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MASTER'S THESIS

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Preface

The present study is a master thesis report being a part of extended and more practice oriented version of the regular master program in Offshore technology with specialization in Industrial Asset Management at University of Stavanger (UiS). The study program is linked to the Center for Industrial Asset Management (CIAM) (www.ciam.uis.no), at the Faculty of Science and Technology of UiS. It is unique program in Norway with combination of technology and management associated with engineering systems and facilities.

The thesis work introduces concepts of lean design process in piping for oil & gas platform's top side maintenance and modification projects. Piping design during detail engineering is discussed based on lean design principles by conducting a case study on a live project at the company named 'Aibel As'. The present work includes identifying the waste and key waste drivers involved in the piping detail engineering, analyses the key waste drivers based on lean design principles, presents the recommendations for minimizing the waste and finally evaluates the theme of the work with respect to practicality, usability, generality and completeness.

Stavanger, 15.12.2016

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Srinivasa Rao Devi

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First, I would like to express my gratitude to my supervisor Prof. Jan Frick at UiS for his invaluable guidance and advice during the whole process of thesis work. I appreciate his continuous support and encouragement for development of the thesis.

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I specially thank my wife (Ragini), children (Preetham Reddy and Dhanya Reddy) and father-in-law & mother-in-law (Suresh Reddy & Sudhamani) for their continuous encouragement and cooperation for completion of the thesis.

Finally, I wish to dedicate this dissertation to my parents, Respected Appa Rao and Appayamma, who struggled much for providing me education and bringing me up to this level.

15.12.2016

Srinivasa Rao Devi

Table of Content

List of Abbreviations

Abbreviation	Explanation
BP	British Petroleum
DE	Detail Engineering
EIS	Engineering Information System (Engineering Database)
EPCI	Engineering, Procurement, Construction, and Installation
FA	Frame Agreement
FEED	Front End Engineering Design
GEMC	Greater Ekofisk and Modification Contract
LP	Lean Process
MMO	Maintenance, Modifications and Operation
M&M	Maintenance and Modification
MTO	Material-to-Order
PDMS	Plant Design and Management System
SAP	Enterprise Resource Planning (Client tool)
STAAD	Structural Analysis And Design (Structural Analysis)
TPS	Toyota Production System
TFV	Transformation-Flow-Value
TWI	Training Within Organization
VSM	Value Stream Map
WBS	Work Breakdown Structure
3D DM	3 Dimensional Design Modeling

List of figures

List of Tables

Chapter 1

Introduction

The use of Lean organizational concept has been accelerated in recent years. Organizations implement the lean concept in detail engineering phase hoping to achieve greater efficiency, reduced or eliminated waste of resources and competitive advantage for projects in oil and gas sector.

As a starting point for the exploration of this thesis, the work focuses on organizational current practices in the organization 'Aibel' within piping during detail engineering phase for maintenance and modification project. The focus is mainly for development of integrative capabilities that raise the questions like what are the variables involved, who is in the design domain and how these variables connect in this specific domain. To address these questions the author asks how the operations are organized for maintenance and modification projects at Aibel, where they see the best potential from improvement of integrative capabilities, what are the current issues within the specific aspect (piping during detail engineering phase) and which initiatives can be proposed for future improvements of the aspect. The inherent information in the above proposed questions is with respect to identify and minimize the waste involved in various domains of interest. This study deals with the waste and key waste drivers and discussing them by applying lean design process in piping during detail engineering.

1.1 Background and choice of topic

Oil and Gas (O&G) companies in Norwegian continental shelf has focus on Maintenance and Modification (M&M) projects to extend the lifecycle of offshore fields for enhancing the production of aging fields. All activities involved in Maintenance and Modification projects should be carried out more efficiently to avoid production interruption. During this process, detail engineering phase has a key role to meet projects' milestones and budgets.

Detail Engineering (DE) phase for maintenance and modification projects will play an important role throughout the lifecycle of oil and gas field. Typically, the detail engineering phase accounts for a small portion of total project cost even though it can impact the life- cycle costs significantly (Verma, A. K., & Dhayagude, S. S. 2009).

The organization Aibel is Engineering, Procurement, Construction and Installation (EPCI) supplier, and undertakes maintenance and modification project for the both green and brown fields in oil and gas market locally as well as globally. Aibel's Maintenance, Modification and Operations (MMO) division located at Stavanger has a high focus on how to improve operational efficiency in piping during detail engineering phase for maintenance and modification projects.

Due to the extraordinary growth in oil and gas sector for detail engineering services under maintenance and modification projects from the last two decades, many detail engineering service organizations like Aibel, have been now paying an attention to the efficiency and effectiveness of their operations for competing the oil & gas sector locally and globally.

In addition, the increased market competition as a result of globalization and the higher level of complexity in M&M projects need a more efficient and predictable detail engineering. Accordingly, it becomes important to ensure that time is spent on value- added activities and provide the value to the customer within a budget and in a timely manner (Lean design process) during detail engineering process.

The above mentioned features can be dealt with Lean design process. The lean design process under detail engineering phase is a learning which adds an additional layer of complexity when trying to define, identify and eliminate waste process (Kalsaas, 2011). It has been implemented at a time when the industrial society was increasingly characterized by overproduction, increasing global competition and survival on margins (Melander, 2015, s. 1). Lean is known as a westernization of the Japanese concept as the Toyota Production System, developed by Mr. Taiichi Ohno, the Vice-President of Toyota Motor Company, in the early 1950s. The purpose of it is to continuously improve quality, cost, delivery time and safety through eliminating waste and creating continuous flow in order to meet customer demands (Plenert, 2006, s. 146).

1.2 Research question and scope

An extensive amount of literature work and research has been performed on the topic of waste in manufacturing and construction. However, it appears to be limited focus on the mechanisms that lead to waste during detail engineering for engineering service organizations like Aibel.

The present thesis work gives an opportunity to explore and implement lean design process in detail engineering phase for piping design under the discipline of ‘piping and layout’ at Aibel to improve an operational efficiency. An industry-developed best practice has been used in the fieldwork and the data was collected from multiple sources like meetings, individual/group interviews, archival record, available documentation (section 2.3), project of Greater Ekofisk and Modification Contract (GEMC) work management model (Way We Work – W3) and an existing research design for detail engineering.

As a part of the present thesis work, a case study was conducted and executed in GEMC modification project at Aibel. The case study is the basis for the initial report on empirical findings. After the initial findings, the theoretical background was presented in Section 3 and perspectives for further discussion of the cases were presented in Section 4. The last sections include recommendations (Section 5), evaluation (Section 6) and followed by conclusions (Section 7). Also the suggestions for future work were given in Section 8. The sections are related to practical feedback from project, literature with implications for practice, theory and methodology (Section 2).

The objective of the thesis is: ***Applying Lean Design Process for eliminating the waste in piping during detail engineering.***

The objective is achieved by performing the following tasks:

- ***To identify and define the mechanisms that might lead to waste in piping during detail engineering process for M&M projects being executed by AIBEL in Oil and Gas sector.***
- ***To assess the influence of the key waste drivers with respect to quality, cost and effectiveness of piping.***
- ***To perform analyses based on Lean design theory and discuss its use for industry practice regarding waste eliminations in piping.***
- ***To propose recommendations for eliminating the waste in piping and evaluate them considering practicality, usability, generality and completeness.***

In summary, the purpose of the study is to increase the design predictability and efficiency during detail engineering phase for maintenance and modification projects, by identifying the mechanisms that lead to waste. This is important in order to implement the methods that can reduce or eliminate waste.

1.3 Research methodology and structure of the work

In the effort to identify and define the waste drivers, the work of Bauch (2004), Oehmen, J., & Rebentisch, E. (2010), Morgan, J. M., & Liker, J. K. (2006), and Oppenheim (2011) has been used as a basis. **Table 1** describes the selected approach and gives the procedure for developing constructions that can contribute to the theory in the field of research. In addition, the practical research approach was applied based on the work experience of the current author as a principal engineer under piping and layout discipline at Aibel.

As mentioned above, the data was collected from multiple sources during the case study, e.g., meetings, interviews, archival records, and documentation (section 2.3). The collected data was used to examine the waste drivers present in piping design. The contents of the different sections are structured as described below in **Table 1**:

Methodology	• Describes the methodological approaches used and the reason for choosing these approaches • Presents the procedure for assessment of quality of research.
Theoretical framework	• Lean design process: Provides a basic overview of the background, basic elements of lean concept and principles of lean. • Brief about Aibel: Provides an overview of the piping design in detail engineering process at Aibel and gives brief about piping design and design process in the engineering management for M&M projects.
Analysis	• Lean Design: Describes value in engineering design; Lean design during piping pre-engineering and detail engineering phase; Defination of waste and waste drivers. • Waste Drivers: Provides a description of how the waste drivers were created during piping design and gives a descriptions of the waste drivers with the examples from the case study at Aibel.
Recommendation	• Made based on survey conducted at case company and author holding practical experience with Aibel for key waste drivers to minimise the waste and improve quality.
Evaluation	• Focuses to construct and evaluate recommendations, based on practical relevance, completeness, usability, and generality.
Summary and Conclusion	• Provides summary about the construct and conclusions made in the present thesis work.
Suggestions for Future work	• Provides suggestions for future work

Table 1 Description of Content.

Chapter 2

Methodology

This section provides a through description of the methodological choices and research process used for this research. It further includes presentation and discussion of research design and methods, description of the research process, data collection procedures and methods, and assessment of the quality of research design. A combination of methodologies applies in order to get a holistic picture of the presented research.

2.1 Research Design and Methods

Kothari (2011) mentioned that the selection of a proper research design and methodology is important for research. The research design is supposed to illuminate common aspects between the collected data and the question of research (Yin, 2014). Researchers should pay an 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 methodologies are most applicable (Grønmo, 2004).

The character of the research and research question itself is central in determining the design and method of research. In this thesis, the goal is to meet the objective of research using design methods in piping design by identifying waste and waste drivers. 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*". In simple, 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 research variables (Yin, 1988).

The constructive research approach is often used to define and solve problems as well as improving an existing system or performance with the overall objective of adding to previous knowledge (Oyegoke, 2011). The organization of Aibel and my research work are intended to apply the lean design process during detail design engineering by having continuous improvement and elimination of waste within piping for maintenance and modification projects. My research utilizes a constructive research approach described by Lukka (2003) for the selected case study presented in **Figure 1**.

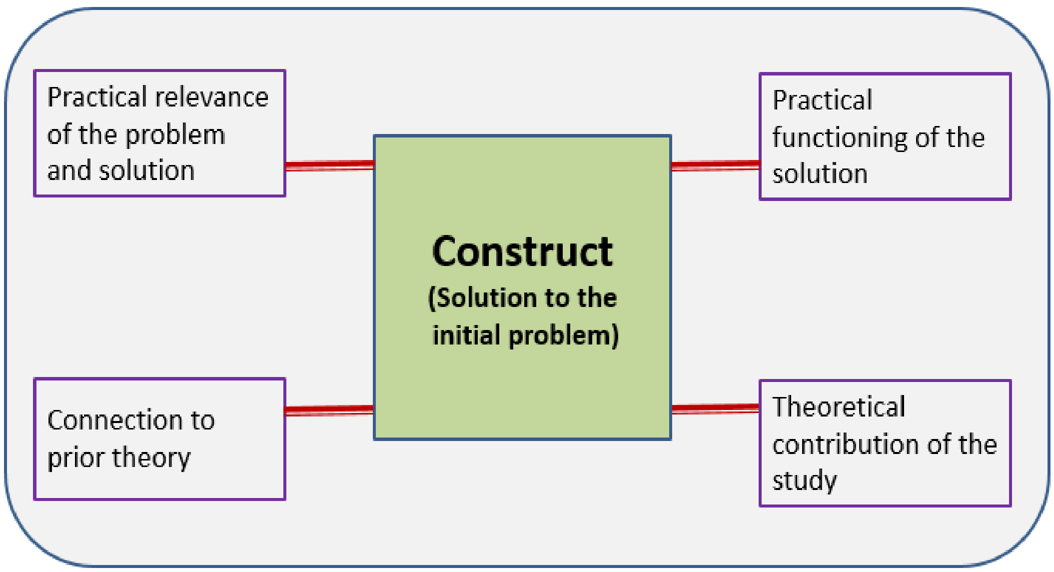


Figure 1 The key elements of constructive research approach (Lukka, 2003)

As shown above in **Figure 1**, the selected approach was constructive for the selected case study, due to the explorative nature (continuous improvement) of the area of the study. The constructs themselves refer to human artifacts such as models, plans, organization structures, diagrams and communication systems, and it is characteristic of them that they are invented and developed rather than discovered (Kasanen, Lukka & Siitonen, 1993).

Close cooperation between the researcher and the organization of interest is critical to obtain a holistic view of the studied topic when dealing with exploratory research like the constructive research approach (Holmström et al., 2009). Based on this, the author had very close cooperation within Aibel among the employees to get necessary information for conducting the case study as desired.

2.2 The Research Process

This section covers the chronological structure of the research process as stated in the constructive research approach by Lukka (2003) in section 2.1. The illustration of research process is shown in **Figure 2.**

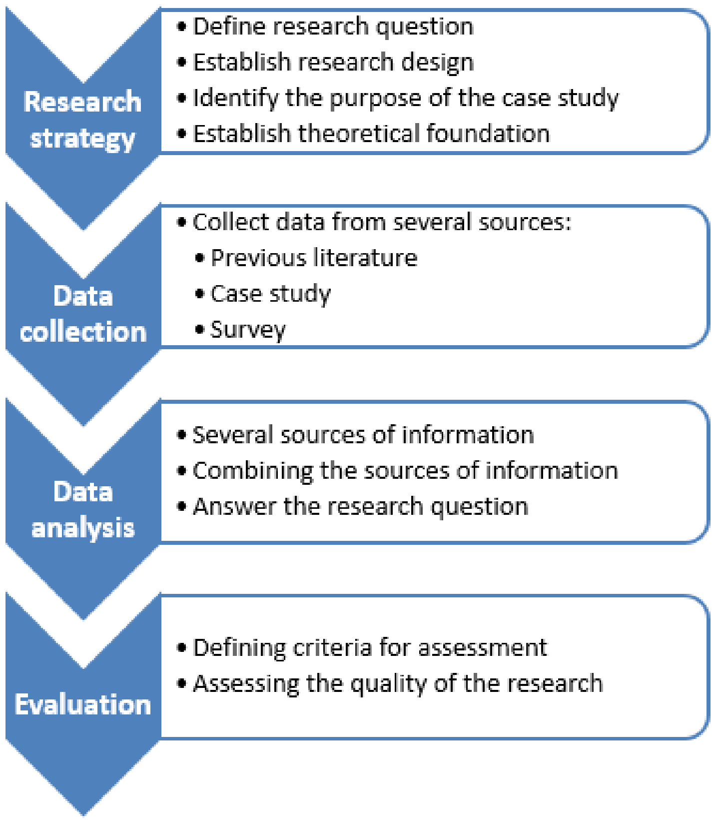


Figure 2 An overview of the research process (Lukka, 2003)

In order to select a research process, the research question had to be determined. Applying the approach shown in above figure, first the research path is described by narrowing down from a broad research area to a specific research problem during case study at Aibel. The practical relevance of both the problem and the recommendations and what benefits the research entails for the Aibel within piping design are described. Additionally, the connection between the research problem and prior theory in its given context was described. Combining this theory with findings, the basis was set for developing a construct. In the third subsection of this chapter, the construct was briefly presented as it aims at solving the problem. Next, the practical functioning of the solution and the possible theoretical contribution of the research in terms of the construct was discussed.

2.2.1 Practical Relevance

In the beginning there were several potential research questions in mind. One of these aimed to be presented by means of reducing waste in piping design. In order to accomplish this, the mechanisms leading to waste had to be identified. This turned out to be a complex task because of the complexity emerging from the broad range of topics relevant to explain these mechanisms.

Thus, author primarily focused on exploring the aforementioned mechanisms. In order to accomplish this, the detail engineering as a phenomenon (see Section 3.3) is needs to be understood. The knowledge acquired through this process revealed that there were limitations in the existing literature on waste in design, due to involvement of different design teams during detail engineering phase.

Based on available literature and author's holding work experience from Aibel, it is believed that human, cultural and social aspects as well as tools with respect to learning, creativity, motivation and standardization are to be considered in the context of waste in detail engineering. These are important aspects as they directly influence on how waste is perceived and identified. Failing to identify waste might lead to sub-optimized solutions that are incapable of improving the system as a whole.

Also author has gone through data from the archival project records (GEMC modification project) and correlated it with data received from experienced personnel of Aibel through several meetings. Based on the results and the discussion with the experts from Aibel, it is released that there is a need of further improvement in piping design in respect of roles and responsibilities (section 4.4.1), communication (section 4.4.2), competence (section 4.4.3), standardization (section 4.4.4), and knowledge sharing (section 4.4.5). It was noticed that Aibel's employees of relevant area of expertise are looking for the ways to improve on the above mentioned points during piping design for maintaining good quality, optimal project & operational cost in the organization. The findings and feedback from relevant experts are covered in the exploratory phase of the study described in chapter 4 and the recommendations are detailed in chapter 5.

2.2.2 Linking to Prior Theory

During the process of investigating the characteristics of detail engineering, several previous works and theories relevant to the research question were reviewed. The emphasis on the elimination of waste is a central element in lean (Womack & Jones, 2003), which led 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 detail engineering has been conducted in previous studies. These studies were used as a starting point for the present thesis work. Some of the previous works reviewed are from International Conference on Engineering Design (ICED) and the International Group of Lean Construction (IGLC).

Since detail engineering processes depend heavily on features such as communication, creativity, and innovation, exploring these topics gained importance. The exploration led me to focus also on other topics such as learning and motivation. Thus, theories of learning, motivation and communication have become subjects of current study. The other theories relevant for design, queuing, leadership and organization were also explored. However, the inclusion of these theories and concepts varies with respect to the relevance of research question. A theoretical concretization related to the theory of this specific study is described under chapter 3.

2.2.3 The Construct

The construct consists of a list of recommendations that are to improve quality by eliminating waste towards lean design as a continuous improvement. The recommendations are based on the case findings and theory, and they are to improve the current situation at Aibel by identifying waste drivers presented in section 4.4. The drivers were derived from existing literature on the topic of waste in piping design during detail engineering. The results from the case study and author's work experiences have been used to verify and supplement the drivers.

2.2.4 Practical Functioning of the Solution

Due to the limited time during research and the projects at Aibel were in the middle of execution stage, the functioning of the constructs was not able to be tested.

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 are presented in Section 6. As was mentioned before, the lean mechanism leads to identify the waste in piping design. In order to identify the lean design mechanism, there is an essence of understanding of detail engineering processes. Thus, the author believes that the presented recommendations in this work can contribute to more predictable and efficient piping design during detail engineering processes.

2.2.5 **Theoretical Contribution of the Study**

Findings based on theories and methods in lean design process incorporate elements from lean product development and the theories of communication, organization, learning and motivation as well as the theory of design. By combining these elements, the construct provides a context specific to Aibel for continuous lean design improvement in piping design.

2.3 Data Collection

The data collection methods used in this study are based on both qualitative and quantitative data. Wacker (1998) argues that no single research category should be considered as superior to another. Thus, the author used several different methods of qualitative as well as quantitative data collection aiming to utilize the advantages of the different methods.

According to Ghauri & Grønhaug (2005), the researcher should use qualitative methods in exploratory case studies for getting a holistic picture of the studies and a deeper understanding of the subject. Ghauri & Grønhaug (2005) emphasizes that qualitative and quantitative data collection methods are not mutually exclusive, but differentiated by the objectives of field of research. In general, for inductive and exploratory research, qualitative methods are most useful, as they can lead to explanations and building of hypothesis. The quantitative methods, on the other hand, can be useful when several units are being studied (Jacobsen, 2005).

However, in the first phase of the quantitative method, the research problem addresses something that needs additional information which is unstructured and unknown to the researcher. But, the qualitative research methods are suitable. Yin (1988, p. 84) states that the case study's evidence can be available from six different sources, which are "documentation, archival records, interviews, direct observation, participant-observation and physical artifacts". Since the case study was used as a supplementing layer to the construct, "sources of evidence" is changed to "sources of information" and added "literature" as an additional source. Literature concerning all the existing theory was reviewed. The six sources of information are illustrated in **Figure 3**.

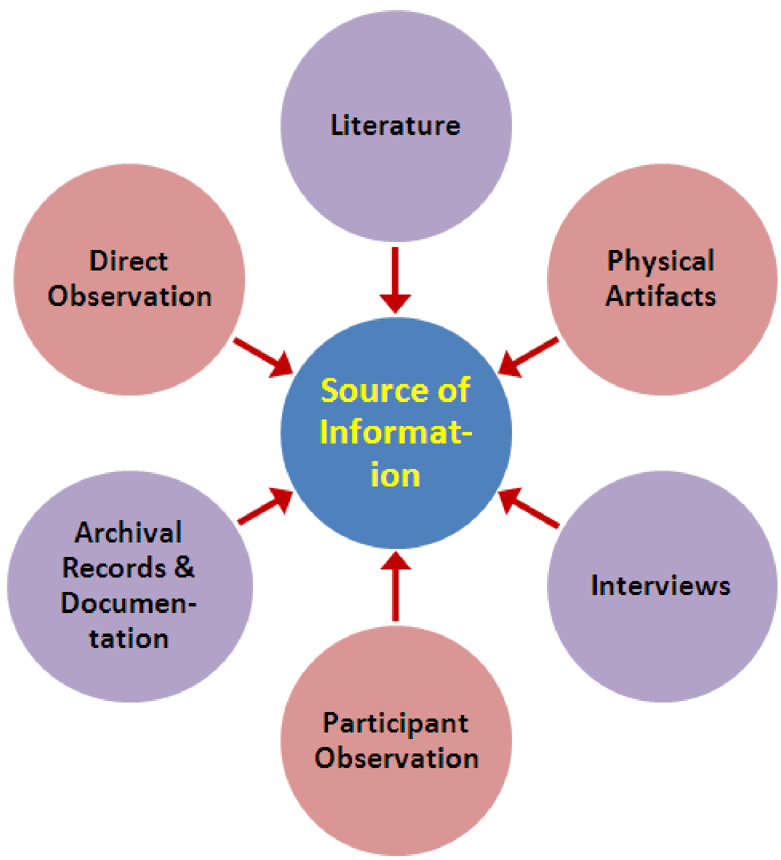


Figure 3 The Six sources of Information, adapted from (Yin, 1988)

Archival records include elements such as organizational records, list of names, and personal records (Yin, 1988). Documentation consists of elements such as minutes of meetings, administrative documents and media coverage of the case company (Yin, 1988). The interviews conducted within the organization of Aibel were also used as sources of information. Direct observation is when the observer covers events in real time (Yin, 1988). It covers broad coverage of data which is difficult to get without team of observers and needs time. Participant observation is the same as direct observation having insightful into interpersonal behavior and motives (Yin, 1988). Physical artifacts cover insightful into cultural features and technical operations (Yin, 1988). The author is an employee at company where case study was conducted and used all the above mentioned six sources of information, in addition to process mapping meetings (section 2.3.4).

2.3.1 **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. The discussions from interviews spanning from open conversations to closed conversations are presented in a specific order in appendix 1. The both open (group) and closed (individual) conversations were arranged with fixed predetermined questionnaire.

The author conducted a several low semi-structured interviews with employees from various levels of the organization to provide a holistic view. The interviews were conducted based on a constructed interview guide so that employees in all levels of the organization speak freely about predetermined topics. Semi-structured interviews are more open and leave more room for discussion than fully structured interviews where the respondent answers specific questions and interviewer leaves little room for him to speak (Kvale & Brinkmann, 2009). Jacobsen (2005) also states that exploratory research requires open or less structured interview forms to make sure that no crucial information is neglected. The objective of the conducted interviews is to get holistic picture on Aibel's way of approach for minimizing the waste in piping through lean design process.

The names and roles & responsibilities of the interview respondents were kept confidential as per the freedom of their interest. The results are presented in such a way that management doesn't cause any inconvenience to anonymity of the respondents.

2.3.2 **Archival Records and Documentation**

Data collection in the early stages of the research also consists of receiving documents, presentations, archival records regarding Aibel's history, work management (Way We Work - W3), and work procedures and methods. The general information was obtained through, e.g. presentations, intranet (Aibel's inside web page), project folder and project documentation tool (proarc) at Aibel. The reviewed information gave the insight about projects, processes, and responsibilities within the company.

2.3.3 **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.

Ackroyd (1992) also stated that there are some disadvantages of questionnaires and 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 are unable to understand the “big picture”.

Survey methods are useful when the research objective is to investigate an incident or a commonness of the phenomenon in question, according to Yin (1988). Thus, a survey was conducted with two purposes. Firstly, the survey was used to identify the waste and waste drivers exist in piping considering lean design process (Appendix 1). Secondly, it was used to measure and exchange the results made based on lean design processes, which are proposed to be fit for an organization (section 5) to minimize the waste and improve the quality.

2.3.4 Meetings

Author has actively participated in a series of weekly meetings at the case study company. The majority of the meetings were dealt with process mapping of the flow of piping design, design quality, schedules and documentation. The meetings provided valuable information for research. Several disciplines that were represented during these meetings are: pipe design, support design, pipe stress, structural, valves, HSE, fabrication, quality control and project management. The discipline meetings provided information from different perspectives which revealed that the participants had different perceptions of how the process was conducted and how it 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 collected data from these meetings was just one source of information.

This exploratory phase of the project work created the basis for further data collection and the data was narrowed down towards the final research question. Through meetings and series of interviews at Aibel, few technical expertees were prioritized as the sources of evidence. During this process it was noticed that few of them were fail to see the future benefits of the current research compared with some of them having knowledge directly relevant to strategy and vision. The exploratory phase required a lot of processing in terms of large volumes of information concerning Aibel's strategy, vision, mission and methods such as lean tools, 5S, learning in reading circles, organizational values, leadership, etc.

2.4 The Quality of the Research Design

According to Yin (2014), the quality of the research can be assessed through certain logical prerequisites that ensure construct validity, internal validity, external validity and design reliability. Yin (2014) emphasizes the importance of several tactics for judging the research quality. A good case study research should always try to minimize problems related to validity and reliability (Jacobsen, 2005). Thus, the author seeks to evaluate all methods of data collection with respect to both validity and reliability in order to establish high research quality.

2.4.1 **Construct Validity**

Construct validity can be controlled by identifying correct operational measures for specific concepts in the company being studied (Yin, 2014). In other words, construct validity is supposed to show: the operational measures, the methods for collecting data correspond with the data pursued to answer and the measurements that are valid enough to support the construct or solution. As Yin (2014) points out that there is a necessity of validating constructs during the exploratory research. In the process of present thesis work, the construct validity has been made by considering the multiple sources of evidence as stated in Section 2.3.

Bagozzi, Youjae & Phillips (1991) emphasizes the fact that measurement error is a particular issue when it comes to construct validity. Because the research findings are threatened by measurement errors, it is important to validate measures and disentangle the distorting influence of these errors before testing theory. 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. Random errors can be errors associated with inference, while method variance relates to inconsistency in research methods (Bagozzi et al., 1991).

2.4.2 **Internal Validity**

Internal validity revolves around the truthfulness- or inter-subjectivity of the study (Jacobsen, 2005). The term inter-subjectivity implies that if several persons agree on a description of a certain phenomenon, it comes closer to the truth. Internal validity also concerns causal relationships, and is most relevant in causal or explorative studies according to Yin (1988). As this thesis was conducted in an explorative manner especially in the beginning, the causal relationships were made that internal validity is relevant. To some extent, the waste drivers presented are arguably causations themselves.

Internal validation through critical discussions of sources of evidence and the information received through section 2.4.1 will increase the internal validity. Important elements in these discussions are the means of utilizing the right sources of evidence regarding the field of study and the truthfulness of the collected data. Considering the exploratory phase with qualitative data collection, lean continuous improvement was the subject of interest. Correspondence between interview results and discussions with internal middle management and project management employees also will increase the internal validity as well.

2.4.3 **External Validity**

External validity concerns whether generalizations based on causal relationships would still be true or if elements of the extrapolation is based on change (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 the question of external validity, if similar examples could be found in another company. Several findings from the case study shared the similarities with the 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.

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). Jacobsen (2005) describes two factors that can weaken the reliability: The data collection influences on the results and sloppiness. When conducting interviews, especially open or semi open structured ones, the conversation tends to be shaped by either the researcher or the interviewee, both in style and content (Jacobsen, 2005).

The author believes that negligence was not an issue since meeting notes were made frequently through the process. In addition, any uncertainties regarding the collected data were dealt with immediately, e.g. by asking questions of clarifications from informants. Data was primarily gathered by using qualitative methods which make it implausible to believe that exactly the same results could be obtained. The quantitative data collection at the Aibel should yield similar results if survey is conducted by others for measuring waste in piping design during detail engineering phase.

Chapter 3

Theoretical Framework

3.1 Theoretical foundation of Lean Design Process

3.1.1 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 labor work division was emphasized on continuous learning and improvement of the system. The repeated engagement of employee with the same task enables to gain the knowledge and skill through learning process. It results in the improvement of efficiency and productivity for the task at hand (Sathe, 2012). However, in contrast to Tayloristic approaches, later research suggests that the empowerment and involvement of employee increases the job satisfaction, and the empowerment supposedly improves the efficiency and productivity (Herzberg, F., Mausner, B., & Snyderman, B. B. 2011).

Focus on employees 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 by Womack Jones and Roos in 1990 and was stated as "The machine that changed the World". The book explores the differences between conventional manufacturing systems and the Toyota Production System (TPS). The essence of the TPS philosophy is the focus on streamlining the value-adding activities and the relentless elimination of the waste within the system to continuously improve in order to increase the customer satisfaction. Furthermore, the employee empowerment is a critical aspect of TPS and in many ways it can be seen as the heart of the system. Ōno (1988) stated, "*The most important objective of the Toyota system has been to increase the production efficiency consistently and thoroughly by eliminating the waste. The preliminary step toward the application of the TPS is to identify the wastes completely".*

According to TPS philosophy the improvement efforts should be conducted at the lowest possible level of the organization using the scientific methods. The employees at the Toyota are explicitly taught how to improve them self and by doing so they are given a learning environment. The learning environment enables the Toyota to develop the problem solving abilities. Spear, S., & Bowen, H. K. (1999) stated that the TPS is comprised of a community of scientists who are the heart and soul of the Toyota culture and adopt the continuous improvement through learning.

The concept of lean has been evolved over the past years. According to Hines et al. (2004) the development of the lean concepts in general can be pictured by dividing it into four stages. **Figure 4** illustrates the four stages of the lean evolution and it gives an insight how the concept of the lean gradually widened over the last three decades.

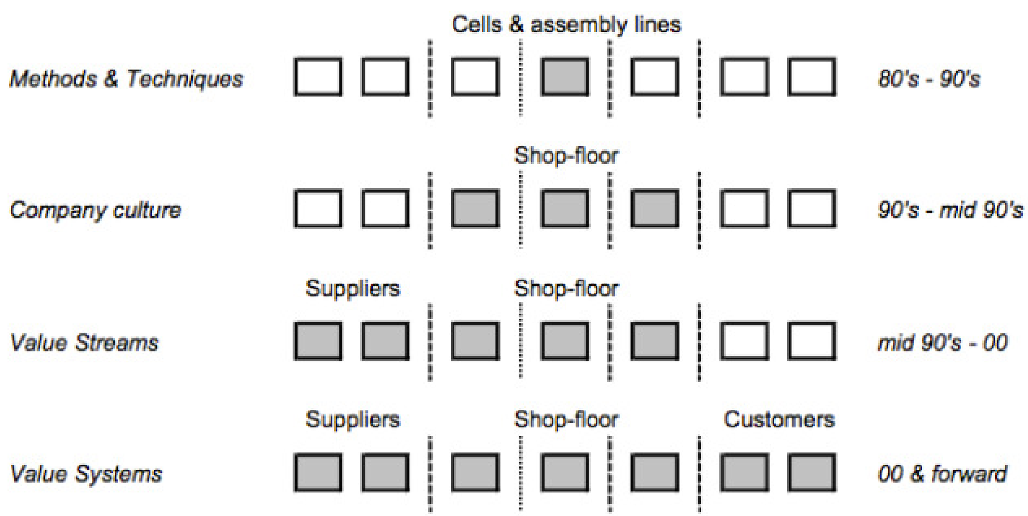


Figure 4 The four stages of lean evolution (Belfrage & Hedberg 2006)

Holweg, M., & Pil, F. (2001) states that the superior's performance can be achieved by the lean producers over the performance of designs of traditional mass production system and techniques of the western manufacturer's shop-floor as the structural parts of lean. But, often it is found difficult to introduce the organizational culture and mindset. So, many early lean efforts showed that their impact was localized within the product design and their fall off showed the impact on the overall system's performance.

The limited ability to cope with variability in demand and the view based on the car manufacturing are the main drawbacks of the lean in the period up to 1990. The lean implementation was solely tool which focused and disregarded the human aspects of the high performance. From the beginning to the mid ‘90s, the lean was gradual widening of focus away from the shop-floor and accelerated by the promotion of successful western case emulation by businesses in diverse sectors. The lean has adapted the production systems to include the new design approaches based upon “Lean principles” (Womack & Jones, 1996).

BCG (2008) stated that the evolution of the lean involves essentially two key things: Those are the better tools and the greater sense of urgency in economic crisis. Today, the TPS has the most respected manufacturing and inventory control system on the earth. These are very hard to duplicate due to the strict implementation of the incrementally improved lean concept.

The Toyota has established a culture of relentless improvement. According to BCG (2008) “the mindset of senior leaders and people on the production floor creates success or failure”. This is the main reason no one can copy the Toyota Production System.

3.1.2 Basic elements of Lean concept

This section aims at describing the idea behind the lean approach and at what the lean concept essentially stands for. Also, it focuses on rectifying the misunderstandings and correcting some misconceptions about the lean.

Taylor (2009) questioned that how lean can be described and made tangible? In a first attempt to keep things simple, the lean approach in a general way can be outlined as:

- A management method or design method employed to minimize the operational waste.
- A system of operation employed to deliver value-added products and services to the customer.

- A practice of producing goods Just-In-Time for the customer orders to lower the inventory holding cost.
- A company’s journey to eliminate the cost of operational waste from selling prices.

Generally, the lean approach is a systematic approach to identify and eliminate the elements of a process that do not add value to the final outcome of the design process (Andersson, Eriksson, & Torstensson, 2006). The lean can be seen as a concept addressing the quality, cost, time schedules and delivery of a company’s business processes by using an integrated set of principles, methods and tools. Furthermore, the lean is a philosophy of leadership, teamwork and problem solving. It results in a process of continuous improvement throughout the entire organization by focusing on the needs of the customer and empowering the employees.

In addition, the lean can be adumbrated as a commitment that can impact the company’s competitiveness significantly. As a strategic approach, the lean can be used for resolving severe organizational problems and uniting several change initiatives running currently in a business (Atkinson, 2010). The lean can be implemented as a strategic cost initiative focusing on major cost efficiencies from the top of the organization. It evolves as smaller discrete and iterative initiatives to lower down the cost in the organization. The preferred route of a ‘top down’ approach will have a major positive impact on the organization. The lean can be the major philosophy to unite the organization in a relentless drive for the improvement (Atkinson, 2010).

Bonaccorsi et al (2011) stated that the lean can neither be seen solely as a cost reduction exercise nor as a toolbox offering specific tools for any problematic situation. Some people interpret the lean as the opposite of ‘fat’ by assuming that the main target of the lean is to lay off people. But, the lean is not about cutting staff and resources in the first place. The lean is about focusing people’s efforts on creative tasks by speeding up the operations through the progressive elimination of the waste and idle time created by paperwork and bureaucracy.

The lean operational system alters the way the company learns through changes in problem solving, coordination and standardization (Hanna, 2007). Many people still picture the lean as being an attempt to withdraw unnecessary cost out of an organization. The lean can be achieved to withdraw unnecessary cost. If this is the only the organizational objective, then the lean will never take its rightful role as a preventative methodology.

3.1.3 Principles of Lean

The principles of the lean production are derived from the methods used in TPS and the types of wastes defined related to the manufacturing background. Lean thinking is a highly evolved approach of managing an entire organization to improve productivity, efficiency and quality of its business processes. Lean thinking is about doing things better and quicker at economical cost. Also it about generating minimal waste in terms of materials, time and rework (Atkinson, 2010).

The lean thinking can be defined as a managerial philosophy which enhances the value perceived by the customers by adding product features and constantly removing waste (Hines, P., Holweg, M., & Rich, N. 2004). The essential principle is combination that constitutes the foundation of lean thinking. The principles transform the conceptual thinking paradigm to concrete actions and functions being versatile in many situations.

The strength of the lean principles is that they are in fact a series of steps to implement the lean thinking (Haque & James- Moore, 2004). The implementing the lean concept as a top down approach starting from top management level restructures the company and finally transforms into a lean enterprise. A lean enterprise focuses on the customer centricity, continuous flow of internal operations and waste free value creation.

Many discussions in the scientific community is about the lean thinking focusing on the shop-floor which proves a limited understanding and about what are contemporary lean approaches. In order to establish a more general understanding of the lean approach, approaching the lean management solely from the lean production principles is not sufficient. Womack and Jones offer five guiding principles for lean practitioners which are the value, value stream, flow, pull and perfection (Womack & Jones, 2003). **Figure 5** represents the five principles of lean thinking.

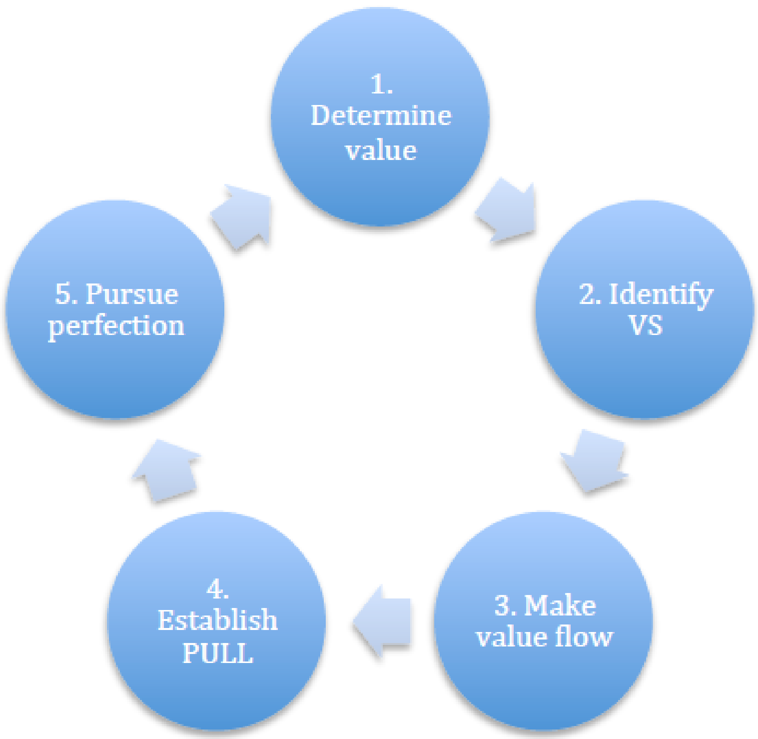


Figure 5 Five principles of lean thinking (Kalsaas 2011)

i. Determine value:

Womack and Jones states, "The critical starting point for lean thinking is value". The value must be defined through dialog with the customer. It is only the customer that can define the value and it must be expressed in relation to a specific product in order to be meaningful. The producer is the one who creates value by making the product for the customer. For the producers it is hard to accurately define the value in the process of making the product. If value is not accurately defined, the waste will be generated during the process of making the product (Womack & Jones, 2003).

According to the Womack and Jones (2003), the most critical task in specifying value is to determine a target cost. The target cost is based on the amount of resources and effort necessary to design a product of a given requirements provided that all the visible waste was removed from the process. The target cost is essential to eliminate waste in the design process as this becomes basis for the development, order taking and the production activities required for the product. Once the target cost is determined, the potential waste can be identified in every step of the value stream process.

ii. Identify value stream:

The value stream is defined by Womack and Jones (2003, p. 353) as “The specific activities are required to design and order of a specific product from the concept to launch and delivery to the customer”.

Womack and Jones (2003) explained that there are three critical management tasks to perform any business which are the problem solving, information management and physical transformation. The value stream is a set of actions that enable a product to move through these management tasks. Identification of the entire value stream for each product and service will typically notify large amounts of waste.

A value stream map (VSM) is the visualization of all the processes involved in the production of a certain product. It takes into consideration a range spreading from the time the order is made by the customer till the product is received and also it includes the range of the aspects of design ‘from the concept to the operation’. The VSM mainly consists of information gathering, current state map drawing and future state of map drawing followed by an implementation plan (Rother & Shook, 1999).

Usually, the value stream analysis will show three types of occurring actions. Firstly, identifying the unambiguous steps to generate the value; secondly identifying the steps those create no value but are inevitable with present technologies and production assets; and lastly identifying the steps those create no value and are instantly needless (Womack & Jones, 2003).

iii. Make value flow

After the waste has been identified and removed, one should make the remaining value by creating the flow of steps. The flow in the context of lean concerns how the entities or information move through a process as fast as possible e.g. without unnecessary interruptions. In other words, the flow is about reducing the waste and improving the customer satisfaction (Womack & Jones, 2003).

iv. Establish Pull

Pull production is often referred to as Just-in-Time production (Evans, J. R., & Lindsay, W. M. 2008). It is about making exactly what the customer wants and when the customer wants (Womack & Jones, 2003). The customer demand dictates the production level in contrast with conventional push production and forecasts the market demands that are used to determine the production level (Evans, J. R., & Lindsay, W. M. 2008).

v. Pursue perfection

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

A lean thinking enterprise sets the sights on perfection through maintaining the constant strive to more precise definition of the value and a continuous alignment of the organization's processes to meet the value proposition. The obfuscated waste can be identified and eliminated from the company's business processes by continuously improving the value specification, challenging each and every step in the value stream and increasing the flow's speed and robustness.

3.2 Brief about AIBEL

This section provides the necessary knowledge to understand the dynamics of the company Aibel. Also it provides an overview of the piping design during detail engineering process for maintenance and modification projects at Aibel. This section was derived from the Aibel's work management system (Way We Work – W3) and the internal documentation available from the case study project.

Aibel reaches the client by proving the excellent engineering design services in maintenance and modification projects for both the green and brown fields in the oil and gas market. The engineering services position the marketing & sales in first place in a value chain process and continue with engineering, procurement, construction and installation. **Figure 6** represents the value chain process for modification project at Aibel.

Figure 6 Value chain of Aibel

Aibel is Engineering, Procurement, Construction and Installation (EPCI) supplier for the oil and gas market competing globally. As shown above in the figure, the marketing & sales starts before the EPCI activities.

Aibel's maintenance and modification division is responsible for the frame agreements within Maintenance, Modifications and Operation (MMO) and the larger modification projects within Norway and at Global level. Aibel has the separate business units in Norway, Singapore and Thailand for undertaking the MMO projects. The engineering and procurement activities are preformed from Norway and Singapore. The construction process is carried out in Norway (Haugesund) and Thailand. **Figure 7** shows the Aibel's MMO organization for an internationally delivery model.

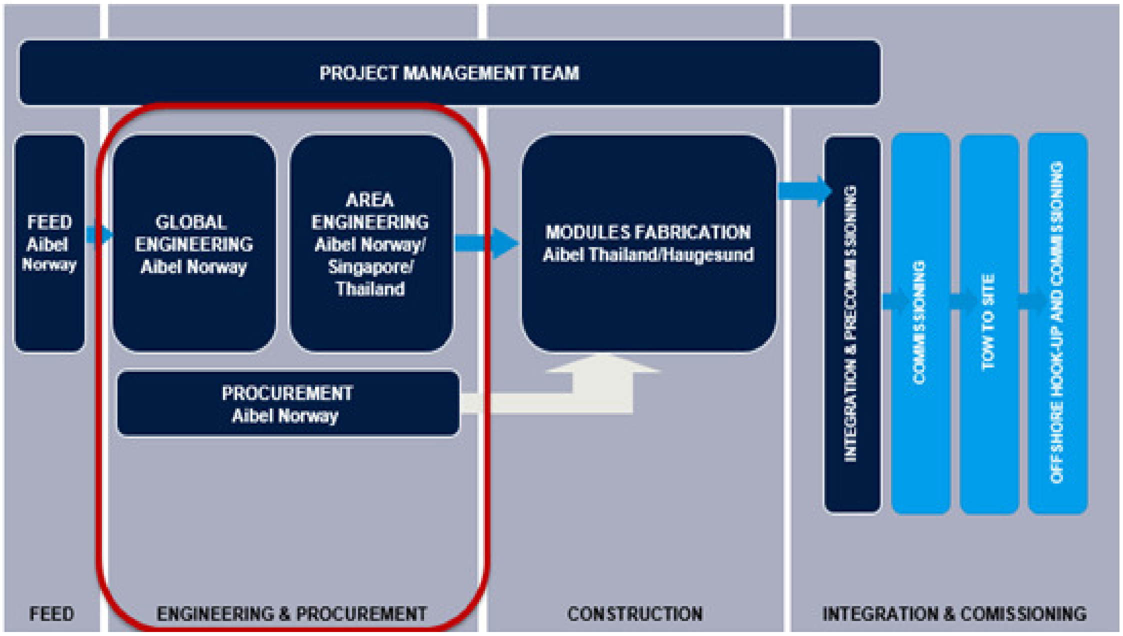


Figure 7 Aibel Internationally delivery model (Aibel 2016)

The MMO projects are the key in the field of Frame Agreements (FA) and Maintenance & Modifications (M&M) contracts in the Norwegian Continental Shelf. Aibel's first M&M contract was on the Oseberg field in 1994. The valuable customers for Aibel in the area of the M&M contracts are Statoil, ConocoPhillips, Shell, BP, etc.

The structure of Aibel's MMO project for M&M contract can be divided into four levels such as Decision-making Body, Project Management, Planning Team and Disciplines / Workgroups.

The modification projects are usually developed in an environment having the budgetary restrictions and the fragmented and adversarial processes of design. Traditionally, the design and construction phases of a project are completely sequential to one another and do not overlap.

Figure 8 shows a typical representation of organizational structure of Aibel's MMO for M&M projects. The core design process takes place under level 'D-Disciplines/Workgroups' and it includes piping design, structural, safety, electrical & instrumentation, automation disciplines, etc.

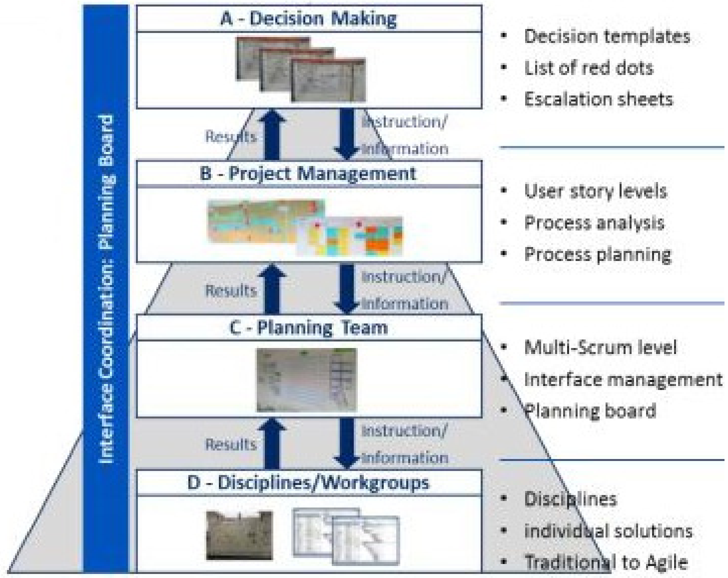


Figure 8 Organizational structure of Aibel's MMO for M&M projects

As the objective of the thesis, the focus of study is to cover details about the piping design during detail engineering for M&M projects. The piping design is executed by the level 'D – Disciplines / Workgroups' as shown in the above figure.

Figure 9 illustrates project's overall engineering process and execution phase at Aibel for maintenance and modification projects. The engineering process covers the study phase and the detailed engineering phase. The study phase covers the feasibility study, basic engineering and front end engineering. Also the construction phase and operating the plant are the part of the execution process.

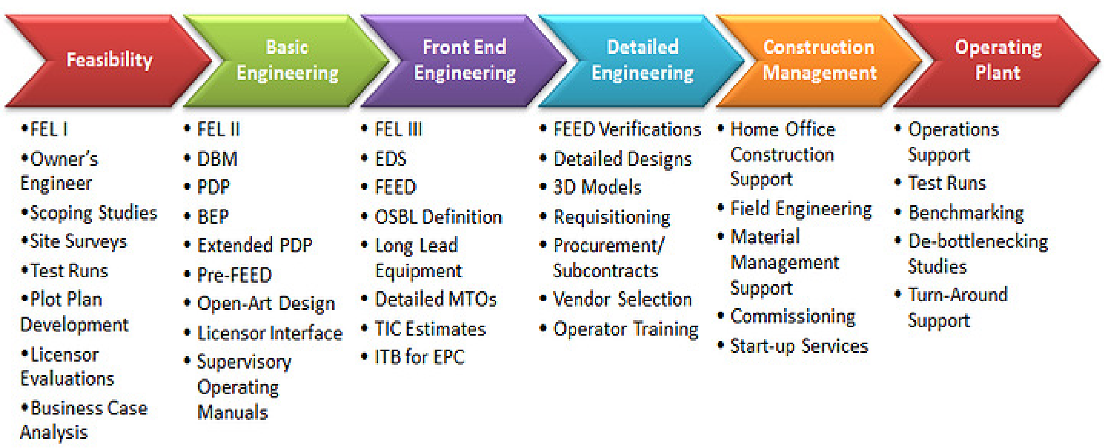


Figure 9 Overall engineering and execution process at Aibel

Aibel's M&M frame agreement model, engineering and design process for maintenance and modification projects are described below and the organizational structure is drawn from the Aibel work management system (W3). The W3 means 'Way We Work' and it provides how to work, interact and have an easy access to the documentation of relevant processes, the supporting documents and the common execution process.

3.2.1 M&M Frame agreement

The organizational model of M&M contracts gives an impression about the operational structure for the maintenance and modification projects to meet the client requirement within allocated budget and time. **Figure 10** represents the project execution model within M&M contracts.

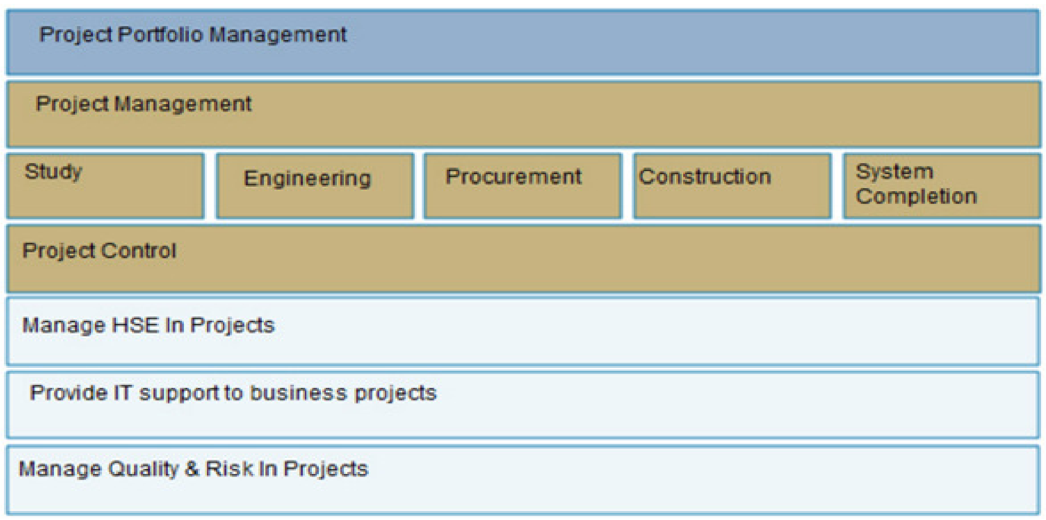


Figure 10 Project execution model for Aibel's M&M contracts (Aibel 2016)

The modification projects in M&M contracts are executed under five phases which are study, engineering, procurement, construction and system completion phases. Each phase has a significant role to complete the project by meeting the client requirements.

The project execution model also provides the method statement documents, supporting documentation, project organization and descriptions of role & responsibilities. The few roles & responsibilities in the piping design are enclosed in appendix from 2 to 6 as a reference and these are referred in subsequent sections for detail study of the roles description in Section 4.4.1.

3.2.2 The Engineering management

The engineering management plays a key role for succeeding in project execution. The piping projects at Aibel are executed under engineering management and the management is divided into parallel working and multidisciplinary teams to perform the different tasks. The multi-disciplinary teams are coordinated by engineering manager on the project level. The engineering management in Aibel is divided into five phases and it starts with study phase and ends with system completion phase. **Figure 11** shows the sequence of phases in the engineering management at Aibel and the management actually begins during the project preparation phase i.e. tender/bidding.

Figure 11 Aibel's engineering management model (Aibel, 2016)

i. Study Phase

Study phase includes Feasibility, Concept and Definition/FEED study. It covers important basic elements such as concept of layout drawings. The concept is typically what the customer provides as basis for the design.

Figure 12 shows the study phase of the project at Aibel.

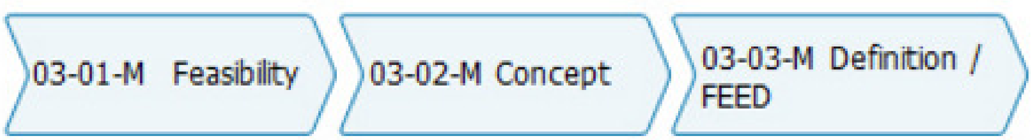


Figure 12 Aibel study model, (Aibel; 03-M Study, 2016)

ii. Engineering Phase

Engineering phase transforms the information from study phase (basic engineering concept) to completed design drawings. It provides fabrication drawings, 3D model using Plant Design and Management System (PDMS), calculations, etc.

The engineering phase operates under the engineering management and it has three phases which are the system engineering, engineering for procurement and area engineering. **Figure 13** illustrates the Aibel engineering model for M&M contracts in engineering phase.

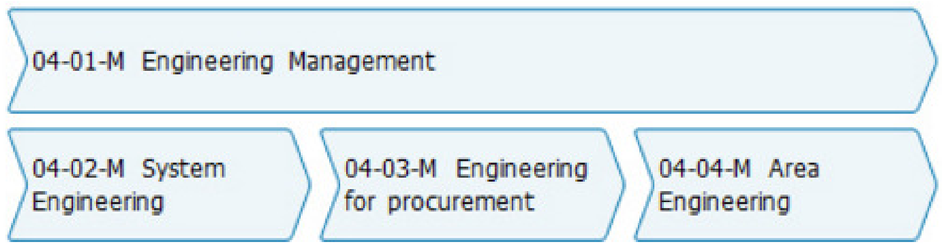


Figure 13 Aibel Engineering model (Aibel; 04-M Engineering, 2016)

iii. Procurement and construction Phase

Procurement phase provides the work processes and it creates a foundation for the procurement processes such as technical requisitions, creating Material-to-Order (MTO) documents, etc.

The construction phase covers the delivery of fabrication engineering documentation and involves transforming the information from the phases of engineering and procurement to the work foundation for fabrications. The work foundation includes creating the work packages and work methods, drawings, etc.

iv. System completion Phase

System completion phase is about the handover of the final updated documentation to the client and it includes as-built drawings, documents, 3D model, etc.

3.2.3 The Design Process (Area Engineering)

The design process within piping and layout has individual design process areas which are, the ‘Design Line, Design pipe support, Design main steel, Design secondary and outfitting steel, Design main steel, Design HVAC ducting, etc. The design process area describes a list of engineering activates within the discipline needed to be perform the task for meeting the client requirement by maintaining the organization procedures and standards.

The design process for the modification projects covers the workflow of control objects of the design areas to perform the task in the engineering management. The design areas are such as equipment, piping, ducting, structural, cable ladders, etc. The design process for the piping design describes the task to perform the pipe design, pipe support design, pipe stress calculations, etc. by using project tools (PDMS). **Figure 14** shows the key areas in the Area Engineering Model at Aibel.

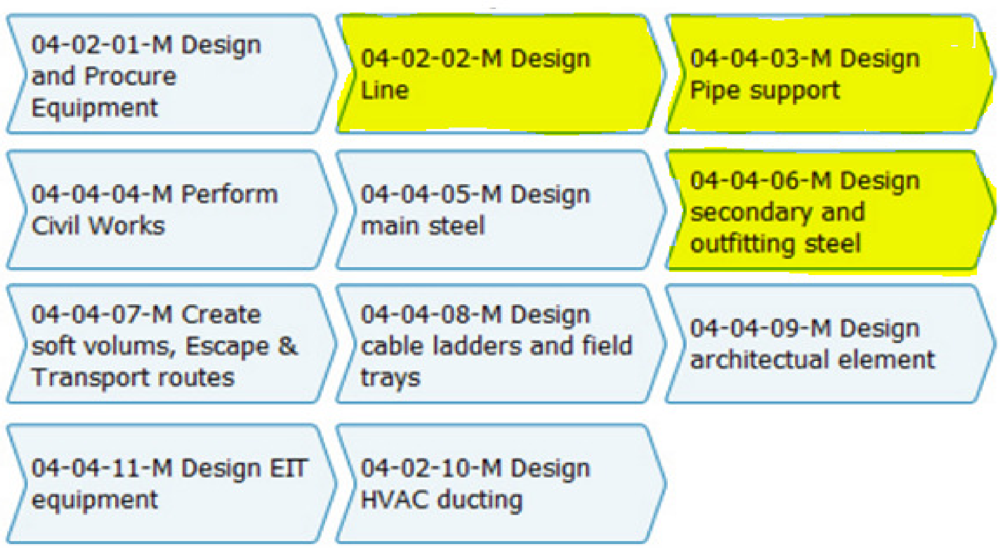


Figure 14 Aibel Area Engineering model (Aibel; 04-04-M Engg, 2016)

As already described in Section 1.2, the objective of thesis is to apply lean design process for eliminating the waste in piping during detail engineering process. To be in-line with the objective of the thesis, the research work covers the piping engineering areas such as **the Design Line, Design pipe support and Design secondary & outfitting steel** shown in **Figure 14 .**

The piping engineering process area is divided into four sub phases of the project, which are layout, design, detailing ad drawing. The company would like to perform these phases sequentially, but unfortunately this is in reality quite difficult to achieve in most projects. **Figure 15** presents the expected design flow in the piping design process at Aibel.

Figure 15 Expected design flow in the piping design process at Aibel

The more realistic piping detail engineering process is overlap and it varies from project to project. The company tries to minimize the overlap to the extent possible to minimize the waste. **Figure 16** shows the realistic design flow in the piping detail engineering process at Aibel.

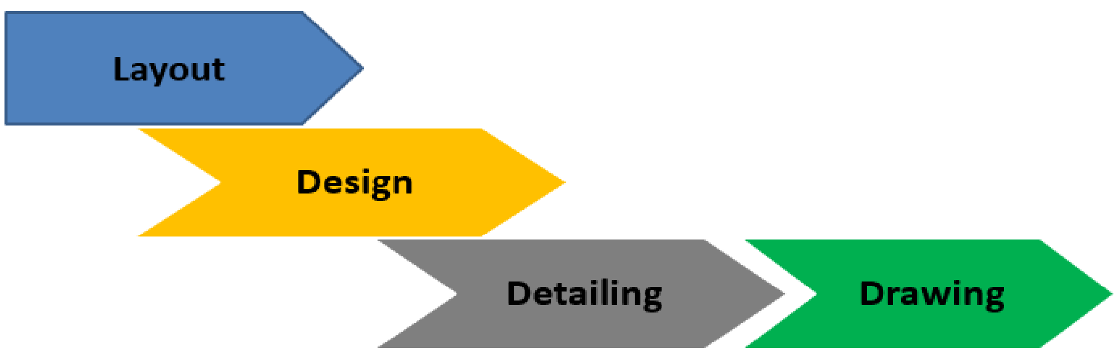


Figure 16 The Realistic design flow in the piping design process at Aibel

i. Layout

The discipline leader (DL) for layout is responsible for coordination of all disciplines in the layout phase. At the layout phase, ideally all the multidiscipline decisions should be determined and layout will be frozen. This enables all the disciplines to work independently without further multidiscipline coordination until the changes affect the layout.

ii. Design

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 were performed during this phase. The 3D model (PDMS) design is developed to an extent based on provided sufficient information such as specifications from customers, project standards, etc.

iii. Detailing

The 3D model is further developed in the detailing phase in order to fulfill the internal and external requirements. The level of detailing should be sufficient in order to prepare the 2D fabrication and construction drawings after the completion of the detailing phase.

iv. Drawing

The Drawing phase is the last phase in the piping detail engineering and it involves the creation of drawings and documents needed for fabrication and construction. The maturity and relevance of the documentation is controlled in drawing phase.

The detail engineering process in the piping is detailed in the following section.

3.3 Detail engineering – Piping design

The piping design phase in modification projects is a complex process and it involves thousands of decisions. Sometimes the design may extend a period of time due to involvement of numerous interdependencies under a highly uncertain environment.

Design has a great importance on the entire life cycle of the products. The initial steps such as the design programs are important to the process as a whole. Moreira & Kowaltowski (2009) emphasize that prior to the design the task starts with a survey of information related to the client needs. The information provided by the client through SAP notification sometimes may need to visit offshore for collecting the offshore design information. The notification intends to describe the conditions under which the design will be operated and the problem that the designed edification must solve. Tilley (2005) points out that the design should be flexible and dynamic. Therefore, the design should be available for changes that may occur throughout the design process and the construction of edifications because the client's needs may change over time to time. Thus, circumstantial changes are likely to bring more value to the client.

According to Tilley (2005), the design process is a mental activity and has product documented ideas in physical or electronic ways. In the latter stages, it facilitates the communication of others who are involved in the design. The design in turn must follow some steps from project's planning activity to execution. The design process demands the interaction and commitment among different disciplines and also the interaction within the piping design teams.

Thus, the nature of the design process can be considered as complex. In this sense Whelton & Ballard (2002) highlighted some problems that influence negatively on the design process as the lack of sharing of the decisions made, the sociopolitical factors that dominate the decision makings and the inefficient processing of information. From the client‘s point of view, the inexistence of a systematic design planning is the ineffective management of the value. According to Venkatachalam et al (2009), the use of the principles of lean production in the design process can correct any defects related to design process.

3.3.1 What kind of Design process in the Piping Detail Engineering Process?

Design process has much variability and the variability is the source of the value creation of design (Reinertsen 1997).

Thompson (1967) states that agenda is to analyze organizations as such. Further he examines that the interdependencies of parts of organizations and divides them into three groups:

1. *Pooled interdependence*:
   This is a situation in which each part renders a discrete contribution to the whole and each is supported by the whole.
2. *Sequential interdependence:*
   In this case the interdependence takes a serial form: X must act properly before Y can act, etc. A sequential interdependence is therefore always also pooled (but not the other way around).
3. *Reciprocal interdependence*
   This is a situation in which the outputs of each part of an organization become inputs for the other parts.

Activities within the organization have to be coordinated and Thompson finds that there are three types of coordination

1. *Coordination by standardization:*
   This involves the establishment of routines or rules. It can be expected to find the coordination by standardization in organizations with pooled interdependencies.
2. *Coordination by plan*
   This involves the establishment of schedules. It can be expected to find coordination by plan in organizations with sequential interdependencies.

3. *Coordination by mutual adjustment*

   This involves the transmission of new information during the process of action. It can be expected to find the coordination by mutual adjustment in organizations with reciprocal interdependencies.

Reinertsen (1997) sees design as the generation of information in contrast to manufacturing which generates products. From this he derives some fundamental differences between design and manufacturing:

- Design is nonrepetitive, a one-time process.
- The cost of changes in making throughout the design process increases exponentially.
- Requirements often change during the design process.
- The design process has much variability and the variability is the source of the value creation of design.
- Design is an inherently expandable task (a better solution is always possible).

Ballard (2000) sees design as the production of requirements for the physical production (‘making’). Considering the nature of the design process, Ballard observes the following:

- The design process is not merely about determining the design criteria and then applying those criteria in the production of the design. Design is, rather, a process of negotiation and adjustment (oscillation or conversation) between criteria and alternatives, a progressive determination of both ends and means.
- In the design process everything is connected to everything and it is a learning process.
- The design process cannot be determined in advance; overly rationalistic models of problem solving processes are therefore inappropriate.

Koskela (2000) first examines the differences between physical production and design from the operations management‘s point of view, and then proceeds to examine design through his TFV concept. From the operations management‘s point of view, the following were found:

- There is much more iteration in design than in production.
- There is much more uncertainty in design than in production.
- Design is a non-repetitive activity, whereas production is often repetitive.
- In the design phase, the customer requirements are translated into a design solution. In the production phase, this design solution is realized. Thus the functional performance is determined in the design phase.

From the transformation point of view, Ballard and Koskela (1999) observed the following:

- Design is seen as a sequential process based on a work breakdown structure (hierarchical decomposition).
- Design is seen as a process through which the needs and requirements are converted into descriptions of the product by means of decisions and problem solving.
- Design management is focused on coordination of the whole and enhancing the efficiency of individual tasks.

From the flow point of view, Koskela finds the following:

- Design is seen as a flow of information, in which a piece of information may be in one of the following four stages: transformation, waiting, moving, or inspection
- The design process is seen as one of three basic flows in construction projects. The other two are the material and work processes (Koskela 1992).
- Changes in requirements are seen as disruptive.
- Iterations may be needed.
- Improvement is seen as eliminating waste and shortening design time.

From the value point of view, the following observations were made:

- Design is seen as value generation by a supplier to a customer through fulfillment of customer needs and requirements.
- The needs and requirements are captured and converted into a product or service delivered to the customer.
- Due to conflicting needs and requirements, tradeoffs have to be optimized.

The design process is a project and can be described through the use of different phases or stage models. For example, the stage models according to Best (2006) are:

- ➢ Design strategy, where the design projects and initiatives are conceived.
- ➢ The design process, where design projects and agendas are developed.
- ➢ Design implementation, where design projects and outcomes are delivered. Cooper and Press (1995) divide the design process into an internal creative process and an external productive process. Gray and Hughes (2001) also make a similar distinction.

Chapter 4

Analysis

4.1 Value in Engineering Design (Piping Design)

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

Within piping engineering, there are many different perspectives on the value. The value will be estimated differently depending on who perceives it, e.g., customers, organization and employees. Also it varies within the organization at each stage of design phase. The emphasis is often on customer value, but once it is identified there are varieties 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 the value into several layers, based on the different perspectives of the value. First, the value is decomposed into basic attributes such as cost, quality, performance and timeliness. Furthermore, the value can be assessed in relation to activities where the value from activities include created information, products, smooth flow of combined activities, or a combination of the values generated through these entities. In addition, these entities can have several attributes or characteristics such as performance, risk, schedule and cost of the design in development, which can be considered valuable.

Lastly, there is an 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 below in **Figure 17**.

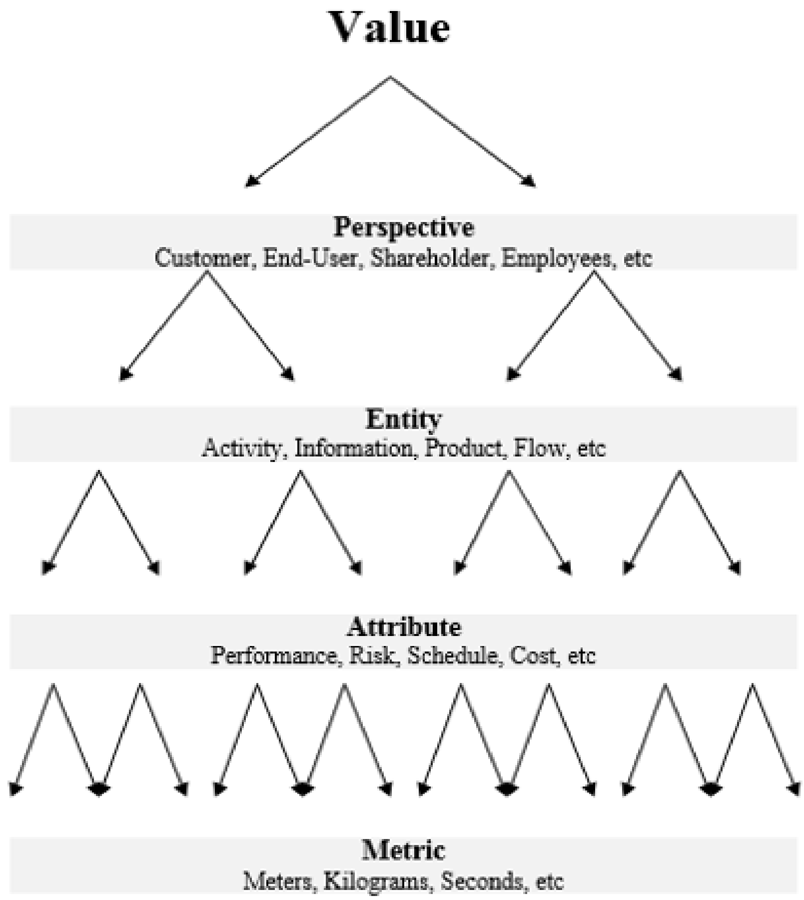


Figure 17 Overview of the dimensions of value (Chase, 2000)

Defining the value is likely to be a never-ending task. Thus, the emphasis should be to gain a working definition, in order to guide for 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, these value processes have for the key stakeholders/client, while considering how that value is created through the individual tasks inside given process. This means, it takes downstream processes into consideration for both internally and externally (McManus, 2005).

Aibel can implement a Lean design process as a value added process in piping design during detail engineering phase for maintenance & modification projects under piping and layout discipline. It has to be treated as a future investment for keeping project cost low and meeting the design quality by competing oil and gas market globally. **Figure 18** illustrates the value added design in piping engineering by adopting lean design principles at different stages, like piping pre-design, piping detail design development, etc.

At the piping pre-design phase, briefing and work transparency through value flow (planning with target dates) are the essential elements of lean design process during piping detail engineering. This gives an option to choose alternate design specification, material selection, possibility to negotiate deliverable dates, and to keep collaborative planning between disciplines to reach milestone delivery dates.

As detailed in **Figure 18**, Aibel organization could meet the value/target cost for modification projects by achieving the cost reduction, improved quality design by maintaining scheduled deliverable dates through adopting lean design process. Piping detail engineering phase demands involvement of various sub disciplines like pipe design, pipe stress, support design, valves, special items and structural calculation for support steel, etc. These sub disciplines can be beneficial by having a lean design process as a value added design process directly to piping engineering and some actions can be gone through by middle management phase before implementation.

Management support is a crucial step in lean design process to implement as a value added activity in piping engineering. It has to undergo process for evaluation and quality management before implementation. During the process, some points can be put over to piping design development stage as plug-in design modifications and the rest directly lead to value added design activities to piping engineering.

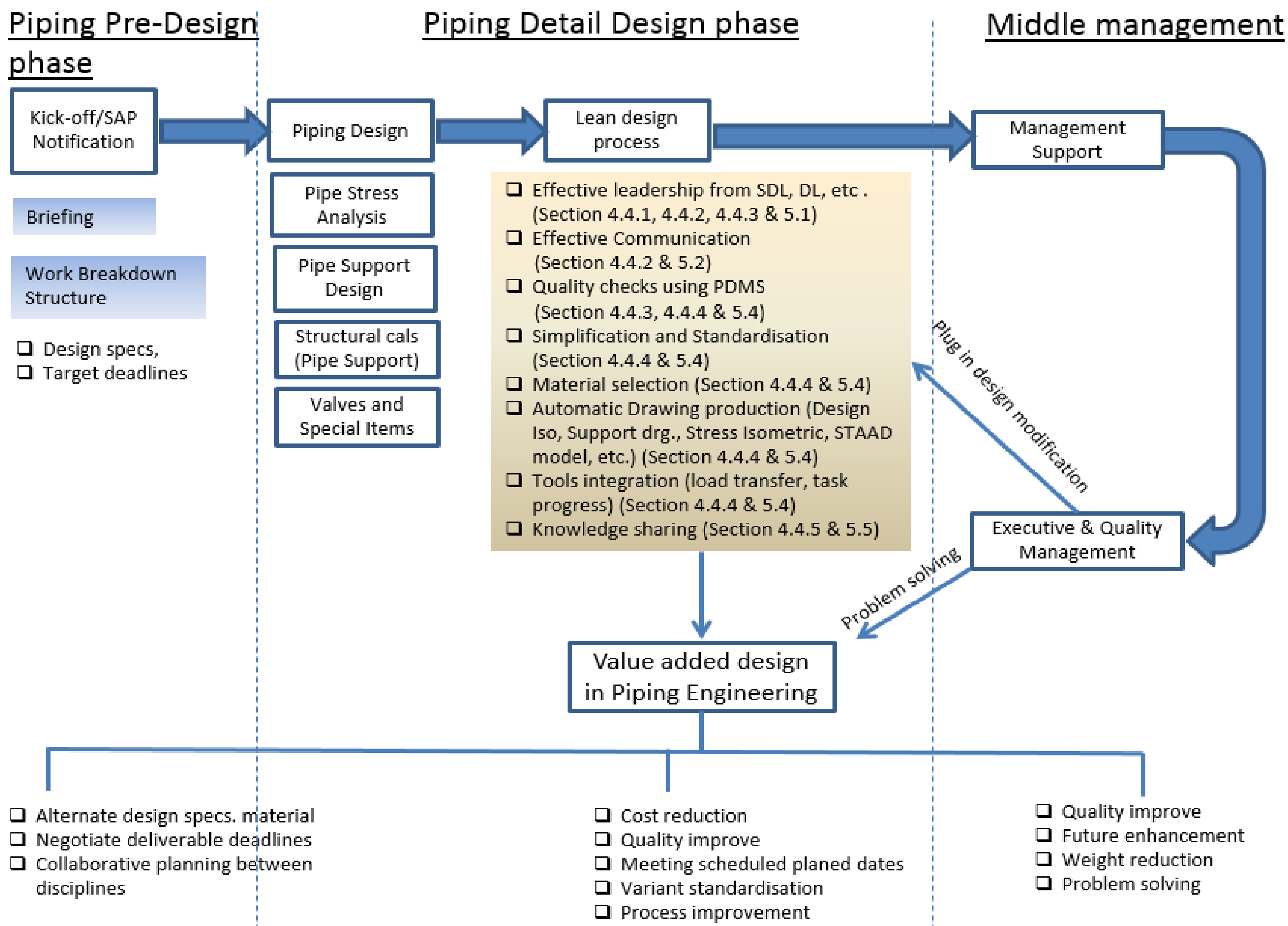


Figure 18 Value added design in piping during detail engineering at Aibel

For value added design in piping under the lean design process, it is an essential to identify and eliminate waste to keep the value/target cost within the limits for the piping by meeting the client requirements. Once the target cost is determined, it is used to identify potential waste in every step of the value stream.

The lean design process gives an ideal thinking of solutions to eliminate the waste from piping engineering process through various different mental models, theories and lean design principles. Through various theories and strategies, the lean design seeks out to accomplish the most fundamental elements of the lean philosophy. The most basic tasks that need to be considered for the process of lean design during piping detail engineering for modification projects are as follows:

- ➢ Elimination of waste;
- ➢ Design simplification and standardization;
- ➢ Effective leadership from SDL, DL, etc.;
- ➢ Increase the reliability of tools (PDMS, STAAD, CAESAR, MIPS, etc.);
- ➢ Strengthen the design process capability;
- ➢ Create continuous workflow;
- ➢ Automatic Drawing production (Design Isometrics, Support drawings, Stress Isometric, STAAD model, etc.);
- ➢ Improve design quality checklist using PDMS;
- ➢ Tools integration (load transfer and task progress using PDMS;
- ➢ Reduction of lead-time for special items (control valves, spring hangers, Lean duplex plates and hollow sections, etc.);
- ➢ Standardize the working methods and procedure;
- ➢ Quick task changeover;
- ➢ Encourage teamwork.

The above core tasks of lean design process are discussed and detailed in the following sections 4.2, 4.3 and 4.4.

4.2 Lean design process during piping pre-design phase

The design phase in engineering projects is a complex process that involves thousands of decisions sometimes over an extended period of time, with numerous interdependencies and under a highly uncertain environment. Traditional piping design approaches were criticized as inefficient and wasteful. As explained above in **Figure 18**, lean design introduces the ways of reducing waste and uncertainty while maximizing the value in the piping detail engineering. The lean design process is an extension of lean thinking, and the principles of lean are modified in it to accommodate the nature of the design process. The lean design offers advantages over more traditional design approaches and contains several methods and techniques in order to generate value and reduce waste.

According to Tzortzopoulos (1999) and Koskela (2000), the application of lean design principles in the design process must take three different views of the project into consideration: (1) design as conversion; (2) design as flow of information and (3) design as a source for generating value (from the customer's point of view).

For maintenance & modification projects in oil and gas sectors, the projects must be oriented by the customer's needs for meeting customer and organizational standards. In the lean design approach, the design must meet the internal organizational standards with the benchmarked/demand quality, in a continuous flow from the beginning to the end of the design process (Cloke, 2000). Furthermore, the project team needs to know what has to be done to satisfy the customer (Ballard, 2008). **Figure 19** compares the preferred design process and traditional design process. It further illustrates the changes occurred in the pre-design phase, which can generate a higher impact on value and functional capabilities with a lower impact on the project costs. However, for normal operation phase of the project, a reverse trend can be seen with respect to cost and the value. The changes made in the later phases of project development may lead to extensive reworks due to involvement of various design disciplines like pipe design, support design, stress, structural calculations, etc.

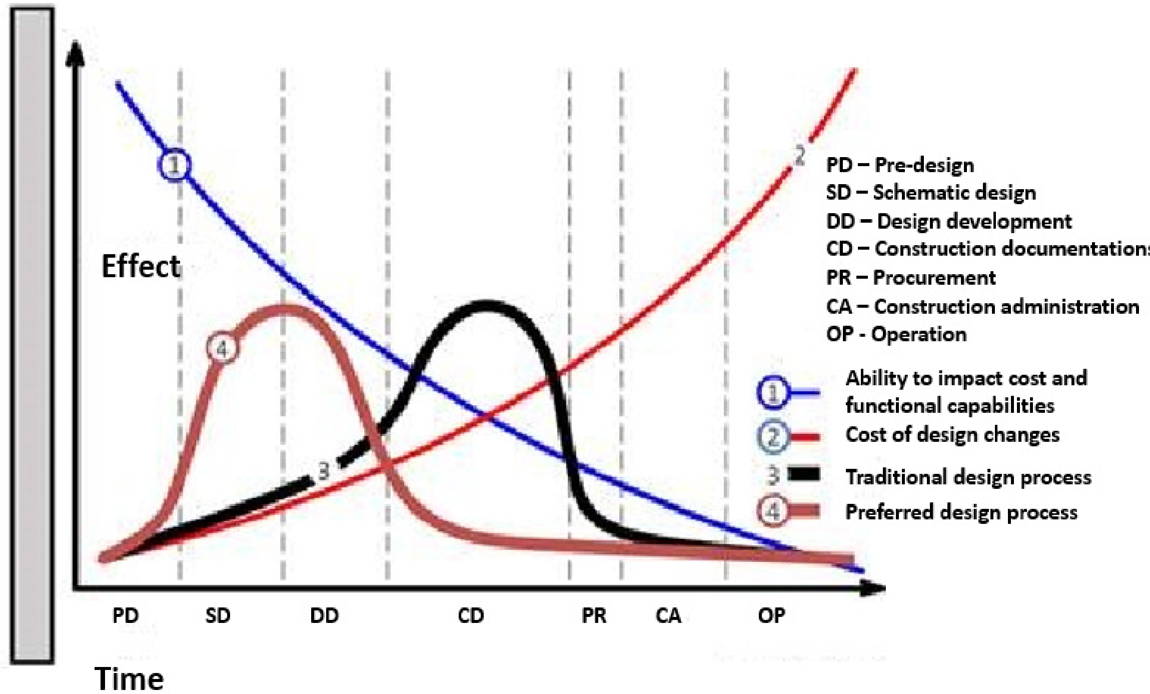


Figure 19 Comparison of design processes (Orihuela's et al, 2011)

A better project execution method in piping detail engineering can take place without increasing the cost of the design and it can be achieved through a clear definition of the project activities on the lean design process. According to Orihuela's et al (2011), in the design phase, the resources and tasks necessary to elaborate the project have been poorly defined and the lead time is not easily measurable. To plan the work in the design phase, the authors suggest that the identification of the different tasks must be carried out during the project definition and elaboration phase.

Due to a large complexity involvement in modification projects and numerous changes in scope of work from project to project, briefing and work transparency through value flow (Work Brake down Structure - WBS) are essential elements of lean design process during piping pre-design phase. The briefing and WBS are discussed in detail in the following sections 4.2.1 and 4.2.2, respectively.

4.2.1 Briefing

Briefing is an important process during piping pre-design phase explained in **Figure 18**. Briefing is the process by which clients express and articulate their desires, and from which the design team develops their design. From the lean design perspective, the briefing is a crucial stage in which values are explored and expressed; and it is a process that could be better managed for helping to eliminate uncertainty and waste in the design, fabrication and construction phases.

From the case study conducted at Aibel for GEMC modification project, the briefing was made by client through SAP notification (Appendix-7). The SAP notification contains the detailed job description with available preliminary data or FEL report. According to Emmitt et al (2004), this is an important process to understand the client requirements and standards. They also argued that under the lean thinking upstream the briefing, conceptual and detail engineering stage should create significant potential to deliver a value throughout the whole fabrication and construction process by creating a synergy between design, fabrication and construction.

When the project requirements are clearly identified and information is well managed through client SAP notification (briefing), the lean design process gives a significant improvement in the decision making by minimizing the unexpected changes during detail engineering as shown in **Figure 19**. This results in a better project quality, better client relations and savings in terms of both time and cost. It is very important for design team to understand the client requirements at briefing stage.

For delivering the quality output within time schedules, the design teams from the piping discipline (pipe design, pipe support design, pipe stress and structural) at Aibel needs to have proper understanding about the client requirements at briefing stage of the project.

Reviewing lean design theory and its success in enhancing the efficiency of value delivery process led to develop a hypothesis based on the briefing process, which can truly add value for the design. A Lean Briefing Model (LBM) for the case study has been developed based on the lean design principles. **Figure 20** illustrates the basic concept of Lean Briefing Model (LBM) for piping at Aibel.

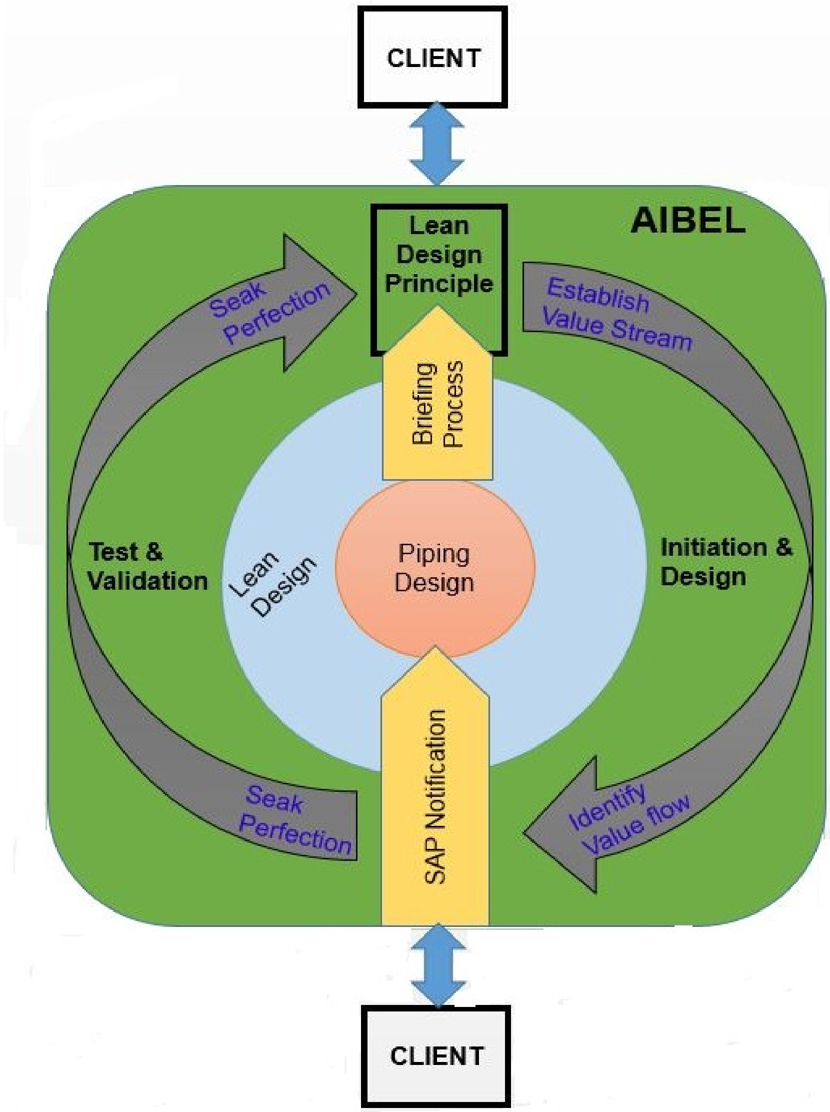


Figure 20 Lean Briefing Model (LBM) for piping (Yu et al., 2007)

From the above figure, briefing process makes clear understanding the client requirements at the project beginning stage (Pre-design phase) by communicating through SAP notification. After the review of the SAP notification by piping design team in Aibel and the implementation of lean design principles, project will have a greater advantage to limit the cost and time incurred due to the changes in detail design phase. This process also helps for improving quality and maintaining healthy relations with clients.

Here, to understand the briefing process from case study at Aibel, SAP notification no 13324638 (Appendix 7) is referred from GEMC project vide PMO no 6297745. The notification briefly explains about the task as "*there are several lines that are poorly supported as they exit the Test Separator 95-5001 on the EKOB platform. If slugging occurs in the test separator then the movement in the lines becomes much worse*".

According to lean principles from Womack & Jones (2003) described in Section 3.1.3, **Figure 5** explains that the 'value' will be the first lean design principle and it must be defined through dialog with the customer/client through briefing process. Based on this, it can be said that when value is not accurately defined waste will be generated. It is known that the waste can be due to over design, miscommunication, etc.

The second principle is to 'identify value stream'. This is an important step to identify value added activities to the project for keeping the cost within budget allocation. For example, from the above referred SAP notification (Appendix 7), the scope of work defined as 'pipes have movements/vibration due to being poorly supported'. However, it was not discussed about the blast design requirements on the pipe and support and the installation method, i.e., the construction work to be carried out during system is in live or during shutdown, if needed. These issues will be cleared during briefing process and there will be possibility to keep the cost low, quality and time as expected.

Based on obtained information from engineers at the case company, this is one of the key issues for piping design to maintain the project cost low and finish the task within the time schedules. For minimizing the waste and better predictable design, the author could suggest that the case company can implement the briefing during piping pre-design phase as shown in **Figure 18**.

4.2.2 Work Breakdown Structure (WBS)

As shown above in **Figure 18**, the work breakdown structure (WBS) is a part of lean design process under piping pre-design phase. According to Koskela et al (2002) and Womack & Jones (2003), the lean design process increases the work transparency through establishing value flow by creating task sequence steps. In the context of lean, the value flow concerns how entities or information moves through a process or system as fast as possible without unnecessary interruptions among the actors of the organization. This is achieved through a Work Breakdown Structure (WBS), which is having a hierarchical decomposition of activities.

Engineering design process in a modification projects is a complex process due to the internationalization of design (multi locations) and the increased need of dramatic specialist knowledge when complexity is growing (Gray and Hughes 2001). In large complex projects like PMO-6297745 from the above referred case study in section 4.2.1, the task demands several of the specialists from design teams like pipe design, support design, valve, equipment, stress, structural engineers, etc. to complete the project by having their own internal coordination.

Due to the nature of the design process, planning serves as a challenging task. Traditionally, several planning strategies used in the design process are based on linear approaches such as “Stage Gate” and “Waterfall” (Kalsaas, 2013). In addition, complex modification projects tend to perform concurrent engineering due to split locations, i.e. a number of engineering activities are carried out simultaneously and the entire set of activities converges to the design solution at once (Hoedemaker, Blackburn, & Van Wassenhove, 1999). Yet, traditional planning techniques take little account of the interdisciplinary, iterative nature of the design process (Austin, Baldwin, Waskett, & Li, 1999).

For the case study project GEMC at Aibel, as stated by Hoedemaker, Blackburn, & Van Wassenhove (1999), the engineering activities are simultaneously under taken globally at difference locations like Norway, Singapore, Thailand, etc. (see **Figure 7**). Aibel’s M&M projects are usually planned and executed using the waterfall model which is discussed below.

Ideally, the waterfall model consists of a sequential process in which the scheduler or planner forecasts all design activities prior to project start, i.e. during pre-design phase. But the result can be obtained and evaluated only at the end of the detail engineering. The transparency of planning activities can be increased by integrating design reviews during the phase. However, systematic and structured response to the design changes is still difficult. There is a clear correlation between the design change, cost and time. For this reason, the waterfall model is superior with respect to the representation of critical path or the checking of feasibility of a schedule.

The waterfall model is not suitable for managing work and tasks in the design phase for few maintenance and modification projects, especially in the early stages such as preliminary design. Forecasting piping design work prior to project start is challenging, because the design is very vague during the initial stages. Design evolves over time means project's initial stages of phase are not clear about what is to be executed or implemented. Early design phases, in particular, need strong coordination and integration. The waterfall model is also called 'free fall model'. **Figure 21** illustrates the free fall model for during pre-design phase of piping at Aibel.

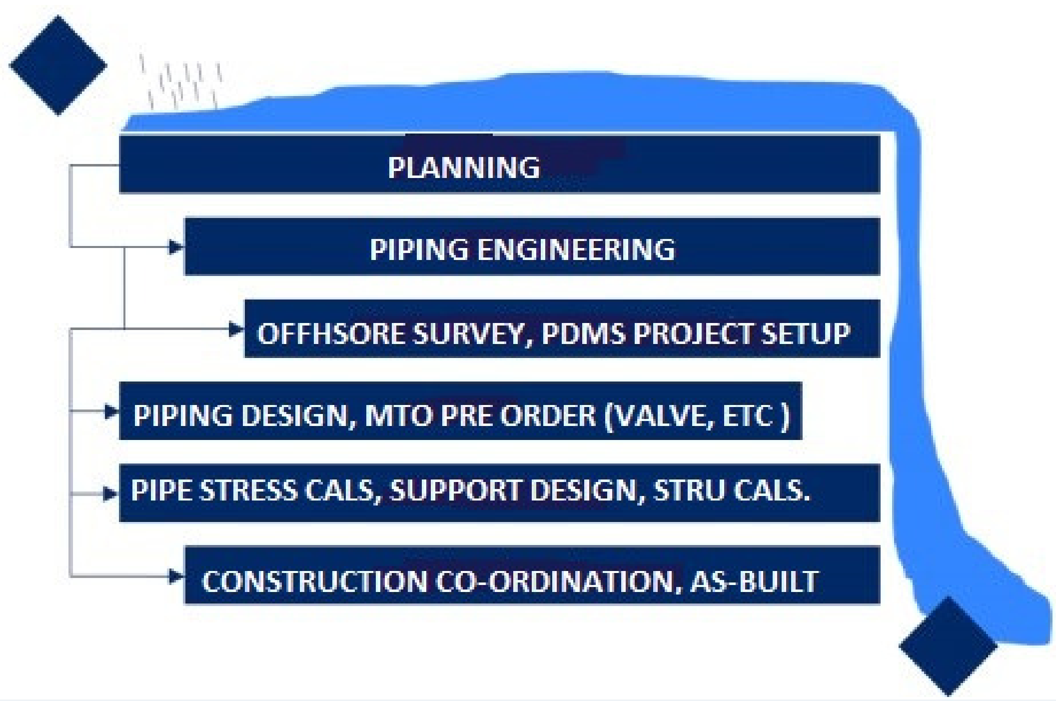


Figure 21 Free fall model in design at Aibel (Demir, S.T & Theis, P. 2016)

Above **Figure 21** illustrates the lack of transparency and predictability of design in detail design phase. This unpredictability results in changes which in turn cause a challenging environment. This uncertainty in design phase is very difficult to manage with conventional design process such as the waterfall model. Adding the high number of design activities and the range of fragmented design disciplines increases the complexity of modification projects. The concepts of briefing and WBS are dependent on each other. When briefing is in place during piping pre-design phase, WBS will be certain by eliminating uncertainties. The WBS provides a collaborative planning among the disciplines and improves quality and design predictability under lean design process during pre-design phase for piping during detail engineering at Aibel.

4.3 Lean Design during Piping Detail Design phase

Figure 18 illustrates that there is a large potential to obtain the competitive advantage in the piping detail design phase for maintenance and modification projects. The implementation of the Lean Design Process (LDP) in piping can contribute to likelihood of success in a competitive market by delivering the quality design within the project's scheduled time and cost. The success can happen due to spending less hours in engineering design, achieving a higher degree of manufacturability (fabrication) and quality (Ćatić & Vielhaber, 2011; Karlsson & Ahlström, 1996). McManus (2005) identified three goals in the lean design process that represents different areas of process improvements. The first goal is to create the right product. It provides the product architecture and design for increasing the value for the stakeholders. The second goal is to create the value by having effective lifecycles and enterprise integration. Thirdly, by eliminating the waste improve the cycle time and the quality in engineering design for creating an efficient design process.

Ko and Chung (2014) states that improper design is one of the biggest causes of the waste and will have the negative implications on further design downstream processes like detail design, construction documentation stages, etc. As shown above in **Figure 19,** the changes of design in detail phase will have an impact on the cost and time. Major decisions that are taken early in the design development process could potentially have a significant impact on the piping detail engineering end results (Morgan & Liker, 2006; Sehested & Sonnenberg, 2011). The design uncertainties regarding the final design solution are high in the early stages of the piping engineering. The concept of briefing can help to mitigate the design uncertainty as explained in Section 4.2.1. The briefing process enhances more structured information to the piping design at early stage and delays decisions until the necessary information is acquired. This helps to reduce the uncertainty and the design time.

The piping detail design for maintenance & modification projects demand sophisticated engineering and careful collaboration between the designers, suppliers, fabricators and the installers. For such projects, the piping detail design also requires a different co-ordination between the disciplines to work together and to ensure that the piping design process is properly integrated and installed. The piping engineering work carried out further with a series of multi discipline units such as the suppliers, fabrication and the installation. These multi discipline units are needed to be integrated so that the piping design team can deliver the desired design by avoiding the waste and rework. The right piping design task is the value added to the project by delivering the quality design for the client recommended schedules by meeting the project standards and requirements of the client Technical Controlled Documents (TCDs).

The piping detail design process is based on three main aspects which are the challenge, uncertainty and the complexity. The design adopts perspective of the client needs and the organization goals. Viana (2015) demonstrated that vast amounts of the waste i.e., waiting time and rework, generates during the detail engineering, fabrication and the installation. The waste can be minimized by implementing the integrated production planning and control system (WBS) as discussed in section 4.2.2.

Sacks, Akinci and Ergen (2003) emphasize the importance of exchanging real time information between the design, fabrication and the installation. Especially the design uncertainty inherent in the detail engineering phase hinders the ability to predict the detail engineering. Few examples are noted during the case study at Aibel for GEMC modification project and are detailed below in the subsequent sections.

Koskela, Ballard and Tanhuanpää (1997) argued that even there is an optimal sequence of the design tasks, internal and external uncertainties, which tend to push the detail design away from the design optimal sequence. The design uncertainties lead to the less design productivity and prolonged duration, and the value of design solution is decreased.

The lean design processes are to aid in the delivery of external value by managing the internal value generation process. The standard work procedures and the knowledge transfers (Section 4.4.5) can be developed by Training Within Industry (TWI). The lean design process can reduce the variability in the piping detail design. The variability in design work processes increases the probability of the design failures, structural cracks, errors and the negative iteration on project schedules and the cost overruns.

Standardizing the design work methods reduces the probability of failures thereby improving the design work flow. The methods are made learning from previously occurred design failures and provide experimentation with alternative design work methods. The standardization process that improves the design work flow and the quality in the piping design at Aibel is presented in Section 4.4.4.

As we discussed above, elimination of the waste in the piping design will improve the design quality by reducing the design uncertainty and design time. More importantly the piping design predictability can be improved. The following sections discuss more details of the waste and the waste drivers in the piping detail engineering for maintenance & modification projects.

4.3.1 Definition of waste and waste drivers

Several authors have provided definitions of the waste. As mentioned in Section 3.1.3, Womack and Jones (2003) stated that the waste is defined as any activity which absorbs resources without adding the value. Ōno (1988) explains that "the waste refers to all elements of the production that increases only the cost without adding the value". In the context of this thesis, the waste can be defined as that it consumes resources without adding the value in piping design. Thus, the resources that can be wasted in piping detail engineering should be identified. Morgan & Liker (2006) describe the waste through the seven conventional waste categories e.g., rework, waiting and over processing. However, these categories do not explicitly describe what is actually wasted.

Bauch (2004) identified and described the factors that are wasted in piping engineering (Design and Engineering). He divides the waste into primary and secondary waste describing the underlying causes for the waste (waste drivers).

The primary waste affects the design flexibility and impacts on the quality, time and cost of design. Bauch (2004) defined the several secondary wastes in detail design, those are:

- **Manpower**: Lack of proper care and attention during the task performance as well as individuals defies the established standards and typically results in the design rework. Some reworks in design require a little manpower but that can also consume the capacity from a whole team or group (Bauch, 2004). The site queries that relate to pipe clashes result in the repetition of involvement of entire the piping design teams to resolve the pipe clash in the design, which are the examples from the case study at Aibel.

- **Machine power:** Tools can also generate the waste. For example, the design rework can be carried out using the tool like computer. The low grade computer works very slowly using the latest project software such as Cloudworx, STAAD, PDMS, etc. These computers could potentially delay the projects schedules.

- **Time**: The waste of time is closely related to the waste of manpower such as unproductive meetings due to poor communication, in adequate meeting preparation, etc., (Bauch, 2004; Oehmen & Rebentisch, 2010). The unproductive meeting often demands more meetings. The waste of time can also be caused by waiting for the software applications to get loaded in computers (Bauch, 2004).

- **Information/Knowledge**: The piping design creates the information and knowledge and can be considered the core task in detail engineering (Bauch, 2004). The lack of knowledge sharing and deficiencies in the information quality can generate the waste.

- **Potential**: Managing the available resources in ineffective manner enables to fail achieving the project targets with less effort. This ineffectiveness due to oversight of the people, tools and the technology potential can be considered as waste (Bauch, 2004).

- ❖ **Money**: In the project, used resources such as man hours and materials can be assessed in the money. The resources using the low grade computers and the inexperienced software tools, etc. can be case of waste (Bauch, 2004).

- ❖ **Motivation**: Motivation should be nourished since motivated employees will get a sense of responsibility regarding their tasks as well as the output of entire the design process. The motivated employees exhibit a more dynamic performance and act more independently. Decreased motivation of the employees is considered as waste (Bauch, 2004).

Even though the waste resources are separated here, in reality they will be inseparable in most contexts. For example, the waste of manpower will often lead to the waste of time as the employees are not efficiently utilized. In addition, the wasting manpower typically means the money spent on maintaining the manpower is also wasted.

Figure 22 illustrates the hierarchy of the primary waste types, resources and the waste drivers.

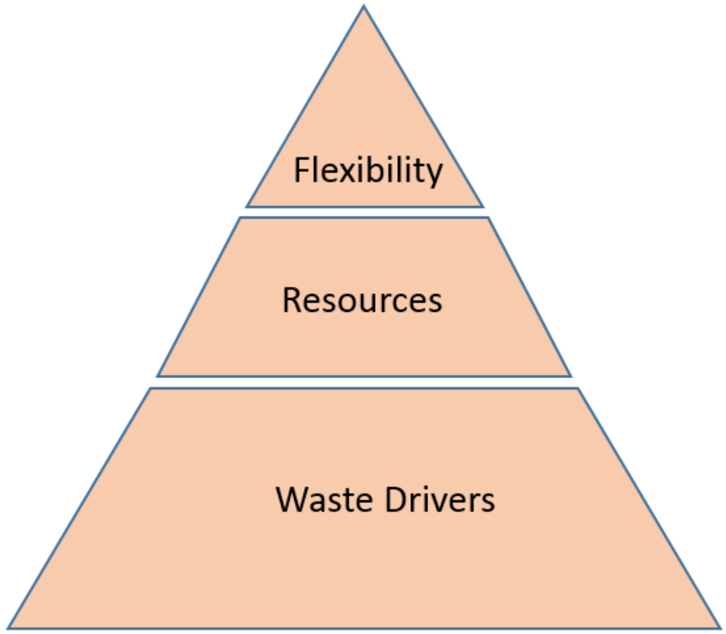


Figure 22 Waste Pyramid (Bauch, 2004)

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

Waste drivers: Waste drivers are defined as the mechanisms that have the capacity to create the waste under certain conditions. The waste can occurs in the piping engineering/design due to the design ability and reduced usability, which increases the costs, time, and the quality. The distinctiveness of the piping engineering process has been central for attempting to identify the waste drivers. The complexity is associated with the waste in the piping engineering and it indicates the conventional manufacturing wastes that do not suffice in the context of identifying the waste in the piping engineering.

Bauch (2004) uses the seven manufacturing waste categories. Bauch (2004) refers to the categories as drivers because these categories describe why waste happens and what the waste is or what is wasted. He further divides the categories into sub-drivers. The sub-drivers might have the potential to create a less ambiguous representation of waste in the piping design and they will make easier to identify the waste.

Based on the sub-drivers created by Bauch (2004) and other authors such as Oehmen and Rebentisch (2010), Oppenheim (2011), etc., a list of waste drivers was created. This was supplemented with findings from the case study and the author's personal experience in Aibel by creating a list of potential waste drivers in the piping design for maintenance and modification projects. The benefit and purpose of the list is "it would be an instrumental in creating awareness on the major waste types occurring in piping design as well as mobilizing the actions towards stemming, reducing and eliminating the waste."

4.3.2 Selecting the waste drivers in the piping engineering

In order to enable the identification of the waste driver mechanisms leading to the waste in the piping design, it is essential to have a basic understanding of important elements and characteristics of the piping design. The piping design for modification projects can be considered as an activity that creates the value for the customers by extending the oil and gas recovery from the reservoir. In essence, this means that the design specifies the required values to meet the customer demands. The value is possibly created by delivering the user friendliness design, achieving good HSE results, etc. (Bonnier, Kalsaas, & Ose, 2015).

The case study project of Greater Ekofisk Modification Contract (GEMC) modification is a complex project and it demands high level of the engineering design, prefabrication and the construction in order to meet fast schedules and overcome the logistical challenges based on the client needs.

The purpose of selecting the waste drivers in piping engineering is for creating awareness about the mechanisms that potentially contribute to the waste. Managers and employees could be getting benefit from the list of waste drivers by knowing what contributes to the waste and could be able to eliminate the waste. Rework and overdesign are too ambiguous in a piping design setting to provide a sufficient image of the waste in this context. The waste drivers enable to provide a better image of waste in the piping design. The drivers are more distinguishable in the context of the piping design compared to the conventional seven categories. The waste drivers in the piping design are more specific and make easier to identify the measures that can mitigate or eliminate the waste.

The author tried to fairly find an ideal path for identifying the waste drivers for the case study project having the criteria in mind to avoid overlapping when creating the list. However, the overlapping was not completely avoided since the waste drivers are highly context dependent and the drivers are the mechanisms that might lead to the waste. This interface is a bit ambiguous as several drivers can affect others, depending on the context. In relation to the piping engineering process, the author argues that this is a task of improvement compared to using the manufacturing waste categories. An overview of the suggested waste drivers for the case study project is given below in **Table 2**.

As explained above in Section 2.2.1 about the practical relevance in the research process, the list of the waste drivers shown below in **Table 2** are made considering the author's practical experience, feedback from employees during the survey at the case study company and the lean design principles from Section 3.1.3. The author focused on to cover all the listed waste drivers and discussed their practical occurrence in piping engineering for maintenance & modification projects in Section 4.4.

Ref. Section	Waste Driver	Description of Waste Driver	Representation from Case study at Aibel
4.4.1 and 5.1	Unclear Roles and Responsibility	• **Unclear expectations in relation to performance and organizational roles.** • Ex: overlapping competencies and responsibilities	• Organization chart, • Roles and Responsibilities among SDL, DL and DRE. • Required knowledge and skills for a supervisor (SDL/DL).
4.4.2 and 5.2	Insufficient Communication and poor co-ordination (Leadership)	• **Communication demanding excessive time and effort, without adding additional value.** • Ex: miscommunication leading to rework	• Leadership, • Informal or formal communication among engineers • Example from EKOM-21 Flow line project.
4.4.3 and 5.3	Lack of Required Competence	• **Not possessing the skill or knowledge required to conduct the task in question.** • Ex: ineffective use of IT tools, due to limited skill	• Competence for discipline leaders and engineers, • Four knowledge domains among roles under piping. • Examples from case study about DRE and Engineers.
4.4.4 and 5.4	Lack of Standardization	• **Information represented in an ambiguous manner, resulting in misinterpretations.** • Ex: Lack of standardization of documentation, tools, etc.	• An overview of piping design standardization (5S) • Integration of Lean design tools and 3D DM (PDMS), • Engineering design in standardization and integration of project tools.
4.4.5 and 5.5	Lack of Knowledge Sharing	• **Not exchanging information, expertise, or skills among entities.** • Ex: New projects the potential not reusing previous solutions	• Relationship between knowledge sharing and lean piping design, • Improvement areas in Aibel • Examples from case study about material, calculations, as-built etc.,

Table 2 List of waste drivers during piping detail engineering

4.4 Waste drivers during piping detail engineering in Aibel

4.4.1 Unclear Roles and Responsibilities

Table 2 shows that the driver of roles and responsibilities is one of the key waste drivers occur in the piping engineering for maintenance and modification projects at Aibel. The driver of roles and responsibility is so important in the organizational life and it deserves more attention as an aspect of professional competence. The competence is an essential part of the organizational culture and growth. In the more complex organizations like Aibel, activities are managed in controlled manner and are governed by the central authorities. The common shared culture of responsibility in the organization can help to function of the organization successfully and develop it adequately. Accordingly, things are maintained by individual members through self-governance and cooperation.

With reference to the positions at work, response-ability means that:

- ❖ **People want to respond (are dedicated):** This is a question of values. Does someone want to acknowledge the responsibility that comes with his or her role at work? Do the role and the responsibility contained within it fit his or her values?
- ❖ **People are able to respond:** This is a question of being qualified to respond. Does a person have the necessary qualifications to be able to give the required response? Does he or she have good command of his or her tasks? Does he or she understand the context of his or her job?
- ❖ **People have the resources to respond:** This is a question of being sufficiently equipped. Does the job provide the means required to respond adequately? Does the individual have access to the necessary authorization and resources?
- ❖ **People have to respond:** This is a question of obligation. Which questions must the employee answer and to whom? Is he or she exempt from responding to questions? What are the wrongs against whom and what consequences can these wrongs carry for whom?.

The word “responsibility” contains the word “response”. When we know our roles and responsibilities and hold to be accountable for our actions, organization will be more effective and achieve greater results. **Figure 23** distinguishes the four dimensions of the system of responsibility.

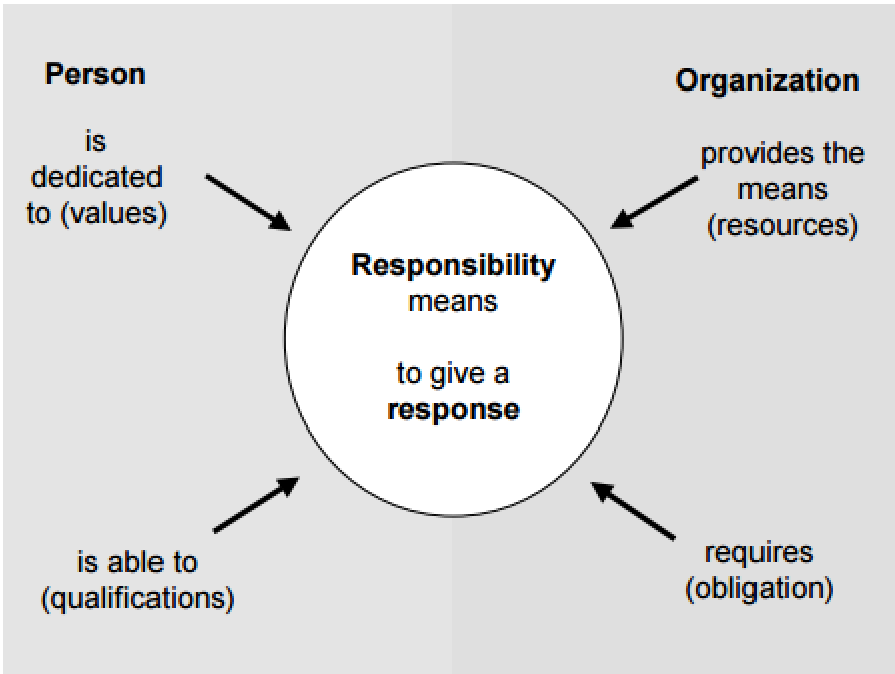


Figure 23 A system of responsibility (Schmid with Messmer, 2004)

In reality, a complex organization like Aibel will always be confronted with situations in which the responsibility of an organizational member cannot be optimized in all four dimensions. For instance, it is possible for someone not to have some of the necessary qualifications for his or her job in the organization. From a systemic perspective, it is not important for all of the requirements to be fulfilled 100% by one person. Rather, it is important that, for example, missing qualifications are activated somewhere else and meaningfully integrated into the system of responsibility. Similarly, the necessary authorization to fulfill certain tasks may not be available in a specific area of the organization. In this case, a functional system of responsibility can be developed by including the authorized person in any relevant processes.

As explained by Schmid with Messmer (2004), for having a better understanding of roles and responsibilities in the Aibel, we need to know how the organizational structure has been built-in by providing the means of resources. **Figure 24** illustrates the organization chart for Aibel in piping discipline (piping engineering) for modification projects. The organization chart was developed during the survey in GEMC project as a part of the case study.

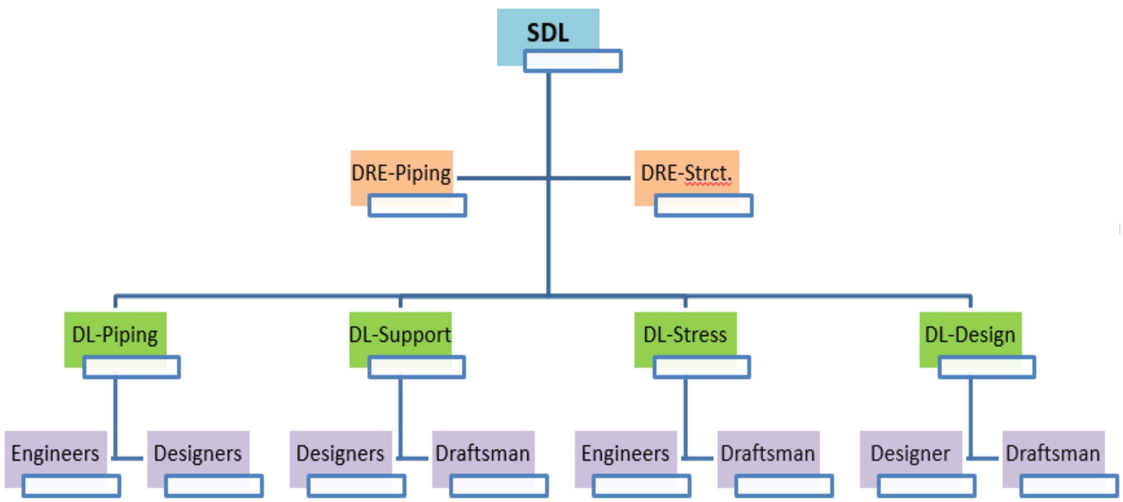


Figure 24 Piping organization chart for GEMC modification project

The organization chart presented above gives a visual representation of how the Aibel intends authority, responsibility and information to flow within piping engineering for modification project. As "being dedicated to responding" and "being able to respond" are connected to the person himself or herself, where the identity and the core competence play an important role. In terms of core processes, roles and responsibilities, the functional role as a part of the organization's chart must be adequately equipped. The organization also requires that members take responsibility for their areas of obligation (through leadership).

Based on 'Make Value Flow' as explained by Womack, J. P., & Jones, D. T. (2003) in Section 3.1.3, optimization of the design information flow in an organization is a key lean design principle for identifying and removing the waste by having a the lean design process. This optimization moves the information flow as fast as possible without unnecessary interruptions by reducing throughput time and also meeting the customer expectation up to satisfaction levels.

In the process of identifying and removing the waste in flow of information under piping engineering for Aibel, the author utilized his research to identify the similarity and overlapping of the responsibilities between the roles of Senior Discipline Lead (SDL) and Discipline Lead (DL) in piping discipline. This is based on existing data available, feedback from interviews and author's practical experience at Aibel.

Senior Discipline Lead (SDL): SDL role is the top position in the discipline of piping and layout and it is to report to engineering manager. This role demands the both management and technical skills. SDL is responsible for leading, coordinating, resourcing, training, implementation of work execution method (W3) and also maintaining the quality assurance & HSE in the engineering discipline (piping). The details of roles and responsibilities for SDL role are annexed in Appendix 2 as a reference.

Discipline Lead (DL) - Piping: As shown in organization chart in **Figure 24**, DL will report to SDL in a project. This role demands the highly technical skills and communication skills. DL (piping) is responsible for coordinating, leading, maintaining the quality output by implementing work execution model (W3), proving optimal design solution and HSE. The details of roles and responsibilities for DL-Piping role are annexed in Appendix 3 as a reference.

The above responsibilities are obligated to perform assigned activities according to Aibel work management (W3) and it is the self-assumed commitment to handle a job to the best of one's ability. The acceptance of the above mentioned responsibilities means that the person is obligated to be a superior (relationship management) to see whether the job activities are successfully completed.

The similarity and overlapping of responsibilities for both the SDL and DL roles in piping were evaluated based on the project archived documents, the Aibel work management methods (w3) and also the feedback from employees during survey conducted at case company. The responsibilities are tabulated below in **Table 3**.

Responsibilities	SDL Role	DL Role (piping)
Leading	√ (yes)	√ (some extent)
Coordinating	√ (yes)	√ (some extent)
Resourcing	√ (yes)	√ (limited)
Quality Assurance	√ (Some extent)	√ (yes)
HSE	√ (yes)	√ (some extent)
Implementing W3	√ (Some extent)	√ (yes)

Table 3 Similarity of responsibilities between SDL and DL for piping at Aibel

From the above table, we can clearly see that there are many responsibilities that overlap between the SDL and DL roles. As Womack, J. P., & Jones, D. T. (2003) stated, in an organization to create a value flow, it is important to avoid the unnecessary interruptions and keep the information flow fast under the process of the lean design principle. Based on the above tabulation, the overlap of responsibilities between the SDL and DL roles are illustrated below in **Figure 25**.

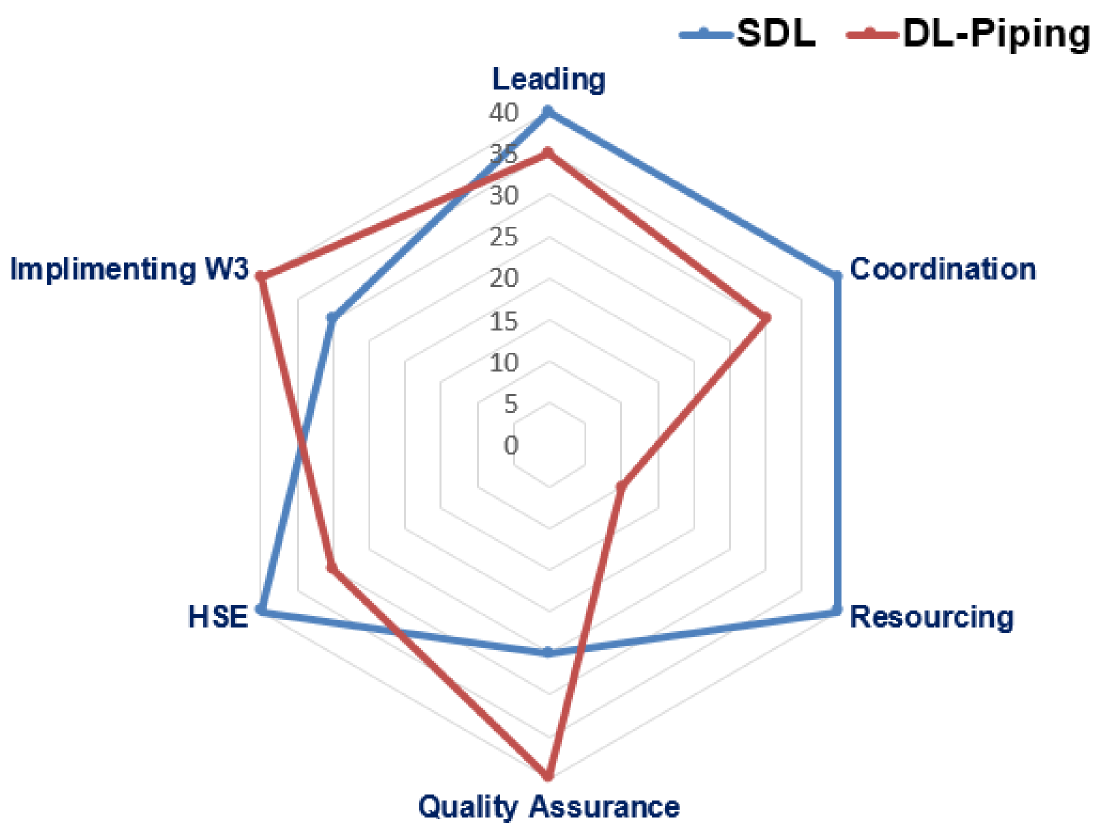


Figure 25 Responsibilities overlapping between SDL and DL roles at Aibel

The above figure is illustrated by allotting the score from 0-40 on a graphical view based on feedback from interviews conducted at case company and on the description of responsibilities available from the Aibel work management method (W3). In view of the above discussion, the author suggested/proposed a new organization layout of piping and layout discipline as per the given recommendations for maintenance and modification projects in Section 5.1.

Till now, we have focused on identifying and removing the waste at the organization level with respect to the roles and responsibilities considering the four dimensions of a system of responsibility defined by Schmid with Messmer (2004).

As explained by Schmid with Messmer (2004) in the four dimensions of a system of responsibility, here the present research includes about a person who is dedicated to values, his abilities and required obligations to take his responsibility at the organization level effectively.

An employee in an organization to maintain his/her roles and responsibilities effectively, he/she must meet the five core competences before any supervisor can successfully distinguish the difference between knowledge and skills.

The five needs are: (1) knowledge of the work, (2) knowledge of responsibilities, (3) skill in instructing, (4) skill in improving methods, and (5) skill in leading. The first two needs are knowledge based and the last three are skill based. Knowledge as defined by Training Within Industry (TWI) is acquired through class attendance or literature. The skills are acquired through practice and repetition (Experience in an industry). There is an important difference between the two. For example, if you read a book on how to play golf, will you be able to actually play? Only by practicing and playing golf repetitively can a person acquire the skill and perform it well. The same will be applicable for key positions having roles in Aibel under piping discipline to meet the organizational objectives and goals. For example, this is the case of nominated person having the knowledge and skills for the SDL, DL roles.

The service industry in oil and gas sector is facing reduced budgets and compressed project schedules. To overcome these challenges, many individuals take to firefighting by focusing an attention on only hot issues and leaving no time to develop personnel through appropriate training within organization (TWI).

As the basic principle of the lean design process, ‘a lean enterprise focuses on customer centricity, continuous flow of internal operations and waste free value creation. This is possibly be achieved as extent by focusing improvement on five core competence skills at supervisory level. The skill in improving methods deals with improving the use of resources, manpower and materials leading to the development of the Job Methods Program. The skill in leading improves how a supervisor improves his ability to work with people.

4.4.2 Insufficient Communication and poor co-ordination (Leadership)

Table 2 shows that the driver of insufficient communication and poor coordination is one of the key waste drivers occur in the piping detail engineering for maintenance and modification projects at Aibel. Egan (1998) and Love & Li (2000) stated that the overall performance of the service industry has declined from past decades. This decline is typically considered as a result of increased complexity and rapid growth in the industry (Grey and Hughes 2001). The design team's integration and the effective communication within the disciplines are the major challenges in the service industry. Even though, participants of the design team make significant effort for working together, the communication difficulties will occur in the design process. These difficulties tend to hinder the cooperation and learning between the actors. The communication difficulties in the design phase often lead to constructability problems at site e.g. an increase of the site queries during the construction phase due to poor design quality. These constructability problems (site queries) influence the project cost and the productivity (Baldwin, 1999).

Reinertsen (1997) argues that, facilitating the effective communication requires the efficient design information flow. When the too much information simultaneously circulates in the design phase, it is difficult to separate what is important or not. Pietroforte (1997) further claims that understanding of the organizational structure is an essential in the discipline.

Figure 18 illustrates that there are several design teams involved in the piping detail engineering for maintenance and modification projects. The design teams as mentioned before are: pipe design, support design, pipe stress, structural, PDMS administration, valves, offshore support, client, etc. As discussed in Section 4.2, the pipe design is ideal in the pre-design phase due to uncertainties and matured in the detail design phase. The design uncertainty in piping requires the coordination of multidisciplinary professions, the design activities and information. These entities play a key role for reducing the design uncertainty in the piping.

The coordination among the engineers/designers is a major challenge in the piping design. The lack of coordination in the design team contributes to ineffectiveness of the design integration. The ineffectiveness leads to variations in the design for the modification projects. Without having a complete and accurate design information flow, it is critical for the engineers to produce and complete the error-free calculations, drawings, documents, etc.

There is often lot of uncertainty involved in the information that comes from various sources in the piping design for modification projects. In order to overcome this uncertainty and achieve acceptable level of information, the design information must be processed (Galbraith, 1973). The processing of the design information is to be low for performing the task, where the nature of work has a high level of design certainty. The coordination among the design team members needs high in order to improve the speed and accuracy of the design information. Further, the coordination in the design process might be viewed as an activity to handle the design uncertainty and synchronize the information flow. The synchronizing is about the collection, processing, storage and transmission of the design information. According to McGeorge (1988), the synchronization process is essential for the effective design process.

Figure 26 illustrates the design information flow among the design teams in the piping design/engineering. The coordination and the communication play a dynamic role to provide a quality design output to the client. **Figure 26** shows that the design information flow starts in a sequential flow from one design team to another as indicated by the black color line in the figure. As the design evolves, the flow of information takes place more frequently across the teams for performing their tasks, as indicated by the brown color line in the figure. This flow of information indicates that there will be a very frequent interaction among the teams to design the piping for meeting the quality according to the organizational and client standards.

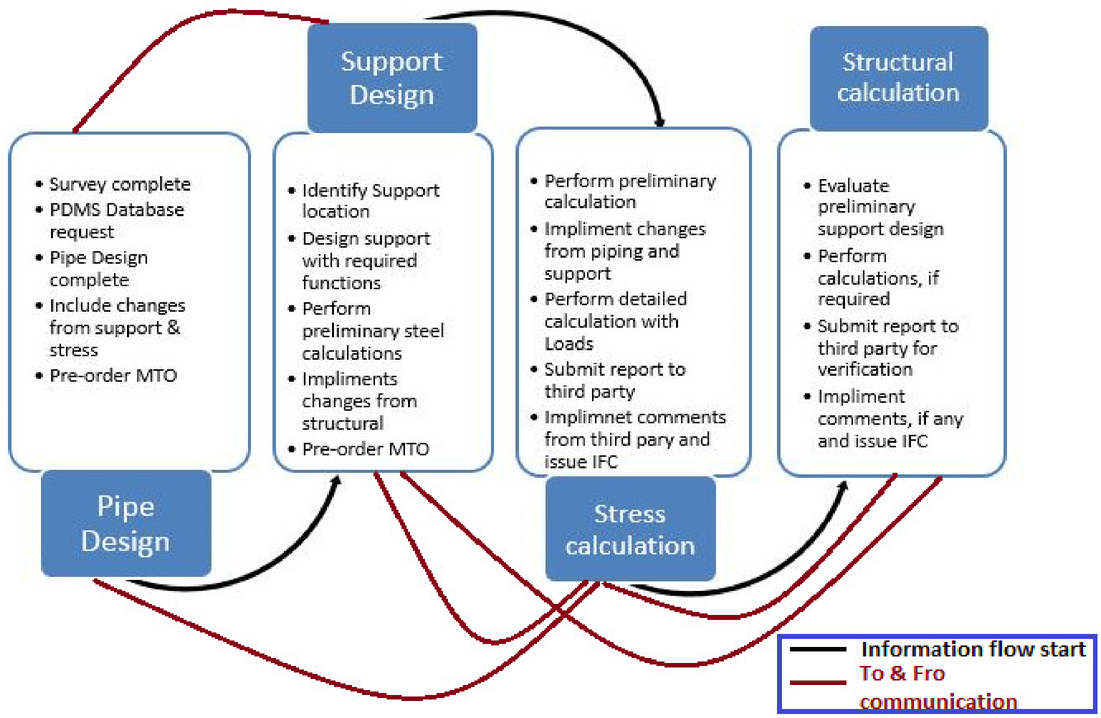


Figure 26 Information flow in Piping Design between design teams at Aibel

The right design information in the right form is to be delivered to the right people at the right time in order to design the piping efficiently. Here, the right information in the right form can be seen as the 'communication' and the right person at the right time can be viewed as 'coordination' issues. For the piping design discipline, the right person at the right time effectively means to have the information in place by effective communication and leadership within the discipline.

At Aibel, the information flow takes place in between the design teams by the formal and informal (verbal) communication for performing their tasks in the case study project. This flow of information demands the good coordination and the effective communication among the designers to produce the piping design to safely construct and operate at offshore.

The informal communication demands a face-to-face contact, and it is the most common and essential communication channel for the project success. The face-to-face contact enables the immediate feedback and transfers the rich information. In some cases, it makes easier to detect and avoid misinterpretations and ambiguities. The face-to-face contact may also be sometimes worse due to the harsh communication followed from the multi-cultural people in the organization.

In the piping discipline, it is important to have a good interpersonal relations and trust across the designers. It seems that the human factors determine whether the process of the piping design is efficient or not. The piping design leads at Aibel like SDL and DL should maintain a good “chemistry” in the design team members in order to be dedicated and motivated, and to collaborate, coordinate and have effective information flow.

The engineers at Aibel in the piping design is to communicate more effectively with a purpose of sharing the knowledge and to determine the level of ambition like reduced cost and time with improved quality. These ambitions define the common goal and application of positive as well as negative sanctions. These goals and sanctions may be often overlooked and underestimated by the design teams which considered at the case study project at Aibel. These indicate the importance principles of teamwork, such as values, dedication, motivation, collaboration, coordination, etc. to contribute a successful final design.

Practical example at case study project: EKOM–21 flowline piping design:

EKOM-21 flowline piping design project was a high priority project from the management. In this project, it was to design the flowline from the production wellhead to manifolds but the complexity was involved due to changeover with EKOM-24 flowline.

The complexity demanded different level of the design knowledge among the design teams. It was immense to solve challenges associated with the different tasks. An effective communication by having good leadership makes a smooth flow of information among the teams and it gives a productive design at the end (Huelat, 2004).

EKOM-21 flowline piping design task gave an opportunity to engineers participated during the piping design. The communication and coordination among the design teams took place as discussed above and shown in **Figure 26**. The design teams like, pipe design, support design and stress design followed the instructions from the piping Discipline Lead (DL) and continued their task for the fast track piping design project. When the support design engineer approached the structural engineer to request for performing the support calculations, the structural engineer had not received the information flow from his supervisor (SDL-Structural) about that task and its priority. Finally, the piping design had to be performed and delivered to the project with re-design due to the lack of actions by the right person in right time.

As there was lot of information involved with regard to the above mentioned re-design work, it was not described in detail here. However, it can be concluded that there is a clear lack of line of communication and the leadership in piping design discipline.

The lack of the communication and the leadership in piping design discipline takes place due to involvement of the different design team's work under different disciplines like piping, structural, etc. The pipe design, support design and stress design teams follow the information from piping SDL. The structural engineer gets the information from the structural SDL and gives a support to the piping design teams. This information flow requires a long chained communication for transferring the project goals to the engineers.

In the lean design process, the leaders are not necessarily top and senior managers. They trust and respect the people and are able to inspire others to follow them (Orr, 2005). As the leadership in the lean design process approaches the linguistic action concept, conversations are the core of the organization work by making and keeping commitments among the design teams. The listening is the master skill of leadership (Howell et al, 2004). The leadership task always motivates the people by inspiring, recognizing contributions to the project performance and committing to meet the quality standards.

4.4.3 Lack of Required Competence

The competence plays an important role to generate waste in the piping engineering and the lack of required competence is one of the key waste drivers occur in the piping engineering for maintenance and modification projects at Aibel as shown in **Table 2.** The waste can be generated by lack of required competence for employees to conduct the assigned task. The Oehmen and Rebentisch (2010) state that lack of required competence need additional communication in order to acquire the necessary knowledge for performing the assigned task. However, the additional communication is to be considered as the waste depends on the circumstances.

The employee goal is learning and it creates value for the organization by expanding his capability. This learning process enables him or her to execute more value creation for the organization and the stakeholders. Adding the value no longer creates a value for the organization in some cases such as, when the newly acquired knowledge that is available in the company is not really useful due to capacity constraints though it is still necessary for the organization. The acquired knowledge that is adding a value is considered as the waste as it is not effectively used.

The engineering organization like Aibel is needs to develop the required competence for the discipline leaders and engineers for performing the piping design tasks. The development of their competencies is through experiential learning, qualifying managerial and technical positions. The core competence is identified as four knowledge domains which are: (1) technical-instrumental knowledge, (2) systemic conceptualization, (3) self-knowledge and self-domain, and (4) social-transformation interaction. These four knowledge domains build into two competences: one is technical competence by combining 1 and 2 and the other is social competence by combining 3 and 4 (Lantelme, 2004). The both technical and social competences are important for the engineers to perform his/her roles & responsibilities discussed in Section 4.4.1 and to manage effective leadership discussed in Section 4.4.2.

Technical competence: The technical competence is the base of the professional work. It contains concepts, theories, rules, methods, tools and technologies mobilized to carry out the work (in general terms) and solve the professional activity problems. For the case study of GEMC project at Aibel under the lean design process in piping engineering, the engineer professionals need competences in design techniques using the project tools like PDMS, STAAD, CESSER, etc., also having the competence from project management and the lean design tools.

Social competence: The social competence is the ability to inspire the people for directing them to the desired performance scenario by bringing the best of their own capacity. It allows developing the informal organization in the right way by focalizing and taking advantage of the conversations and social networks that the organization produces. It is a key element to create high performance teams and this acquires more relevance as people's hierarchy gets higher. For developing this competence area, it is necessary to have a self-domain and social skills (leadership, teamwork, communication, etc.).

Figure 27 illustrates the importance of technical and social competence required for the piping design at Aibel and also explains about various competence requirements in different knowledge domains to become a productive engineer/designer by maintaining goals and objectives of an organization.

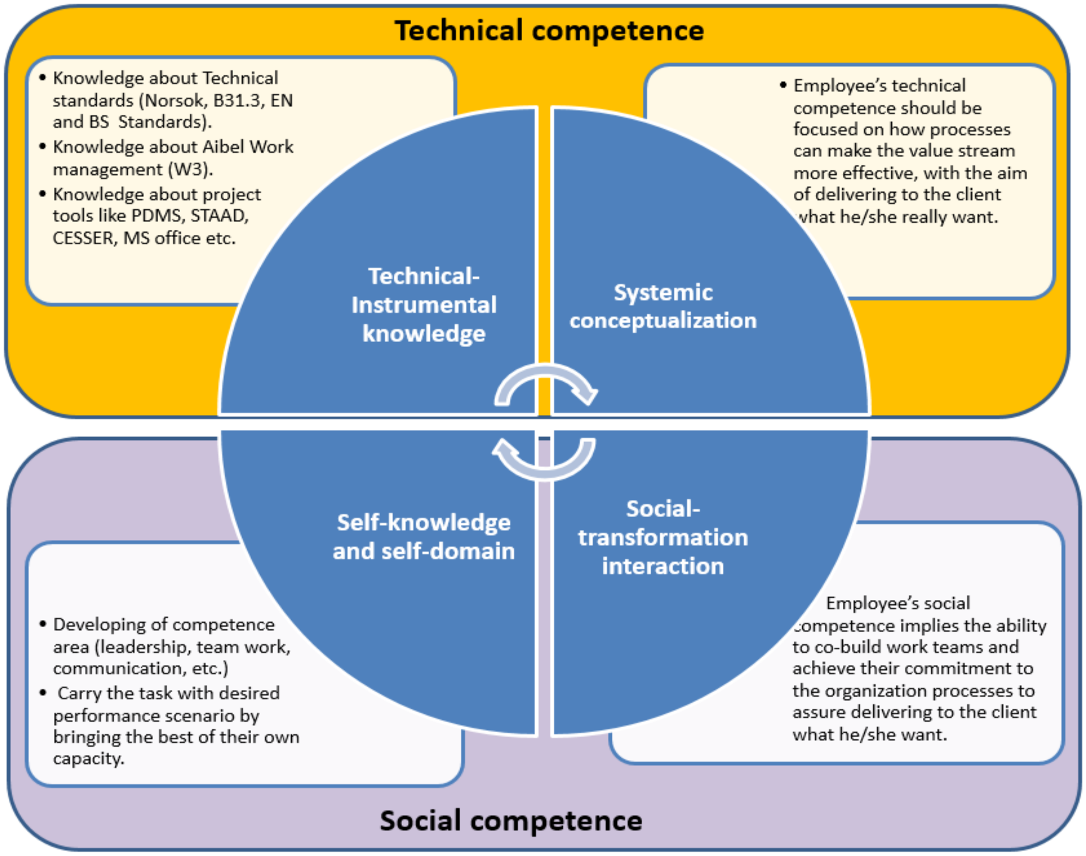


Figure 27 Knowledge domains of competence required for piping design at Aibel

In a complex organization like Aibel, which is built with vast organization structure as shown in **Figure 24**, has a greater demand to maintain right competence for people among the piping discipline to compete oil and gas market by meeting the customer demand with right quality in a right time. Aibel has some key roles in piping discipline, which are SDL, DL, DRE, etc. as represented through organization structure in **Figure 24**. The nominated persons for these roles are identified from the piping base organization. i.e. they have key competence at design level based on their specializations like pipe design, support design, calculation, etc.

The piping design is mainly carried out by using the project tools, like PDMS, STAAD, CAESAR, etc. The DL, DRE and Engineers/Designers need to be expertise using the project tools, standards and procedures shown in **Figure 27**. Few examples at Aibel organization within GEMC project from the piping disciples are described below.

DRE: According to survey conducted in GEMC project, some peoples are holding very good competence in technical and having loose ends with instrumental knowledge like expertise in the projects tools (PMDS) and social transformation interaction. This demands good communication and co-ordination with engineers and designers to transfer piping surveyed information conducted by DRE. This generates not value added activities as mentioned by Womec and Jones. In some cases, DRE may use hand sketches, power point presentations, 2D tools to have better co-ordination and communication with other users. The whole process demands time in project, which directly impacts on the cost and the quality.

Engineers: Engineers should have required competence in their specialization as shown in **Figure 27**. During survey it was observed that, in some cases support engineers hold PDMS knowledge to some extent only, like very good in PDMS design and not good enough with PDMS Draft tools, STAAD, etc. Also the structural engineers having lack of PDMS skills will also demand time to transfer the communication from engineer-engineer, which will impact on the project cost.

4.4.4 Lack of Standardization

The lack of standardization is one of the key waste drivers occur in the piping detail engineering for maintenance and modification projects at Aibel as shown in **Table 2.** Womack and Jones (2003) and Liker (2004) state hat standardization has great potential advantages by standardizing the process in design process by reducing indirect costs. Womack and Jones also stated that the “5S” standardization concentrates on making the processes standardized, simplified, cleaned, sorted out, and finally it seeks to make the procedures sustainable.

The lack of standardization can be viewed as one of the reasons for the inefficiency in the piping design and it generates the waste. Womack and Jones (2003) suggested that the standardization of processes can be a means of reducing the cost and time. Santos et al. (2002) suggested that the standardization should be viewed as an approach aimed at waste reduction by the critical disentanglement of processes to reduce the design variability.

Ungan (2006) stated that reduced process variability also contributes to decreased uncertainty in the complex projects. The information flow can be increased by using processes as instruments to encourage homogeneous practices through knowledge sharing. The homogeneous practice is the more efficient ways of controlling the processes within the project to be performed regarding the both quality and safety (Santos et al., 2002). The root causes of the design problems need to be identified and the routines are to be established for introducing the standardization process in the piping design. The standardization process leads to more consistent design and increase design efficiency. It also makes easier to control the fabrication and construction process.

The standardization process in the piping design mainly focuses on three major factors which are the product quality, cost and delivery time. It is accomplished through the “5S” and “Kaizen” theory of the lean design principles. The 5S stands for five different lean design elements and these are supposed to bring the stability to the lean design structure. Further, the 5S is a measure and it is broadly aims to systematize the efforts to minimize various forms of the waste in design to improve the productivity.

Also, 5S stands for basically five Japanese words and the measures originated from the automotive industry in Japan. It is therefore important to adapt 5S to the project specific in service industry like the maintenance and modification projects. In Japanese words, 5S is defined as Sort, Straighten, Shine, Standardize and Sustain. The main objective of 5S is to increase the quality, safety, well-being, confidence and business growth through increased productivity. The standardization is the key element of 5S lean design principle and it covers the process standardization in the piping design. The standardization process in the piping design is to maximize the value for the customer by eliminating waste.

Liker and Meier (2007) stated that the standardized process is not to make only the highly repetitive tasks. The intent is to define the best design methods and reduce variations in the work method as much as possible. The repeatability is not as important for non-routine work as it is for routine work.

Figure 28 demonstrates the overview of the piping design standardization based on the lean design principles (5S) for maintenance and modification projects at Aibel. The piping design standardization was developed based on feedback from interviews conducted at the case study company and based on the author's practical experience at Aibel.

As shown below in **Figure 28,** the piping design standardization took place in the four potential areas which are, design tools, engineering design, procedures (W3) and planning & documentation tools. Each potential area has the core piping design elements and the possibility of task standardization based on the lean design principle (5S) is described below in **Figure 28**.

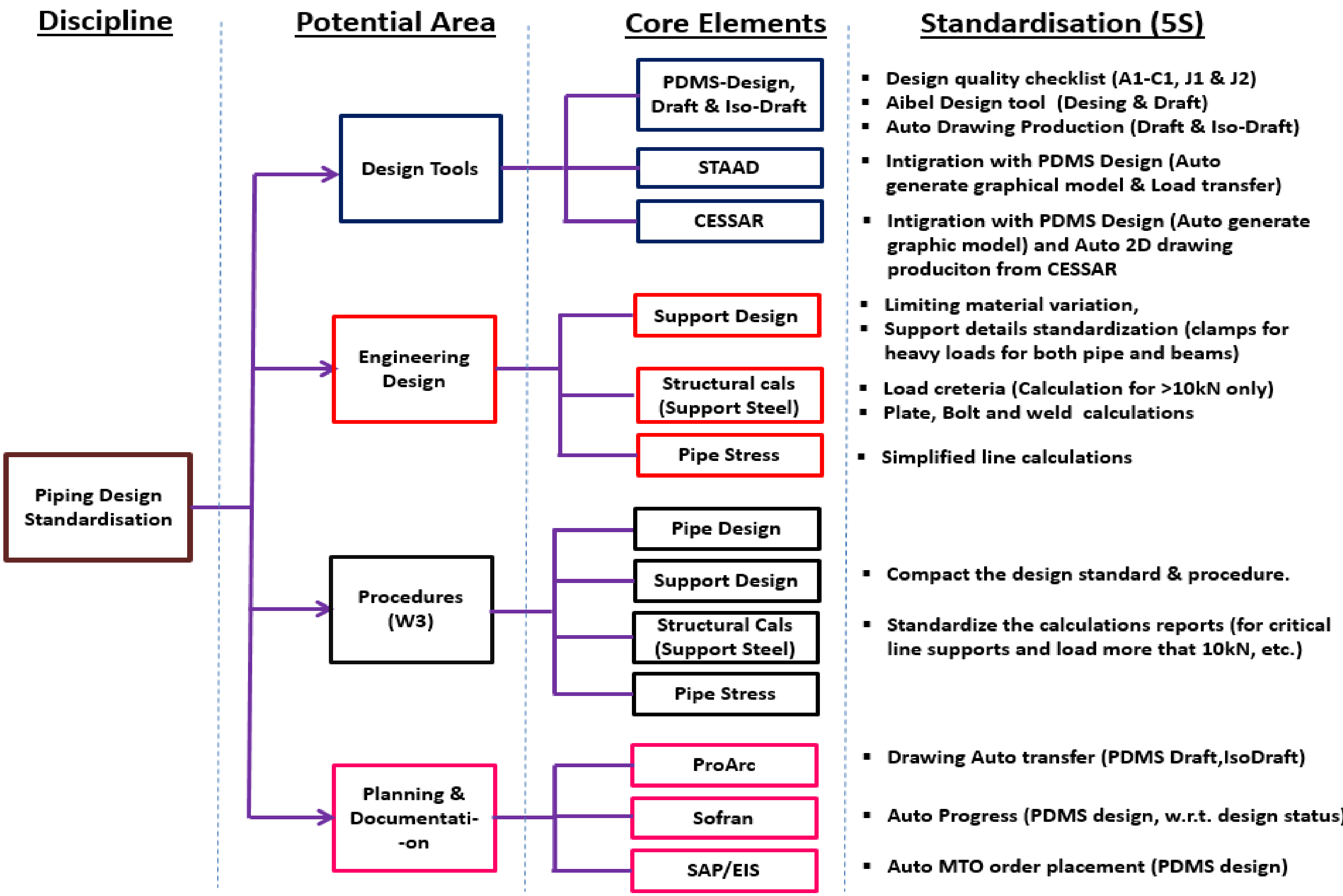


Figure 28 An overview of piping design standardization (5S) possibilities at Aibel

Based on the above figure, the four potential areas of the piping design standardization and the standardization measures needed for different core piping design elements are briefed below.

i. **Design Tools**:

3D Design model (3D DM) tool is recognized as the beneficial concept and it helps to reduce the design, fabrication and construction waste (Sacks et al. 2010). Dave, Boddy & Koskela (2000) states, "Lean construction and 3D DM have significant synergies and can bring benefits, if implemented together". The 3D DM tool improves the workflow in the fabrication and construction process and the improved workflow helps in reduction of the waste (Eastman et al. 2011, 298).

Plant design Management System (PDMS) is a 3D Design model (3D DM) tool and it is widely used in Aibel by the pipe design team and the pipe support design team. It used in various stages of the project such as layout, design, detailing and drawing as described in Section 3.2.3 and shown in **Figure 16**. PDMS is used to generate 3D model and 2D drawings for the piping isometrics and pipe support fabrication drawings.

Sacks et al. (2010) explained that integration of the lean design principles with 3D DM (PDMS) can be beneficial for the organization provided the good understanding of the design theory in service industry for the oil and gas sector. 3D DM (PDMS) demonstrates about the people, processes and technology (Arayici et al. 2011). Koskela (2000O) stated that the foundation of the lean design is based on the theory of design and it is focused on the people and process.

Therefore, the 3D DM with its technology capability and the lean design principles with its theoretical foundation (5s) implementation in piping design can be complemented for a better project efficiency. **Figure 29** illustrates the integration of the lean design tools (5S) and 3D DM (PDMS) tool in the piping design at Aibel.

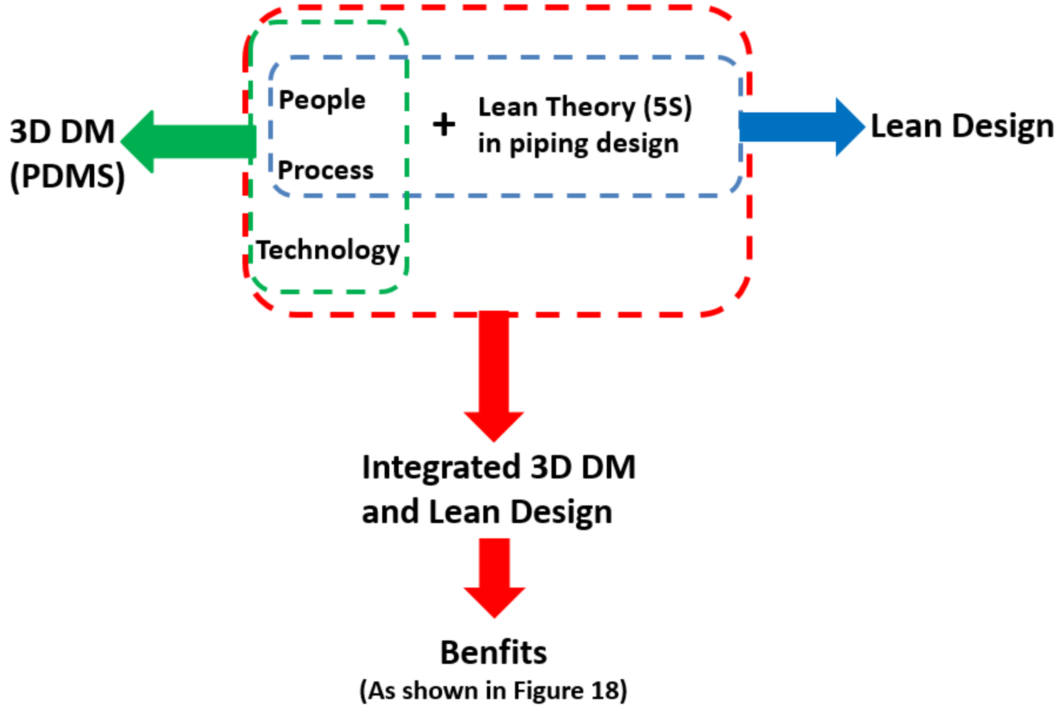


Figure 29 Integration of lean design tools and 3D DM in piping design at Aibel

The integration of the 3D DM tools and project tools applying the lean design principles (5S) will eliminate the waste and it is beneficial to the organization. The benefits are:

- Reducing the design development life cycle,
- Reducing rework,
- Increasing the number of iterations for value improvement,
- Improving predictability and cost,
- Enhancing the ability to engage with client with more transparent.

As mentioned before, the lack of standardization is the key waste drivers in the piping design/engineering at the case study company and it generates the waste. Considering the above said benefits in the organization and the integration of the 3D DM tools and the project tools, the standardization of the 3D DM tools (PDMS) is needed in various PDMS design modules. Based on the feedback from the employees at Aibel, the following standardization is required within 3D DM modules to improve the cost reduction and quality by meeting the customer schedules in the piping design:

- Standardization of quality checklists in the PDMS design module,
- Standardization of task progress in the PDMS design module,
- Standardization of fabrication drawings in the PDMS draft module,
- Standardization of 3D DM tools by tools integration.

The standardization processes in above tasks are given in the recommendations in Section 5.4.a.

ii. Planning and Documentation tools:

Planning tool (Safran) is for managing the complex projects and the documentation tool (proarc) is for managing the project documentation, drawings and other project relevant information. There is advantage of integrating the documentation and planning tools with 3D DM tools using technologies. The integration using the lean design principles creates maximum value and continuous information flow in the piping design as shown in **Figure 28.**

Table 4 shows the possible integration between the 3D DM tools and the tools of planning and documentation, using the lean design principles (5S). This enables to reduce the time of design development, documentation & progress transfer and placing material order and further to improve the quality.

Integration between the planning tools and the 3D DM tool (PDMS)	**Integration between the documentation tools and the 3D DM tool (PDMS)**
PDMS – Safran PDMS – SAP	PDMS – Proarc PDMS – EIS

Table 4 Project tools integration with 3D DM tools at Aibel

As shown above in **Table 4**, having integration between the 3D DM tool and the EIS, the required piping material for the construction can be indented without any manual editing. This will minimize the short fall of material needed for construction (site queries) and improve quality. The integration between the 3D DM tool and sofran enables to generate the design activity progress from the PDMS design module. Also having the integration between the 3D DM tool and proarc, it enables the auto drawing transfer from PDMS draft module to proarc. All the above mentioned integration process will eliminate the waste and improve the quality as well as cost.

iii. Engineering Design:

The detail engineering contributes to produce the waste at all stages. The most significant cause of the waste is related to the design changes or the lack of standardization. Therefore, it is important to understand the benefits of the lean design tools (5S) in the engineering design in terms of reducing the waste by standardization as shown in **Figure 28**.

As shown above in **Figure 29**, the human interface (engineer) plays an important role for effective utilization of the standardized designed tools and the engineering design. An engineer with an attitude of problem solving or optimum design solutions strives to reduce the complexity and provides the smaller and easier design solutions. Seeing the world through the eyes of an engineer, the core aim of each theory is expressed as the standardization effort and the efforts further emphasize the link between the different theories. The simplified and orderly view of the lean design process can make the theory more readily understandable by an engineer.

The engineering design in the piping design can be seen as a representation of the production system while the applied forces are the representation of the system inputs and outputs. **Figure 30** illustrates the engineering design standardization in the piping design at Aibel.

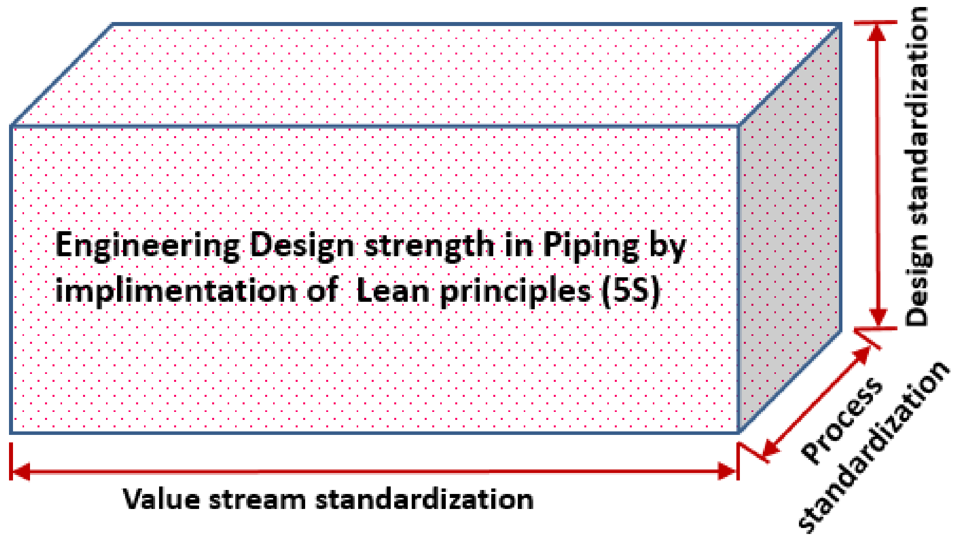


Figure 30 Illustration of engineering design standardization in piping at Aibel

Process standardization: The lean theories and tools for process standardization have the goal of reducing the variation of performed work throughout the whole design process by developing and utilizing practices for standard work.

At Aibel for the case study project, it needs the standardization and simplification of the pipe stress calculation for non-critical pipelines and pipe stress calculation report for simplified pipelines as process standardization.

Design standardization: The theories and tools for work standardization have the goal of reducing the variation in the design output by limiting the number of unique design and by reducing the use of unique steel.

At Aibel for the case study project, it needs to limit the material variations of the pipe support design steel such as the material, shape and size. Also it needs to standardize the pipe support steel calculations based on the load criteria such as critical and non-critical pipes loads.

Value stream standardization: The theories and tools for the value stream have the goal of preventive reduction of variation within a chain of processes. It strives to reduce the amount of unique independent activities to be performed.

At Aibel for the case study project, it needs to standardize the pipe support design steel plates, bolts and the weld calculations. This could be achieved by having the design standardization in front.

iv. Procedure (W3):

The work procedures and standards are the key elements to maintain the organizational design quality standards in the piping design. As already discussed in Section 3.2, the Aibel work management method (W3) provides the frame agreement model, engineering and design process for maintenance and modification projects. It gives a description about how to work and interact. It also provides the relevant processes and supporting documents, and secures common execution design process for end user.

The standards and procedures needed to be standardized to reduce the waste in scheduling, quality, cost, safety and environment-related activities. It allows high levels of performance to be constantly achieved from the engineers. In the piping design the engineers frequently swipe from one project to another before familiar with the appropriate methods. The frequent swipe results in repetition of a low level of performance. The standards are in a way to be designed to enhance improvement.

The standards and procedures (W3) are needed to evaluate frequently to identify the waste by adopting the lean design tools (5S) for optimum use as shown above in **Figure 28**. During the case study at Aibel it was noticed that the pipe support design standard is not easily readable and understandable. Also the procedures need to be evaluated continuously to improve the quality and eliminate the waste.

4.4.5 Lack of Knowledge Sharing

Knowledge sharing is the process of exchanging information, expertise, or skills, among entities (Serban & Luan, 2002). Thus, not doing these exchanges can be defined as the lack of knowledge sharing. The lack of knowledge sharing causes the solutions to be recreated without use of legacy knowledge and the learning outcome from previous mistakes (Oppenheim, 2004). It has the potential to create the waste in the piping detail engineering phase. **Table 2** in Section 4.4 shows that the driver of lack of knowledge sharing is one of the key waste drivers occur in the piping engineering for maintenance and modification projects at Aibel.

The knowledge is the true asset of the service-oriented organization and its integration across the departments and disciplines should be emphasized (Carneiro, 2001). Many service oriented organizations like Aibel are now engaged in Knowledge Management (KM) efforts in order to leverage the knowledge within the organization and externally with the customers (Malhotra 2000, 2001).

Valuable knowledge from the brilliant ideas of the experts is available in different forms and media such as operational procedures, documents, databases, intranets, etc. The knowledge sharing in the piping design aims to effectively and systematically collect and share the experience and knowledge.

Aibel modification projects like GEMC project often have sophisticated control and planning systems to produce large quantities of valuable information. The information is available in a large number of formats disseminated through variety of mediums. **Figure 31** illustrates the relationship between the knowledge sharing and the lean design in the piping engineering at Aibel. **Figure 31** shows the lack of common methodology to capture and communicate the knowledge. At present at Aibel in case study project, the Tacit Knowledge (TK) and the Explicit Knowledge (EK) stay as standalone knowledge in the organization. These need to be processed, well managed and keep available to user for better results in the organization as shown below in **Figure 31** (ref. Clough, 2000).

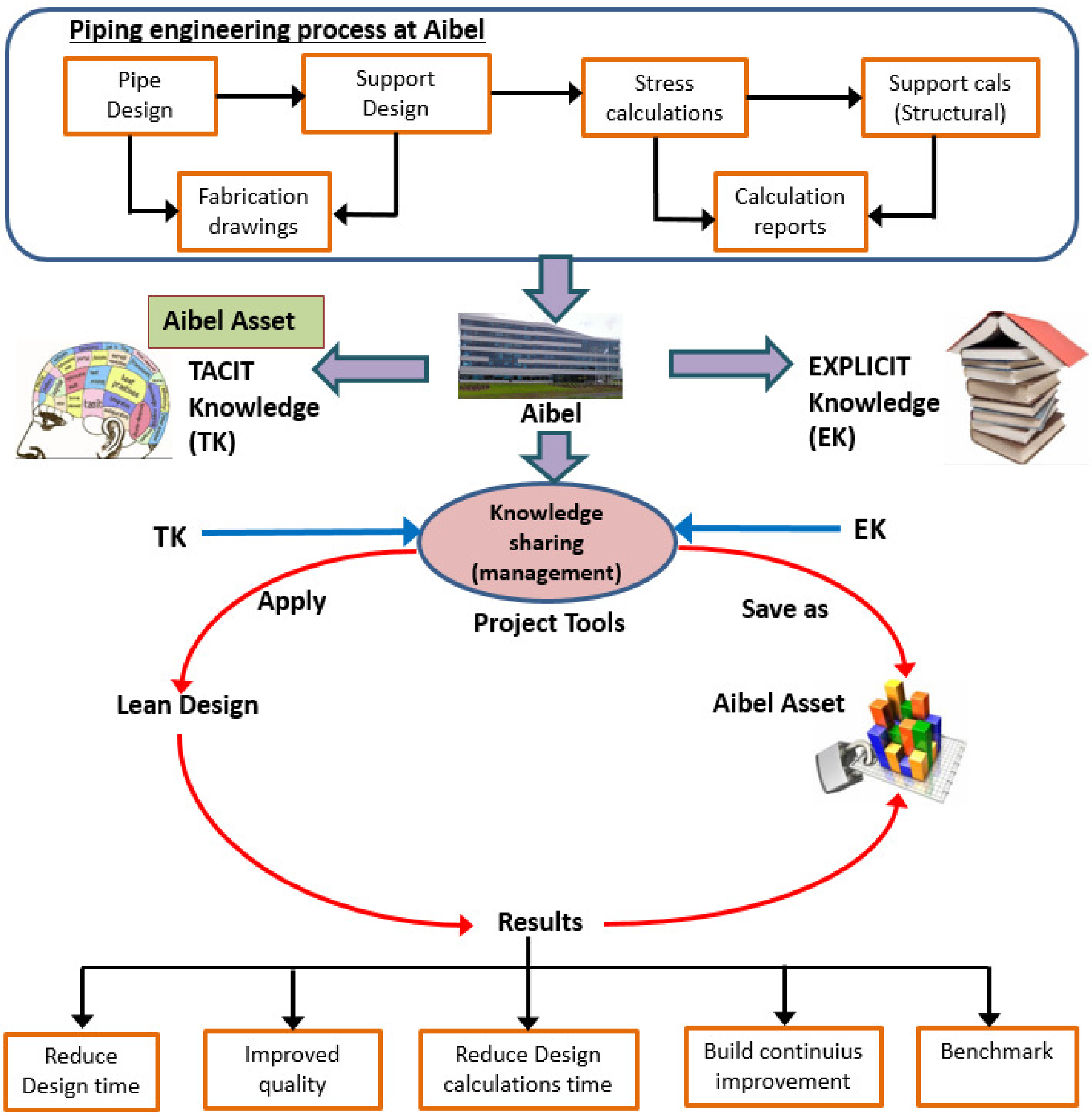


Figure 31 Relationship between knowledge sharing and lean design in piping

At Aibel, the Tacit Knowledge and the Explicit Knowledge are to be created based on the knowledge and experience generated from the project. The explicit Knowledge (EK) can be reused for other current and future projects to avoid repeating the same or similar mistakes. The application of knowledge sharing of EK in the lean design can reduce the cycle time, waste, design calculation time and can increase output quality in the piping design.

The practice in the lean design should apply the knowledge sharing in the whole design process. With the application of knowledge sharing, the storage and management of project-oriented tacit and explicit knowledge can be reused for others or future projects. Therefore, the advantage of knowledge sharing may meet the objectives of the lean design. It can be said that the knowledge sharing is one of the important and necessary tools for the lean design.

As described above in Section 4.4.2, the insufficient communication can be effect of the lack of knowledge sharing. The engineers as participants of up and downstream design processes do not communicate about each other's processes and requirements (Bauch, 2004) and this can be treated as lack knowledge sharing.

Practical example from the case study project at Aibel:

Pipe support material: During the case study at Aibel in GEMC project it was noticed that the lack of knowledge sharing was apparently contributing to the waste. Here, lack of knowledge sharing is discussed against use of pipe support material. For selection of the material for designing the pipe supports, the experienced employees at Aibel had adopted the different standards and procedures. This was due to veteran employees assumed that it was common knowledge. In fact they never shared their knowledge with others about the selection of the regular material for the pipe support. This is due to lack of communication as discussed in Section 4.4.2. The use of different material apart from the standards and procedures, results in increase of non-value added activities from design phase to the installation phase. In this case, according to the client's pipe support design procedure, the material should be Lean Duplex (LD) or stainless steel (316L). Whereas Aibel experienced employees used the Carbon Steel (CS) material. The CS material demands the maintenance in long run operations and the weight increases compared to the LD or 316L material. Here, the use of different material resulted in non-value activity in terms of increased weight and maintenance.

As mentioned above, if the entities of a process are unaware of the requirements then the adjacent processes down the value stream process. It might cause the waste due to a lack of knowledge sharing. In the piping design for modification projects, the designer needs to create the design to be more functional and should have the construction phase in mind.

The adjustability needs less resource demanding for makes potential rework during the construction phase (Bang & Stykket, 2015). For modification projects, the design should also be made with adjustability for example using bolts instead of welds to possible extent. The adjustability in design can be seen in relation with engineers' attitude. The engineers do not make use of the potential learning outcome from studying realized designs and it is in essence a lack of knowledge sharing. Consequently, the engineers had lack of required competence as discussed in Section 4.4.3 to create such designs.

As-built procedure: The pipe support drawings need to be as-built after received red markup drawings from the construction. The red markup drawings need to be updated in the design and re-produce drawing using the PDMS draft. At Aibel in the piping design, the process of updating the drawings is done using 2D tool as routine. The use of 2D tool is mainly due to the lack of standardization (Section 4.4.4). In the process of updating the red markup drawings, the pipe supports engineers edit the drawing by removing pipe support spool numbers, etc., even there is no need and red markup comment from the construction. The removal of spool numbers from the support drawings is not any value added activity to the piping design process. It was due to lack of knowledge sharing between design teams, disciplines, etc.

Support design calculations (structural): According to Aibel's pipe support work procedure from the W3, the pipe support design calculations shall be performed for critical lines (see Appendix 8) and for the supports loads more than 10kN. Whereas, in Aibel at the case study project the calculations were performed for all pipe supports including non-critical line support and also for the support loads below 10kN. These activities are non-value added activity to the project and to the client either. This is due to the lack of knowledge sharing among the discipline, design teams and client.

Chapter 5

Recommendations

This section provides a thorough description of the measures that eliminates the waste in the piping design during detail engineering phase. The measures were developed to eliminate the waste for the key waste drivers which were identified and analyzed in Section 4.4. These measures are based on the survey conducted at the case study project, the lean design principles described in Section 3.1 and the author's participant observation and physical artifacts at the case study company.

There are several techniques and tools that can be helpful to identify the waste. McManus (2005) identified that the value stream mapping and the Design Structure Matrix (DSM) are some of the most versatile tools for analyzing and changing the processes to eliminate the waste. The process analysis can uncover some of the wastes occurring in the processes and activities. Kotter (1996) states that eliminating the identified waste is not necessarily an easy process by making changes in the organization. Therefore, it might be necessary to show what extent the waste is present in order to give incentive to initiate the changes in the organization.

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 of waste can be applied to the total number of engineering hours and their respective costs which can show the direct economic impact on the measured waste. This might give the incentive for management to direct the focus towards continuous improvement for eliminating the waste.

Kalsaas (2013b) too supported this 'continuous improvement' statement and suggested that the direct focus towards continuous improvement is the most important aspect of measuring the percentage of hours wasted. However, it is important that the measurements do not focus too much on the cost. The measurements can be the resource of demanding. The relevant measurements need to be identified because the excessive measurements might be a wasteful activity in itself (Forsberg & Saukkoriipi, 2007).

Based on the above information from various sources, the author suggests that the perceived waste within the organization is more likely to be measured by surveys. The efforts to reduce the waste proven as economically beneficial to the organization and it should increase the likelihood that management will support the future efforts. The amount of the reduced waste is not able to be quantified but it can be specified in results as an improvement efforts.

Figure 32 illustrates the key waste driver's degree of occurrence in the piping design at Aibel [General results (5 people)]. The illustration was made based on general results of the survey from the collected data using various sources as described in Section 2.3 at the case study project.

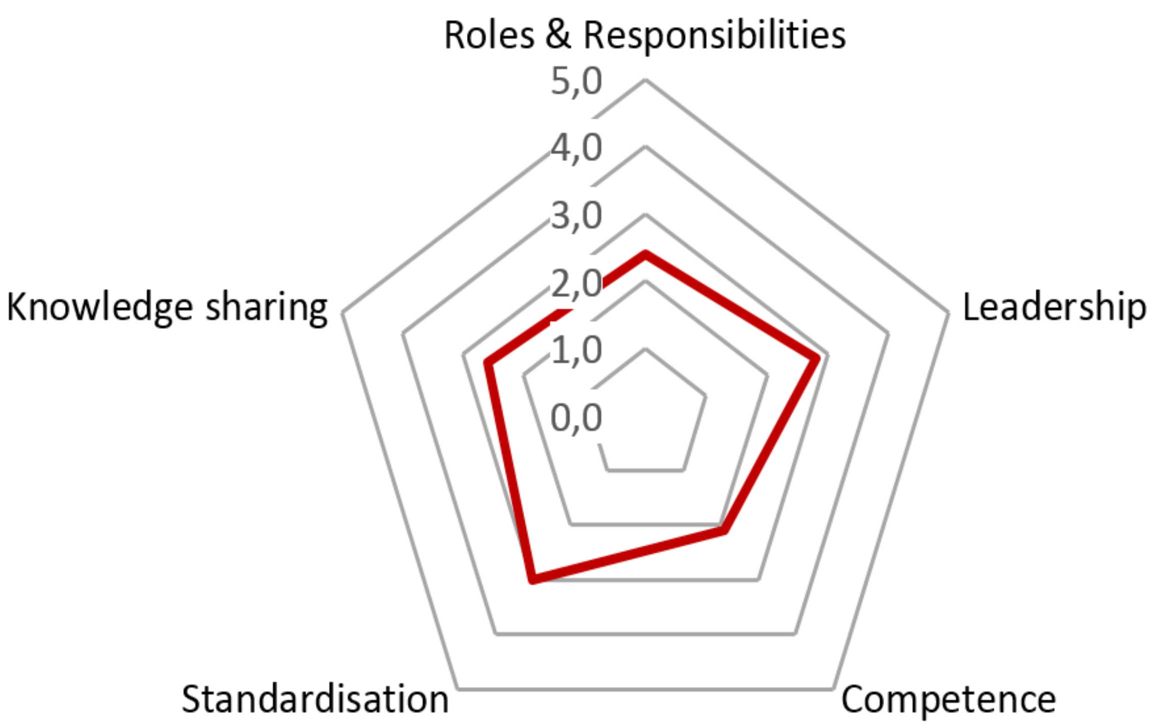


Figure 32 Key waste driver's degree of occurrence at Aibel in piping

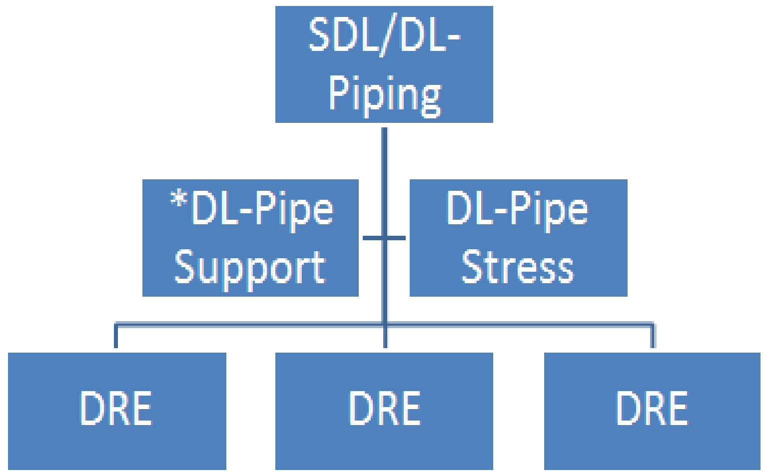
The presence of key waster drivers was measured during the survey given the range from ‘0 to 5’ to identify the extent of occurrences in piping design during detail engineering at the case study project. This motivates to identify and eliminate the waste in the piping design using the lean design principles. **Figure 32** illustrates that the presence of the waste is high due to the presence of the key waste drivers in the piping design, when it is placed away from the origin i.e. 0,0. Based on **Figure 32**, the few recommendations were made in the piping design to minimize the waste and were mapped here in subsequent sections.

5.1 Roles and Responsibility

a. After detailed review of responsibilities of the Senior Discipline Lead (SDL) and Discipline Lead (DL) roles in Section 4.4.1, it can be said that there is a functional similarity and overlapping of the responsibilities between the roles of SDL and DL in piping discipline. This overlapping of the responsibilities creates a responsibility gap between the roles. The overlapping roles make unclear about who should do a job and that usually leads to conflict and poor working relationships. Often, the Job is not done because each employee assumes that the other will do it. Due to overlapping of the responsibilities in a situation, nobody within those roles in the organization is obligated to perform certain necessary activities.

As noted above in section 3.1.2, Hanna (2007) states that the lean design process makes an attempt to withdraw unnecessary cost out of the organization having an objective of clear and rightful role & responsibilities between the employees.

Figure 33 illustrates the proposed organization chart for the piping discipline and it is based on the lean design principles and the surveyed results from the case study project at Aibel.



*Pipe support calculation for the load above 10kN (cumulative) will be done within a group and co-ordinate with Structural DL for structural integrity.

Figure 33 Proposed organization chart for piping discipline in Aibel

Figure 33 presents that the responsibilities of the Senior Discipline Lead (SDL) and the Discipline Lead (DL) roles in piping were merged into a single role. The merge is based on the overlap of responsibilities between SDL and DL as discussed and shown in **Figure 25** in Section 4.4.1. The SDL/DL assigns the projects to the Design Responsible Engineer (DRE) who gets the support from other design teams such as pipe support, pipe stress, etc.

The author recommends that the pipe support team should have the resources to perform the pipe support calculations. As discussed in Section 4.4.2, at present the structural engineer performs the support calculations and follows the information flow from his supervisor (SDL-Structural). In the piping design, the involvement of structural engineer makes presence of two different disciplines such as piping and structural. The involvement of more disciplines in the piping design may create a waste due to waiting time for other discipline to act. This waste can be eliminated by having the needed resources within the support design team.

For leading the team, the roles and responsibilities of leaders shall be such that they should have a great respect of their own with inherent confidence and also have the respect on the roles of actors in the team. Contrastingly, the informants in Aibel described an unstructured situation with actors and often felt unsure about their place in the organization. Additionally, the responsibilities in the design phase often differed from what was defined in early-phase. This raises question whether the roles and responsibilities have been clearly communicated to participants or simply forgotten.

b. Traditionally the organization can be drawn as a pyramid similar to an organization chart with the SDL at the top of the pyramid and the engineers at the base. The engineers can be highly skilled and sometimes very specialized. **Figure 34** illustrates that in the traditional organization the directions are given from the top in a command and control manner. In the lean design organization the pyramid is inverted so that the engineers are at the top and are supported by the rest of the organization. For having effective roles and responsibilities in the organization, the leader at the bottom of the pyramid in the lean organization is the critical success factor of effective lean design principles.

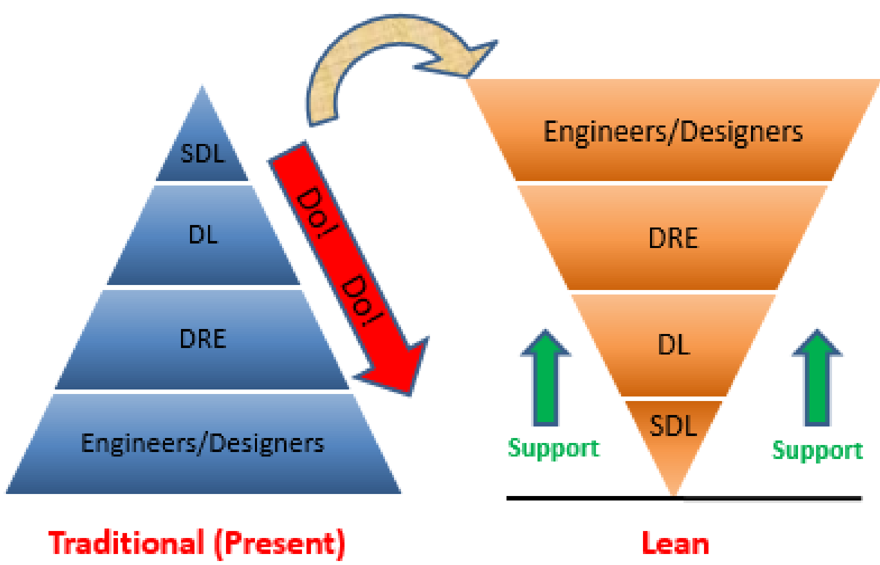


Figure 34 Roles with Lean leadership behavior (Based on Choppin, 1997)

5.2 Communication and Coordination (Leadership)

a. **Leadership**: Pietroforte (1997) states that understanding the organizational structure is an essential to have an effective leadership. The leadership plays a key role for the development of communication in the organizational structure.

The managers and the supervisors need to experientially learn and understand the values of facilitative leadership either as individuals or as a team in the piping discipline at the case study company. This leadership added benefits of enhancing the business projects as well as providing pre-defined business outputs, which lead to the direct organizational benefits shown in **Figure 18**.

As mentioned above in Section 4.4.2, Howell et al, (2004) stated, “the leadership in the lean design process approaches the linguistic action concept and conversations are the core of the organization work by making and keeping commitments among the design teams”. Based on this statement, the recommended qualities are given for the leadership roles at Aibel such as SDL and DL. The qualities are to improve the better understandings of transformational actions relevant to modern working status in various categories, which are:

- **Motivation**: This enables to understand the situations and motivate the team members as well as the individual practices.
- **Clear communication**: As the name implies, this falls into category that revolves around achieving the targets bound to fail if not properly communicated.
- **Change Implementation**: This provides insight related to the behavior within a team dynamic. It attempts to provide success during periods of restructuring through strategies arising from problems that occur during the process. The change implementation establishes clear objectives to achieve success and an individual will often have to take notes on the task.

b. As discussed in Section 4.4.2 through **Figure 26**, the practice of the current information flow at Aibel allows many actors in the decision-making process due to involvement of more informal communication. It increases the complexity in piping design. The information flow and communication are the integral part of design effort in piping design. Better communication and coordination between design teams keeps the effective information flow in piping design. It shows the importance of establishing the common mode of information flow using project tools in the piping design.

Figure 35 illustrates the recommended information flow diagram in piping design at Aibel for effective communication and coordination. This information flow diagram keeps the communication and information flow through using project 3D DM tools such as PDMS, STAAD, CAESAR, etc. It minimizes the informal communication and keeps the effective formal communication using 3D DM tools.

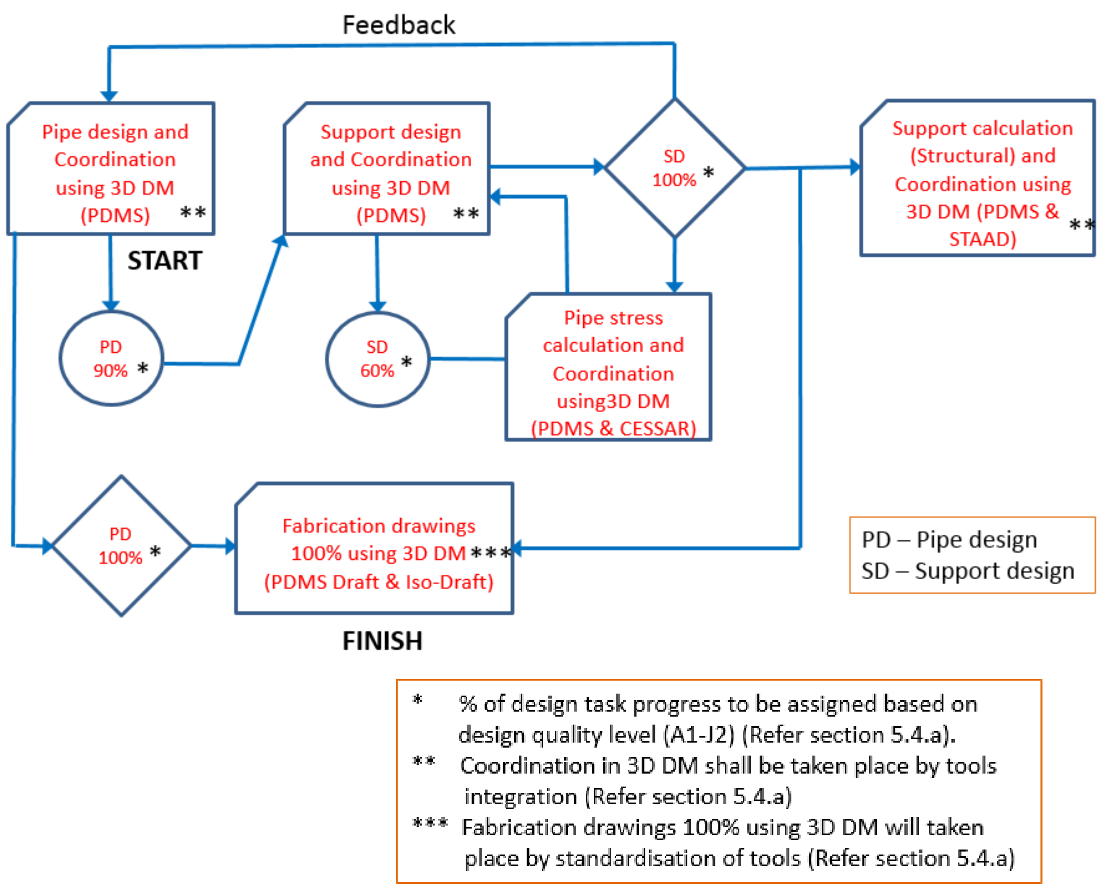


Figure 35 Recommended information flow for piping design at Aibel

Figure 35 demonstrates that the design information flow starts at the pipe design in the process of the piping design. After completing the 90% of design activity, the pipe design communicates the information to the support design using the 3D DM tool such as PDMS. The support design task is to identify and design the support and communicate to team of pipe stress using the 3D DM tool. The team of pipe stress needs to import the model of the pipe design and support design into the model of CEASAR and to provide the necessary information back to the support design. The support design needs to finalize the design by having close coordination with structural and having the information flow using the 3D DM tools as shown above in **Figure 35.**

The above information flow in the piping design can be established by standardizing the use of project's 3D DM tools. The project 3D DM tools need to be integrated for effective design information flow as discussed in Section 4.4.4. The needed integration of 3D DM tools in the piping design is given in Section 5.4.

5.3 Competence

Implementation of the lean design process in the piping design is an innovation process. This process results a growth in the organization and brings a new challenges every day. In order to compete the present oil and gas market the organization needs new approaches. The implementation of new approaches associated with the improvement of the organizational effectiveness and the role of people is essential.

Womack, J. P., & Jones, D. T. (2003) and Atkinson (2010) defined about the new understanding of the lean organization as discussed in Section 3.1.3. Based on this, the employees in the organization need to support the transformation of the lean organization by using the lean design professional profile. **Figure 36** illustrates the lean design professional profile in the pipe design at Aibel. It indicates the required competence by an employee as a change agent in the organization.

The conceptualization of the lean design professional profile provides a good framework to drive employee development within the piping design. Because it presents a complete model of competence areas needed by design professionals. The lean design professional profile focuses on each competence area required by an employee in piping design at Aibel for maintenance & modification projects as shown above in Section 4.4.3 through **Figure 27**.

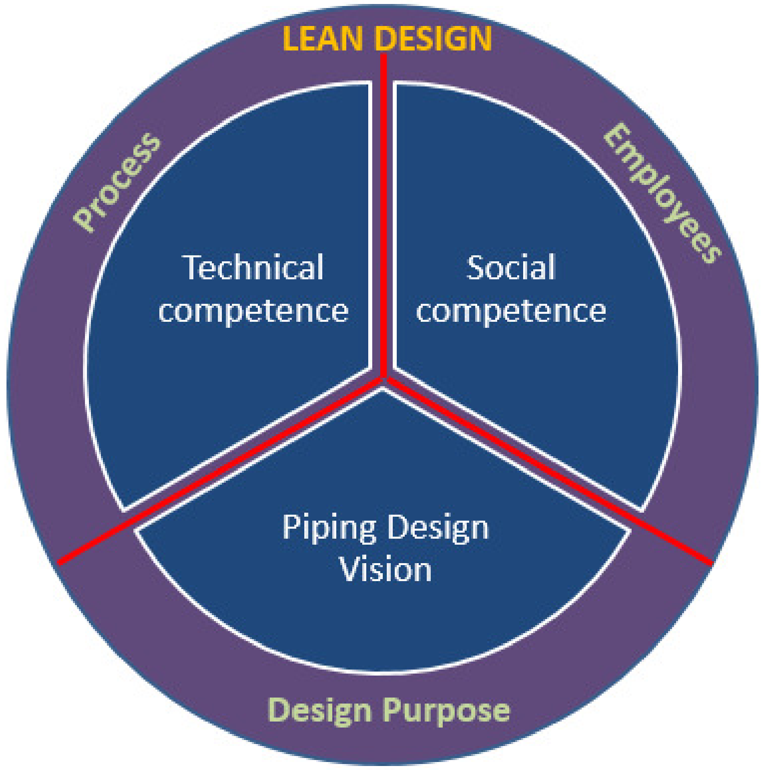


Figure 36 Use of lean design professional profile for Aibel in piping design

As shown above in **Figure 36,** the lean design professional profile includes the design purpose, design process and the employees. The core competence of an employee needs to be identified with respect to the technical competence, social competence and the piping design vision. The application of this profile is to evaluate employees at Aibel with respect to the characteristics of the lean design professional profile. This includes:

- Identifying the specific competences for each competence area as noted in **Figure 27**;
- Studying the differences among the professional's positions by each competence area;
- Defining the most important competences needs in each competence area to support lean design efficiently;
- Organizing the training programs to develop each competence area for the professional staff at Aibel.

5.4 Standardization

Figure 32 shows that there is greater need of standardization in the piping design to eliminate the waste. It motivates to use of the lean design principles and tools in the piping design to improve the quality and cost. The principles and tools allow reaching the design stability as a result of basic standardization which is one of the key successes of the lean design implementation. The implementation of the new design techniques and the design methods is a key element for eliminating the waste in the piping design. These techniques need to be standardized in the 3D DM tools, project documentation and planning tools.

The standardization needs to be in four potential areas of the piping design to eliminate the waste as shown in **Figure 28** in Section 4.4.4. The potential areas are the design tools, planning & documentation tools, engineering design and design procedures (W3). The recommendations are given in the four potential areas which are:

a. **Design Tools**: The relationship between the project and design tools (IT) and firm performance continues for interest of academics and practitioners (Devaraj & Kohli, 2003; Vickery et al., 2003). The Plant design Management System (PDMS) at Aibel is the key 3D DM tool in the piping design. The PDMS at Aibel is widely used as a design and drawing production 3D DM tool. The PDMS needs to be standardized for optimal use in the piping design to improve the productivity by eliminating the waste as shown in **Figure 29** and described in 4.4.4. The standardization process in PDMS is given below:

- **Design quality checklist**: The use of quality checklists is important to maintain the design quality according to the organizational standards. At preset in Aibel, the design checklists are available in the work management method (W3) and they need to be maintained at each stage of the design development. The waste is generated using the PDMS and quality checklists separately.

Based on the above, there is a greater need to maintain the quality checklist within the 3D DM tools. For example, maintaining the quality checklists of the pipe design and pipe support design in the PDMS Design and Draft modules. The maintenance enables the designer to set the status of the design and draft quality levels of checklists named at Aibel as A1, A2, B1, B2, C1, C2, J1 and J2. The status is usually set by reviewing the quality checklists in PDMS. This process enables eliminating the waste and delivering more predictable and quality design to the client.

- **Design tools integration**: The integration between the design tools such as PDMS, CEASAR, STAAD, etc. improves the communication between the design teams as discussed and shown in **Figure 35** in Section 5.2. The integration reduces the time required for developing the design models which are generally developed by the team of pipe stress and structural design. The reduced time is achieved by transferring the pipe design and the support design data to CEASAR model and STAAD model. The integration also eliminates the waste occurs due to changes in the piping design development. **Figure 37** shows the possibility of integration of 3D DM tools at Aibel in the piping design.

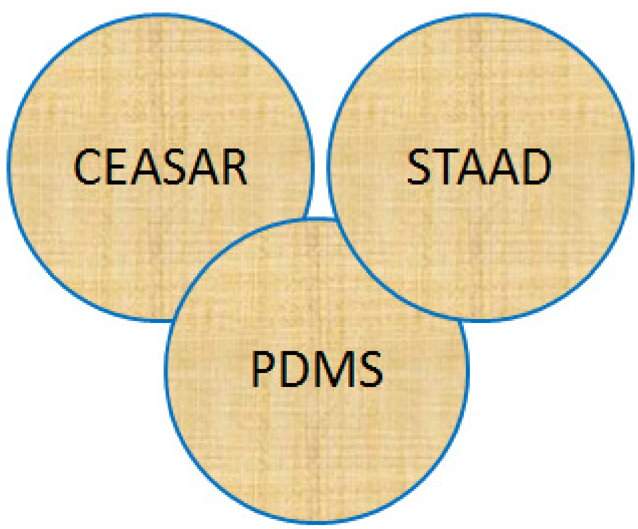


Figure 37 Integration of 3D DM tools at Aibel in piping design

- **Auto drawing production**: The auto drawing projection can be achieved by standardization of 3D DM tools such as PDMS Draft, CEASAR etc. This needs customizing the PDMS Draft and Iso Draft modules to produce the auto fabrication drawings for both pipe and support. The auto production can improve the project quality as well as delivery scheduled time and implement the site changes quickly.

During the survey at the case study company, it was noted that 2D tool (micro station) is partly used to produce the pipe support and pipe isometric fabrication drawings instead of using the 3D DM tool (PDMS). This can be overcome by having the standardization process within the PDMS Draft and Iso Draft modules. **Figure 38** presents the possible auto drawing production in the piping design using the PDMS.

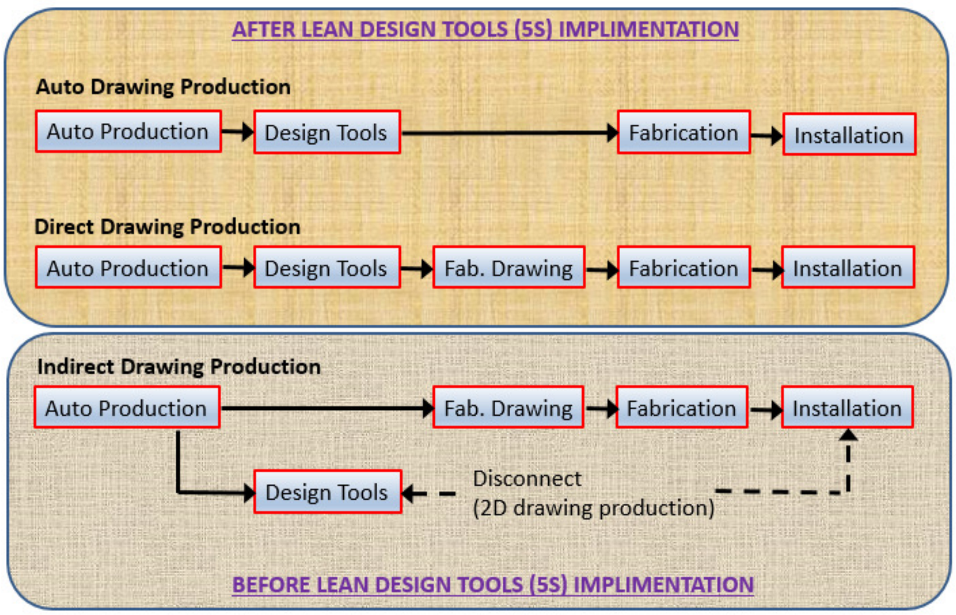


Figure 38 Auto drawing production at Aibel in piping design

Figure 38 shows the disconnection of the 3D DM (PDMS) tool during generating the fabrication drawings in indirect drawing production before implementation (standardization) of the lean design tools. The indirect drawing production demands greater effort to implement any changes from fabrication shop and construction. The PDMS can be standardized up to auto drawing production level or direct drawing production. The standardized method within the 3D DM tools needs to be available for the employees by sharing the knowledge as discussed in Section 4.4.5.

- **Auto progress**: The auto progress for each task can be made by using 3D DM tools after the design checklist standardization is in place as discussed above. This needs to be standardized within 3D DM tools (PDMS) by assigning the numerical value in ratio (%) for each stage of status of the given quality checklists: A1, A2, B1, B2, C1, C2, J1 and J2. This provides an overview of the status of predictable deliverables to the client and Aibel's management. The predictability plays a key role for managing the complex maintenance and modification projects in oil & gas sector as stated in Section 1.1.

b. **Planning and documentation tools**: The integration between the design and project tools (such as planning and documentation tools) leads to improve the organizational performance by reducing actual time needed to perform the task. As shown in **Figure 29** in section 4.4.4, there are advantages by establishing the integration between the 3D DM tools and project tools at Aibel. The integration benefits are accountable for the organization and the client through delivering the piping design in right time with right quality. **Figure 39** represents the possible integration between the 3D DM tools and project tools. This is made based on the survey conducted during the case study and the author's practical experience at Aibel.

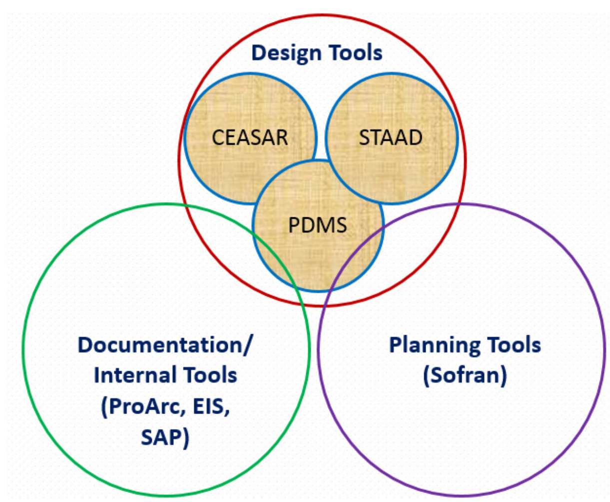


Figure 39 Integration of the 3D DM tools and project tools at Aibel

Integration of the tools at Aibel, as shown above in **Figure 39,** provides more effective and efficient performance of the task. As discussed above in Section 5.4.a, the customization of the PDMS design generates the auto progress. Whereas, the integration between PDMS and planning tool makes easier to generate the progress automatically in planning tool. The fabrication drawings can be transferred by having the integration between PDMS and documentation tools such as Proarc. Also, having the integration with EIS, the material order can be placed from PDMS design.

c. **Engineering Design and Work procedure (W3)**: Engineering design and work procedures are to be adopted for continues improvement process for eliminating the waste. This helps to minimize the design variability and reduce the non-added value activities to the design. The variability increases challenges for production of drawings and performing the design calculations. This needs to be minimized by standardization of engineering design and procedure as the continuous improvement process. **Figure 40** shows the wheel of continuous improvement process using the lean design tools (5S) in the engineering design and work procedures in relation with the time and improvement.

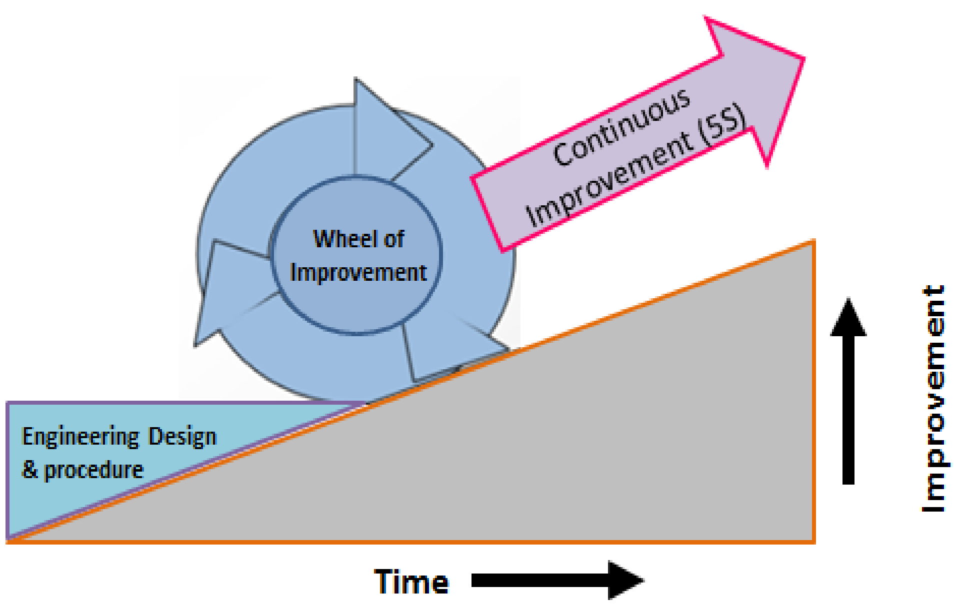


Figure 40 Wheel of improvement process in Aibel during piping design

5.5 Knowledge sharing

Knowledge sharing is the reuse of the information and knowledge from previous projects. It reduces the design time and problem-solving time in the piping design. Sharing the experience and knowledge solves the same problems quicker in the design, fabrication and construction phase. The knowledge sharing leads to the benefits that are: (1) the reduced cost of the problem solving; and (2) the decreased probability of repeat problems. To enable the knowledge sharing in place, the experience and the knowledge should be preserved and managed. It needs that experience and knowledge is captured, modeled, stored, retrieved, adapted, evaluated and maintained (Bergmann 2002). The latest communications and information technologies are to be used for improving collaboration, coordination and information exchange within the projects.

At Aibel, the knowledge sharing needs to focus on the integrated development of the piping design using by all project parties. It makes immediate access to all the piping design information of projects to everyone at various phases in the project. In order to enable re-using of the piping design solutions, the solutions must be created with reusability in mind and must be stored in an accessible location within 3D DM tools and project tools.

The knowledge sharing in Aibel can be optimized in different areas such as the design methods, project tools, replicate project data, etc. The best knowledge sharing methods could be achieved by optimization of the tacit knowledge (TE), the explicit knowledge (EK) and tools. It enables to keep the project cost low and improve the quality by meeting the organizational and client standards & procedures.

Figure 41 presents the possible improvements by knowledge sharing in the piping design at Aibel.

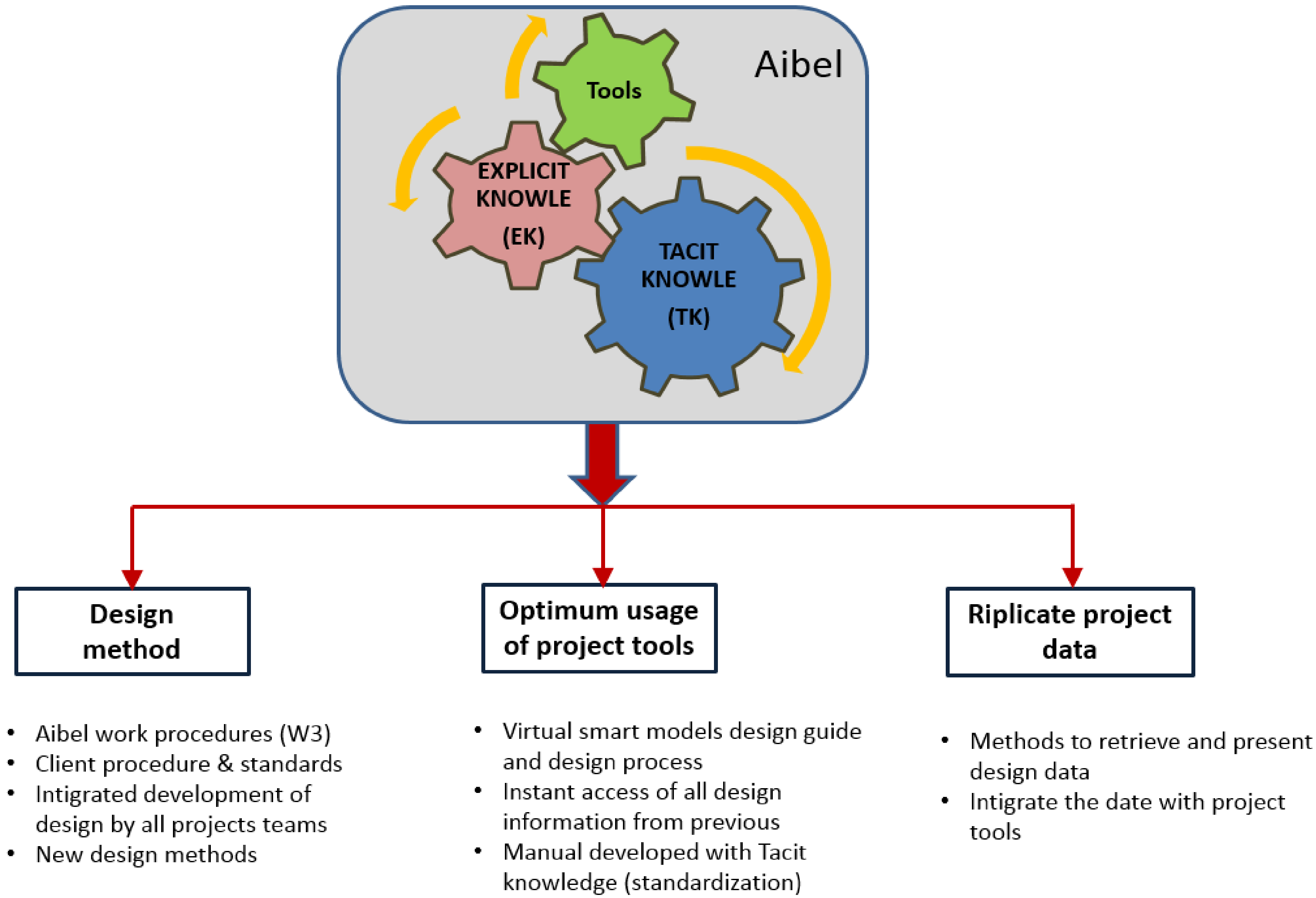


Figure 41 Areas of improvements for Knowledge sharing in Aibel

Chapter 6

Evaluation

Evaluation of an activity is central and essential in conducting the Design Research. The research evaluation is concerned with examining the research outputs such as recommendations given in Section 5.1 to 5.5, the design artifacts and the design theories (described in Section 3.1 and 3.2). Hevner et al (2004) stated that the evaluation is "critical" and "The utility, quality, and the efficacy of the design artifact must be rigorously demonstrated via well-executed evaluation methods".

The evaluation provides evidence that the new technology developed in the design research "works" and the research achieves the purpose for which it is designed. Without the evaluation, outcomes of the design research are unsubstantiated assertions of the designed artifacts. The artifacts can be achieved the design purpose after implementing and deploying in the practice. The design research requires evidence and it is to live up to its label as "science", and the evaluation must be sufficiently rigorous.

Hevner et al (2004) also further explain that the completeness and the effectiveness of the constructive research are determined based on the requirements and constraints of the research questions. They also state that the method of evaluation should match the construct.

For the evaluation, it needs to consider what kinds of qualities are useful. Hevner et al (2004) identified that the utility, quality and the efficacy are the attributes need to be evaluated. He further states, "Artifacts can be evaluated in terms of functionality, completeness, consistency, accuracy, performance, reliability, usability, fit with the organization and other relevant quality attributes".

Thus, the author would like to identify the feasible evaluation criteria for the research at the case study company at Aibel. For the evaluation process, the present design research work adapts some of the criteria suggested by Hevner et al. (2004). **Figure 42** presents the evaluation criteria for the design research

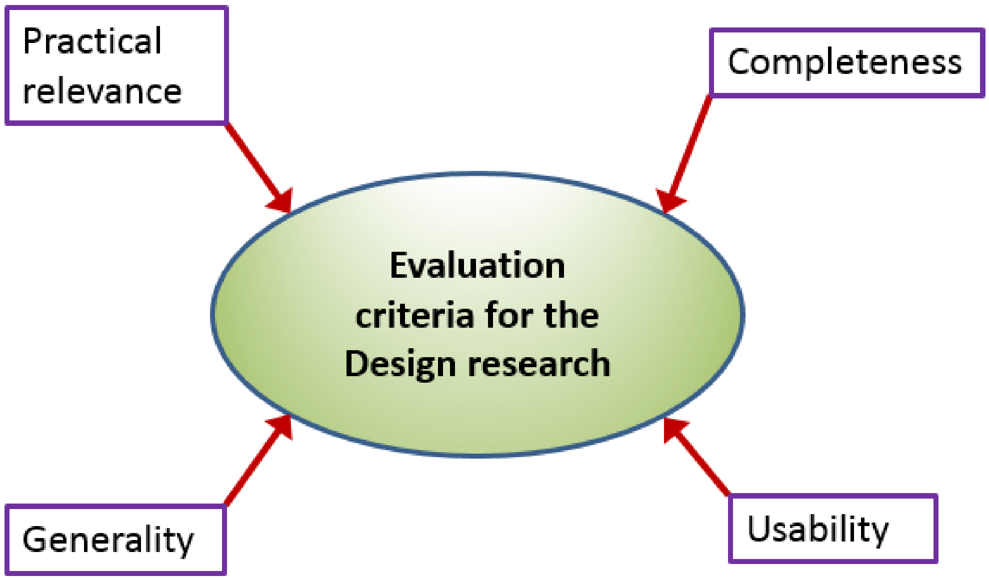


Figure 42 Evaluation criteria for the design research

Practical Relevance: The piping design phase plays a significant role during detail engineering for the maintenance and modification projects. Thus, it is of great importance to have good design processes. The piping design is common in many different engineering service industries. It indicates that making this process more effective and should be of interest to every organization. By creating awareness, the construct might enable the managers and the engineers to identify the waste related to the piping design in the organization.

When waste has been identified (Section 4.4), it becomes possible to implement the measures in order to eliminate or mitigate. In addition, it might contribute to more predictable piping design processes during detail engineering. Thus, the construct has the potential to contribute a higher level of productivity and efficiency which could result in more profitable operations. The profitable operations increase the potentiality of the organization to provide and ensure the jobs. Creating and ensuring the jobs will in result serve the society as it contributes to a healthy economy. Based on these aspects, the author believes that the construct has high practical relevance.

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

Here, the construct is to identify the waste drivers in piping during detail engineering process at Aibel, i.e., to identify the mechanisms that may potentially lead to waste. However, it is extremely challenging to create a list of waste drivers that account for all these possible mechanisms during the piping design process (see Section 5.1-5.5). This is partly due to the fact that the waste drivers and their relationships are context dependent. As the standardization (described in Section 5.4) demands interface with the Information Technology (IT), it can be expensive for a company to adopt IT due to the involvement of quantum of man-hours to be invested. Considering this aspect, it can be argued that the construct may not be feasible in some cases.

Structural barriers can be considered as independent waste drivers. Oehmen and Rebentisch (2010) explain that structural barriers can be perceived as those that create waste through organizational barriers which might cause ineffective communication. The physical location and distribution of team members can create organizational barriers, like executing the piping design task at multi locations in Aibel (see **Figure 7**). For example, making communication and coordination is more difficult, as face-to-face communication is not possible. Based on this, the author perceived that the structural barriers are important contributors to generate the waste in an organization level and that the barriers are not considered as independent waste drivers during the research.

Most importantly, the author is able to place all findings of the key waste drivers (see Section 4.1-4.4.5) holding the experience, the help from the Engineering Manager of the case study project and the several interviews at different levels in the discipline. Thus, the author argues that the construct yields, to a certain extent, completeness in relation to the requirements and constraints for minimizing the waste in the piping design for modification projects.

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 driver. Thus, the extent of its effectiveness, efficiency, and satisfaction will determine the usability of the construct while applying them in the piping design.

The purpose of the drivers is to create a more predictable piping design 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. However, the author has given the recommendations, considering practical existence of them at other organizations located locally and globally. Thus, the organization of the case study company can have the usability of the construct which can be presumed effective with its own degree of effectiveness.

Koskela et al. (2013) introduced the terms core and lead wastes. 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 design process. The purpose of categorizing of the wastes in this manner is to identify chains of them. In essence, the chains of wastes are described as chains of causes and effects, where one waste leads to another. As the majority of waste drivers listed in Section 4.4 can affect one on another depending on the context, the author argues that categorizing waste drivers into core and lead waste can be of limited benefit.

Employees in the organization need to identify the elements in the engineering process innovatively by doing their roles and responsibilities. This could perhaps improve the economy and productivity of the organization, which arguably will satisfy its members. Thus, it is believed that the Aibel will get benefit of improved productivity and economy by using mechanisms of the key waste drivers. In essence, it is also believed that the usability is to be adequate when the purpose is to create awareness of the waste drivers.

Generality: Evaluating the generality of the construct is an important element of the constructive research design, as one of the objectives is to apply the theoretical background to the construct used in the present research. In addition, it should be beneficial for the case company being studied. It is believed that the main theoretical contribution is related to the conceptualization of the waste in the piping design during detail engineering for modification projects.

The objective is to provide a construct that is applicable for the oil and gas service industries and organizations like Aibel, for which the piping design is part of it. The construct demonstrates that the prominence of the key waste drivers might differ among the industries and organizations. The degree of which different drivers are present will vary depending on the type of the industries and organizations. For this reason, the present study considers that the construct is possibly of limited usefulness to generalize the importance of the different key waste drivers.

Furthermore, the product of any piping design activity is information. In addition, the concept of waste elimination is equally relevant for any organization, despite if the lean is the philosophy or not. 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 the piping design. It can be said that the findings from this case study might vary from other organizations or different projects at Aibel. Thus, the author believes that the findings from the case study only strengthen the generality of the construct.

Chapter 7

Summary and Conclusions

At present, there is a greater competition in oil and gas market for winning the maintenance & modification projects. This is basically due to the increased competition between competitors globally. In order to be sustainable in the present competitive market, it is essential for the companies like Aibel to develop effective organizational operations in the piping design during detail engineering phase for maintenance and modification projects.

Over the years, manufacturing companies have been able to improve their effectiveness by using the lean design principles. The present study considers the use of the lean design principles in the area of the piping design for engineering services companies like Aibel. The main objective of the present study is to apply the lean design principles for the elimination of the waste in the piping design during detail engineering process. For the elimination of waste, the lean principles based on the previous studies of "lean manufacturing" and "lean construction" was used as a starting point for the present thesis work.

The key waste drivers in the piping design were identified based on the author's industry experience and the interviews conducted at Aibel. As listed in Section 4.4, the identified key waste drivers in the piping design are: Unclear roles and responsibilities; Insufficient communication and coordination between the design teams and leadership; Lack of required competence; Lack of standardization; and Lack of knowledge sharing. The waste drivers have been analyzed by applying the lean design principles. The recommendations were given for eliminating the waste to improve the operational effectiveness of the piping design at the case study company at Aibel. An evaluation of the given recommendations was performed using the feasible evaluation criteria based on the above mentioned lean design principles. The evaluation process was based on the design artifacts such as the usability, completeness, practical relevance, and the generality.

Based on the present study, the following conclusions are made:

- The use of the lean design process enables predictable piping design during detail engineering process through increased awareness about the mechanisms that lead to the waste.
- The key waste drivers need to be identified to mitigate or eliminate the waste.
- There is a functional similarity and overlapping of the responsibilities between the roles of leadership. It creates gap of responsibility between the roles.
- It is important to establish common mode of information flow using the project tools for better communication and coordination between the piping design teams.
- Leadership requires the qualities to improve the better understandings of transformational actions related to motivation, clear communication and change implementation.
- The core technical and social competences of an employee need to be evaluated with respect to the characteristics of the lean design professional profile.
- The standardization and integration of design tools, planning & documentation tools, engineering design and design procedures (W3) need to be done.
- The evaluation study shows that the generality and practical relevance of given recommendations is high.
- The practical relevance, completeness, usability and generality need to be considered relevant for the managers and engineers to identify the waste related to the piping design in the organization.
- The elimination of the waste yields the reduced design variations, reduced cost and improved quality of design, and further makes the operational process more effective and predictable.

Chapter 8

Suggestions for Future work

The present section gives summary of suggestions for future work based on the assumptions considered in the present study. The following suggestions are with respect to the hidden waste and waste drivers, standardization, and implementation of set of recommendations described in Section 5 for live project:

- Present study covers the elimination of the waste considering the selection of few important key waste drivers only. But, practically speaking, there are lots of hidden waste and waste drivers such as 'Underutilization of Resources, Over-engineering, Unclear Goals, Objectives and Visions, and Interpretability of Information', which were not part of the present study. These hidden waste and waste drivers need to be considered for analyzing the organizational performance and obtaining more refined results with respect to the quality, predictability, cost and time in the piping design.

- The work suggests the recommendations to be applied for the selected project. Due to the limited time and the selected project is in the middle of the execution phase, the suggested recommendations were not fully applied for quantifying the real waste in the piping design. In other words, the obtained results are qualitatively feasible, but they are further to be assessed quantitatively with respect to live project.

- In the current industry practice, it has been traditional to look for robust solutions which sometimes lead to overlook practical situations. For example, the design uses client's Technical Control Documents (TCDs) which were standardized for a long while ago and may not be economically suitable for some cases in current competitive situation. This standardization hinders to provide the simplified design solutions in the piping design. Therefore, for quantifying the waste during the analysis, the waste due to client's TCDs needs to be assessed in addition to the waste and waste drivers from the service industry.

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Appendices

Appendix 1: Interview guide

Part 1: General information

- Age
- Education
- Total work experience (years)
- Responsibility in the company
- How long in this position?

Part 2: Value creation in piping design

- How would you describe value creation process within the piping design?
- What are the primary and support activities?
- How would you describe the structure of the department based on roles and responsibilities within piping design including SDL, DL, etc.?
- How would be the impact of leadership in the process of piping design?
- What are core competency required and its unique contribution for piping design?
- How would you describe the culture within the piping discipline?

Part 3: Innovation - standard and routines within the piping department

- What do you relate with concept of innovation during piping design?
- Is workload in your department associated with innovation?
- If yes, to what degree? In what way?
- How does innovation contribute within the organization to eliminate waste?

Part 4: Lean concept – comprehension

- What do you relate with concept of lean in piping design during detail engineering for maintenance and modification projects?
- Which principles are in your opinion the most important?
- What percentage would you consider "necessary waste" - needed under the current system, but needed to be eliminated under some conceivable improved system?
- What can be done to eliminate waste due to cause of waste drivers?

Appendix 2: Senior Discipline Lead responsibilities

Role Description

RD-ENG-M Senior Discipline Lead MMOFA

Project/Area: M&M Frame Agreements
Organization unit: Engineering

Reports to: RD-ENG-M Engineering Manager

Status: Approved
Revision: 4

Approved by: Joffre Jatem

Approval date: 05 05 2015

Description of change:
Updated to be PEP specific

1. PURPOSE AND SCOPE

The purpose of this job description is to define organisational placement, responsibility and authority for the Senior Discipline Lead

2. RESPONSIBILITY AND AUTHORITY

The position has authority according to the area of responsibility unless stated otherwise elsewhere.

Senior Discipline Lead:

- is responsible for leading and coordinating the engineering team under the relevant section.
- is overall responsible for all engineering processes and resources within the contract under the relevant section.
- is overall responsible for design carried out in accordance with the governing documents provided in the project's QA system (procedures, instructions and procedures) and that these are available, updated and well known in the engineering teams under the relevant section.
- is overall responsible for that the engineering disciplines, under the relevant section, is manned with adequate resources with correct competence to meet the mandatory scope.
- is overall responsible for training and experience transfer.
- is responsible for developing and implementing supervisory and QA plans to verify the quality of the project deliverables
- shall ensure the use of correct methods and tools for engineering tasks are maintained and implemented within the relevant section.
- is responsible for identifying any requirement for optimizing W3 execution method
- is responsible for Aibel's HSE goals are implemented and followed up in the engineering

3. JOB TASKS

Senior Discipline Lead shall:

- define, estimate, schedule, execute and co-ordinate all activities within areas of responsibility.
- mobilise and maintain the engineering organisation staffed with qualified personnel and sufficient resources within the relevant section..
- be familiar with applicable statutory requirements, laws, rules and regulations, and be responsible for implementing those in own organisation
- ensure that the work is done to the specified quality. Perform verifications as required
- ensure that the engineering personnel have a responsible attitude towards manhour budgets and schedule. Arrange required training as required
- ensure that the engineering disciplines are performing as planned and execute corrective actions as required
- ensure integration of supplier or other contractors personnel in the organisation when required
- together with Engineering Manager identify office space and determine correct rate category for the discipline personnel
- manage the discipline’s resources between the ongoing projects based on requirements given from the Discipline Responsible Engineers in the various projects
- ensure a smooth integration of new personnel within own discipline. This includes appointing of a mentor for each new person and a close follow up during the first months in the project
- assign project resources with appropriate expertise from the reported demand of Engineering Team Lead in cooperation with the Discipline Responsible Engineer. This implies both mobilisation and demobilisation of personnel
- ensure that HSE activities within area of responsibility are carried out.
- give guidance and instructions to subordinates, and create good relations between the members of the team
- ensure that all personnel are placed in the correct category
- report changes regarding the workforce situation in RePro on minimum a monthly basis
- ensure that personnel rates correspond with the average manhour rates
- work actively towards achieving a good working environment (professionally and socially)

4. GENERAL

- This Job Description is valid until a new revision is made.
- Authority, not responsibility, can be delegated.
- HSE is a line responsibility. All employees are responsible for quality, health, safety and environment care in the daily work.
- Report to Engineering Manager on actual or envisaged problems, which might have an effect on overall project execution.
- Experience transfer is a part of all employees' job tasks.

Appendix 3: Discipline Lead responsibilities

Role Description

RD-ENG-L Discipline Lead

Project/Area: MOD
Organization unit: Engineering

Reports to:

Status: Approved
Revision: 1

Approved by: John-Helge-B Ekrene

Approval date: 02 05 2016

Description of change:
Updated approver.

1. PURPOSE AND SCOPE

The purpose of this role description is to define authority and responsibilities for the relevant role.

2. AUTHORITY

The project role has authority according to the area of responsibility unless stated otherwise elsewhere, ref. Project Authority and Responsibility Matrix Procedure.

3. RESPONSIBILITIES

The role is responsible for the following:

3.1 HSE

The Role is responsible for the following HSE requirements:

- Ensuring that all HSE requirements are attended to and becomes a natural part of the daily work
- To communicate and implement Aibel's HSE program and objectives under his/ her managemen
- To ensure that responsibilities described in "HSE my responsibility" are communicated to personnel under his/ her management
- To communicate a positive HSE attitude, and to demonstrate commitment to proactive and continual improvement of the HSE performance
- To ensure that all HSE risks related to the responsibility are identified and assessed, and that preventive measures are implemented when required

3.2 PERSONAL RESPONSIBILITIES

- Organize own unit according to W3 principles and mobilize qualified personnel.
- Initiate, schedule, follow-up and report own organisation unit's activities.
- Ensure that the work is carried out according to applicable governing documents in W3.
- Ensure that personnel within own organization have a good understanding of the project contractual requirements, goals and risks.
- Familiar with applicable statutory requirements, laws, rules and regulations.
- Give guidance and instructions to subordinates, motivate and arrange for good relations between the members of the team.
- Ensure that personnel in own organisation is familiar with he organisation principles and thus who is mandated to give instructions.
- Proactivly seek information and/or clarification needed from other roles / organisation units to enable continuation and completion of own organisation unit's work.
- Develop colleagues and support resource owners with feedback on employees.
- Ensure that own organisation unit have focus on cost-effective solutions.
- Link to Aibel Values, People and leadership: http://waywework.aibel.com/waywework/BusinessProcessNetwork/75ece7f8-201e-4047-ac44-4a763dcf018f.htm

3.3 ROLE ESSENTIALS

Discipline Lead is responsible for discipline(s) engineering activities and to ensure that they are carried out in accordance with pertinent specifications, statutory and other contractual requirements, with due regard to safety, operability, maintainability and constructability aspects The Discipline Lead shall ensure that the work within the discipline(s) is carried out according to plan and that progress is reported. The Discipline Lead shall ensure that potential changes/deviations are identified and logged in accordance with project change control system.

- Report to Engineering Manager on work progress and actual or envisaged critical activities, which might have an effect on overall project execution.
- Define, budget, schedule, execute and co-ordinate all activities within own areas of responsibility
- Ensure that all deliverables are completed on time, in accordance with the project schedules
- Ensure HSE activities within area of responsibility are carried out
- Prepare and maintain a positive working environment for the members within the discipline
- Give input to overall Scope Alignment document
- Participate in system and/or 3D model reviews and HAZOP's as required
- Define and request required resources within discipline group
- Establish, implement and maintain procedures and work instructions required by the discipline work groups
- Define and communicate need for IS/ IT systems and support
- Ensure that vendor information required to progress the work are identified and communicated
- Implement project strategies and philosophies
- Make contract, specifications, project requirements, challenges and success criteria known
- Report technical status and progress for discipline scope of work
- Plan , execute and report discipline verification on the work performed in the multidiscipline work groups
- Establish filing system, including master files
- Identify external interface requirements and supply timely information to the agreed quality
- Shall at all times encourage to and seek improvements to the project's cost and schedule
- Is responsible for establishing and maintaining a discipline document list for the discipline deliverables
- Is responsible for performing DIC/IDC activities within own discipline and IDC checking of other discipline documents when applicable for the discipline Scope of Work
- Is responsible for co-ordination of resources to the multidiscipline work

3.4 ROLE SPECIFIC RESPONSIBILITIES

Perform activities according to W3

1. Discipline Approver
2. DRE Disciplines

Appendix 4: Discipline Responsible Engineer Responsibilities

Role Description

RD-ENG-L Discipline Responsible Engineer

Project/Area:	MOD
Organization unit:	Engineering
Reports to:	
Status:	Approved
Revision:	1
Approved by:	John-Helge-B Ekrene
Approval date:	02 05 2016

Description of change:
Updated approver.

1. PURPOSE AND SCOPE

The purpose of this role description is to define authority and responsibilities for the relevant role.

2. AUTHORITY

The project role has authority according to the area of responsibility unless stated otherwise elsewhere, ref. Project Authority and Responsibility Matrix Procedure.

3. RESPONSIBILITIES

The role is responsible for the following:

3.1 HSE

The Role is responsible for the following HSE requirements:

- Ensuring that all HSE requirements are attended to and becomes a natural part of the daily work
- To communicate and implement Aibel's HSE program and objectives under his/ her management
- To ensure that responsibilities described in "HSE my responsibility" are communicated to personnel under his/ her management
- To communicate a positive HSE attitude, and to demonstrate commitment to proactive and continual improvement of the HSE performance
- To ensure that all HSE risks related to the responsibility are identified and assessed, and that preventive measures are implemented when required

3.2 PERSONAL RESPONSIBILITIES

- Organize own unit according to W3 principles and mobilize qualified personnel.
- Initiate, schedule, follow-up and report own organisation unit's activities.
- Ensure that the work is carried out according to applicable governing documents in W3.
- Ensure that personnel within own organization have a good understanding of the project contractual requirements, goals and risks.
- Familiar with applicable statutory requirements, laws, rules and regulations.
- Give guidance and instructions to subordinates, motivate and arrange for good relations between the members of the team.
- Ensure that personnel in own organisation is familiar with the organisation principles and thus who is mandated to give instructions.
- Proactively seek information and/or clarification needed from other roles / organisation units to enable continuation and completion of own organisation unit's work.
- Develop colleagues and support resource owners with feedback on employees.
- Ensure that own organisation unit have focus on cost-effective solutions.
- Link to Aibel Values, People and leadership: http://waywework.aibel.com/waywework/BusinessProcessNetwork/75ece7f8-201e-4047-ac44-4a763dcf018f.htm

3.3 ROLE ESSENTIALS

Discipline Responsible Engineer (DRE) is responsible for discipline engineering activities. The DRE shall ensure that the work within the discipline is carried out according to plan and that progress is reported. The DRE shall ensure that potential changes/deviations are identified and logged in accordance with project change control system.

- Taking ownership for own discipline plan activities and report to Discipline Lead on critical activities, which might have an effect on overall project execution
- Ensuring that schedule and man-hour budgets and plan activities are understood and followed within the discipline
- Ensuring timely delivery of LCI information both in IT-system and in document format
- Actively communicate and ensure implementation of approved changes
- Responsible for establishing and maintaining a discipline document list for the discipline deliverables within own areas of responsibility
- Responsible for performing DIC/IDC activities within own discipline and IDC checking of other discipline documents when applicable for the Scope of Work.

3.4 ROLE SPECIFIC RESPONSIBILITIES

Perform activities according to W3:

1. Discipline Approver
2. DRE Disciplines

Appendix 5: Piping Engineer responsibilities

Role Description

RD-ENG-L Piping Engineer

Project/Area: MOD
Organization unit: Engineering

Reports to:

Status: Approved
Revision: 1

Approved by: John-Helge-B Ekrene

Approval date: 02 05 2016

Description of change:
Updated approver.

1. PURPOSE AND SCOPE

The purpose with this role description is to define authority and responsibilities for Job tasks for a Piping Engineer.

2. AUTHORITY

The project role has authority according to the area of responsibility unless stated otherwise elsewhere, ref. Project Authority and Responsibility Matrix Procedure.

3. RESPONSIBILITIES

The role is responsible for the following:

3.1 HSE

- The Role is responsible for the following:
- To ensure that health, safety and environment as described in "HSE my responsibility" is a natural part of the daily work
- To assess HSE risks related to own work, and to implement and comply with necessary measures

3.2 PERSONAL RESPONSIBILITIES

- Ensure that own work is performed according to applicable governing documents in W3, correct IT applications, the clients governing documentation and the authorities' rules and regulations.
- Ensure that own work is performed according to project schedules and that information is exchanged according to agreed dates allowing time for quality control.
- Proactively seek information and/or clarification needed from other roles to enable continuation and completion of own work.
- Ensure quality and self-check of own work performed.
- Ensure that changes to own work is handled according to the Change process.
- Respect the line of authorities as written in the contract.
- When facing improvement proposals and changes, ensure that instructions are coming from mandated personnel.
- Reporting of status / progress for own work to DRE / Team lead on a regular basis.
- Contribution to continuous improvements through reporting of Non Conformances and suggestions for improvements.

3.3 ROLE ESSENTIALS

- Be familiar with PDMS handbook
- Perform PDMS structural design including 2D Draft work
- Perform Piping design work in Study phase, Detail Engineering and As-Built phase
- Ensure correct communication between discipline members
- Produce discipline drawings and documents
- Assist / Input to work packages
- Perform offshore survey as requirednter-act with other disciplines
- Perform discipline and inter discipline checks of drawing and documents
- Participate in the internal design review if required
- Follow up piping design Prefab and Offshore Installation work if required

3.4 ROLE SPECIFIC RESPONSIBILITIES

Perform activities according to W3:

04-02-02-L Design Line
04-04-03-L Design Pipe support

Appendix 6: Structural Design Engineer responsibilities

Role Description

RD-ENG-L Structural Design Engineer

Project/Area: MOD
Organization unit: Engineering

Reports to:

Status: Approved
Revision: 1

Approved by: John-Helge-B Ekrene

Approval date: 02 05 2016

Description of change:
Updated approver.

1. PURPOSE AND SCOPE

The purpose with this role description is to define authority and responsibilities for Job tasks for a Structural Design Engineer.

2. AUTHORITY

The project role has authority according to the area of responsibility unless stated otherwise elsewhere, ref. Project Authority and Responsibility Matrix Procedure.

3. RESPONSIBILITIES

The role is responsible for the following:

3.1 HSE

• The Role is responsible for the following:
• To ensure that health, safety and environment as described in "HSE my responsibility" is a natural part of the daily work
• To assess HSE risks related to own work, and to implement and comply with necessary measures

3.2 PERSONAL RESPONSIBILITIES

• Ensure that own work is performed according to applicable governing documents in W3, correct IT applications, the clients governing documentation and the authorities' rules and regulations.
• Ensure that own work is performed according to project schedules and that information is exchanged according to agreed dates allowing time for quality control.
• Proactively seek information and/or clarification needed from other roles to enable continuation and completion of own work.
• Ensure quality and self-check of own work performed.
• Ensure that changes to own work is handled according to the Change process.
• Respect the line of authorities as written in the contract.
• When facing improvement proposals and changes, ensure that instructions are coming from mandated personnel.
• Reporting of status / progress for own work to DRE / Team lead on a regular basis.
• Contribution to continuous improvements through reporting of Non Conformances and suggestions for improvements.

3.3 ROLE ESSENTIALS

• Perform PDMS structural design including 2D Draft work
• Be familiar with PDMS handbook
• Perform Structural work in Study phase, Detail Engineering and As-Built phase
• Ensure correct communication between discipline members by using Structural Design Input (SDI)
• Produce discipline drawings and documents
• Assist / Input to work packages
• Perform offshore survey as required
• Inter-act with other disciplines
• Perform discipline and inter discipline checks of drawing and documents
• Participate in the internal design review if required
• Follow up structural design Prefab and Offshore Installation work if required

3.4 ROLE SPECIFIC RESPONSIBILITIES

Perform activities according to W3:
04-04-05-M Design main steel
04-04-06-M Design secondary and outfitting steel
04-04-10-05-ABL Establish structural design basis
04-04-10-08-M Establish SDI

Appendix 7: Client SAP notification – PMO 6297745

aibel

ConocoPhillips

KONTRAKT NR.: 4600007588 GEM

Greater Ekofisk Modifications

PMO FEL STUDIERAPPORT

01A		Issued for Approval		
Rev.	Utarbeidet dato	Beskrivelse	Prosjektingeniør	Prosjektleder

Kunde:

ConocoPhillips

Kontraktør:

aibel

Aibel AS

Prosjekt nr: **3003**	Prosjekt tittel: PMO	Disiplin:	AFE/PMO nr.: **6297745**
Dokument type: RF	Område: P05	System: 140	Plant.: EKOB

Dokument tittel:

FEL REPORT PMO 6297745 BEVEGELSE AV LINJER UT TESTSEPERATOR

Dokument nr.: **3003-G-RA-00232**	Rev.: 01A	Side: 1 of 14

Appendix 7: Client SAP notification – PMO 6297745

INNHOLDSFORTEGNELSE

Kap. Side

Appendix 7: Client SAP notification – PMO 6297745

1 GENERELT

1.1 Problembeskrivelse

Notification 13324638 has highlighted that there are several lines that are poorly supported as they exit the Test Separator 95-5001 on the EKOB platform. If slugging occurs in the test separator then the movement in the lines becomes much worse. Oil line 5002-c1-4" suffers from the largest deflections of approximately 20cm. One pipe support has broken off completely from the structural steelwork. The line numbers affected are: oil lines 5002-c1-4", 5002-c1-6" and 5003-p601L-4", and water line 140-06172-dd10-4"-pw-0. The pipes are located at the test separator / slop oil area, east of the pig launcher.

The details of these lines are as follows:-

Line No's:	5002-c1-6", 5002-c1-4", 5003-p601L-4" & 06172-dd10-4"
P&ID:	FDSD-02-MF-00010
Line design conditions:	91 barg @ 130 ºC
Piping classes:	C1, P601, DD10

1.2 Foreslått teknisk løsning

DELETE BY AUTHOR. Not relevant to case study.

1.3 Kostnadssammendrag

DELETE BY AUTHOR. Not relevant to case study.

1.4 Installasjonsperiode

DELETE BY AUTHOR. Not relevant to case study.

1.5 Mekanisk

1.6 Struktur

1.7 Sikkerhet

Appendix 8: Aibel pipe support work procedure (W3)

Work Instruction

04-04-WI-KL-06-L Pipe Support Design

Sub process: 04-04-L Area Engineering

Discipline: Piping

Valid area: MOD

Responsible: Yavuz Renda

Status: Approved
Revision: 2

Approved by: John-Helge-B Ekrene

Revision date: 16 06 2016

Description of change:
Updated responsible and approver.

1 PURPOSE AND SCOPE

The purpose of this Work Instruction is to outline the philosophy of Pipe Supporting and to define the basis for the pipe support engineer's responsibilities and activities to be performed.

This WI shall be used for both onshore and offshore projects.

This WI does not cover instrument Tubing, Subsea Pipe work and Risers, Flexible Hoses, HVAC Ducting, Buried onshore Piping.

2 RESPONSIBILITY AND AUTHORITY

It is the responsibility of the pipe support designer to make them selves aware of and familiar with all current Codes, standards and regulations.

It is just as important that they make themselves aware of the 'Contract' document for the project.

The Process owner is the owner of this procedure.
The Process responsible is responsible for updating and maintenance of this procedure.
The Pipe Support Discipline Leads in projects are responsible for implementing this procedure to all personnel in their groups.

3 DESCRIPTION OF ACTIVITIES

DELETED BY AUTHOR. NOT RELEVENT TO CASE STUDY.

4.0 General Pipe Supporting Requirements

DELETED BY AUTHOR. NOT RELEVENT TO CASE STUDY.

5.0 Pipe supports shall be positioned and designed so that:-

DELETED BY AUTHOR. NOT RELEVENT TO CASE STUDY.

6.0 Design

Loads

DELETED BY AUTHOR. NOT RELEVENT TO CASE STUDY.

Requirement for a calculation

DELETED BY AUTHOR. NOT RELEVENT TO CASE STUDY.

Calculations

All pipe supports with a loading in any direction of 10KN or more shall have an Aibel approved computer programme or hand calculation.
All frames for critical lines shall have a calculation, or be referenced back to a similar support and calculation.
Frames for non critical lines shall be evaluated individually for the need for a calculation.
For all welded attachment to a pipe a calculation shall be performed.
Trunnion calculations shall be performed based on the trunnion calculation found in the Aibel PDMS pipe support system.

All calculations shall be filed in the project file for future reference.

7.0 Interfaces with other disciplines

8.0 Pipe Stress

9.0 Structural

10.0 Document Control

11.0 Mechanical

12.0 Materials

13 Safety

14 Process

15 Civil

16 Fabrication

17 Installation

18 Electrical

19 Considerations / requirements in pipe support design

4 RECORDS

5 DEFINITIONS

6 REFERENCES

7 ATTACHMENTS