Bauch, 2004). Costs related to storing information can be maintenance costs of databases (Oehmen & Rebentisch, 2010). According to Zhao et al. (2007), many organizations gather information regardless to cost, resulting in information waste and excessive costs. In essence, excessive data storage occurs when more information than needed is kept (Bauch, 2004). According to a study by Kato (2005), waste related to inventory were prevalent in all the companies he studied, emphasizing the need for effective inventory management in DE. Due to the perceived low storage cost of information, Ronen and Spiegler (1991) consider it a trap that can result in the decision, of what to store in the database, to be postponed or avoided, leading to accumulation of data. Eventually, this can render the database less effective and more costly. Furthermore, Ronen and Spiegler (1991) suggest that the Pareto rule[6] of 80:20 is applicable to information storage systems. They assume that approximately 20

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[6] *"The Pareto Principle says that a small number of causes account for most of a problem. It is often described by the 80/20 Rule. This rule says that in many situations roughly 80 % of the problems are caused by only 20 % of the contributors"* (Joiner Associates Staff, 1995, p. 15)

percent of the information available is often used, while the remaining 80 percent are almost not used at all. The results of studies on the topic suggests a similar percentage (Zhao et al., 2007).

Keeping inventory exposes the stored items to the risk of becoming obsolete, often referred to as rotten information. If information becomes obsolete this can indicate that the underlying processes are not well synchronized (section 6.3.2). Well synchronized processes will reduce the time information needs to be stored. Obsolete information can further destabilize the processes, due to resources and time spent on rework, leading to even more information being stored. Furthermore, in order to fix obsolete information people might be reassigned from their original tasks, i.e. firefighting. This can destabilize the processes even further, and increase the probability of creating defective information. The interruption of activities will increase the inventory as well, as the information from the work in progress is stored between processing. In short, information inventory creates more information inventory in a vicious circle. This overlaps with the vicious circle of firefighting creating more firefighting, exacerbating the issue (Oehmen & Rebentisch, 2010).

Information can also be stored and updated several places at once, e.g. the same information is often kept in both electronic databases and in printed archives. Some stored information could potentially be merged into one, e.g. fragmented reports could be merged into one report making it more accessible and help people get a better overview of their documents (Bauch, 2004). Another factor is poor 5s in databases (Oppenheim, 2011). Outdated and obsolete data can be purged or archived, reducing the amount of information hunting. Employees often lack awareness of the impact of excessive inventories, resulting in little effort in managing and conserving these resources. Inadequate standards and practices regarding the administration of information is also common (Bauch, 2004).

Generally, inventory is considered waste, but it can be value-adding, e.g. an unnecessary feature from one project can be stored and used on a later project. The size of the information inventory in DE can also be an indicator of effectiveness of the process (Oehmen & Rebentisch, 2010). Information is not only stored long term, but also exists between process steps. Downstream activities receive batches of information from upstream processes, and the information is stored until the downstream activity continues the processing. In a perfect world there will be no such inventory, since the information will be processed continuously (Oehmen & Rebentisch, 2010).

In the context of DE, batch size refers to the quantity of information that is passed from an upstream to a downstream process. Queuing theory suggests that larger batch sizes will result in longer queues, resulting in increased cycle times (Bauch, 2004). It seems obvious that a larger amount of information would take longer to process.

A large batch size often occur when a function of an organization are completing all their work, and send the information in a batch to a downstream function. This downstream function can be of limited capacity (section 6.3.4) leading to queues. Large batch sizes can be a consequence of work towards milestones. This can create a barrage in the value stream, resulting in the conglomeration of information. Since milestones are a useful in project management, it is unrealistic to eliminate queues completely. However, keeping the benefits of smaller batch sizes in mind, when creating milestones, can be favorable. Poor synchronization of processes (section 6.3.2) can also contribute to large batch sizes (Bauch, 2004). In a similar fashion, P. G. Smith (2004) explains that incremental deliveries of features is often overlooked by developers, who rather deliver large packages at once.

6.3.8 Unclear Authority & Responsibility

Unclear authority and responsibility include roles, rules, and rights. A role is defined as a person’s task or duty in an undertaking. Responsibility is defined as being legally or morally liable for carrying out a duty. A rule is defined as a law or custom which guides or controls behavior or action. Rights are defined as having the proper authority or claim (Hornby, 1974).

Morgan (2002) states that intricate systems, such as DE, require that all participants have a clear perception and understanding of their own role and responsibility, in addition to understand the roles of others. The role structure can become very complex in DE projects. Unclear authority and responsibility might result in challenges associated with overlapping competencies and disagreements among participants, and thus, result in a loss of productivity (Bauch, 2004).

Keller (1975) suggests there is a correlation between role conflict and ambiguity with a multidimensional measure of job contentment and personality-related values. Data collected from 51 employees at a research and development organization revealed that role conflict had a negative correlation with extrinsic job satisfaction dimensions, such as salary, supervision, and opportunities for promotion. It was also exposed that role ambiguity had a negative relation to the intrinsic dimension of contentment with the work itself. This indicates that employees are more likely to be satisfied with their job when they have a clear understanding of the expectations associated with it. Hence, best practices should aim to let employees know what is expected of them, in relation to the performance of their organizational roles.

During the INPRO board meeting, participants spoke of unclear interfaces and responsibilities as the main challenges regarding the construction of a new hospital. A lot of time and effort was wasted on clarifying issues, related to the unclear interfaces and responsibilities. It seemed that these issues influenced the majority of disciplines, and thereby exemplifies the importance of resolving such issues during the early stages of planning. Oehmen et al. (2012) suggest that a program kick-off meeting should be held with key stakeholders, in order to indentify the program benefits and the mechanisms required to realize these benefits. Furthermore, it is suggested to assign a program manager with ultimate authority. This probably reduces the confusion and disagreements associated to roles, responsibilities, and rights.

Rules are often used to ensure coordinated and efficient processes by providing guidelines for personnel’s work activities. This includes practices related to decision making and the entry of data in different software systems. In addition, it includes how employees should conduct themselves during work hours. Other elements are announcement of absence and how to use internal project templates. It is essential that rules are clear, understandable, and accepted by the employees (Bauch, 2004). An example of challenges related to unclear rules deals with insufficient standardization regarding handling and naming files. If different standards are used, it might impact the time required to find these files when needed. Another issue is information pushed to the wrong people as a result of the insufficient standardization (Bauch, 2004).

During the process mapping meetings at the case company, it was revealed that the process of updating MTOs was not standardized. In addition, there was an absence of procedures regarding the responsibilities of updating the MTOs. This resulted in uncertainty and confusion during projects. Furthermore, it was mentioned that the interface between fabrication and engineering was unclear. The level of detail in design was not clearly defined, in particular regarding fasteners. The interviewee explained that if this was actually defined, it was not sufficiently followed (Bang & Stykket, 2015).

6.3.9 Insufficient Communication

Goldhaber (1993) states that research on the topic of organizational communication shows a correlation between an effective communication system and high organizational performance. The general efficiency of a communication process is believed to be less than five percent, where efficiency is the amount of information actually understood. Thus, communication is a critical element of project performance, and is closely tied to individual's performance. Bauch (2004) and Morgan (2002) claim that people's soft skills play a major role in this aspect. Non-standard terminology, inadequate discussions of project objectives, and ineffective feedbacks, are the main reasons for misunderstandings in projects.

According to DiFonzo and Bordia (1998), significant uncertainty and rumors arose when organizational change was communicated insufficiently. The results of their study indicate that communication is particularly important in such a setting. Insufficient communication in this aspect might initiate resistance among employees (section 6.3.18) and can result in disagreements and hostility, which in turn affects productivity.

Information transformation is part of communication, and during this process the possibility of generating defects is present (Oehmen & Rebentisch, 2010). Graebsch (2005) discusses four categories used to characterize information quality (IQ): intrinsic IQ, availability of information, contextual IQ, and representational IQ (section 5.3.4). Oehmen & Rebentisch Oehmen and Rebentisch (2010) state that deficiencies related to any of these characteristics do not necessarily indicate that the information is worthless, since deficiencies may be compensated by the designer's knowledge. However, defective information might lead to a flawed interpretation of information, which in turn might lead to waste (section 6.3.10).

When we attended elementary school, our teacher wanted to demonstrate how information quality deteriorates during communication. This was demonstrated with the telephone game, where one person whispers a secret to another, and so on, until the last person repeats the secret out loud. The comparison with the original message revealed significant differences. One can only imagine how the intentional meaning of information is changed as it moves up, down, or across an organization. This example demonstrates how good information might turn bad, as it is transmitted between entities. It is obvious that this can escalate into serious issues, especially when dealing with large communication networks consisting of hundreds of communication paths. Katzenbach and Smith (1993) suggest that teams should ideally be small, and consist of no more than 25 people, since a larger team has trouble communicating. The following formula is used to calculate the potential number of communication channels, where n represents the number of participants:

$$\frac{n(n-1)}{2}$$

It is obvious, when looking at his formula, that communication might become exponentially complicated as more people are communicating. If n equals 25 participants, the result will be 300 communication channels, which is a lot. Hence, the suggestion of not exceeding 25 people may be defended. Furthermore, the formula clearly shows why it is not a good idea to add more people to a project that is already behind schedule, e.g. firefighting, since this makes communication efforts even more difficult. However, the formula should not be considered definitive, but rather an indicator.

Redundant meetings are a typical example of ineffective communication (Oppenheim, 2011). It wastes time of the participants, and may result in rework and scrap. Another example deals with how communication is conducted, such as people sending a letter, which physically has to travel to the recipient instead of calling the recipient. Oppenheim (2011) points out that a lack of co-location might exacerbate communication issues. During the construction of a major project at the case company, some of the design activities were outsourced to Poland. This led to some communication issues. Several technical queries and poor follow up, were mentioned as examples. Another mentioned issue was the lack of an engineering manager during the early stages of a major project, resulting in too much responsibility for the project manager. This obstructed communication, as each discipline had to wait for the project manager to become available, to get the information they needed (Bang & Stykket, 2015).

Insufficient communication can include the distribution of irrelevant information (section 6.3.7), or using means of communication (section 5.4), that makes the information harder to encode, transmit, or decode, than what could potentially be accomplished otherwise (Oehmen & Rebentisch, 2010). If a mean of communication demands excessive effort and time, without adding additional value in comparison to alternative methods, then the extra time and effort is considered waste. An example of insufficient communication was uncovered during the case study. Employees were sometimes unaware that important information had been shared with them. This was because the mean of communication involved sending information to a local printer at the recipients department. Since the local printers were frequently used for many different purposes, the information sent from other departments sometimes never reached their intended recipient.

When conducting the survey (section 7.2) at the case company, it was revealed that employees perceived insufficient communication to be the most significant source of waste. Insufficient communication when dealing with design changes was a predominant issue, since it increased the likelihood of rework, due to unpractical designs. This was further exacerbated since it often led to assumptions being made, which resulted in defects and rework. A specific example that was mentioned, dealt with the construction of a frame. After the frame was completed it was discovered that the engineering department had forgotten to add which type of steel quality that was supposed to be used, resulting in the work being scrapped. This resulted in rework that cost the company a lot of money, according to the interviewee.

Communication is further explained in section 5.4.

6.3.10 Interpretability of Information

Interpretability of information is what Graebsch (2005) terms as Representational IQ (section 5.3.4). Thus, the level of interpretability arguably relates to information quality. Interpretability concerns if information is comprehensible, simply put, it is easily perceived and understood by the user (Mencar & Fanelli, 2008). Bauch (2004) adds to this, and explains that ambiguities are deficiencies in the interpretability of information. Kahn, Strong, and Wang (2002) explain that the extent of using appropriate languages, symbols, units, and clear definitions, will determine the interpretability of information. According to Mencar and Fanelli (2008), interpretability is often considered as a synonym of transparency. While there are some nuances to the definitions of interpretability of information, it is in essence defined as representing information in a way that is easy to understand for the user.

People might have different interpretations of information (Bauch, 2004). Furthermore, if information is incomplete, ambiguous or inaccurate it might result in rework (Oppenheim, 2011).

At the case company issues were identified regarding the accuracy of MTOs. For example, missing article numbers might result in that procurement must make assumptions or spend extra time and effort on communication with engineering. The assumptions might result in procuring materials that do not conform to the actual requirements, which could delay the entire process. A mentioned example from a process-mapping meeting was the procurement of steel with wrong steel quality, which led to extra work and delays.

Transformation is required in the process of creating information. Consequently, the interpretability is a prerequisite to transfer information accurately. This is also true for the transfer of knowledge, i.e. knowledge sharing, where the knowledge is transferred as information (section 5.3). The transfer of information is dependent on communication. Thus, effectiveness of the transfer will be influenced by communication (section 6.3.9).

The interpretability of information is arguably dependent on the representation. Hannaha, Joshia, and Summers (2012) emphasize that it is important designers are aware of the usefulness of different ways to represent information, and how it can save time and money in projects. When choosing a representation, designers typically rely on previous experience. Hannaha et al. (2012) studied the interpretability of different information representations on inexperienced engineers. The study showed that more information can be extracted from high fidelity models. In our perception, the result of the study appears to be quite obvious, as high fidelity models will contain more information compared to low fidelity models. Consequently, more information can be extracted. However, the result from the study could indicate that when engineers are unsure of the needed level of representation, high fidelity models might be the best choice to ensure interpretability. Although it is worth pointing out that too much information can also be a problem, which is discussed in section 6.3.7. Deficiencies in the interpretability of information are often caused by a lack of standardization. The issue can be aggravated by the use of different terminology among departments (Bauch, 2004). During the interviews at the case company, inconsistent use of terminology was mentioned. This could lead to miscommunication. The interviewee suggested creating guidelines for terminology to enable consistent use (Bang & Stykket, 2015). The use of different terminology was also mentioned as a potential issue during the process mapping meetings, e.g. MTOs were named differently, even though they represent the same information.

There are also different information processing abilities among people, which could affect the accuracy of the transfer. Selecting appropriate parameters when representing information will influence its accuracy and interpretability. The interpretability of information can be affected by several of the waste drivers, such as, unnecessary data conversions (section 6.3.14). The accessibility of information (section 6.3.11) will obviously also impact the interpretability.

6.3.11 Accessibility of Information

Accessibility of information is defined by Kahn et al. (2002) as the extent which information is available when it is needed, or if it can be easily and quickly retrieved, hence availability and accessibility of information are closely related (Graebsch, 2005; Zhao et al., 2007). Thus, missing input is a part of this driver.

Information is not necessarily directly accessible for the user, thus it may require information hunting (Oehmen & Rebentisch, 2010). Some estimations indicate that engineers spend about 60 percent of their time to locate the correct information (Iyer, Kalyanaraman, Lou, Jayanti, & Ramani, 2003). According to Bauch (2004), information accessibility is a major problem within information systems. Some information might require the user to move to another location in order to retrieve the information, e.g. another facility. This information is available, but not directly accessible. This type of traveling leads to a loss of time, and might even include travel expenses, depending on the distance. Bauch (2004) uses the example of user manuals, which is not stored digitally, but physically. Thus, the user has to change location in order to access the information. Remoteness of information also indirectly acts as a barrier, since people might not take the trip, as they would, if the information was closer (Bauch, 2004; Oehmen & Rebentisch, 2010). The accessibility of information can also be dependent on the availability of persons, e.g. when their knowledge is not yet shared as information.

Missing input or poor accessibility of information might result in the need to make assumptions. This can affect the quality of the processed information, which can affect the interpretability (section 6.3.10) (Bauch, 2004). Several issues regarding the accessibility of information were mentioned in the interviews at the case company, such as, unavailable input after project start, too late answers on technical queries, and late input from customers (Bang & Stykket, 2015). The issue of missing input was also identified in the survey, and was perceived to be a major contributor to waste (section 7.2). This is in accordance with our perception of the importance of this waste driver.

If the information inventory is badly designed, e.g. the database where information is stored, finding the information takes more time than necessary. Too much information (section 6.3.7) can also make the required information harder to find, and thus affect the accessibility. Thus, the database should be easy to use and optimized for seamless integration. Sufficient training in the use of database systems, could also improve the accessibility of information (Bauch, 2004; Oehmen & Rebentisch, 2010). The synchronization of processes (section 6.3.2) can also affect the accessibility of information, as it, e.g. can impact the timeliness of information (Bauch, 2004). Information must be accessible when needed, and up-to-date for the task at hand (Bauch, 2004; Kahn et al., 2002; Westin & Päivärinta, 2011). If information is accessible too early it might render obsolete, if it is too late it will often lead to delays in the process (Bauch, 2004). The timeliness of information became apparent at the case company regarding the creation of MTOs. There were examples where a MTO should be delivered at a certain date, but the procurement department had not received it, i.e., the information was not accessible at the correct time. Since fabrication is dependent on getting materials, they are influenced by the procurement processes. Thus, it can be argued that late MTOs could delay entire projects.

Koskela (2004) introduced the term making-do as a waste, and refers to situations where a task or activity is started without all the required inputs, e.g. design has started without the necessary requirements and specifications. Making-do will typically trigger a chain of wastes, which often include rework. This is particularly wasteful when dealing with physical products, since this would involve re-designing and re-building. In the context of DE, the lacking input will typically be information. Thus, it can be argued that common causes for the making-do phenomenon are insufficient communication (section 6.3.9) and missing input. However, making-do does not necessarily have to be waste, since it depends on the context. DE is a learning process (section 5.1), thus, one can argue that making-do has the potential to create value in the form of lessons learned. Although this requires that there is some form of mechanism or system in place that is able to capture these lessons.

6.3.12 Underutilization of Resources

Resource allocation is a critical managerial task, which decides where resources are used (Chase, 2001). Resources that can be underutilized are assumed to include, e.g., competency, man-hours, and tools. In essence, man-hours are ineffectively utilized if they are allocated in a way that hinders the full potential of the man-hours spent. The most important resource in engineering is employees and their competence (Koltnerová, Chlpeková, & Samáková, 2012).

According to Bauch (2004), the core tasks of engineers consists of problem solving, design, creation, changes, et cetera. Still a lot of engineers spend time on necessary non-value adding activities, such as, creating project status reports, and updating databases and schedules. These activities are beyond the competence of engineers, and can therefore be considered underutilization of resources, which in essence is a waste of resources (Bauch, 2004; Oppenheim, 2004). However , there are some exceptions, such as creating important presentations to upper management (Bauch, 2004). Management might not empower the engineers, and intervene in the details of a project (Ulrich & Eppinger, 1995). Thus, giving presentations to management is important to convey the basis for the engineers' decisions. The issues behind underutilization of resources are often associated with poor insight in time management. Another issue is insufficient support from management to hire support personnel for the engineers, such as, assistants, trainees, or students (Bauch, 2004). Not using cross-functional teams, especially when making key development decisions, might also be considered underutilization of resources (Ulrich & Eppinger, 1995). This is mainly because cross-functional teams have a better foundation to make decisions, as personnel from several disciplines are represented and able to influence the decisions. Thus, different disciplines are able to communicate issues related to them, which might not be considered otherwise. Insufficient task management can also lead to underutilization of resources. During the case study, one interviewee stated that the case company should become better at task management, to make sure engineers always have work available (Bang & Stykket, 2015).

Organizational structures can impact the effectiveness of employees, especially personnel with authority, such as engineering managers. Senge (1999) explains that only complex, divergent issues should reach senior managers in effective organizations, where most issues should be dealt with locally. When senior managers spend too much time on convergent issues, and have insufficient time to deal with the complex issues, Senge (1999) states that it is an indication that management work is being handled poorly. It is assumable that when managers have to do convergent tasks over and over, the effectiveness of the organization will decrease. Senge (1999, p. 341) writes: *"It is fruitless to be the leader in an organization that is poorly designed".* This implies that the manager and organization will be unproductive, perhaps affecting managers' motivation to work, which could expand the issue further. However, Mintzberg (1993) explains that decentralizing decisions, i.e. not only one person making the decision, will be beneficial, due to the human limitations of grasping complex and vast problems. Consequently, it can be assumed that convergent issues should be tackled by employees with near relation to the issue, while divergent and complex tasks should be handled in collaboration with managers and employees with the technical understanding of the issue.

Another aspect of inappropriate use of competency is that engineers lack the required qualifications or training to do the task at hand. This can result in the process taking more time than necessary, and even result in inadequate and deficient results (Bauch, 2004). It is also possible to ignore expertise. This can lead to processes being less effective, since employees might have to reinvent or relearn something, which is already known (section 6.3.15) (Oppenheim, 2011). In order to enable effective DE processes, tools should be used efficiently. Tools in DE are often modern computer aided tools, such as computer aided design (CAD) (Zapf, Alber-Laukant, & Rieg, 2011). Furthermore, tools are defined by the functionality they provide in an activity (Kerosuo, Mäki, Codinhoto, Koskela, & Miettinen, 2012).

Slack (1998) explains that inappropriate tools include using outdated software, or software that is unnecessarily complex for a simpler task. Oppenheim (2011) provides the example of using complex software in cases where a spreadsheet would do. Employees' proficiency in the use of tools could also affect its efficiency (section 6.3.5). Using inappropriate tools will typically lead to additional processing steps. Thus, resulting in longer processing times (Oehmen & Rebentisch, 2010).

There are two aspects that should be considered regarding inappropriate tools. Firstly, there is the inappropriateness of a single tool. Secondly, there is the extent tools are capable of working together seamlessly among different stations (Bauch, 2004). Seamless communication between tools will result in less effort when converting, reformatting, and reentering data (Bauch, 2004;

Oehmen & Rebentisch, 2010; Oppenheim, 2011). At the case company procurement converts MTOs from engineering into a program called Movex. This can be considered as use of inappropriate tools, since engineering in reality could directly enter the data into Movex. Furthermore, the conversion could be done automatically by using a different software solution.

6.3.13 Over-engineering

Over-engineering, in this context, is defined as exceeding internal or external requirements. Thus, this driver includes activities such as, adding unnecessary features, details, and accuracy. Bauch (2004) separates features, and details and accuracy, as the macro and micro level of requirements.

Requirements vary in stability and accuracy, and are not always clearly defined, which might lead to assumptions. Designing beyond requirements can add robustness to the design, and might be considered value-adding. The information created, when producing unnecessary features, contains information that is needed, but the quality or functionality are exceeding the requirements (Bauch, 2004; Oehmen & Rebentisch, 2010). Exceeding requirements can be especially value-adding if it satisfies a need unknown to the customer. In addition, if exceeding the requirements results in new market opportunities, it can be considered value-adding. For example, smart phones initially exceeded the customers' requirements, as they were unaware of potential use of phones, outside the specter of making phone calls, such as the integrated camera. A Kano-diagram can be used to assess if the additional effort of exceeding the requirements are beneficial. In addition, exceeding the requirements can be value-adding due to the potential learning and knowledge the engineers might gain.

If over-engineered parts are incorporated into the final solution, it might be considered waste, due to unnecessary information embodied in the solution. This might increase development and production costs, and might lower the value of the delivered solution for the customer. The increased complexity can increase life cycle cost and decrease its reliability (Oehmen & Rebentisch, 2010). Bauch (2004) uses the example of software development, where the software engineers can add smaller features in a matter of minutes. These additional features might require additional steps further downstream, like testing, debugging, and service. This can prolong completion of projects, which is in line with our experience from software development.

There are several causes for over-engineering, including influence from activities upstream. Upstream departments such as marketing, and decisions made in the early stages of the product definition, can result in over-engineering. One of the main causes is that product or process requirements are unanalyzed, or actually not understood. During the process of writing this thesis, writing began early, without full knowledge of what should be included in the report. This led to writing several unnecessary sections, which were later scrapped. This was due to the increased understanding of the requirements needed to answer the research question. These activities can be considered as waste, but the scrapped work could also be considered a learning process, and thus, value-adding. However, activities such as structuring and correcting grammar in the scrapped work could arguably be considered waste.

Individual interests of system participants, and lack of commitment to the product's or company's benefit, is another factor that can result in over-engineering (Bauch, 2004). Engineers can also create unnecessary deliverables out of their own initiative, or to hedge against uncertainty (Oehmen & Rebentisch, 2010). However, this is not always waste, such as in set-based design. Legacy requirements can also be retained while writing product specifications, resulting in the transmittal of requirements that the customer actually do not require (Slack, 1998).

Over-engineering can generate unnecessary details and accuracy, such as overly rigid tolerances. For example, if the constructors receive drawings with a higher accuracy than necessary, they might spend unnecessary resources to achieve this accuracy. This can be caused by tendencies of perfectionism in organizations or individuals. It can also be caused by lack of understanding of how unnecessary details and accuracy affects the downstream tasks, and poor insight in business economics and life-cycle costs (Bauch, 2004; Oehmen & Rebentisch, 2010). The over-engineering facet should be considered in the context of the whole information creating environment of DE, and not only in terms of the final outcome, which are specifications and requirements. Even when requirements are accurately defined, exchange of information with too much detail and accuracy can occur, particularly in the early stages of design. The information formatting can also be partially excessive and customized to meet someone's standards. This frequently points to a lack of standardization of information (Bauch, 2004). Thus, if the necessary details and accuracy are specified, the engineers should be less likely to exceed the required level of accuracy.

6.3.14 Unnecessary Data Conversions

Data conversions can be described as the process that enables data to be communicated among different reference systems, without changing the actual content (Oehmen & Rebentisch, 2010). Data conversions often involve re-formatting and re-entering data. According to Bauch (2004), conversions lead to excessive data traffic. This is not just due to the transmittal of the converted data, but also due to the underlying communication effort that might be required to convert data. We also believe data conversions will increase the risk for errors. For example, when employees re-enter data, they might enter the data incorrectly. This could result in defective data being processed (section 6.3.16). Thus, unnecessary data conversions should be avoided.

Some data conversions are considered necessary at different stages. If the conversion occurs due to issues with compatibility and connectivity, e.g., among different IT systems, or a lack of clear process guidelines Such conversions could be avoided, and therefore considered unnecessary (Oehmen & Rebentisch, 2010). Thus, unnecessary data conversions could arguably result in overprocessing, and waste resources that could be avoided.

Data conversions might occur when converting among different measurement systems, IT systems, and languages. Conversions can also include making data more broadly accessible, such as converting detailed measurements into a simplified overview for a management presentation. Reports can be reformatted for different stakeholders, which might be considered unnecessary data conversions (Oehmen & Rebentisch, 2010). Most information is shared through IT systems. Hence, issues with compatibility can be tied to the use of inappropriate tools (section 6.3.12). Activities, such as, re-formatting, converting, and re-entering data, can indicate issues with the IT systems. Conversions can be caused by a lack of standardization for data representation, e.g. when different departments use different terminology for the same thing (Bauch, 2004).

6.3.15 Lack of Knowledge Sharing

Knowledge sharing is the process of exchanging information, expertise, or skills, among entities (Serban & Luan, 2002). Thus, lack of knowledge sharing can be defined as not doing these exchanges. It causes solutions to be recreated, without use of legacy knowledge or the learning outcome from previous mistakes (Oppenheim, 2004). Consequently, a lack of knowledge sharing has the potential to create waste, since previously acquired information might be re-produced by another entity. Knowledge is generated by incorporation, linage, and transfer of information, where the transition from data to information only is possible if the recipient know the relevant context. In order to transfer information into knowledge accurately, the information must be interpretable for the recipient (section 6.3.10) (Bauch, 2004). In addition, it is critical to understand the learning processes (section 6.3.15) in order to optimize knowledge sharing.

During the case study it became apparent that lack of knowledge sharing was contributing to waste. Long term employees had different standards regarding documentation, compared to newly appointed employees. This was due to veteran employees assumed this was common knowledge, while in fact it was never shared to the new employees. The result was that the receiver of the documentation could be forced to spend unnecessary resources converting information.

If entities of a process are unaware of requirements of adjacent processes down the value stream, it might cause waste due to a lack of knowledge sharing. A representative from the mechanics at the case company mentioned that designs should be created more functional. He explained that designers should have the construction phase in mind, while designing, to create designs that are easier to realize. The design should also be made with adjustability in mind, such as using bolts instead of welds where possible, to make potential rework for the construction less resource demanding (Bang & Stykket, 2015).This issue can be seen in relation with engineers' attitude towards fabrication (section 6.3.18). The engineers do not make use of the potential learning outcome from studying realized designs, which is in essence a lack of knowledge sharing. Consequently, the engineers lack the required competence to create such designs (section 6.3.5). Representatives from several disciplines emphasized this during the interviews.

It is important to understand the different types of knowledge to comprehend the different aspects of knowledge sharing. There have been several attempts to classify knowledge in different fields (Frost, 2010). Knowledge is often divided into explicit, implicit, and tacit knowledge. However, in order to simplify the explanation of this driver, we focus on explicit and tacit knowledge.

Explicit knowledge can quite easily be communicated and put to use, since it is often described by words and numbers (Bauch, 2004; Davies, 2015). Some knowledge can be contextual, such as the stipulations of the development process. This is often personal knowledge and the information might only be shared through informal communication (Bauch, 2004).

Polanyi (1966) introduced the term tacit knowledge as the framework that makes explicit knowledge possible, and is often perceived as difficult to communicate from one entity to another. This type of knowledge is formed through individual activities and experiences, and from the exchange of experiences with others. Thus, tacit knowledge is most easily shared by joint activities (Bauch, 2004; Polanyi, 1966). Tacit knowledge is personal, thus, sharing it might depend on the availability of the person who possess it (section 6.3.11). Consequently, replacing an engineer might render knowledge inaccessible. Attention to tacit knowledge is important in order to reap the full benefit of knowledge and information within the company. This might bring the company considerable business and market advantages.

The information and knowledge created during the development process should not be lost, since the product in DE is information (section 5.3). This can be become a serious issue with a high number of handoffs. During each handoff there is a risk that valuable knowledge and time is lost. Insufficient communication (section 6.3.9) can affect knowledge sharing, as participants of up and downstream processes do not talk about each other’s processes and requirements (Bauch, 2004). Insufficient knowledge sharing can lead to assumptions, potentially creating defective information (Oehmen & Rebentisch, 2010). Not sharing process knowledge can result in longer lead times, as the insight in how to improve processes are lost. Furthermore, ideas on improving product solutions can be lost, potentially affecting the build and solution quality (Ćatić & Vielhaber, 2011). The relationship between knowledge waste and its effects are shown in Figure 17.

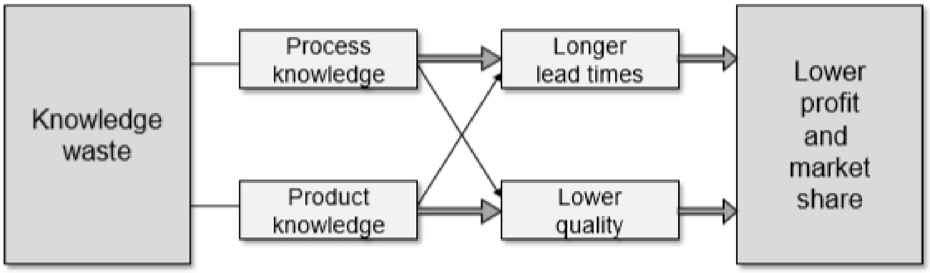

Figure 17: Effects of knowledge waste (Ćatić & Vielhaber, 2011)

Lack of knowledge sharing can exacerbate knowledge barriers, resulting in additional communication to acquire the necessary knowledge (Oehmen & Rebentisch, 2010). Acquiring necessary knowledge is obviously not waste. However, if the process of acquiring knowledge is done in a less effective way than possible, then it could be considered waste. Wheelwright and Clark (1992) explain that it is necessary to analyze the information to enable continuous improvement, such as identifying the lessons learned and investing in the findings.

During the waste workshop in Huddersfield, the panel of experts argued that lack of knowledge sharing is not a waste driver, but rather an obstacle to continuous improvement efforts. While we agree that a lack of knowledge sharing is an obstacle to continuous improvement, it is also a mechanism that can lead to waste in DE. This is because DE is a continuous improvement effort, all the way from concept to completion, and beyond (section 5.1). With this in mind, we argue that if lack of knowledge sharing is seen as an obstacle to continuous improvement in general, then it must also be true in relation to DE processes. Forgues and Koskela (2008) explain that the ability of team members to share knowledge to enable continuous learning is considered a core principle of integrated design teams. There are multiple barriers within the team that can hinder the ability to share information, thus, causing a lack of knowledge sharing, such as cognitive inertia, lack of self-regulation, and knowledge boundaries.

Lack of knowledge sharing can also contribute to less solutions being re-used, and thereby is re-invented. There might be a big potential to increase the quality and efficiency of DE by re-using existing designs and knowledge (Bauch, 2004; Shahin & Sivaloganathan, 2005). According to Bauch (2004), this is unfortunately often not the case, since new projects often start on levels far below what could be possible by re-using. Busby (1999, p. 277) summarizes his research of problems with re-use, and states: *"Most reuse problems concerned transfer that was inhibited in* *some way"*. In other words, the main problem with re-use is that it does not happen, or is not made possible. This could lead to re-invention, which occurs when something previously produced is not re-used, but rather created once more. When something is re-invented upstream it can result in re-inventing taking place downstream as well (Oehmen & Rebentisch, 2010). In essence re-inventions happens when knowledge is lost, discarded or unused (Bauch, 2004).

Re-use is not necessarily a direct transfer, but can require some modifications. This is related to what Illeris (2007) refers to as accommodative learning, which is explained as applying knowledge to a different context than where it was originally used. This is critical when attempting to improve solutions and existing work processes (section 5.5). Reusability does not only apply to design solutions, but also experience and knowledge gained through the processes. For example, failures in one process can provide valuable information that can help improve other processes (Bauch, 2004; Oehmen & Rebentisch, 2010). Baxter et al. (2007) suggest that the re-use of previous knowledge can increase the competiveness in the modern global market, since it enables robust designs to be created in less time, with lower production costs.

According to Bauch (2004), a lack of re-use is often caused by poor knowledge and information management systems (section 6.3.12). It is understandable that if finding the reusable solutions is complicated, such solutions are not found, or the engineers do not want to waste time finding them. Even if this knowledge can be shared, it is not shared effectively, e.g. there is a lack of knowledge of existing solutions (Oehmen & Rebentisch, 2010). Busby (1999) provided a detailed study into problems with design re-use. Most re-use problems were cases of re-use not taking place, even if it was often perceived to be beneficial, it was not practiced. Another common problem was the unexpected amount of additional effort needed to re-use. Other issues included knowledge loss through inappropriate replication, and errors when existing designs were reapplied to new purposes.

In order to enable re-using of design solutions, the solutions must be created with reusability in mind, then it must be stored in an accessible location (section 6.3.11) (Ammar, Scaravetti, & Nadeau, 2010; Bauch, 2004; Baxter et al., 2007). The process of creating re-useable design requires more time. Thus, it will often not conform to short term budgeting (Bauch, 2004). The lack of re-useable solutions is exacerbated by poor administration of design models, e.g. a database that is difficult to use, rendering the information less accessible (Bauch, 2004; Shahin, Andrews, & Sivaloganathan, 1999). Frequent job changes can also contribute to the problem, since engineers are prevented from getting a sufficient overview of the previous made solutions (Bauch, 2004). In addition, the organizational aspect can affect re-use. According to Ong, Xu, and Nee (2008), design re-use can be restricted by the traditional individual based management strategy.

6.3.16 Processing Defective Information

Defects in information are perceived to be quality defects. Defective information is generated based on a valid need for information, where the need is not sufficiently fulfilled (Oehmen & Rebentisch, 2010). Processing defective information can be considered as waste. However, it is also considered as a waste driver, since the defects can affect other processes.

Attributes of information (section 5.3.4), such as accessibility (section 6.3.11) and interpretability (section 6.3.10), can impact people's decisions and assumptions. This can result in that information is not correctly processed, thus, leading to defects (Bauch, 2004). Experience can assist in recognizing deficiencies in information quality. This could help avoid the processing of defective information, and enable its correction. Mistakes from, e.g. testing and verification, can also lead to defects (section 6.3.1) (Bauch, 2004).

Defective information can be generated through communication, where information often is required to be condensed and transformed (Gries, 2007; Oehmen & Rebentisch, 2010). This opens the possibility of generating defects through, e.g. data conversions (section 6.3.14), where the defect typically is a result of wrong interpretations of the information (Oehmen & Rebentisch, 2010). Defective information can come from adjacent processes. This can result in defective information being processed, often as a result of undiscovered errors from upstream processes. This will usually lead to rework and waiting, since the processed information becomes useless. Processing information that does not meet current requirements can also become defective. This can be caused by stockpiling (section 6.3.7), long lead times or unaddressed changes (Oehmen & Rebentisch, 2010). Processing defective information can lead to legacy issues. This is often caused by a defect that remains dormant, since its discovery was not properly documented, or the defect was not corrected (Long, 2013; Oehmen & Rebentisch, 2010). The sooner defects are identified and dealt with, the less they will negatively affect the processes downstream. The process of correcting the defect will also be a lot simpler if it is discovered at an early stage. At worst the defect are not discovered by the company at all, and the customer is the one who discovers it (Bauch, 2004).

6.3.17 Changing Targets

Changing targets in the context of DE mainly concerns engineering changes. An engineering change is defined by Jarratt, Eckert, Caldwell, and Clarkson (2011, p. 104) as: *"changes to parts, drawings or software that have already been released during the product design process, regardless of the scale of the change"*. Furthermore, they explain that changes can happen throughout the entire product life cycle, which is supported by several authors (Shankar, Morkos, & Summers, 2012; Sommer, Storbjerg, Dukovska-Popovska, & Steger-Jensen, 2013). This can indicate that there is a need to design with reliability and maintainability in mind (Blanchard & Fabrycky, 1990). Eckert, Clarkson, and Zanker (2004) divide engineering changes into emergent and initiated changes. A similar division is done by Sommer et al. (2013), they recognize two fundamental types of changes. First, there are the changes that have to be avoided, such as changes due to bad design decisions. Secondly, there are changes that provide an opportunity for the company, and emerge from an outside source, such as changing targets from customers or certification bodies (Eckert et al., 2004; Sommer et al., 2013). Regarding the first type of change, Hubka and Eder (1988) state that it is clearly an illusion to get all the design decisions right the first time, due to the iterative nature of design processes.

During Kato's (2005) study of three companies, rework and overprocessing came out as some of the dominating types of waste. Oehmen and Rebentisch (2010) list rework as a consequence of changing targets, i.e., changes in the value definition. Kato (2005) listed unclear and shifting goals as some of the causes of overprocessing, with inconsistency in the customer's decisions, and instability in the market, as some of the underlying causes. Changes are necessary when undesired decisions have been made, and when customers make changes in the requirements. Necessary changes can be comprised of only changing some information. More severely, it can affect downstream processes. This could result in, e.g., production being suspended, or recall of delivered products. If a change is discovered, the issue should be managed in a controlled fashion, where the impacts of the changes are identified. This typically includes finding all the information that needs to be changed (Pikosz & Malmqvist, 1998).

Changes can sometimes be considered value adding. Internal changes can be based on a perception that the changes will add value for the customer. Changes initiated by customers can be regarded as value adding activities (Wasmer, Staub, & Vroom, 2011). However, this can become extremely costly. This issue is often mentioned in media. For example, changes in regulations regarding dams, led to analyst estimating that it would cost almost two billion USD to make the changes (Lie, 2015). Knarr, an off-shore project, exceeded the budget with more than 500 million USD. This was mainly caused by changes in the design, since new information from the well was provided (Ramsdal, 2014). The mentioned examples from media indicate that changing targets can lead to excessive expenditure. This emphasizes the need to mitigate the issues related to changing targets. It was mentioned in the interviews at the case company, that customers in some cases made changes late in the process, resulting in additional work (Bang & Stykket, 2015). While this is often economically compensated, the delivery date is often not changed, thus putting more pressure on the organization. This could lead to, e.g. burnout of employees (section 6.3.4). In addition, there might be several hidden costs that the customer does not compensate for, such as additional planning hours.

As mentioned, changes initiated by customers can be regarded as a value adding. However, emphasizing that decisions should be made early when communicating with the customer could help mitigate the extra resources required to tackle such changes. To some extent, we assume that changing targets might be the biggest visible waste in engineering, based on the impact in costs. However, external factors are typically the force behind these changes. Thus, it might be a difficult issue to mitigate.

6.3.18 Cooperation Barriers

In this context we define cooperation as entities working together towards a common goal. An example of cooperation barriers is the unwillingness to cooperate among employees. Katz and Kahn (1978) recognize three categories of behavior that are required for an organization to achieve high levels of effectiveness: the employees must stay in the organization; they must be dependable in their performance of their assigned roles; and occasionally conduct innovative and cooperative actions that serve the organizational objectives. Consequently, unwillingness to conform to any of these categories can be perceived as cooperation barriers, impacting the effectiveness of the organization.

Sosa and Danilovic (2009) state that in order to maximize the innovativeness, the individuals within the organization that needs to cooperate to facilitate innovation should be identified, and, e.g. create a temporary task force with the respective individuals. Kemmer, Koskela, Sapountzis, and Codinhoto (2011) further emphasize the need for teams, stating that cooperation is essential when integrating design and production. They add that this is in corroboration with the ideas of lean (section 4).

Bauch (2004) and Katzenbach and Smith (1993) consider unwillingness to cooperate as a critical factor in the context of projects and organizations in general, since it negatively affects productivity. People are to a certain extent taught from a very early age, e.g. through school and sports, that personal rewards are gained through individual achievements. It seems plausible that this social system might negatively influence people’s willingness to cooperate if their efforts are less likely to get noticed, and thereby reduce the probability for rewards and recognition. Furthermore, if the tasks assigned are perceived as uninteresting or too hard, it might influence the individual’s motivation to cooperate in an unfavorable manner, from the perspective of the employer. This is in accordance with Illeris (2007), who claims work content relates to the social importance of the task and to its importance to the individual. Hence, a strict division of work can have a negative impact on an employee’s perception of work as meaningful. The negative effects can be exacerbated if there is a lack of accountability, since people might not be held responsible for their lack of cooperation. Furthermore, Bauch (2004) points out that if employees are unable to understand the impact of their behavior, it might negatively affect their willingness to cooperate.

Managers in organizations can also act as cooperation barriers. Faria (2000) recognizes some issues when selecting mangers. For example, managers can be selected based on how long they have worked at a company, potentially resulting in employees being promoted into positions where they are unqualified. If managers are perceived as less qualified than the employees, it can leave the employees cynical about the effectiveness of the mangers (Feldman, 2000). Arguably, this might negatively influence the motivation of employees, making the organizations less effective.

During the interviews at the case company a cooperation barrier was identified. A representative from the mechanics revealed that the engineering department did not take them seriously enough.

This perception resulted in that the mechanics were reluctant to bring forth issues and problems to engineering. Thus, problems were addressed at such a late stage that they had escalated significantly, being harder to correct, and potentially leading to more rework. The somewhat negative attitude from engineering towards mechanics was also addressed by representatives from engineering. A general example of engineers' negative attitude was that they dismissed communication from mechanics. When the mechanics approached engineering with issues, the engineers stated it was too late to change anything. Another mentioned issue was the meeting culture, where some people always arrived late, and some people only presented their issues, and then left. Attitude issues appeared to be serious, and should be addressed by the case company. Kalsaas and Moen (2015) state that "bad chemistry" between employees can have a negative impact on the ability to learn, which indicates that knowledge could potentially be lost in such circumstances.

We have experienced several situations, in the context of software development, where the unwillingness to cooperate have been demonstrated by various team members. Disagreements regarding how work is performed have negatively influenced people's willingness to cooperate in several projects. Sometimes, the discontent of having to work on solutions that one does not agree with evolves into personal feuds. This has usually led to a further hampering of progress and productivity, since more time is spent discussing issues irrelevant to complete the project. Forgues and Koskela (2008) points out that lack of ownership may be a problem among design professionals. The lack of ownership might have a negative effect on people's motivation. Lack of ownership can arise from not being sufficiently involved in the creation or selection of possible solutions.

It is necessary to understand what motivates people in order to get to the root causes of these aforementioned cooperation barriers. According to Deming's (1986) 14 management obligations it is necessary to drive out fear in order for employees to perform efficiently. However, Juran disagrees with Deming and argues that fear itself may be a force of motivation (Evans & Lindsay, 2008). Although, while this might be true, it seems quite implausible that people would want to live in constant fear. Hence, using fear as a tool to motivate employees should be reserved for times of crisis. Mintzberg (1993) explains that empowerment can be used to motivate people. However, in organizations with too much empowerment of employees, this could be viewed as a barrier. As Senge (1999, p. 285) puts it: *"The great irony of freedom of action; by itself, it can result in helplessness, in feeling trapped and impotent".* Herzberg et al. (2011) argue that the factors that motivate people are not the same as those that create dissatisfaction (hygiene factors), and motivation and job satisfaction may not increase just by removing the hygiene factors. Further, Herzberg et al. (2011) points out several re-occurring characteristics that can be related to increased intrinsic motivation and job satisfaction, such as, recognition, advancement, growth, and responsibility. Common hygiene factors identified include: bad relationships among peers, company policies, and supervision. However, it is important to point out that Herzberg did not address the relationship between motivation and productivity, which is the assumption the theory is based on.

Rewards for individuals or the team can be effective in some instances, however, often they backfire (P. G. Smith, 2004). Deming (1986) points out that rewards tied to meeting arbitrary cost-reduction goals might be self-destructive to an organization. This might not motivate employees to improve the system or customer satisfaction, but rather motivate people to optimize their individual rewards. This phenomenon is commonly known as the principal-agent problem, according to the *Theory of Agency* (Mitnick, 1975). Swink (2003) argues that rewards for speed will slow down development projects, since the emphasis for speed can result in sloppiness, which could lead to rework (P. G. Smith, 2004). Challenges also emerge when presenting rewards for the entire project team, e.g. the free-rider phenomenon. Langeland (1999) points out that participants may be tempted to rest on their laurels, knowing they will be rewarded for work of other project members, despite their lack of effort.

Another aspect related to cooperation barriers, concerns how people resist change. Prejudice against new or not before used approaches might influence employees' productivity (Bauch, 2004). This is often driven by a lack of competence (section 6.3.5) of how to use new methods, tools, or procedures. Illeris (2007) believes mental defense mechanisms, such as defending identity, are of great significance in this context. Psychodynamic barriers are amplified in relation to the perceived complexity and difficulty of the learning requirements (section 5.5). Lewin (1947) suggests that in order to accept change and to make change successful, employees need to know how the changes will gain them. Baker (2011) argues that organizational change management has a direct impact on employee engagement and performance. Further, Baker

(2011) claims that change management assisted by open communication can increase productivity in an organization (Gill, 2012).

Ulrich and Eppinger (1995), Bauch (2004), and Morgan (2002) argue that functional allegiances transcending project goals has a negative impact on cooperation and productivity. Members from different disciplines may influence decisions in an attempt to increase the political standing of themselves or their functions. Thus, they disregard the overall success of the product. This cooperation barrier is often referred to as opportunistic behavior, which is typically discussed in relation to *Transaction Cost Theory* (Williamson, 1975).

7 Survey

There are several existing techniques and tools that can be helpful when trying to identify waste. McManus (2005) identifies value stream mapping and Design Structure Matrix (DSM) as some of the most versatile tools when analyzing and changing processes. Process analysis can uncover some of the wastes occurring in processes and activities. However, even if waste is identified, making changes is not necessarily an easy process. This is described by several authors, such as Kotter (1996). Therefore it might be necessary to show to what extent the waste is present, in order to give incentive to initiate the changes. Different types of measurements can often be used as an incentive. For example, McManus (2005, p. 14) states: *"data confirms that 30%– 40% of engineering effort is typically wasted"*. This percentage wasted can be applied to the total number of engineering hours, and their respective costs, which can show the direct economical impact the measured waste has. This might give the incentive for management to direct the focus towards continuous improvement. This is supported by Kalsaas (2013b) who suggests that the most important aspect of measuring the percentage of hours wasted is to direct focus towards continuous improvement. However, it is important that measurements do not focus too much on costs. Leong and Tilley (2008) explain that focus on costs can lead to a shortsighted perspective, as the focus lies on reducing costs, where elements such as, quality and customer satisfaction often are neglected.

Measurements can be resource demanding, and the relevant measurements should be identified, since excessive measurements might be a wasteful activity in itself (Forsberg & Saukkoriipi, 2007). When measurements are conducted, it can provide objective information that can be used to, e.g., communicate effectively throughout the project organization, identify and correct problems early, and defend and justify decisions (Haskins, 2011). The measurements can also be compared with the target performance in order to identify deviations that will indicate a need for continuous improvement (Costa et al., 2014).

According to Koskela (1992), measurements are extremely important in lean production. However, we were unable to identify any standardized methods for measuring waste in DE. The approaches of measuring waste differ from author to author in the researched literature. According to Forsberg and Saukkoriipi (2007), the most used measurement in construction is lead time. However, this is not a measurement of waste, per se, but can be a valuable indication of the effectiveness. In the context of measuring waste in engineering some variation of surveys was perceived to be the most commonly used method in the researched literature. For example, Graebsch et al. (2007), Bourne, Neely, Mills, and Platts (2003), and McManus and LAI PD Team (2000), base their findings on surveys. Kato (2005), who were referenced several times in other researched literature, used a different approach. He used value stream mapping optimized for quantitative analysis in order to measure waste using waste indicators. This method is also mentioned by Oehmen and Rebentisch (2010). While measurements using value or process maps might be the most accurate way to measure waste, Pieńkowski (2014) states that the data collection process from a value stream can be highly time consuming. Thus, it might be difficult for companies to allocate the necessary resources.

Surveys and similar techniques, are probably the most used, since this is not very resource demanding. However, Koskela (1992) states that measurements should be able to identify waste inherent in processes. Arguably, it is unlikely surveys are able to identify or measure waste inherent in processes. We suggest that surveys are more likely to measure the perceived waste within the organization. Consequently, the usefulness of measuring waste using surveys is debatable.

Instead of measuring the actual waste, another possibility is to measure productivity. In addition, such measurements are the only way of knowing if improvement efforts worked (Horner & Duff, 2001). If efforts to reduce waste can be proven as economically beneficial, it should increase the likelihood that management will support future efforts. It might not be able to identify the amount of waste, but it can indicate if improvement efforts are working. The construction management system the Last Planner System (LPS) uses Percent Plan Completed (PPC). PPC shows the percentage of the amount of planned work done, and is easily calculated by dividing the number of planned activities completed by the total number of planned activities. PPC makes it possible to benchmark, to set targets, and to monitor progress across projects. This has been lacking in traditional design management, thus, hindering its improvement (Koskela, 2000). By using PPC to measure the proportions of promised tasks completed on time, the project planning can be improved through continual assessment and learning from potential failure (Koskela, Stratton, & Koskenvesa, 2010; Lean Construction Institute, 2015). A similar system within planning systems in DE could prove useful in order to measure increases of productivity, thus being able to identify the impact of waste reduction.

In order to explore the feasibility of measuring waste, we conducted a survey (Part One) based on a method by LAI, which are commonly referred to in the researched literature. In addition, we attempted to measure the perceived waste at the case company (Part Two).

7.1 Survey - Part One

We were asked by the case company to investigate why there were anomalies between the results from a survey conducted by Finsådal and Hasle (2014) at the case company (CS14), and results presented in literature. It was discovered that several of the results presented in literature were based on a survey conducted by McManus and LAI PD Team (2000)at a workshop (LAI99). This survey was not available online, but we were able to retrieve it, thanks to some very helpful people at MIT. This enabled us to conduct a survey (CS15) with the same questions. The purpose was to compare the results from the surveys. The result of the survey we conducted (CS15) indicated 21.3 percent waste.

Case Survey 2014 (CS14)

The purpose of the CS14 was to measure the amount of time wasted during DE tasks at the case company (Finsådal & Hasle, 2014). They used a self-evaluation form, which was based on findings from interviews and workshops at the case company. The results from this survey indicated 13 percent waste.

The survey consisted of a predetermined list of factors that led to waste, which eliminated the possibility for the respondents to report any waste that was not in accordance with the list. This means the amount of waste might be lower than if the respondents could report all perceived waste.

LAI Survey (LAI99)

The purpose was to identify perceived time wasted during design tasks (McManus & LAI PD Team, 2000). A questionnaire was distributed to participants during a workshop on the subject of *"flow and pull in product development"*. The workshop was comprised of working sessions where key problems were identified and then explored in depth by the participants (McManus &

LAI PD Team, 2000). The questionnaire consisted of four questions[7], and was distributed to all the participants of the workshop. Question one asked the respondents to estimate the percentage of pure waste (clearly unnecessary tasks) during design tasks. Question two asked respondents to estimate the percentage that was necessary waste, inter alia, tasks that could be eliminated with improved methodologies. Question three and four looked at the ideal state in product development cycle time, and in a sense these were trick questions. Respondents were asked about the duration of their last project, and how fast it could be completed under ideal circumstances. The results from question three were divided by the results from question four to reveal the ratio of possible improvement (McManus & LAI PD Team, 2000). The results from this survey indicated 40 percent waste.

LAI99 was not administered scientifically, and the respondents were workshop participants, which could indicate a certain level of bias, according to McManus and LAI PD Team (2000). Also, the questionnaire is based on subjective opinions. It is quite interesting that the majority of the reviewed literature, dealing with waste in DE, referred to this survey when discussing the amount of waste in DE. We believe it is alarming that so many authors have used the results from this survey without questioning its validity. The survey's usefulness is questionable in terms of measuring waste. Even the authors of the survey criticize its validity.

7.1.1 Discussion of Survey – Part One

We compared the results between CS14 and LAI99, and between CS14 and CS15. This was considered useful, since it could be used to indicate if the method had an influence on the results. Furthermore, the results from LAI99 and CS15 were compared to find out if there were anomalies when using the same method.

The comparison showed significant variance (standard deviation of 13.8 percent) regarding the amount of perceived waste. This is especially true when comparing the results from CS14 and LAI99, which showed a difference of 27 percent. To some extent, the anomalies might be caused by using different methods. This belief is further strengthened when comparing CS14 with CS15, since the perceived waste increased significantly when using the method from LAI99.

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[7] Only questions and results relevant in the context of comparison are presented. Several other questions were part of the questionnaire.

CS14 and CS15 were conducted on the same population in a similar context. This adds to the belief that the methods played an important part regarding the results obtained. Another aspect, which might have influenced the results, is that CS14 included a predetermined list of possible causes. This limited the respondents in the sense that they could only report waste that was in accordance with the causes on the list. Thus, indicating there could be additional waste not covered by the self-evaluation form. Although, it could be argued that the anomalies might be caused by a variance regarding the effort and thought put into the questionnaire by the respondents. Also, the respondents could have misinterpreted the questions. However, we believe the questionnaires were clearly formulated, and it was little room for interpretation.

When comparing the results from the LAI99 with the CS15 it shows a significant difference, 18.7 percent, regarding the amount of perceived waste. Thus, we tried to identify the reasons for the anomalies. It is important to be aware of the difference between the populations and the contexts for which the questionnaires were conducted. In this aspect there is a considerable difference. To some extent, the respondents of LAI99 were experts on the topics of lean product development. This indicates that they possess a high level of awareness regarding different mechanisms that lead to waste. This could have enabled the respondents to consider a broader selection of waste drivers, which might influence them to believe that a higher level of waste exists, compared to respondents lacking this knowledge. The respondents of CS15 had different positions within the engineering department. This might indicate that their knowledge of waste drivers in DE could be subject to substantial variation. Thus, we believe one of the reasons for the anomalies is related to the different levels of awareness regarding waste drivers in DE. Even with a high level of awareness, it might be difficult to provide an accurate estimate of waste.

In general, we question the usefulness of measuring waste in DE. Several of the waste drivers are extremely difficult or even impossible to measure directly, such as lack of knowledge sharing and cooperation barriers.

7.2 Survey – Part Two

In the second part of the survey the respondents were asked to mention three drivers they felt contributed to waste in the company, in prioritized order. In order to explain the concept of waste drivers, some examples were provided. The respondents had to fill out the answers themselves, and were able to elaborate if they wanted. This part of the survey used the same sample as CS15 in part on of the survey (section 7.1).

The purpose of this part of the survey was to get an understanding of what employees perceived as waste drivers. Furthermore, it could provide a measure of the perceived prominence of the different waste drivers. Lastly, the survey could help uncover aspects we had not considered.

Measuring the perceived prominence of waste drivers is arguably beneficial. This is due to that in change management it is important that the employees are included in the change process, and understand why the changes are done. Described by Kotter (1996) as creating a sense of urgency. We believe that if issues are prominent in this type of measurement, it can be assumed that employees have a sense of urgency regarding these issues. Thus, a course of action associated with these issues might lead to a smoother change process.

7.2.1 Results from Survey – Part Two

The respondents' answers were often formulated differently, while having the same meaning. These were identified, and similarities of the answers were compared. Each answer was seen in relation to the waste drivers (section 6.3), and were placed in the driver they resembled the most. This resulted in the Pareto chart shown in Figure 18.

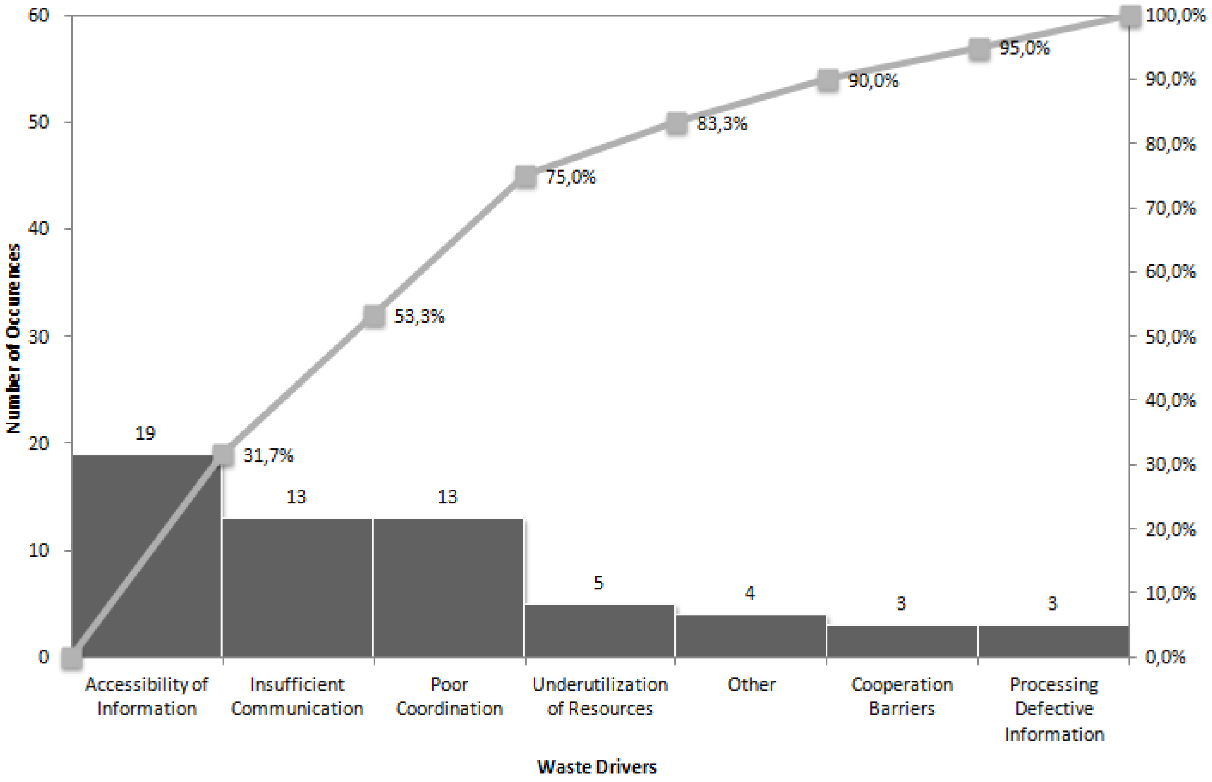

Figure 18: Pareto of Perceived Waste Drivers

From the Pareto it can be seen that, Accessibility of Information (section 6.3.11), Insufficient Communication (section 6.3.9), and Poor Coordination (section 6.3.2), are the most prominent. As the respondents had the possibility of elaborating, several explanations or examples were given to some of the drivers. Regarding the waste driver Accessibility of Information, missing input was mentioned several times.

The prioritized order (Figure 19) showed that more than 66 percent of the respondents, perceived Accessibility of Information to be the most prominent driver for waste.

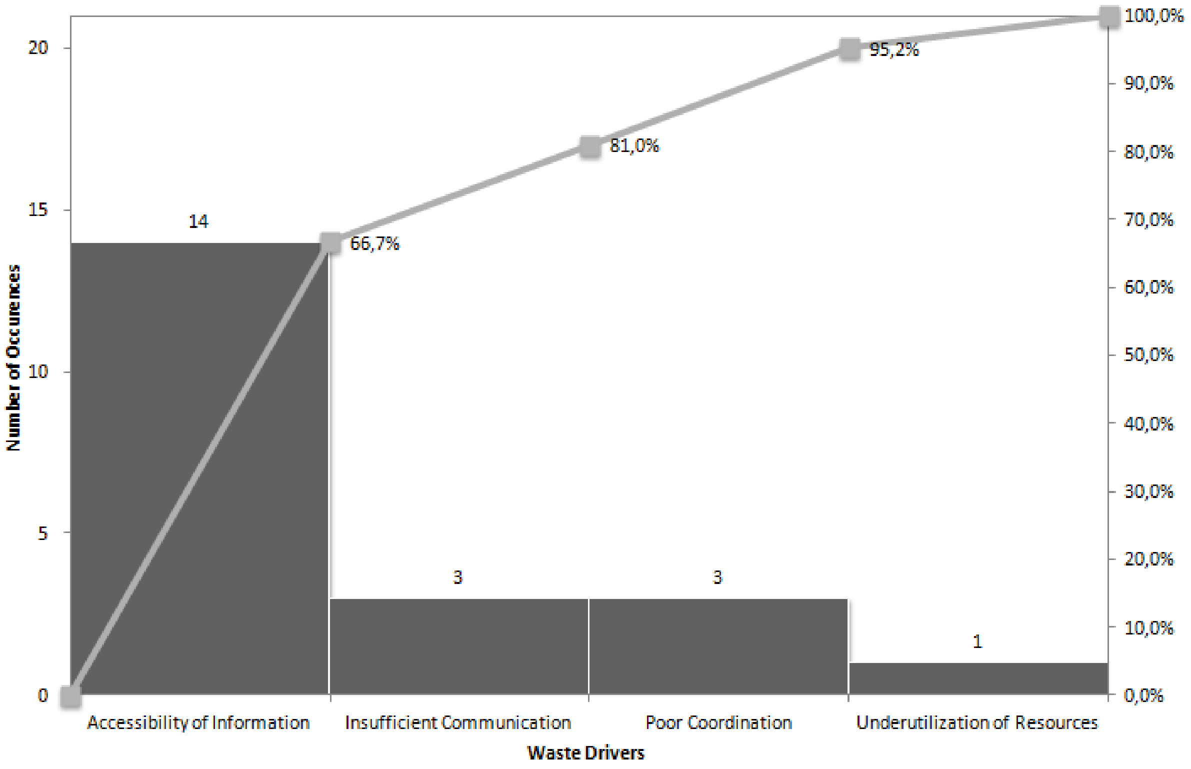

Figure 19: Pareto of Perceived Prominence of Waste Drivers

7.2.2 Discussion of Survey – Part Two

We had to interpret the information. Thus, the results might be misinterpreted due to, e.g. subjectivity (Ackroyd, 1992). The open questions might have made it difficult for the respondents to answer as intended (Ackroyd, 1992). The answers were interpreted to fit into the waste drivers. The interpretations might not be in accordance with the intended meaning. Thus, it might be deficiencies in the data. Therefore, the results of this survey are perceived as indications, not facts.

The survey helped us get an understanding of what the perceived waste was at the case company. It also provided quantitative data of the prominence of different waste drivers in engineering. However, some of the answers were similar to the examples provided. This might indicate that the examples affected the answers, as questions in surveys should not be leading (Evans & Lindsay, 2008). Still, there were other examples provided, which were almost not mentioned at all. In addition, several of the answers were formulated differently compared to the examples. Furthermore, insufficient communication was provided as an example based on discussions with employees at the case company, where this was already mentioned to be prominent.

The survey did not indicate a need for other waste drivers, as all the answers from the respondents could be seen in relation to the waste drivers used in this thesis (section 6.3). However, this does not prove that the drivers cover all aspects of waste in DE, since this survey at best only show what the employees perceive as waste drivers.

The examples were given to provide a simple explanation of waste drivers. An explanation without examples would be lengthy, which could lead to respondents not completing the survey (S. Smith, 2012). Instead of using a survey, we suggest using, e.g. a workshop. In the workshop waste drivers could be sufficiently explained, and a survey could be conducted during the workshop. The workshop could provide quantitative and qualitative data of perceived waste drivers. Thus, this might provide a good arena to create awareness of waste drivers.

8 Evaluation

The constructive research approach used was inspired by the description provided by (Lukka, 2003). However, his approach of evaluating the solution did not fit very well with the construct of this thesis. Hevner, March, Park, and Ram (2004, p. 85) explain the purpose of evaluating constructive research: "*The utility, quality, and efficacy of a design artifact must be rigorously demonstrated via well executed evaluation methods*". They further explain that the completeness and effectiveness of constructive research is determined based on the requirements and constraints of the research questions. They also state that the method of evaluation should match the construct (Hevner et al., 2004). Thus, we wanted to identify feasible evaluation criteria. Based on Lukka (2003) and Hevner et al. (2004) we adapted some of their suggested criteria into our evaluation: practical relevance (section 8.1), completeness (section 8.2), usability (section 8.3), and generality (section 8.4).

8.1 Practical Relevance

The design phase plays a significant role throughout the product life-cycle. Thus, it is of great importance to have good design processes (Verma & Dhayagude, 2009). Furthermore, DE processes are common in many different industries, which indicate that making these processes more effective should be of interest to every organization in these industries. By creating awareness the construct might enable managers and employees to identify waste related to DE in their organization. When waste has been identified it becomes possible to implement measures in order to eliminate or mitigate it. In addition, it might contribute to more predictable DE processes. Thus, the construct has the potential to contribute to a higher level of productivity and efficiency, which could result in a more profitable operation. If the organization becomes more profitable it will have an increased potential to provide and ensure jobs. In turn this will serve society, since it contributes to a healthy economy. Based on these aspects we believe that our construct has high practical relevance.

8.2 Completeness

"A design artifact is complete and effective when it satisfies the requirements and constraints of the problem it was meant to solve" (Hevner et al., 2004, p. 85).

Our construct is the waste drivers in DE, i.e., the mechanisms that may potentially lead to waste. However, it is extremely challenging, or even impossible, to create a list of waste drivers that accounts for all these possible mechanisms. This is partly due to the fact that waste drivers and their relationships are context dependent. With this aspect in mind, it can be argued that the construct is not complete.

Other aspects could have been included in the waste drivers, potentially resulting in additional drivers. For example, duplicate work can be considered a waste driver by some. Duplicate work can take place when there are redundant functions, or there is inability to adjust the division of labor when needed, within teams or companies (Oehmen & Rebentisch, 2010). However, in our opinion, duplicate work can be considered more as an effect of other waste drivers, such as Poor Coordination (section 6.3.2).

Structural barriers were considered as an independent waste driver. Oehmen and Rebentisch (2010) explain that structural barriers can be perceived as something that creates waste through organizational barriers, or the ineffective communication the barriers might cause. The physical location and distribution of team members can create organizational barriers, e.g. making communication and coordination more difficult, as face-to-face is not possible (Oehmen & Rebentisch, 2010; Ulrich & Eppinger, 1995). According to Bauch (2004) companies with a hierarchical structure often have high levels of handoffs, and low levels of accountability. In a hierarchy, communication typically leaves through several channels before reaching the recipient, increasing the chances of miscommunication (section 6.3.9) (Oehmen & Rebentisch, 2010). Furthermore, Oppenheim (2004) adds that excessive conservatism, bureaucracy, compartmentalization and stovepipe organizations are factors that can be perceived as structural barriers. The technical organizational learning environment can also be considered as a structural barrier. Illeris (2007) argues that the organization of work might impact the possibilities of learning, such as the scope for deciding over one's work (section 5.5). While we perceive structural barriers to be an important contributor to waste in organizations, we chose to not include as an independent waste driver. Structural barriers are an organizational issue of the highest level. Thus, the extent DE might do anything to mitigate waste related to this is questionable. Only upper management has the authority to changes the organizational structure. Consequently, the idea of structural barriers as an independent waste driver was abandoned. However, some aspects related to structural barriers are incorporated into other waste drivers.

We were aware of the difficulties and challenges associated with making a list of waste drivers, and our ambitions have been adjusted accordingly. Thus, our requirements and constraints are defined as presenting a list containing the majority of waste drivers. We have based our research on previous literature, i.e., existing theories. In addition, we have incorporated elements into the waste drivers from theories, which has previously somewhat been neglected in the context of waste in DE. However, there are numerous theories and literature that could prove relevant, which has not been investigated. This affects the completeness of the construct. Although, we argue that it is close to impossible to get a complete overview of all relevant information.

We supplemented the waste drivers with findings from our case study and a previous study at the case company. In addition, we had access to collected data from other students at the case company. Most importantly, we were able to place all these findings, without exception, into the waste drivers we created. Thus, we argue that the construct is, to a certain extent, complete in relation to the requirements and constraints of the problem we set out to solve.

8.3 Usability

Usability is defined by the International Standardization Organization (ISO, 2015b) as: *"Extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use"*. In this context, the product is the waste drivers. Thus, the extent of their effectiveness, efficiency, and satisfaction, while applying them in a DE setting, will determine the usability of the construct.

The purpose of the drivers is to create a more predictable DE process. This might be done by creating awareness about the mechanisms that lead to waste. The effectiveness of the construct is hard to determine without proper testing. Measuring waste in DE is difficult, as discussed in section 7. Thus, we have not been able to test our construct, and had to rely on other means to evaluate the usability. Through this thesis we have gained an increased awareness of waste. This became apparent as our perception of the processes at the case company changed throughout the development of the construct. Since we are engineers, we assume that our perspective is similar to that of other engineers. Thus, studying the waste drivers might enable other engineers to become more aware of mechanisms that lead to waste in DE. This might improve their ability to indentify elements that contribute to waste in their organizations, which is necessary to create a more predictable DE process. Consequently, we can assume the construct is effective, while the degree of effectiveness is open to discussion, and is suggested for future research.

The efficiency can be evaluated as the extent the waste drivers are better at creating predictable DE processes, through increased awareness, when compared to other conceptualizations of waste in DE. While the seven manufacturing wastes might be easier to understand, as they are fewer, and their descriptions are short, we concluded in section 5.7.1 that they appear to be too ambiguous to represent waste in DE. If the goal is to create awareness, less ambiguity should be beneficial, since it will increase the interpretability of the information. If employees understand how waste is created by using the waste drivers, it might be beneficial in order to create awareness. The seven manufacturing wastes can enable the employees to understand that, e.g. a task done over and over again, due to defects, is waste. However, the employees do not explicitly gain an understanding of how waste is created, i.e., they only understand that there *is* waste. We believe the waste drivers will enable employees to actually gain an understanding of *how* waste is created. Consequently, the waste drivers might be more efficient when compared to previous conceptualizations. However, it might be beneficial to create new categories. The presence and importance of the different waste drivers vary in relation to the different phases in DE. Thus, it could be beneficial to represent this visually. This could increase the usability of the construct, since it might be easier to get an overview of the most relevant drivers for the different phases. Furthermore, some waste drivers are more relevant to certain employees than others, depending on the role and responsibilities of the person in question. Thus, it might be beneficial to organize the waste drivers with this aspect in mind. Another possibility is to arrange the drivers in relation to core and lead wastes. Koskela et al. (2013) introduced the terms core and lead waste. They explain that a core waste is a waste in itself and is at the same time a waste driver. Further, a lead waste is described as a dominant core waste with substantial negative impact on the production system. The purpose of categorizing in this manner is to identify chains of waste. In essence, chains of waste are described as chains of causes and effects, where one waste leads to another.

As the majority of our waste drivers can affect one another, depending on the context, we argue that categorizing waste drivers into core and lead waste is of limited benefit.

The satisfaction, i.e. the extent to which the expectations are met, when using the waste drivers, will differ based on the expectations different users have. We argue that the waste drivers should make employees better at identifying waste. Thus, this should also be their expected outcome. Perhaps employees identify elements in the engineering process that could improve the economy and productivity of the organization, which arguably will satisfy its members. Thus, we also believe that the owners of organizations will benefit from the use of waste drivers.

In essence, we believe the usability to be adequate when the purpose is to create awareness of waste drivers, in order to contribute to more predictable DE processes.

8.4 Generality

Evaluating the generality of the construct is an important element of the constructive research design, since one of the objectives is to contribute to the theoretical background used in the research. In addition, it should be beneficial for the case company being studied. We believe that our main theoretical contribution is related to the conceptualization of waste in DE.

Our objective is to provide a construct that is applicable for any industry or organization for which DE is part of. However, the degree of which the different drivers are present will vary depending on the type of industry and organization. For example, in software development, drivers such as Ineffective Verification (section 6.3.1) might be especially relevant, since tests are often done continually. While we believe this driver is important to other industries as well as software development, it was not perceived to be among the most important waste drivers at the case company. This is based on results from the survey (section 7.2) and interviews we conducted at the case company. Thus, this demonstrates that the prominence of the waste drivers might differ among industries and organizations. For this reason it was considered to be of limited usefulness to generalize the importance of the different waste drivers.

We have gathered information from existing literature, especially on the topics of DE. We describe the phenomenon of DE in section 5.1, and the distinctive attributes, such as learning, creativity, iterations, cooperation, and uncertainty are all common for DE processes, regardless of industry or organization. Furthermore, the product of any DE activity is information. In addition, we argue that the concept of waste elimination is equally relevant for any organization, despite if lean is the philosophy or not. Based on this we believe that our construct is applicable to a broader context. However, the relationship between the drivers are context dependent and may indeed vary from organization to organization, and from project to project, but the mechanisms themselves should be applicable to any organization dealing with DE. It might be argued that the findings from our case study might vary from other organizations or industries, but the findings are only used as supplements to the findings from literature. Thus, we believe that the findings from the case study only strengthen the generality of our construct.

By submitting a paper to the 23rd annual IGLC conference, which in essence consists of a summarized version of this thesis, we believe that our construct has an increased potential to contribute to existing theories. We conclude, based on the discussion in this section, that our construct has a high level of generality.

9 Conclusion

As the competition on the global market increases, creating effective organizations appears to be essential in order to be sustainable. By using lean principles, manufacturing companies have been able to improve their effectiveness for years. This inspired the use of lean principles in other areas, such as DE. One of the main objectives of lean is the elimination of waste. Eliminating waste will reduce variation and, thus, make processes more effective and predictable.

The purpose of this thesis is to contribute to more predictable DE processes, through increased awareness about the mechanisms that lead to waste. DE processes rely on creativity and innovativeness, and consist of iterations and loops. Thus, detours are a part of the process. This complicates things when trying to conceptualize waste in DE. Previous attempts at conceptualizing waste have typically involved transposing waste in DE into the seven manufacturing categories. However, we concluded that this approach was not feasible, since it, to some extent, fails to account for the waste in DE. In addition, this approach does not provide enough information for employees and managers to actually do something about waste. This is because the approach does not explain why waste is happening. In contrast, our waste drivers are, in essence, explanations to why waste happen. Thus, it is possible to implement measures to mitigate or eliminate waste by using the waste drivers.

We have evaluated the construct based on usability, completeness, practical relevance, and generality (section 8). We believe that generality and practical relevance is high. However, the usability is hard to determine, since we have not been able to test the construct. The completeness is also debatable, since there are several theories and literature that might be considered relevant when conceptualizing waste in DE. Obviously, we have not been able to investigate all the possible aspects, but we believe that our construct provides an improvement compared to previous attempts at conceptualization. Based on our findings, we believe that the waste drivers presented in this thesis, or a similar system, is currently the best representation of waste in DE when the purpose is to increase the awareness of waste. However, we believe there is potential to make the construct easier to use. The waste drivers, which are presented in section 6.3, are summarized as follows:

Ineffective Verifications	• Include ineffective testing, prototyping, approvals, and transactions • Example: tests that are more costly than the risk they are trying to mitigate
Poor Coordination	• Poor planning, scheduling, prioritizations, unsynchronized processes • Example: Tasks completed in a sequential order, when they can be performed concurrently
Task Switching	• Interruptions that forces a person to reorient themselves • Example: meetings can often interrupt other tasks
Capacity Constraints and Overburdening	• Interruptions of workflow as du to unavailable resources or exceeding the capacity of an entity • Example: too many projects going on at once, which might lead to burnout of employees
Lack of Required Competence	• Not possessing the skill or knowledge required to conduct the task in question • Example: ineffective use of IT tools, due to limited skill
Unclear, Goals, Objectives, and Visions	• Misaligned goals, objectives, and visions in relation to, e.g., customer requirements • Example: employees pulling in different directions, reducing the efficiency
Information Overload	• Large batch sizes, and distributing and storing information that is not needed • Example: excessive information can make the relevant information harder to access
Unclear Authority and Responsibility	• Unclear expectations in relation to performance and organizational roles • Example: overlapping competencies and responsibilities
Insufficient Communication	• Communication demanding excessive time and effort, without adding additional value • Example: miscommunication leading to rework

Interpretability of Information	• Information represented in an ambiguous manner, resulting in misinterpretations • Example: Lack of standardization of documentation
Accessibility of Information	• Information cannot be accessed when needed • Example: missing input
Underutilization of Resources	• Allocating resources in a less effective way than possible • Example: inappropriate use of competence
Over-engineering	• Adding features that do not add value for the customer • Example: increased development and production costs as a result of exceeding requirements
Unnecessary Data Conversions	• Avoidable data conversions occurring due to, e.g., use of inappropriate tools or a lack of standardization • Example: re-formatting and re-entering data
Lack of Knowledge Sharing	• Not exchanging information, expertise, or skills among entities • Example: New projects starting below the potential starting point by not reusing previous solutions
Processing Defective Information	• Processing information that is based on a valid need for information, but the need is not sufficiently fulfilled • Example: defective information processed is not discovered and affects other processes
Changing Targets	• Internal or external changes of requirements • Example: changes can lead to rework, especially when the changes occur late in the process
Cooperation Barriers	• Unwillingness to cooperate • Example: lack of ownership negatively affecting motivation

10 Future Research

While we believe that the waste drivers presented in this thesis is a good foundation for creating awareness of waste in DE, we believe it to be beneficial to further research elements of the drivers, which we were unable to sufficiently explore. Testing and verifying the waste drivers in a scientific way would also be beneficial, as it could prove the usefulness of the waste drivers.

- *Increasing Usability* – We believe it is possible to make the construct easier to use in order to aid organizations in their efforts to eliminate waste. Thus, it is suggested to find ways to accomplish this. We have discussed the possibilities of categorizing waste, and believe there is some potential in investigating if waste drivers can be categorized in accordance to the activities, phases, or roles they influence the most
- *Evaluating and testing the waste drivers' ability to create awareness* – In order to thoroughly evaluate if the waste drivers create awareness for waste, this has to be tested in practice. We suggest doing qualitative interviews were the participants are explaining what they perceive as waste in the organization. Then after the first interview the waste drivers are presented for the employees, and explained in detail. After the drivers have been introduced, the employees should work without other interference from researchers, until after a chosen time period, were the interviewees will be interview again with the same question as last time: what they perceive as waste. The proposition is that they should now have a higher understanding of waste, and thus their described perception should differ from the perception in the first interview. The researcher could then evaluate if the perceived wastes from the employees could be used to identify and eliminate waste at the company
- *Develop methods to measure the waste drivers* – In order to get managerial approval of using resources to change processes, measurements are believed to be a good tool in order to communicate the importance of doing the changes. Thus, methods for measurements would be beneficial. Based on the research done in this thesis, quantifiable VSMs appeared to be the best method. However, several aspects of the drivers appear as difficult to measure with this method. For example: how can a VSM identify if the information a process receive is not interpretable. Based on the work by Kato (2005), and

others, a more adequate method might be possible to create. An important aspect of the measurement method would be that it is not a wasteful activity in itself

- *Information as a product* – as defined in this thesis, information is the product of DE, thus analyzing, e.g. the flow of information in a similar manner to how the flow of materials would be analyzed, could provide new insight in where the waste occurs

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13 Appendix

13.1 Appendix 1 - Survey Part One

Survey - Part One: CS15 and LAI99 Survey Questions

The four questions (McManus & LAI PD Team, 2000):

- Question 1 **-** *The last time you worked on a design, what percentage of your time did you considered "pure waste" (waiting, looking for information, doing clearly unnecessary tasks, etc.)?*
- Question 2 **-** *What percentage would you consider "necessary waste" - needed under the current system, but eliminatable under some conceivable improved system?*
- Question 3 **-** *How long a design you worked on or were familiar with take, from inception to first functional prototype delivery?*
- Question 4 **-** *In a perfect world, how fast do you think the design could be done?*

Survey - Part One: Results

Question 1	**LAI99**	**CS15**
Count	35	22
Mean	40	21,3
Minimum	0	2
Maximum	90	50
Standard Deviation	24	12,6
Question 2	**LAI99**	**CS15**
Count	35	22
Mean	29	10,8
Minimum	10	1
Maximum	90	40
Standard Deviation	17	9
Question 3	**LAI99**	**CS15**
Count	35	22
Mean	36	9
Minimum	6	0
Maximum	144	24
Question 4	**LAI99**	**CS15**
Count	35	22
Mean	14	6,5
Minimum	0	0
Maximum	60	18

Ratio of Possible Improvement	**LAI99**	**CS15**
Count	35	22
Ratio	2,6	1,4

- The result from the CS14 indicated *13 percent* waste
- The results from the LAI99 indicated *40 percent* waste
- The results from the CS15 indicated *21.3 percent* waste

	Perceived Waste
LAI 99	40
CS14	13
CS15	21,3
Mean	24,8
Standard Deviation	13,8

13.2 Appendix 2 - Comparison of Waste Drivers

This table was used to create the foundation for the waste drivers.

Bauch	Oehmen & Rebentisch	Oppenheim
Waiting	**Waiting of people (for information)**	**Waiting**
Waiting for data, answers, specifications, requirements, test results approvals, decisions, releases, review events, signs	Scheduled waiting	Long approval sequences
Poor project management skills	Excessive buffer time	Waiting for data, test results, information, decision …
Low knowledge of the benefits of concurrent engineering	Long internal / external lead times	Late delivery
Bad planned and scheduled milestone and data release events	Strong dependencies	Poor planning, scheduling, precedence
Lack of access	Lack of resources (bottlenecks)	Unnecessarily serial effort
Multiple authorizing signatures	Unscheduled waiting	
Extensive approval of engineering change document	Neglecting of schedule	
Information is waiting for people	Unbalanced processes	
Insufficient synchronization of processes (Unsynchronized processes)	Low performance	
Waiting for capacity available (human or machine)	Wait time due to other wastes	
Poor scheduling		
Different task priority of different people		
Lack of computing capacity (Limited IT resources)		
Transport/Handoffs	**Miscommunication of information (inefficient or ineffective communication)**	**Conveyance**
Excessive data traffic	Change of ownership	Hand-offs/excessive information distribution
Missing interoperability and incompatibility of the different software and hardware systems and tools (Limited IT resources)	Unclear responsibility / authority	Disjointed facilities, political *made in 50 states*, lack of co-location
Converting, re-formatting or even re-entering data (Overprocessing)	Unnecessary hand offs	Uncoordinated complex document taking so much time to create that it is

		obsolete when finished
Unsynchronized processes	Structural barriers	
Handoffs	Organizational / process barriers	
High specialization of tasks	Insufficient communication channels	
Low process view	Knowledge barriers	
Unclear roles and responsibilities	Learning of basic knowledge	
Unclear information path	Learning from practice	
Stop and go tasks/ Task switching	Process barriers	
Poor synchronization of tasks	Interruptions	
Too many running projects	Multitasking / Task switching	
Ineffective Communication		
Miscommunication, inaccurate communication owing to non-standard terminology and meanings used by different departments		
Lack of communication e.g. ineffective feedbacks, inadequate discussions of project objectives		
Unclear goals and objectives, rules and roles		
Movement	**Unnecessary movement of people (to obtain information)**	**People motion**
Lack of direct access	Badly designed, insufficient information system	Long travel distances
Lack of direct access, i.e. distributed (paper) or online access (digital files)	Lack of direct information access	Redundant meetings
Poor information system design (Limited IT resources)	Difficult information search	Superficial reviews
Information hunting	Inefficient use of tools	People having to move to gain or access information
Unclear and thus poor performed rules in handling and naming files	Disparate locations	Manual intervention to compensate for the lack of process
Lack of clear information paths	Communication difficulties	
Unclear roles and responsibilities	Inefficient work environment	
Lack of clear information creating processes (Unsynchronized processes)		
Remote locations		
Physical restrictions of company buildings		
Obsolete organization structures		
Poor awareness of creating a success enabling project environment		

Over processing	**Overprocessing of Information**	**Processing**
Unnecessary features and processes	Over engineering (unnecessarily rigid tolerances)	Stop-and-go task
Unanalyzed or rather not understood product or process requirements	Specifying too many details	Redundant tasks, reinvention, process variation - lack of standardization
Tendency of carrying-over of requirements from the last product	Exceeding specifications	Creating documents that nobody requested
Individual interests of system participants	Data conversion	Point design used too early, causing massive iterations
Unnecessary detail and accuracy	Incompatibility	Uncontrolled iterations (too many tasks iterated)
Engineer's tendency to perfectionism	Lack of standards	Work on a wrong release (information churning)
Poor insights and feedback in business economics and life-cycle costs	Re-invention	Data conversions
Lack of standardization	Existence unknown	Answering wrong questions
Just to meet an individuals' standard	Inability to reuse	Many contractual obligations (e.g., 2D drawings)
Excessive approvals	Processing defective information	Unclear or unstable requirements
Old and strongly hierarchical organization structures with no or poor cross-functional teams	Undiscovered errors	Excessively complex software *monuments* (using complex software when a spreadsheet would do)
Prevalent command and control mentality	Outdated information	
Turf protection		
Failure of defining some significant business cases for approvals		
Excessive transactions		
Complex supplier structure		
No win-win-relations with suppliers		
Inappropriate use of competency		
Poor insights in time management		
Insufficient support from management regarding the employment of students/ assistants		
Use of inappropriate tools/ methods		
Incompatibility and poor interoperability of software and hardware systems - Incompatible information types		

Lack of availability, knowledge or training in conversion and linking systems		
Poor knowledge/experience with methods		
Different departments use different tools		
Data cannot be transferred from the old to a new system due to various incompatibilities (Limited IT resources)		
Poor farsightedness of executives in respect of the potential of IT technology		
Deficiency in training		
Poorly designed and incompatible user interfaces		
Incompatible software suites		
Too huge amounts of information to sort through		
Poor knowledge or experience		
Prejudices versus new or not before used approaches		
Inventory	**Stockpiling of information**	**Inventory**
Excessive data storage	Information inventory	Batching
Tremendous increase in computing systems over the last 15 years	Process design and variability	System overutilization
Tremendous increase in electronic file traffic, size, and storage	High capacity utilization	Arrival variation
Little effort in managing and conserving these kinds of resources due to an insufficient awareness of this kind of waste	Large batch sizes	Poor configuration management and complicated retrieval
Lack of integrated information systems (Limited IT resources)	Product feature inventory	Poor 5Ss in office or databases Lacking central release
Inadequate standards and practices concerning the administration of data and information	Legacy feature	
Lack of a disciplined system (Lack of system discipline) for updating new and purging old files	Unused option	
Over-engineering	Over engineered part	
General uncertainty with development processes	Capabilities inventory (excess capacity)	
Missing understanding of the essential things in development	Project portfolio mismatch	
Bad experience with executives focusing on negligible issues	Underutilization	
Critical Path related queues		
High system variability		

Exceeding capacity utilization		
Large batch sizes		
Arrival rate of the tasks but also on their duration, which is again effected by		
Differences in the contents		
Differences in the productivity of the operators		
Multiple projects		
Poor awareness of system behavior (queuing theory)		
Expediting of single projects of a product development program due to time delays		
Organization of development projects: Creation of and work to milestones, data release events or check points within the process		
Inadequate synchronization of up and downstream processes		
Overproduction/ Unsynchronized processes	**Overproduction of Information**	**Overproducing**
Poor synchronization as regards contents	Delivering unnecessary information	Creating too much information
Participants of up and downstream processes do not talk about each other’s process and its requirements	Performing duplicate work	Engineering beyond the precision needed
No holistic view of the process	Creating unnecessary deliverables	Overdissemination = sending information to too many people (e.g., excessive email distribution)
Poor synchronization as regards time and capacity	Delivering information out of sync	Sending a volume when a single number was requested
Poor understanding of concurrent engineering’s capabilities	Delivering excess information	Ignoring expertise
Insufficient transparency of functional organization’s capacities	Delivering information too early	
Unrealistic planning by project managers		
Insufficient communication		
Low commitment to hold schedules (Lack of system discipline)		
Over-dissemination of information		
Poor understanding and overview of the process by single process participants		

Unclear roles, responsibilities and rights (Lack in system discipline) and the resultant information requirements of the process members		
Redundant tasks		
Poor synchronization as regards contents		
No holistic view of the value stream		
Different testing standards and scales in testing		
Defects	**Generating defective information**	**Correction**
Deficient information quality	Defective deliverables	The killer "re's": Rework, Rewrite, Redo, Reprogram, Recertify, Recalibrate, Retest, Reschedule, Recheck, Re-inspect, Return, Re-measure …
Poor synchronization as regards contents of up and downstream processes (Unsynchronized processes)	Defects and legacy defects	Incomplete, ambiguous, or inaccurate information
Missing understanding of technical issues	Defective architecture	External quality enforcement
Poor information systems	Obsolete deliverables	
Lack of disciplined data administration	Long lead times	
Poor synchronized processes	Unaddressed changes	
Frequent changes regarding to product and process	Defective information attributes	
Lack of standardization for data representations	Insufficient knowledge sharing	
Different terminology of different departments for the same things	Information deterioration during communication	
Erroneous data and information	**Correcting information**	
Requirements overlooked	Repairing and reworking	
Appropriate analyses not conducted	Optimization iterations	
System interfaces not adequately considered	Unclear or shifting targets	
Standard processes not followed	Partial information	
Lessons learned are not captured	Lack of time	
Poorly designed input templates	Scrapping	
Undisciplined reviews	External inspecting	
Poor tests, validations and interpretation	Unreliable processes / complexity	
Haste	Lack of information	
Poor testing and verification		
Low awareness of testing and verification		

Testing is often limited to the first physical prototype built up		
Insufficient test of thoughts and ideas in the early stages of the process		
‘Wishful thinking’ and a less realistic view of the engineer		
Low knowledge with systematic testing as suggested by Design of Experiments DoE		
Quick and dirty' experiments due to short-term problems		

Additional Categories

Bauch

Reinvention	
Poor design re-use	
Modeling components were not created re-usable	
Insufficient awareness of the ‘real’ costs engineers cause by their acting	
Inadequate system with special functions for the administration of design models (part families)	
Engineers poor overview of previous designs due to frequent job changes	
Poor knowledge re-use	
Lessons and experiences from precedent projects are often documented bad, and scarcely transferred to subsequent projects	
Poor knowledge and information management systems	
Poorly defined, undisciplined product development processes	
Multiple handoffs	
Poor accountability	
Lack of System Discipline	
Unclear goals and objectives	
Poor insights into the factors of successful project management	
Lack of communication	
Unclear roles, responsibilities and rights	
Poor focus on the framework or rather the preconditions for successful project management	

Insufficient readiness on part of the team participants to accept the own role and the roles of the others	
Lack of communication	
Unclear rules	
Poor awareness of the usefulness of such rules	
Focus on the effort instead of the benefit of that approach	
Rules are not open communicated, everybody has his own standard	
Lack of communication	
Poor schedule discipline	
Poor awareness of the impacts of such acting (High process variability)	
Poor commitment to the job due to low accountability caused by a lot of handoffs	
Insufficient readiness to cooperate	
Social system in general, in which people are usually rewarded for their individual achievements	
Hierarchical structure of a company, often associated with high levels of handoffs and low levels of accountability	
Some people's readiness to cooperate was misused by other team members	
Incompetence/ poor training	
Unwillingness of employers to offer regular training	
Unwillingness of employees to take it as a chance	
Limited IT resources	
Poor compatibility	
Big variety of existing IT components within information systems	
Poor capability	
IT resources are a low budget priority	
Low capacity	
IT resources innately are a low-budget priority	
Expensive software licenses	
Outdated band-width communication lines	