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Design Process in Investment Projects

Helsinki Metropolia University of Applied Sciences

Master’s Degree

Industrial Management

Master’s Thesis

7 May 2014

Author(s) Title Number of Pages Date	Ilkka Heiskanen Design Process in Investment Projects 71 pages + 2 appendices 7 May 2014
Degree	Master’s Degree in Engineering (M. Eng)
Degree Programme	Industrial Management
Instructor(s)	Juha Haimala, DSc (Tech) Principal Lecturer Tom Gustafsson, Manager (Mechanical Engineering)

This Thesis investigates the design process in investment projects of the case company. The existing piping design process in investment projects of the case company is defined and improved based on the findings from the current state analysis and literature related to project engineering.

The design process is described from the perspective of piping design process that involves two key design stakeholders: the process design and the mechanical design. To be able to form more in-depth understanding of the piping design process, other stakeholders such as the installation and quality control stakeholders and their needs are also taken into account. The design process was defined through the current state analysis and best practices were found through literature search. Before the current state analysis was conducted, three investment projects are analyzed by conducting a multiple case study.

The project challenges found from the multiple case analysis were mostly located on the design process. It was found out that the design stakeholders in the design process of the investment projects are not completely aware of the whole process and how and where the other stakeholders are implementing the data one stakeholder is providing.

As a conclusion of the summarized results from the multiple case analysis, the piping design process is defined to improve the understanding between design stakeholders and the usage of data they are providing. The process of the piping design is chosen because all the three case projects included piping design.

This study helps to understand the needs and challenges of different design stakeholders in the piping design process of an investment project. The visualized piping design process can be used in the beginning of the project to define tasks and recognize possible risks.

As piping is considered as a pressure vessel, the piping design process introduced in this Thesis can also be applied with minor changes in to design of pressure vessels that are widely used in process and energy industry.

Keywords	Design process, Investment projects, Piping

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1 Introduction

Planning, scheduling and budgeting are the key factors in a successful project-oriented business, especially in such demanding area as investment projects. Investment projects are often complex, time restricted, common efforts that include unique tasks that have never been done before (Dvir and Lechler, 2004:1). In the early planning stage it is consequently difficult to understand accurately what actions need to be taken in account to complete the project, and in what cost and schedule it is possible. This uncertainty demands preparation against deviations and understanding that the original plans will have to change dynamically.

This Thesis concentrates on improving the design process in investment projects of the case company. Section 1.1 introduces the idea of design process before explaining it more thoroughly later in the Thesis. Section 1.2 introduces the case organization of this Thesis. Section 1.3 describes the research objective and Section 1.4 introduces the research process that was followed in this study.

1.1 Design Process

Design process involves continuous decision-making, organizing of elements and efforts to find the most important factors in creating something new. The following aims can be considered as crucial parts of design. Identifying the relevant issues of the project, understanding how elements of the project are related to each other and organizing the elements in a required and meaningful way to create a competent product. All the previous might sound obvious aims in process demanding logic, but these issues are seldom clear for designers in practice. (Tunstall 2006:25)

Brainstorming, mind mapping and daydreaming are methods that are studied to improve the design process. However, the typical development design process consists usually of the following four actions: Analysis, Synthesis, Appraisal and Feedback. *Analysis* means dividing the entity in its relevant parts so that they are easier to analyze and determine. In *synthesis* the analyzed parts are again assembled into more meaningful entity. *Appraisal* means evaluating of the designed proposal against the analysis. Client, authority and members of the design team are typical participants in appraisal. After appraisal the *feedback* needs to be taken into account.

The advice, recommendations, approvals or instructions received in appraisal will ensure that the proposal is acceptable. The feedback can also suggest the proposal to be analyzed again, which will lead into a new synthesis and a new proposal. (Tunstall 2006:25)

As Figure 1 shows, this repeating circular process improves the design and becomes practicable and more economical until eventually it is accepted as being the best solution under the current circumstances, as Figure 1 shows.

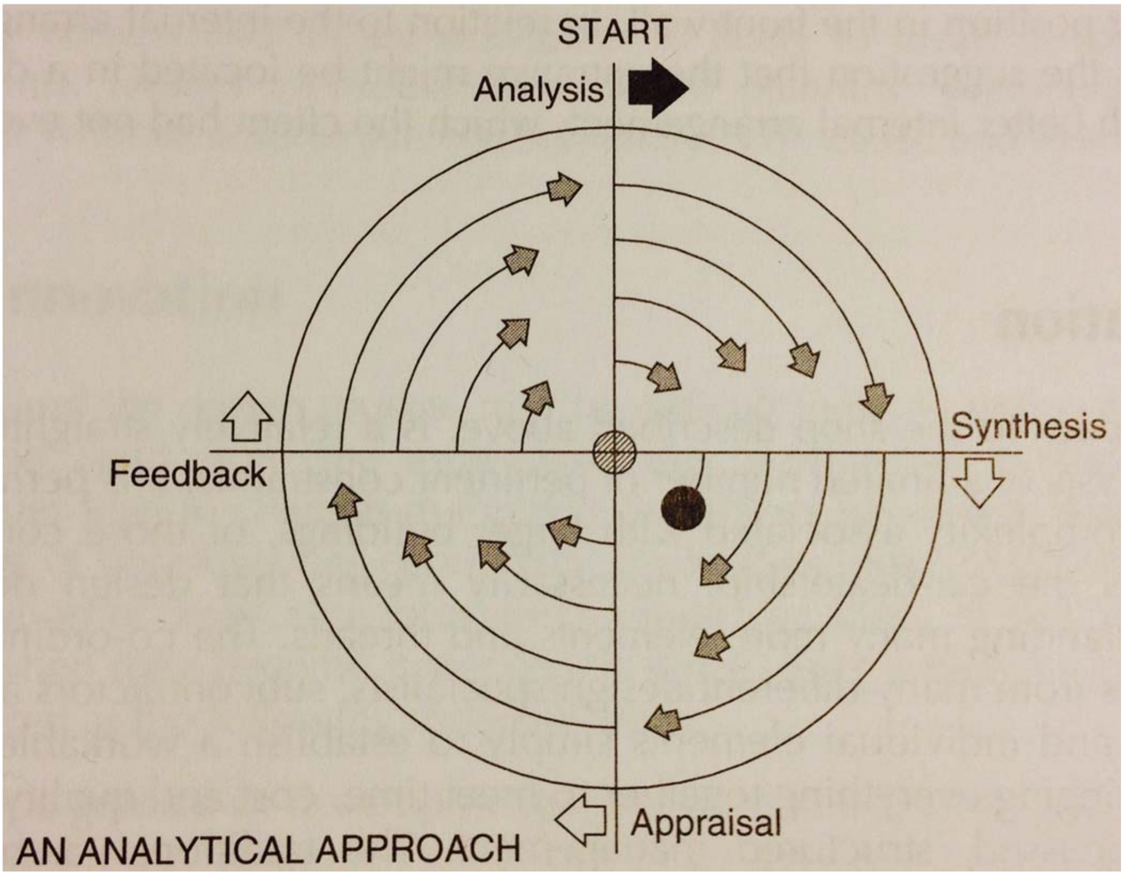


Figure 1. The design spiral with an analytical approach. (Tunstall 2006: 27).

Figure 1 shows the four actions in the design process where analysis, synthesis, appraisal and feedback are repeated. The four actions in the design spiral are not necessarily linear or starting from the analysis. Ideas and decisions are influenced by each action and the spiral can also change direction. (Tunstall 2006: 25)

As shown in Figure 1, the design work is a repetition of analysis, synthesis, appraisal and feedback. The design work moves in circles towards the grey circle that is the best possible solution in the middle of the spiral. However, the black circle is the best compromise that achieves the required quality and cost in a given time and, therefore, is the final approved solution. One of the designer’s most important skills is to recognize the goal and understand when the solution is in the black circle. (Tunstall 2006: 26-27)

1.2 Case Organization

This study focuses on improving the investment projects in the case organization. The case organization is a technical support unit in a large Finnish energy company. The energy company has a license to generate energy by nuclear power and STUK, Finnish Radiation and Nuclear Safety Authority controls the license. The case organization supports and develops the safety and technical process of the company's nuclear power plant in various investment projects. The nature of these projects is very challenging as they are implemented on the running power plant that was originally designed and built decades ago. Therefore it is important to gain experience and comments from operating personnel as well as installation teams when designing new technical solutions along with the existing ones.

The overall research problem in this Thesis is that the case company does not have a specified design process for a typical investment project. The reason for this is probably that there has not been a need for clear step-by-step instructions to follow, as every project has been unique. Typically the project managers have coordinated the design process in their own preferred manner applying the power plant's design instructions. Design instructions at the power plant are originally written as maintenance design instructions and there are no clear instructions how to operate in a project environment. In a fluent design process of project the inner processes overlap if the needed starting information for the next stakeholder is provided on time.

However, different stakeholders have their own challenges in their working processes. One aspect of it that the design work is often concentrated on the internal process without taking the whole design process into consideration. If the previous stakeholder cannot confirm their information, the next stakeholder is not able to start or finalize their own process. In other words, the consecutive steps of the design process depend on each other. Problems in the consecutiveness often lead to delays and wasted hours. Very experienced project managers and engineers are familiar with the tactics and traps of the design process from experience which is why many investment projects are already finished successfully and many are still running in various project phases. However, people and working environment change from project to project. Therefore it is vital that different stakeholders in the design process are aware of the next stakeholders' needs.

Another challenge for investment projects is that the case organization that is responsible for running the projects is located in a different office than the power plant's personnel who are ordering the projects. These locational and organizational differences cause additional challenges to projects when building the project organization. The power plant's organization is a line organization that operates the power plant, while the case organization is an expert organization supporting the plant operations. Power plant's personnel are usually working in the investment projects along with their daily tasks. Thus, these organizational and cultural differences between the two organizations have to be taken into account when planning roles in a project.

Finally, the collaboration and communication between the stakeholders make special focus for an investment project. In the case organization, the project organizations for each investment project are formed according to instructions of case company. There the project manager is the one who is responsible of the implementation phase. Managing the project and the design process takes significant amount of experience and consulting. But even the most well evaluated projects still face unexpected problems and delays. Thus, the key to a good project management is the ability to forecast problems and evaluate resources accurately, but most importantly, it is the collaboration and communication with different stakeholders that is required for the design process of a successful project. These areas have become the focus points in building an improved design process in this Thesis.

1.3 Research Objective

The aim of this Thesis is to define and improve the design process in investment projects. The design process is defined by studying the typical design process and the projects from the previous experience. This was done by collecting and investigating experiences from three case projects gathered from the project managers and engineers. All three case projects included the design of a new piping system. Therefore, the proposed model is a piping design process that is built from the process and mechanical design to installation and final inspection. Other possible design stakeholders in the process, such as electrical and automation design, are left out of the scope of this study to simplify the process.

Presently, what happens between the investment decision and final inspection is a complicated design process where official information flows in the form of various documents. Every stakeholder is an expert in their own area of competence and they are able to produce the needed documents to keep the information flowing and project running. Improvements are needed to enable the parallel design process by understanding the effects of the provided information on other stakeholders. Therefore, it is also important to map the tasks of each design stakeholder to recognize the relevant data that should be first finalized and transferred to the next stakeholder.

The goal is to help the design stakeholders to understand the piping design process and project managers to estimate and recognize possible risks earlier in the project. This should lead to better collaboration between different design stakeholders and decrease in the amount of design deviations in the design process and thus staying on project schedule.

1.4 Research Process

The research process in this study includes the following steps. First, the research objective is formulated and the scope of the project is defined. Then, a typical piping design process is mapped based on the design processes from the case projects and examples from the project literature. Finally, when the challenges in the current design process are identified, the steps to improve the process are suggested.

Figure 2 shows the step-by-step research process applied in this study.

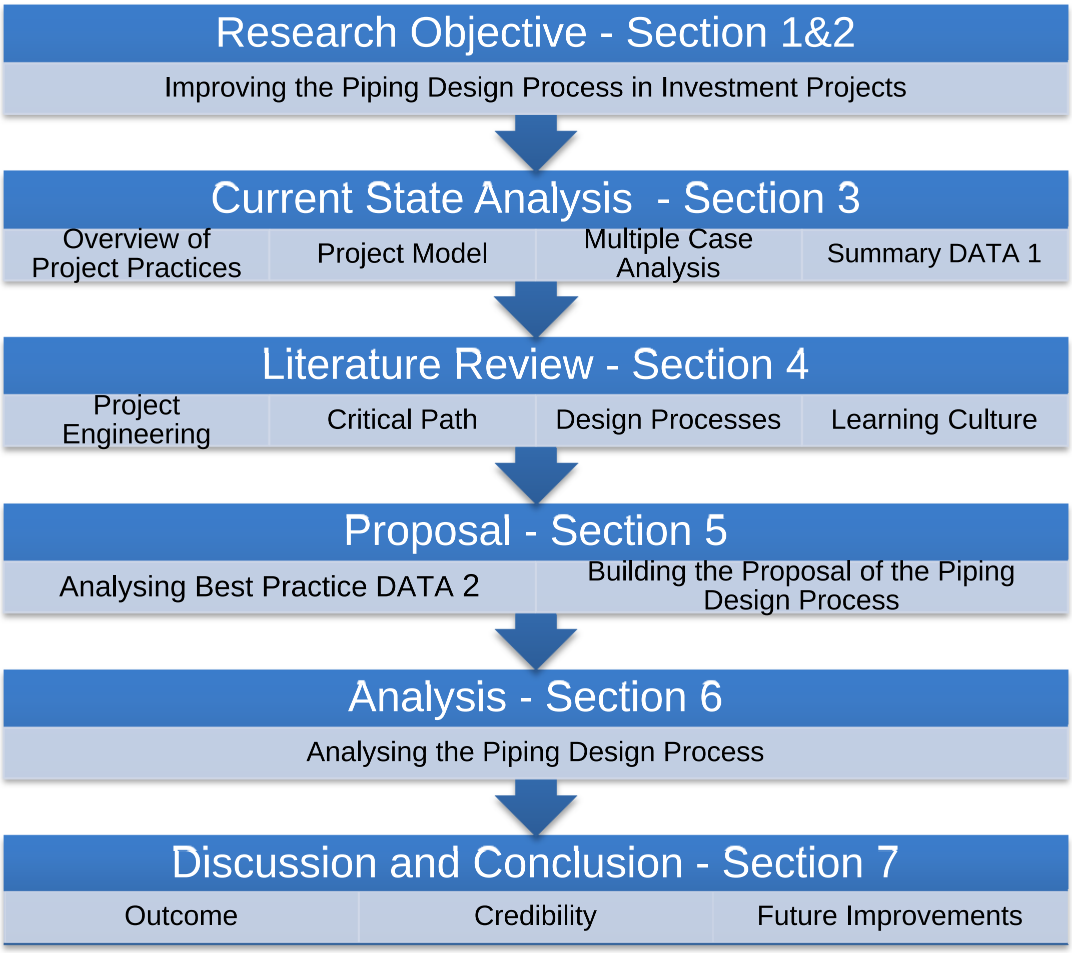


Figure 2. Research design.

As seen from Figure 2, the first step in the research process is recognizing the research problem and defining the research objective. Section 2 explains the chosen research and data collection methods. Also, the data analyzing method and reliability and validity plan are explained in Section 2.

Following the object definition, a current state analysis is conducted in Section 3 to collect Data 1 (Appendix 1). The current state analysis is based on a study of the current project instructions and interviewing project managers and engineers. Three case organization projects are chosen for the multiple case analysis to identify challenges and best practice from their implementation phase. After identifying the challenges and practices, they are compared to the current project model of the case company.

When the initial current state analysis is completed, a literature search is conducted on the topics of project engineering, design processes and collaboration identifying best practice in investment type of projects in Section 4. The main objective in this phase is to gain knowledge of characteristics of project engineering and design processes from other similar fields of business, such as product design in mechanical engineering, chemical engineering design and building processes. This literature helps to identify theories and ideas to understand the challenges of the case organization’s projects. The approach is called inductive (Saunders et al 2007: 57).

Section 5 reviews the challenges and practice in the projects of the case organization. Data 2 is collected in Section 5 by asking comments and summarized in the table of responses (Appendix 2). After categorizing the challenges and locating them in the current project model, it is found that most of the challenges relate to the design process of the current project model. New piping system was designed in every case project. Therefore the piping design process is chosen to be further studied in the Thesis. The piping design process is visualized and its challenges are located in it.

After locating the challenges in the current piping design process, it is found that the collaboration between the design stakeholders could be improved. In Section 6, the tasks and required decisions of different design stakeholders are visualized to improve the understanding of their associations. The actions and findings are discussed in Section 7 together with the proposed improvements. The implementation of these suggestions should lead to a more synchronized design process and more effective scheduling in the investment project of the case company.

2 Research Approach

This section introduces the research approach applied in this study. Section 2.1 introduces the research methods used in this study and Section 2.2 discusses the data collection. Section 2.3 explains how the collected data was finally analyzed and Section 2.4 introduces the reliability and validity plan for the study.

2.1 Multiple Case Study Approach

The research approach used in this Thesis is a multiple case study. The case study strategy is defined as “a strategy for doing research which involves an empirical investigation of a particular contemporary phenomenon within its real life context using multiple sources of evidence” (Robson 2002:178). A case study means that data is organized in specific cases for studying and comparison. Cases can be individuals, groups, neighborhoods, programs and organization. Case is everything that can be defined as “specific, unique, bounded system” (Patton: 2002: 446). In this study, a case is an industrial investment project in case company.

The purpose in case study is to collect information through qualitative analysis and create an analysis process. The result and the product of the process is a case study. Interview data, observations and documentary data from a case make the case data. The raw data is written into a case record which is complete package of data, but still changeable. After case record, data is further refined into a final case study which defines the situation and experience accurately to reader (Patton 2002:451). The final case study is the reportable version and the complete final study may be consisted of multiple case studies as it is done in this Thesis.

The qualitative research approach was chosen in this Thesis to better describe and understand the significant issues related to the topic (Hirsjärvi, Remes & Sajavaara 2010: 161, 164). The chosen projects were too different from each other to have meaningful results from a quantitative data analysis, but qualitative findings can help to collect meaningful data from three different projects. According to Patton (2002:4), the basic methods for qualitative data collection are open-ended interviews, direct observation and written documents. *Interviews* collect experiences, opinions, feelings and knowledge of interviewed people. *Observations* consist of descriptions of people’s behavior, activities and all observable action between organizations and humans. *Document analysis* means studying of the official publications and reports from case organization.

The typical mode for qualitative research is fieldwork. During the fieldwork period, the researcher spends time in the organization or team where the research is made and interviews, observes and analyzes the surrounding people, actions and data. Sometimes researcher participates in the activities as a *participant observer.* In this study, the researcher participated as a participant observer and interviewer with all the respondents from the case organization since the researcher has been involved in every case project as a mechanical design engineer. This allowed for more insights coming from contacts with colleagues and groups involved in the studied area, and these findings made the core of this qualitative inquiry. It also helped to address the sensitivity in interviews as some answers might have variance due to timing or atmosphere. The quality of qualitative data comes from the practices, procedures and methods used in a qualitative and case study research. (Patton 2002:5).

2.2 Data Collection

In this study, three case projects were chosen to be investigated. The researcher has worked in every case project as a mechanical design engineer, which was one of the criteria when choosing the case projects. The chosen projects were also similar in their nature and represented the investment type of projects without any attachments to other projects. The nature of these projects is defined in Section 3.

The process of data collection started with the current state analysis including interviews and discussions with project managers and project engineers. The aim of the interviews was to identify the main challenges in project engineering; the parts in the process which work well and those that could be improved. The project managers and engineers all worked in the three case projects. As the phase of each project was different, some parts of the data were treated as estimations. Project engineers and managers were interviewed first to collect the everyday issues of the projects (Appendix 1) through open-end interviews. The questions were first sent to interviewees by email. The replies were checked and discussed in open-end interviews.

In a qualitative research methodology, there are three different approaches to open-end interviews. The informal conversational interview, the general interview guide and the standardized open-ended interview. This Thesis combines the standardized open-ended interview and informal conversational interview. The first interviews are standardized open-ended interviews where members of each case project are interviewed with the same structure. The second round of interviews is based on the first standardized open-ended questions and their answers. The approach is informal conversational interview, which aims to explain the differences and similarities in answers between the case projects. The standardized open-ended interview consists of questions that are structured before the interview. These questions should be the same from word-to-word with every participant. The informal conversational interview is a more spontaneous set of questions and also called unstructured interviewing. The interviewing is flexible and allows the possibility to find information that was not planned beforehand. The negative side of the informal conversational interview is that it may require more time or several interviews to complete the conversation. Data gathered from an informal conversational interview might be challenging to summarize and analyze. The results might not fit into single pattern or standard (Patton 2002: 342-344).

The informants from the case projects were project managers and project engineers introduced in Table 1 below.

Table 1. Presentation of multiple case study informants.

Role	**Code**	**Experience in years**	**Information**
Project Engineer	PE-A	>10	Case A experiences
Project Engineer	PE-C	<10	Case C experiences
Project Manager	PM-A	>10	Case A experiences
Project Manager	PM-B	<10	Case B experiences
Project Manager	PM-C	>10	Case C experiences

Table 1 presents the informants who were interviewed or asked for comments in the Thesis. Before the interviews, the informants were sent the questions by e-mail and the answers from the standardized open-ended interviews were checked afterwards to collect Data 1. These answers are summarized in Table 7 and presented in Section 3 as Data 1. Data 2 was collected by asking comments to the summarized and categorized findings from Data 1.

The interview method used in checking the answers (Data 1) and paper questionnaire (Data 2) was a non-standardized one-to-one interview that allowed interviewees to speak freely. In this study, this method was chosen since It was important to understand the reasons for certain decisions that the participants in these projects had taken as well as their attitude and opinions. The opportunity to probe the answers gave more possibilities for the interviewees to explain their responses. Qualitative interview provides this opportunity to lead the discussion through the unplanned areas, which was useful for the Thesis. Each interviewee was able to hear them selves thinking aloud which, as pointed by researcher might help the interviewees to find new thoughts. (Saunders et al 2007: 315-316). Table 2 shows the interview details in this Thesis.

Table 2. Interview details.

Participants	Date,	Data From	Topics	Documents
Project Engineers	27.1.2014	E-Mail Questionnaire	Experiences from Case Project A,B,C	Notes, Data 1
Project Managers	27.1.2014	E-Mail Questionnaire	Experiences from Case Project A,B,C	Notes, Data 1
Consultant	31.1.2014	Phone interview	Background of LABC – project Model	Notes
Project Engineers	3.4.2014	Paper Questionnaire	Detailed questions based on Data 1	Notes, Data 2
Project Managers	3.4.2014	Paper Questionnaire	Detailed questions based on Data 1	Notes, Data 2

After the data collection from the projects, yet another person was interviewed. The consultant who has been creating the project model the case company, was interviewed by phone. The consultant explained the background of the project model and challenges from their point of view. The LABC project model that the consultant has discussed is explained in Section 3.1.

Also an hourly design work data from the projects was collected and analyzed. Due to the differences in the projects, the data was not compared between the projects, but it was used as an additional information to illustrate the challenges in the projects.

After the experiences from case projects were summarized in to Table 7, the informants were asked to locate the challenges and practices in the LABC-project model (Appendix 2). The marks were analyzed in discussions with the project engineers and managers to find differences between the LABC project model and the case projects. The findings formed Data 2. The issues found from Data 1 and Data 2 showed that the design process in investment projects is both, suffering from and causing these issues. Therefore the aim of this Thesis was to define and improve the typical design process in investment projects.

2.3 Analysis of the Data

In case study research, interviews and documentary analysis can be collected at the same time (Saunders et al 2007: 139). A multiple case study gives more data and evidence to be analyzed, as it allows more than one case to be studied (Yin 2003). In this study, three case projects were chosen to collect the sufficient data. In this study, the data collected from the projects is gathered and categorized to describe the typical design process in case company's investment projects. The statuses of the projects varied from pre-planning stage to finalized stage. Project managers and project engineers were interviewed to collect qualitative data from their project successes and challenges and to collect best practice of project management.

The challenge of analyzing the qualitative data is in understanding the massive amount of it and categorizing the material. The guidelines for analyzing the data can be found from the content analysis methodology and examples of qualitative analysis. However, since every qualitative study is unique, the research results depend on the skills, training, insights and capabilities of the researcher (Patton 2002:432-433).

According to Spiggle (1994:495) there are several different operations that can be used to analyze the data. *Integration* is used in data analysis. In this study, the data was analyzed case by case, and then categorized and integrated into a single database where relationships where mapped between conceptual elements. This phase formed Data Collection 1. The categorized answers were then analyzed and compared to instructions of the case company by the same informants (Appendix 2). This phase formed Data Collection 2. The findings from the data were used to build the proposal for typical piping design process.

2.4 Reliability and Validity Plan

Since the data utilized in this Thesis is qualitative, validity and reliability need to be ensured. In qualitative methodology, *validity* means that multiple sources were studied and key stakeholders' opinions were taken into consideration to meet the construct validity of the case study. For internal validity, patterns were compared to each other and explained after analysis and alternative explanations. *Reliability* means that the findings of the study should not differ significantly even though the study would have been conducted by another researcher, using another research method at another point of time (Huhta 2013: 5).

As for the reliability and validity of analysis methods, in a qualitative research interviews and observations are the important tools that help to understand the situation. In a non-standardized interview the reliability may be a concern. Compared to a quantitative research there is a possibility that alternative researcher might end up with different interview results. Interviewer bias has to be taken into account as comments, tone of voice or other non-verbal communication might have an effect to interviewees answers. Also the response bias can disturb the interview results (Saunders et al 2007:317-320).

When exploring events or seeking explanations, the nature of the topic can be too sensitive to be fully revealed. In a case study such as this Thesis, the number of cases is not sufficient to make generalizations. Even though there is a risk of compromising reliability, it is worthwhile to use non-standardized research methods as the results found from the complex and dynamic multiple case study cannot be directly foreseen and multiple methods can be especially helpful. The results also reflect the current state and reality of the time when interviews were conducted (Saunders et al 2007:317-320).

3 Current State Analysis

This section presents the current state of the design process in the case organization. It is based on the findings from the interviews with the project managers and project engineers from three case projects described in Data Collection, Section 2.4. It also incorporates the hourly data from the project databases to specify the distribution of work. Section 3.1 discusses the current project model applied in investment projects. Section 3.2 discusses the practices and challenges identified in the design process of the investment projects. The case projects and their design processes are presented in Section 3.3. Section 3.4 summarizes the current state of the design process in case organization and findings from case projects.

3.1 Project Model of the Case Company

Currently, in investment projects of the power plant, the case organization applies the LABC project model. LABC model is created by the Project Institute, a Finnish consulting and partnering company that aims to develop a project culture in companies in Finland and internationally (Projekti-Instituutti 2013). The model was created in 2010 together with the project experts of the case company and Project Institute.

LABC Project Model defines the project process showing the decision points and project phases. The internal instruction of the case organization defines project as a non-recurring task that is targeted to renew part of safety or performance of the process (Lindqvist 2013). The project owner and steering group are responsible of the success of the project. The resources and goals are given to the project manager in charge of the implementation of the project. Projects are divided into different categories. A project is usually categorized into one of the following: maintenance of production equipment, improvement of the production process, securing the nuclear safety, EHS, renovation of facilities, extension of facilities and other R&D projects. Project stages and decision points from P0 to P4 control the project and help to follow the schedule.

According to LABC model, investment projects of the case company are usually phased in pre-study, planning, implementing and commissioning. The work in projects can be divided for example in research, coordinating, documenting, piloting, inspection etc. Figure 3 illustrates LABC-model applied in the case organization.

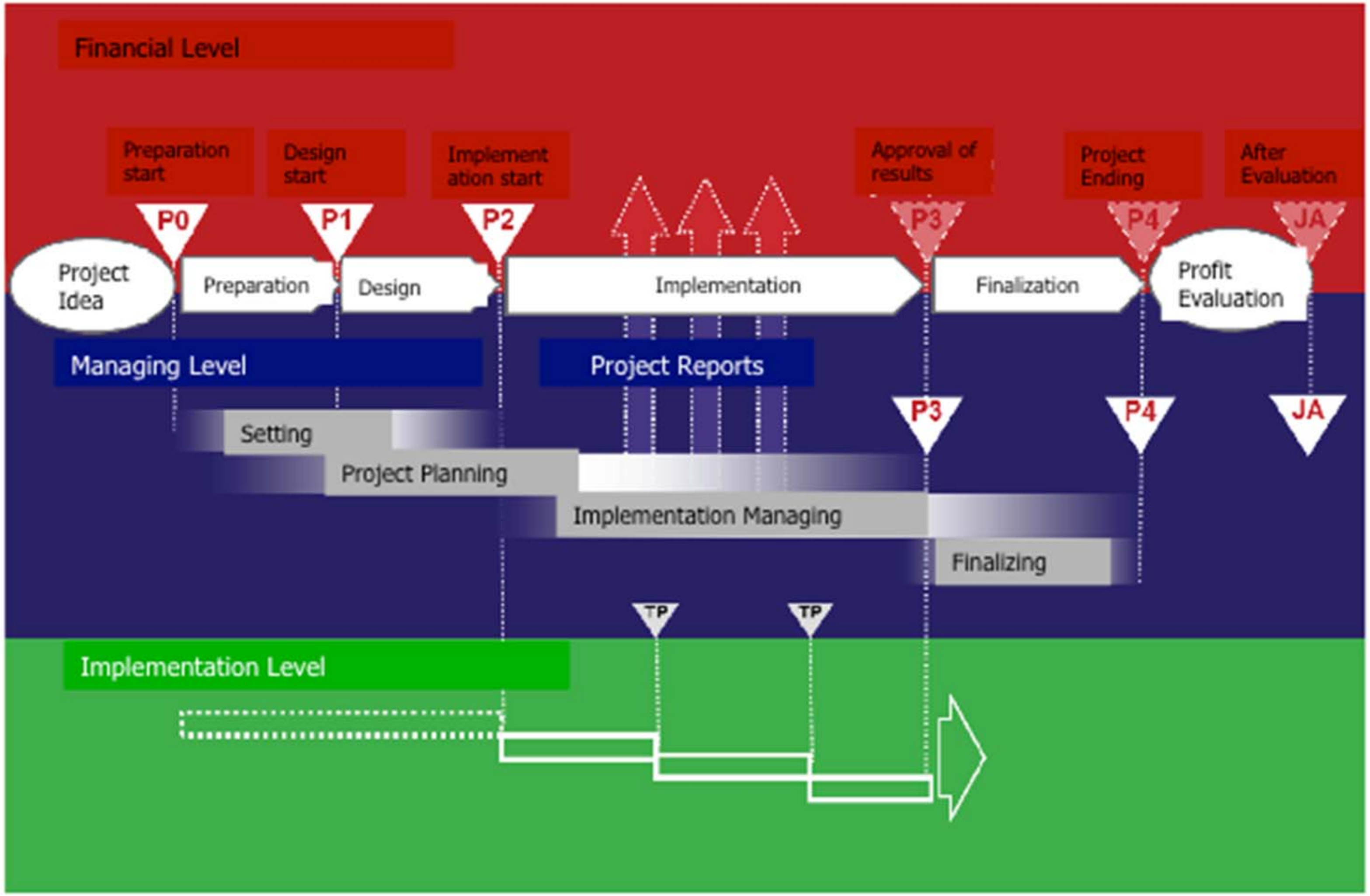
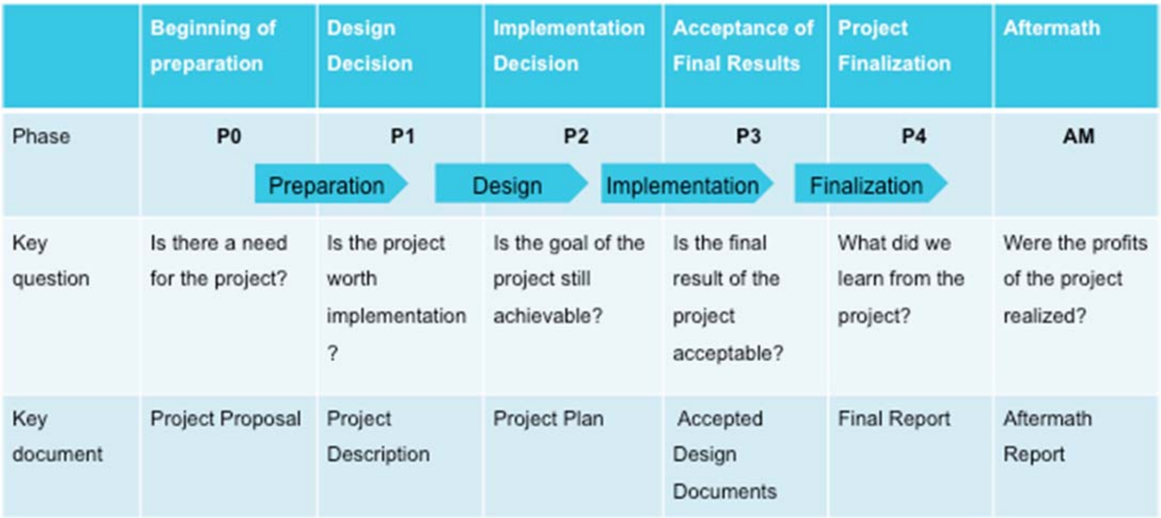


Figure 3. LABC project model of the case company.

As seen in Figure 3, Case Company’s LABC Project Model that case organization applies has three management levels, the green level, implementation level, is the level where the design process is located. It is important to separate the project design from the design process in a project. The project design means planning of the resources, budget and schedule. The scheduling in the project can be evaluated for example by dividing the amount of work by the amount of resources. If one design engineer is able to use 50% of his time to finish the work, and work is evaluated to take 100 hours, then the schedule is 200 hours. This study focuses on the implementation level of the project.

The actions decided in the project planning stage make effect to the design process and valuable information can be transferred from the design process to project planning. Design process takes action between decision points P1 and P3 where the process between P2 and P3 is the detailed implementation design process. The key questions in the decision-making process are introduced in Table 3.

Table 3. Decision points and their key questions and documents.



	Beginning of preparation	Design Decision	Implementation Decision	Acceptance of Final Results	Project Finalization	Aftermath
Phase	P0	P1	P2	P3	P4	AM
	Preparation	Design	Implementation	Finalization		
Key question	Is there a need for the project?	Is the project worth implementation ?	Is the goal of the project still achievable?	Is the final result of the project acceptable?	What did we learn from the project?	Were the profits of the project realized?
Key document	Project Proposal	Project Description	Project Plan	Accepted Design Documents	Final Report	Aftermath Report

The steering group operating on the red financial level of the LABC model gathers regularly to evaluate the statuses of projects and the possibilities of projects to move to the next phases. Key questions in Table 3 are answered yes or no and they determine if the project is moved to the next phase. The decision of starting the P0 phase can be for example made, if the project is not in conflict with the 10-year plan of the case company, the options to be solved are documented and the economical and human resources are reserved. The decision is based on the approved project proposal.

P1 decision is possible if, the risks of the project have been evaluated and different options and solutions have been discussed and documented. The economical and human resources have to be already reserved for the planning and implementation phase together with the ABC –classification to accomplish the P1 decision. The ABC –classification is introduced in the following paragraph (Karhapää 2013:6). The design process of investment project is located between the P1 and P3 phases. Answering the question “Is it worth implementation?” is a gate to P1 phase. If the answer is yes, the design process starts and it is based on project description.

Design and pre-design from the key design stakeholders are required to be able to answer the gate question to P2 phase “Is it still achievable?” to determine for example the project budget. If the needed result is still achievable, the project is taken to P2, the implementation phase that is based on project plan. The steering group can also decide to quit or postpone the project or demand additional preparation or re-processing (Karhapää 2013:7).

The tangible design and installation work is done in the implementation phase and it aims to answer: “yes” to the question “is the final result of the project acceptable?” Key documents of the implementation phase are the accepted design documents that are presented in Figure 9 in section 3.3. If the final result is acceptable, the project moves to P4, the finalization phase where the final report is being produced.

The complexity of the project is categorized in three levels: A, B and C where A is very complicated and large project, B is typical project and C is very simple and straightforward project. Categorizing the complexity helps to define the needed resources for the project. The implementation phase after P2 decision requires instructed reporting of the project progress from the project manager. The changes in project between P2 and P3 are reported to project owner and steering group by project manager who evaluate the effects to project. Significant changes in project are extensions in schedule, if costs increase more than 10%, the goal or quality needs to be changed or the risk level has grown.

Figure 4 shows the goal setting phase, design work, implementation control and finalization phase of the project are distributed on the project timeline in the case company's LABC project model.

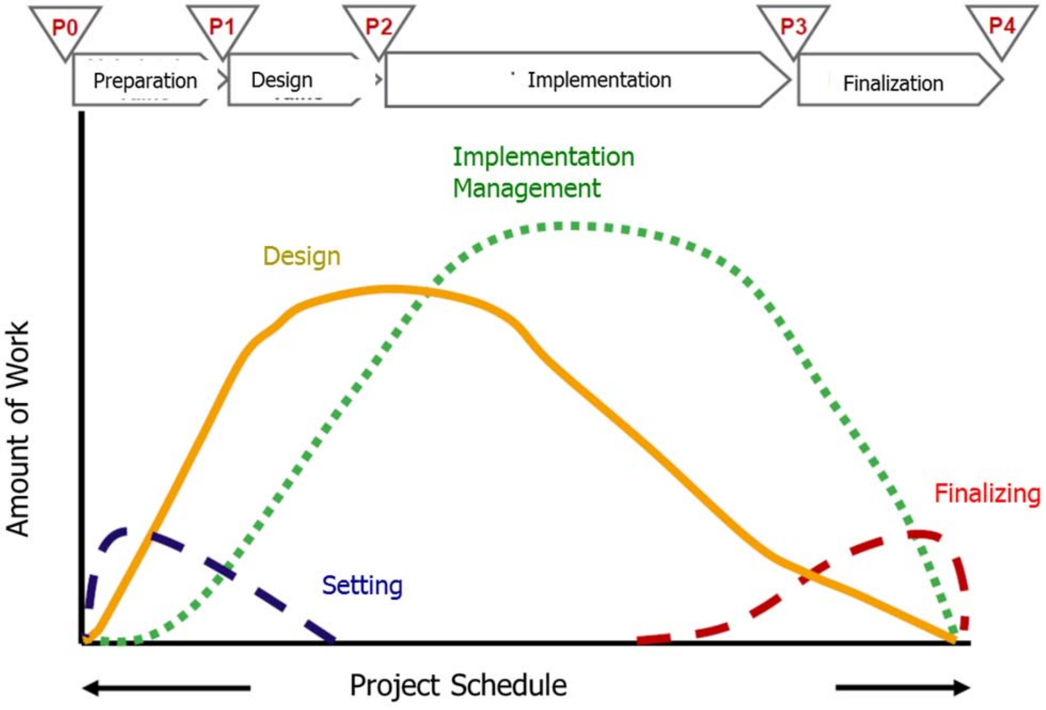


Figure 4. The distribution of work in LABC project model of case company.

As seen from Figure 4, the design work starts already in P0 phase and grows steadily in design phase, until P2 phase. Problem of this graph is that it does not make difference between different design stakeholders because it is designed to present all types of projects in case company universally.

In power plant's investment projects the design work in P0 and P1 phases is mostly process design. Mechanical design usually starts after P2 decision and continues along the installation phase. However some investment projects require mechanical design already in P1 phase to help in budgeting (Lindqvist 2013:17). The peak in the amount of design work should come before the P2 decision. Often the preliminary design before P2 decision is not adequate, and the amount of design work tends to grow after it.

3.2 Multiple Case Project Analysis

The design processes of three case projects are analyzed by interviewing the project managers and project engineers who participated in the project. Projects were investment projects to case company's nuclear power plant and their purpose was categorized to "securing nuclear safety". All three projects included process design, mechanical, layout and piping design as well as electrical and automation design. Every project was in a different project phase varying from P1, P2 and P4. Even though the design stakeholders in every project were the same, the projects were still differing from each other.

3.2.1 Case Project A

Case Project A was a new plant project to develop an end process handling system for case company's waste. The aim of the project was to build the full chain for waste management from waste tanks to handling process and to final repository. First construction phase of the project was finalized earlier. Second phase, Case Project A, consisted of improvements to the first phase and aimed to finalize the process of the plant. The LABC project model was initialized during the second phase, and therefore it was not affecting the start of the project.

Tasks involved in the project were process design, piping design, equipment and automation design and normal final testing routines. Case Project A can be described as a new independent plant project that did not have effect to nuclear power plant's operation. There are no similar waste management plants anywhere in the world and therefore project included many variables during the design process that had to be piloted. The experiences collected from interviews consider the whole project. However, due to the large size, the Case Project A was divided in smaller sub-projects. The distribution of work presented later in the section, is based on sub-project of Case Project A.

After the first phase of Case Project A, it turned out that the minor participation of power plant's personnel caused problems in the commissioning phase of the waste management plant. The key operating personnel from power plant were not aware of the background of the project, reasons for technical solutions or other issues that were previously agreed. Collaboration and communication between the project personnel and power plant's key personnel was paid more attention in the second phase of the case project.

During the design phase, project manager arranged monthly meetings to get power plant’s key personnel better involved in the project. This secured the transfer of information between project organization and operating personnel. The decisions made during the design phase, were discussed together with the operating personnel to avoid unwanted solutions. Increased collaboration with the nuclear safety authority STUK has precipitated the approval of documented plans.

The new more efficient collaboration practice was implemented so, that project manager presented larger design materials to STUK as they were finished. In the meetings with STUK, project management also proposed a schedule of future documents to be approved. This has helped STUK to prepare the needed resources in advance to ease the workload of their inspectors and project management to stay in project’s schedule.

The internal personnel who were responsible of approving the design documents were mostly located in power plant’s facilities. The design material was in printed mode and person from power plant was responsible of following the document package. This precipitated the approval round, as the responsible person could answer the questions in approval round immediately.

Case Project A included many technical solutions that were not tested before. Solutions were tested by building piloting equipment before applying them into final design. Testing of the pilot equipment gave valuable data to design phase, as some original ideas did not work in practice and some basic ideas worked after adjustment. However, the piloting equipment was designed and implemented inside project’s schedule and therefore too late.

Piloting and testing of technical key solutions should be implemented in the pre-planning stage or even before the project kick-off as separate research and development tasks. The most important findings from Case Project A, that can be applied in future projects are comprehensive advisory between all participants in project and naming one person from power plant’s personnel who is in charge of following the approval round of design documents.

Monthly design meetings together with project personnel and operating personnel from power plant was found to be a good practice to share information and discuss the decisions made in project. This together with the responsible person from power plant decreased the obscurities in approval round of design documents. The greatest challenges in Case Project A were the phasing of design process, availability of design resources, preparation of purchasing and design schedule. The phasing of design should be done in correct order.

When schedule is tight, the pre-design and implementation design phases are overlapping. Pre-design phase should finalize the technical background for implementation design phase. When pre-design phase is done under tight schedule pressure it leads into changes later in implementation phase. This is why certain design phases have to be done many times. Pre-design phase should be ready and approved before giving starting information to implementation design phase.

According to interviews, projects have continuously shortage of design resources. In the pre-planning stage of the whole project, the need of different designers should be thought thoroughly. This would help the designer resource planning between different projects. However, as in Case Project A, the resource planning is very challenging in the early phase of the project when only the goal of the project is known but all the technical solutions are yet to be designed.

Using external design resources is also challenging due to internal design practices and national design requirements for nuclear power plants. These practices and requirements require training from external design resources who have no design experience from nuclear power plant environment. Training and educating the external resources requires also effort from internal design resources especially in the beginning of the project, which then decreases the design effort from more experienced personnel.

The purchasing department is responsible of purchasing in projects. However, the equipment or material to be purchased has to be specified and prepared by design stakeholders. Specification and preparation of purchasing is challenging because it has to be done simultaneously with design work. Specifying equipment of material is part of normal design work, but for purchasing designers have to prepare separate documents which have to be approved by responsible persons. In Case Project A, the preparation of purchasing documents was continuously done in the last minute or slightly late due to lack of resources. The preparation of purchasing should start earlier in the project as the documents require significant amount of expertise and consulting from for example the quality control department.

When scheduling the design process of the project, enough time should be reserved for pre-design phase to be able to provide as finalized starting information for implementation design phase as possible. All the operant factors in implementation design phase should be taken into consideration. For example, the design work itself is possible to evaluate rather accurately, but the approval rounds and auditing might require more time than expected.

Following Figure 5 shows the distribution of design work in a sub-project of Case Project A. The Figure is based on an hour usage data from the database of Case Project A. The schedule of the project with the releases of two Construction Plans and the revisions of construction plans are located on the x-axis. The y-axis describes the monthly amount of work in sub-project of Case Project A. Figure 5 shows that the sub-project started with mechanical design that first aimed to create solution for the problem given from the actual Case Project A. The mechanical proposal was build and tested outside the plant area. The findings from the pilot test were taken into consideration at the next mechanical design phase. The pilot test results also confirmed the starting information for process design that already started the final implementation design for plant facilities. After the final results from the second pilot test, mechanical design started the implementation design to finalize the construction plans for plant facilities.

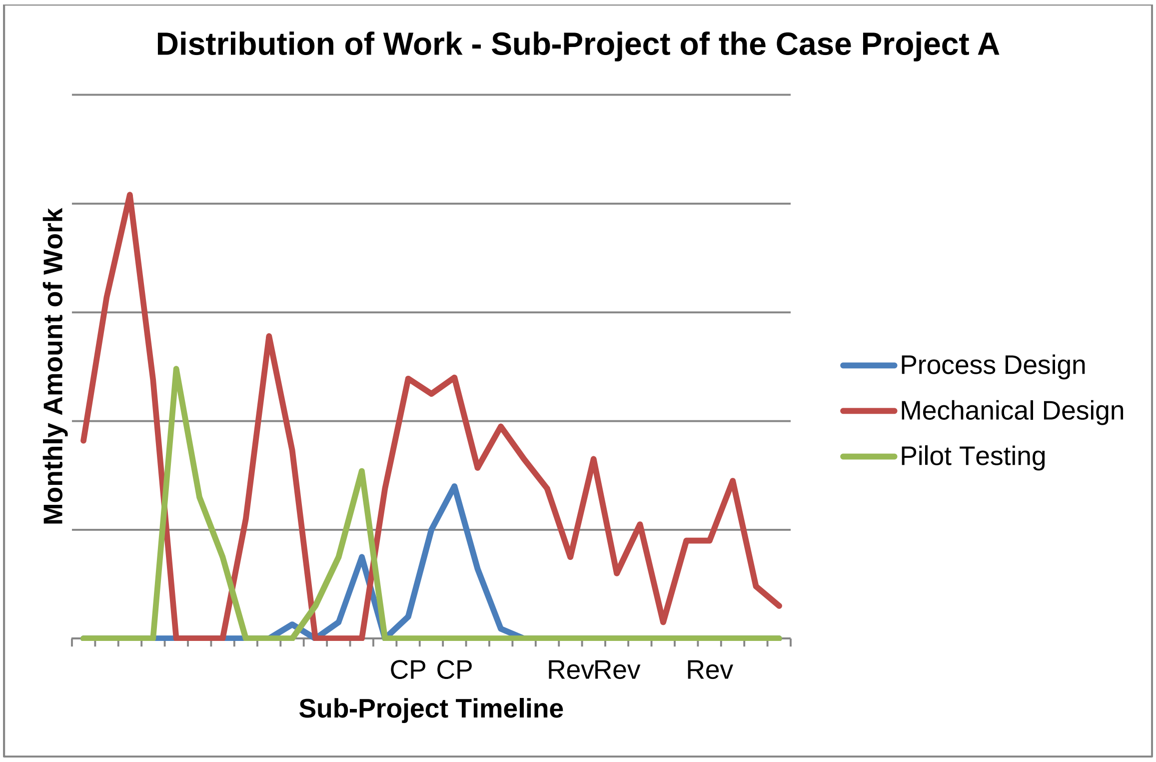


Figure 5. Distribution of design work in a sub-project of Case Project A.

Figure 5 proves that the design work does not end at the release of construction plans (CP), but it continues by revising them (Rev) according to the findings during site installation or late updates in design. Design resources should be reserved for the installation phase to act against deviations caused by design errors, installation errors or other unpredictable challenges. The experiences from Case Project A are summarized in Table 4.

Table 4. Experiences from Case Project A.

Positive	**Negative**
Learning from previous projects	Scheduling the design process
Collaboration with authority	Resources
Collaboration between organizations	Purchasing practice
Building the pilot Equipment	Providing starting information in design process

In Case Project A, many practices from previous projects were applied. Focusing on collaboration in this project produced positive experiences. Also the building of pilot equipment gave valuable information to the actual design and installation of the construction. Negative experiences in Case Project A were recorded from scheduling the design process and coping with resources.

3.2.2 Case Project B

Case Project B was launched to secure the safety of the power plant in cases where sections of the power plant are not accessible. Project tasks included process design, and mechanical design for piping and piping accessories. Employees interviewed in Project B were responsible of process design. Case Project B was in the P1 stage when this Thesis was written.

According to the interview, the purpose of P1 phase decision should be more standardized higher levels of project control. Very often different technical solutions were still discussed in the P2 phase, when the solution that was chosen in P1 should already be documented for authorities. With various technical solutions still on the table, it is impossible to start negotiating with suppliers without knowing the approximate budget. To be able to make decisions, different experts had to be consulted to gain sufficient information.

The experts of different fields did not necessarily have clear view of the total project and its challenges. Demands for nuclear-grade equipment have increased since the case organization has previously been purchasing them4. The amount of various documents has increased significantly and the purchasing practices need to be updated continuously. If the needed documents are not specified in the quotation, it is very challenging and time consuming to receive them from supplier after purchasing phase.

According to interview, the quality control that is related to purchasing practice, needs to be more standardized to ease the future purchasing. Some actions have already been taken to standardize the equipment specifications. The internal inspection practice is very time consuming as some inspectors are alone responsible of checkups in their own areas of expertise. Equipment and installation in nuclear power plant environment are more expensive than for example in conventional power plant environment. The cost of equipment is higher due to safety requirements that are certified with different factory tests. Also the contractor team's personnel need to have special training to be able to work in nuclear power plant. When making pre-budgeting quotations for the project, it is important that suppliers and contractors understand the nuclear safety requirements.

The higher level of project management should also be able to understand the reasons for higher than normal project expenses. Since last year, project manager has to make estimation of the authority expenses of STUK inside project's budget, when it previously was own independent expense out of project's budget. According to interview, this has been very challenging as it is impossible to forecast authority's needed hours. Controlling the expenses of project has gotten too much weight of project owner's role. According to interviews, owner should take more part to technical decision-making or give the whole technical responsibility to project manager.

Figure 6 shows the cumulative amount of work in Case Project B so far. Figure is based on data of hour usage from the database of Case Project B. As the case project B is still in P1 phase, the Figure 8 shows that mostly analytical pre-planning has been done. The stakeholders are trying to find the best technical solutions in the project to start defining the budget more specifically for P2 decision phase.

However, Figure 6 shows that different design stakeholders are needed already in the P1 phase to give estimations for material amounts and equipment specifications. To be able to provide reliable estimations, some preliminary design must be conducted which requires collaboration between the design stakeholders.

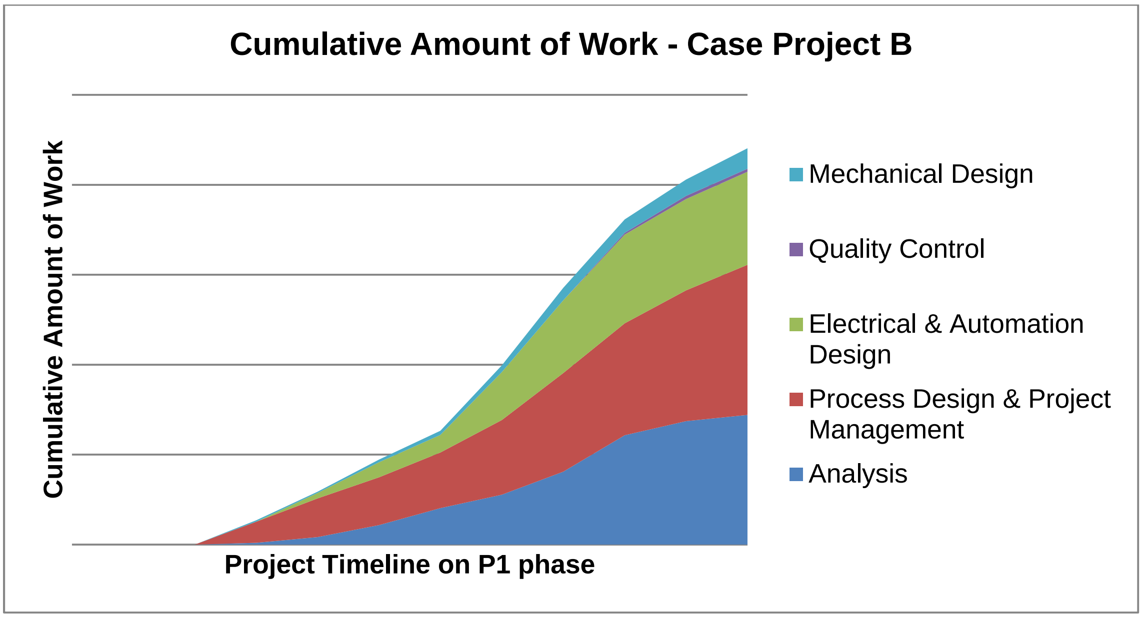


Figure 6. Cumulative amount of work in Case Project B so far.

As it was found from the interview results, it is very challenging to work with various technical options on the table. Project should aim to find best option and drop the unqualified proposals before P2 decision phase. Sometimes dropping the unwanted technical solutions requires preliminary design work from design stakeholders. Therefore it should be considered in the project pre-planning that some design resources have to start their work before P2 decision. The actual implementation design process after P2 decision phase could then start without any unnecessary obscurities and technical speculations. To meet this proposal, project practices should be more standardized to be able to understand the demands and needed documents on the whole project path. The most important experiences from Case Project B are summarized in Table 5 below.

Table 5. Experiences from Case Project B.

Positive	**Negative**
Recognizing challenges beforehand	Challenging to freeze starting information
Communication	Purchasing practice - Specifications
Knowledge sharing	Resources

In Case Project B, many design challenges were recognized before the implementation design phase by visiting the power plant and consulting various experts. Also, the communication and knowledge sharing are in significant role as Case Project B aims train and gain experience to younger engineers. Because of the challenging nature of the project, several solutions are still being reviewed and starting information is not frozen.

3.2.3 Case Project C

Case Project C was formed around large equipment supplied by external partner. Tasks in Project C consisted of checking equipment providers design and delivery package and the case organization’s design process considering the connection of the equipment’s to the existing power plant technology. Challenges in this project were the collaboration with the supplier and implementing the new large equipment into existing power plant environment.

The equipment supplier was an international equipment manufacturer from middle Europe. Case organization and supplier have had previous collaboration in the past when case organization was ordering similar equipment to co-owned power plant. The supplier was conducting a significant amount of engineering to fulfill the requirements and technical demands of case organization. Many technical change requests by Case Project C were taken into account even though the design by supplier was almost finished. These changes improved the safety and simplicity of the equipment.

The amount of mechanical engineering was relatively low in Case Project C as the equipment was designed by supplier. Only the delivery limit connections of the equipment to existing constructions and process at the power plant required mechanical design resources from case organization. Figure 7 shows how the work cumulated in Case Project C.

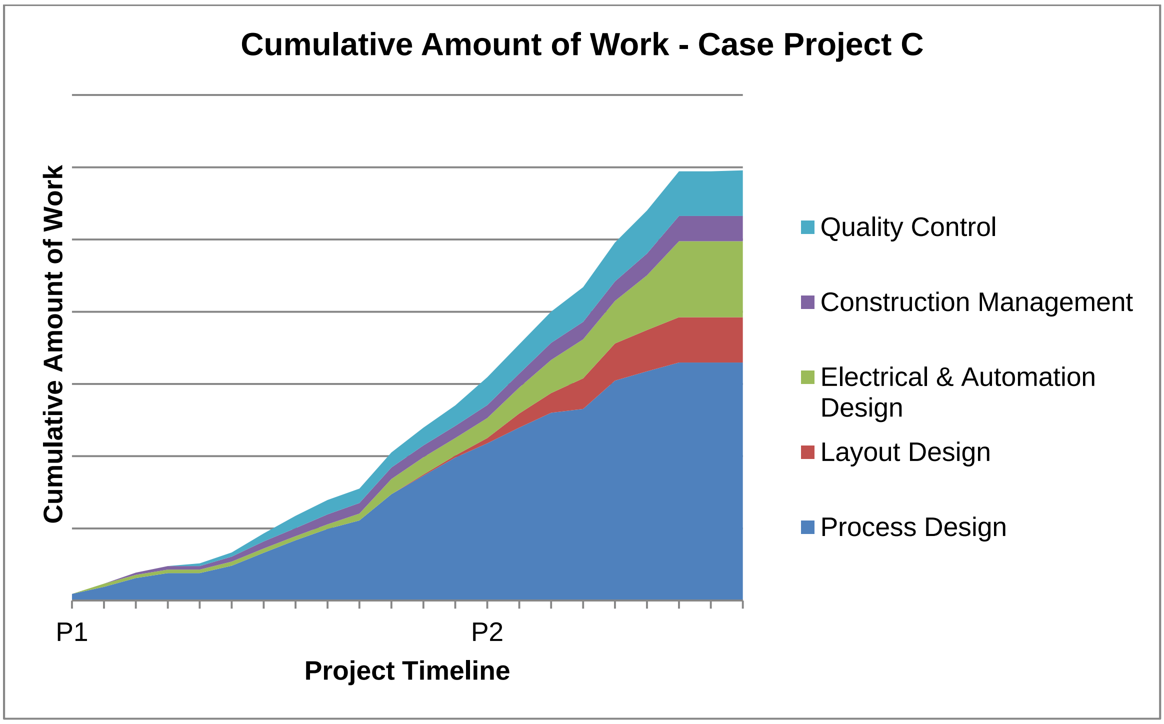


Figure 7. Cumulative amount of work in Case Project C.

The specification of the equipment and negotiation with the equipment supplier took place between P1 and P2 project phases, where process design was the main design stakeholder. After the P2 decision, the equipment was ordered. When equipment supplier was finished with their parts of design, they were able to provide starting information to design stakeholders of the case organization, who started to design the connections between plant operations and equipment.

As the equipment supplier did the design of the equipment, it had to be checked by the case organization. As the equipment included process, mechanical, electrical and automation design it required the same resources from case organization to comment and approve the design.

The resources were reserved from case organization on time, but the scheduling of the approval was challenging as the documents were received piece by piece and relevant information was presented in various documents that project manager had to manage. It was challenging to finalize the Construction Plans because they mainly consisted of the supplier's documents, which had to be revised continuously to meet the design standards of the case organization. The design stakeholders that were active after the P2 decision in Figure 7, where working on connection design and controlling the quality of supplier's design. The construction design was outsourced to consultant engineering company, but it required certain amount of management already in P1 phase. Even though the design phase should be mainly finished before P2 phase according to the LABC model, it can be seen that layout and other design were mainly done after the P2 phase.

In Case Project C, some best practices were applied from the previous projects. The supplier delivered the design documents to case organization through extranet. The delivered documents were updated into controlling table were inspectors could check the received documents and updates. However, the amount of documents was larger than expected and the delivery practice wasn't clear from the beginning of the project. Project manager was responsible of updating the documentation control table, which took significant amount of working hours. If the project had been aware of the volume of the documents in the beginning of the project, a separate project assistant would have been authorized to take care of the document controlling to avoid delays in table updating.

The benefit of using a purchasing engineer was learned from previous projects. Purchasing engineer knew the power plant environment and material demands. Project included mechanical and constructional design to connect the new equipment to existing power plant environment and the material in this design was summarized and purchased by purchasing engineer.

The collaboration between case organization's project organization and power plant's line organization was seen challenging. In this project both the project owner and project manager were from case organization. The project was presented to power plant's organization, but everyday comments considering safety and operation would need a named responsible person from power plant.

The requirements for equipment specification were on very high level. Some obscurity was reported when writing the specifications to certain equipment. Also the planning of equipment commissioning was demanding as the equipment were meant for safety use and connected to safety process piping. How can the equipment be tested without disturbing the ongoing process? And how to verify their performance in extreme conditions? The most important experiences from Case Project C are summarized in to Table 6.

Table 6. Experiences for Case Project C.

Positive	**Negative**
Successful pre-design	Resources
Collaboration with supplier	Collaboration in internal design process
Collaboration with purchasing department	Handling the documents

Positive experiences from Case Project C included successful pre-design where improved technical solutions led to simplified product. Positive development was found from collaboration between supplier and case organization and collaboration between project organization and power plant purchasing department.

3.3 Overview of the Current Design Process in the Case Company

Presently, the schedule, the budget and the needed resources are challenging to estimate in the beginning of the project. The total schedule rarely allows enough time for conceptual design or wide enough auditing in the beginning of the project. Various unseen deviations often lead into delays in schedule and costs might exceed the original estimations. The investment projects are usually unique which is why there is no sufficient database of former projects where to find help to estimations. The designers are usually asked to give estimation of their needed hours or for example amount of materials without having adequate information of the project.

In the case company, some projects are linked to plant operation or other projects and therefore schedules must be well prepared, followed and updated. This is why different stakeholders need to understand what the next stakeholder in the project needs in order to continue work and stay on project’s schedule.

According to the interviews, the design process in case organization is conducted on a case by case basis depending, for example, on the safety classification of the construction. Usually Process Design department has finalized their design into complete Process Plan document by the P1 phase. Mechanical design uses the Process Plan document as their starting information. Mechanical design phase starts between P1 and P2 phases. Earlier the process department can give finalized process data the earlier the mechanical design can start. Next stakeholder group after mechanical design is installation. It is important from mechanical design to give sufficient data for installation group to be able to start purchasing material or equipment that have long delivery times. Mechanical design usually continues after the installation and purchasing work has started as there are always some changes need to be done in the original design.

For example, a most typical project for technical support unit is a modification of the process at nuclear power plant to secure safety and efficiency. Three projects from this area were chosen to be investigated in the study. The safety improvement culture in the case company is continuous and has a long history. However, after Fukushima nuclear accident in 2011, the safety demands in nuclear power plants all over the world have become even higher. Incidents and problems in nuclear power generation have global effects in politics, as the nature of the production mode is controversial. For example the post-Fukushima reports given to STUK have launched new projects to improve and secure nuclear safety also in Finland and in the case company’s nuclear power plant. As a result, an increased number of projects have tied resources from case organization.

These typical projects usually start from the need for an improvement. After the need is clarified, a safety analysis is implemented for the prospective investment project. After the project officially starts after P1 decision, as introduced in Table 3, the design process starts. Design process in design and implementation phase can include risk analysis, process design, construction design, mechanical design, electrical and automation design. Installation, trial run and final inspection are carried out following the decisions made in design phase. The previous arrangement is typical in many process industry's projects, but in nuclear power plant projects the final information is provided to next stakeholder in various official documents that are inspected by the responsible persons. Documents of projects that include modifications to constructions with higher safety class must be approved by STUK. The involvement of authority makes the project process more challenging as possible deviations in approved documents need to be approved again.

Quite often the investment projects to case company's power plant include *piping design*. Therefore, the simplified piping design process is used as an example of the design process. Figure 8 illustrates the typical piping design process in investment projects.

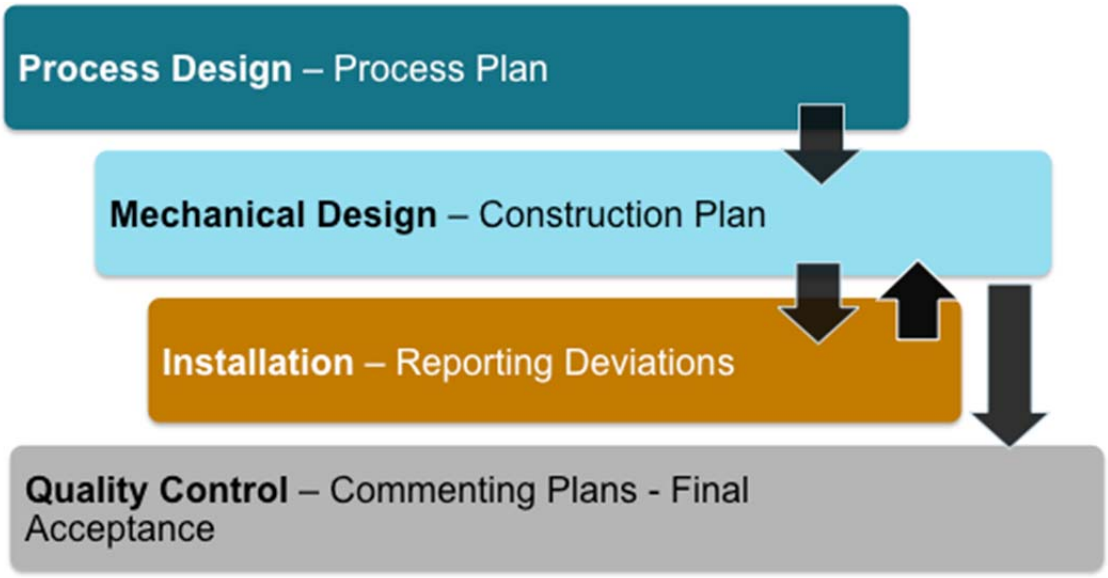


Figure 8. A typical piping design process in an investment project.

As seen from Figure 8, the piping design process in investment projects follows roughly the path, *process design, mechanical design, installation and quality control*. These stages also represent the stakeholders that are involved and being examined in this Thesis.

The installation stakeholder should be included in the *design* process because of their valuable comments to design stakeholders before installation and reports of the deviations from original design during the installation phase. The deviations need to be confirmed or updated by designer into "as built" drawings after installation and final testing.

The quality control is also part of the design process by commenting and consulting the solutions of design stakeholders. The quality control checks the documents and approves the final construction.

The official documents of each design stakeholder that have to be approved are also introduced in Figure 8 above. The *process design* stakeholder releases the final approved information in the form of *Process Plan*. The Process Plan has to be approved by responsible persons when a modification of the equipment or process that the document is covering might influence the operability of the process due to a change in process, construction, electrification or automation (Honkala 2013:18).

The responsible person who checks the Process Plan before the approval round is the head of mechanical and process design department in the technical support unit or the process design engineer. Process Plan must include the basis of design, the operating and design parameters and the normal operation of the process and the operation in failure or emergency situations. The responsible persons approve the validity of the P&I-Diagram and the operability of the process to achieve the target. The feasibility of the chosen components in to the target has to be evaluated together with the impact to the operability of the other process systems by the user experience of the responsible persons (Honkala 2013: 18).

The *mechanical design* stakeholder releases the official information in *Construction Plan.* Construction Plans in investment projects are sent to checking and approving round to responsible person of the areas that the plan is considering. The responsible person who checks the Construction Plan before sending is the head of mechanical design or a mechanical design engineer.

The Construction Plan must be made according to the instructions and specifications of the case organization and content and the structure must be appropriate and sufficient. The mechanical drawings in the Construction Plan have to be checked and approved according to the instructions of the case organization and the safety level has to be classified according to the safety classification instructions. The Construction Plan has to fulfill the requirements of the national nuclear instructions (YVL). It is also important that the technical design presented in the Construction Plan is economically reasonable. (Honkala 2013:8)

If the mechanical design in the Construction Plan is complex or includes constructions whose mechanical strength has been analyzed, the Construction Plan has to be approved by a person who has the qualification to it. Mechanical strength is usually analyzed from pressure equipment and its parts and supporting, piping and its parts and supporting. The responsible person checks that the quality of the strength analysis is adequate and that the starting information of the analysis is correct. Responsible person also checks that the pressure classification of the pressure classified equipment is adequate. (Honkala 2013:14)

Person who checks the Construction Plan needs to evaluate if the chosen material in the technical solutions has to be checked by material specialist. If needed, the material specialist checks the applicability of the material in the target. The corrosion threat in the target and the compatibility of the surrounding materials is also evaluated by the material specialist. (Honkala 2013: 13)

Quality Control stakeholder checks the quality requirements in the Construction Plan. Quality requirements are depending on the starting information from the Process Plan (see the final proposal in Figure 14).

The released Construction Plan is the basis of information for the installation team. The possible deviations in the design that are found or requested during the installation are updated in to the revised Construction Plan. The quality control stakeholder controls the final inspection and testing of the new system. Figure 9 presents the design, checking and approval process of document in case organization.

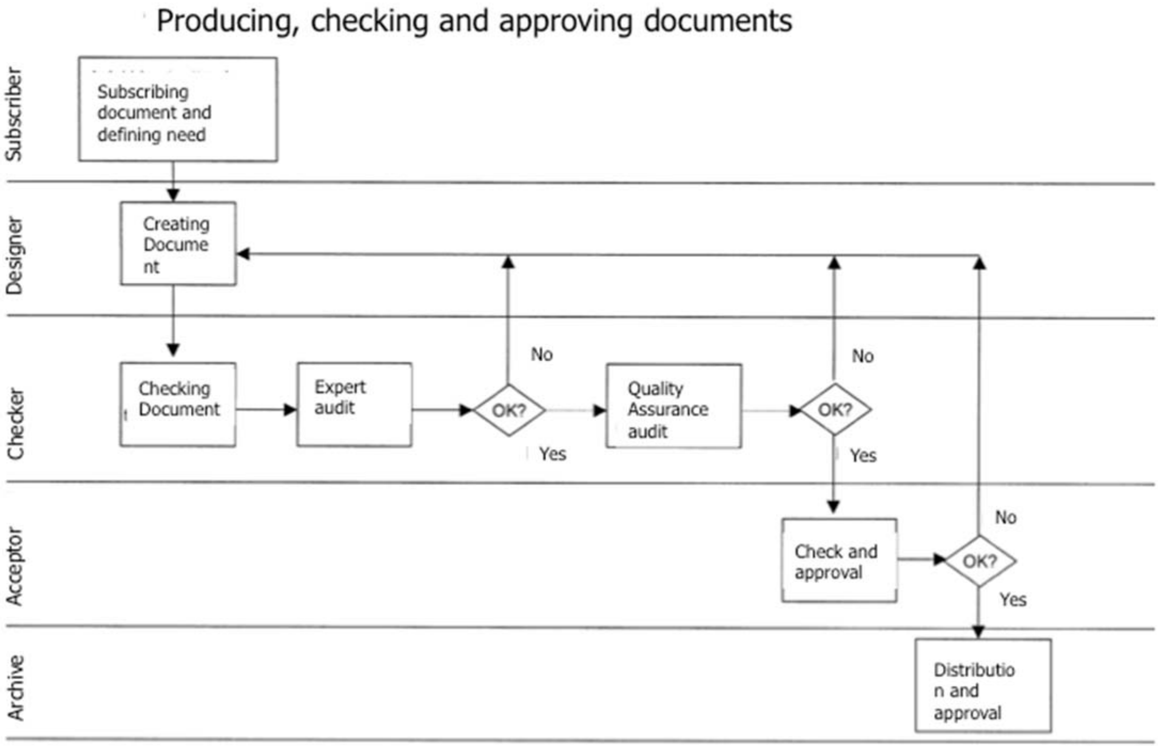


Figure 9. Producing, checking and approving documents in case company.

3.4 Summary of the Current State Analysis

The current state analysis helped to find best practice for investment type of projects. Many of the practice in case projects were implemented from the previous project history and some were developed during the case project. Even though the case projects have challenging technical problems to solve, the quality requirements are achieved. In some cases the cost, quality and schedule are all achieved, which is not an easy combination in project-based business.

The interview results showed that all the case projects had similar challenges in their design process and project management in general. Project A was the only project that had reached the final P4 phase and therefore had already found actions to act against the challenges and had also evidence of their effectiveness. Other case projects reported challenges and suggested actions how to prepare against them. All the challenges and actions were summarized in Table 7 below.

Table 7. Challenges and best practice based on case project interviews. Data 1.

	Project Challenge	Best Practice	Case
1	The effects of certain decisions to the whole design process should be understood more clearly.	Collaboration between design stakeholders, mapping the design process, “Freezing points”	B, C
2	Project includes technical solutions that have to be tested after design.	Solutions can be tested by building pilot equipment outside the plant area.	A, B
3	Design stakeholders are unable to provide starting information to each other early enough, which causes breaks in design process.	Design process must be phased so that each stakeholder has enough time to provide information to next designer.	A, B
4	Communication between project organization and power plant.	Naming responsible person from power plant, Monthly meetings, Owner or manager from Plant personnel	A, C
5	Not enough design resources	The need of resources should be evaluated and reserved in project pre-planning stage.	A, B
6	Not enough time to prepare the purchasing, Purchasing practice are unclear.	Using a Purchase Engineer	A, B, C
7	Specification requirements and commissioning practices are challenging for new safety equipment.	Purchasing practices and specification requirements should be more standardized	B,C
8	Handling a large amount of documents consumes management and design resources	Use of extranet or sharepoint, Using Project Assistant	C
9	Scheduling the authority acceptance round of documents	Presenting the project and schedule to help the authority prepare their resources. Approx. 3 months	A
10	Scheduling the internal acceptance round of documents	Responsible person from power plant follows the acceptance. Electrical acceptance.	A, B, C

Similar or same challenges presented in Table 7 that were found from every case project were scheduling the internal acceptance round (10), low resources or obscurities in purchasing practice (6). Case Project A had a practice of naming a responsible person from power plant personnel who was aware of the project and who was guiding the documents among the personnel of the power plant.

When project management is planning the project schedule, it is challenging to evaluate the time needed for various acceptance rounds. Project management should be aware of the workloads of responsible person several months beforehand. Also, the time needed for authority acceptance round was found almost impossible to evaluate, as it cannot be known who is the responsible person and what kind of workload the authority would have in future. Informants from case project A were suggesting an approximate of 3 months to authority acceptance round. To give some reasonable evaluation for project schedule it was suggested to consult the responsible person to ask their own evaluation of the time needed.

According to the interviews, *the equipment requirements and purchasing practices* should be more standardized. Design stakeholder prepares the purchase and specifies the equipment that are needed for the project. Purchase engineer implements the purchase that is based on definitions of design engineers. However, the purchasing practice change continuously due to increasing demands on nuclear business. Therefore the design and purchasing stakeholders should increase the collaboration to improve the purchasing practice. Case project C had reserved a purchase engineer to work full time with the project after P2 decision. This was reported to give advantage in purchasing, as the purchase engineer was familiar with the purchase practices and demands of the power plant.

The LABC model was applied in case projects B and C since the beginning. In Case Project A it was applied later in the implementation phase. The reporting procedures in LABC project model require significant amount of time from project manager, but are useful in steering the project. The design process between the design stakeholders and their tasks is not clear enough as it is slightly different in each project.

Common challenges for case projects A and B were new technical solutions that should be pilot tested (2), phasing of the design process to secure the parallelism (3) and the lack of design resources (5). *New technical solutions that should be pilot tested* were considerable challenges in both Case Project A and B. Both projects included critical technical functionality that was proposed in the design but had to or has to be tested before implementing them in to power plant facilities.

In Case Project A, the pilot testing was conducted inside the design process with project resources. Therefore, it had also the schedule pressure of the project. The proposed design had to be pilot tested outside the nuclear power plant, because of the challenging installation and operating conditions at the actual site. The pilot test was designed with project resources and the test was conducted in power plant area, but outside the nuclear power plant. The test results were the foundation and starting information for significant part of the Case Project A. The new technical solution of the Case Project B will be pilot tested to confirm the functionality and feasibility before expensive and challenging construction and installation work.

Phasing the design and *lack of design resources* are related to each other as they are challenges of resource planning. Design process should be parallel in order for different design stakeholders to receive and provide information to next design stakeholder as smoothly as possible. The design stakeholders that are neighbors chronologically in design process should have some overlap between their tasks. This sets challenges for the project management, as they should be able to estimate the needed hours for each design stakeholders. This estimation is necessary since much overlap between the design stakeholders can lead to wasted hours if the starting information is not provided early enough. Lack of overlap could lead to breaks in design process if the previous design stakeholder is able to provide the starting information earlier than planned and the next stakeholder is scheduled to start later and is still possibly working on other project. Planning the design schedule requires understanding of the design process from the project manager. Constant lack of resources makes it difficult to repair the pre-planned schedule afterwards.

It seems that the answers from Data 1 were all related to project engineering and project planning, which includes schedule and resource planning. Other recognized issues were related to knowledge sharing, communicating and collaboration. All the previous cause challenges to design process or can be located in to it. As all the projects included piping design, defining the piping design process is seen important in this Thesis.

4 Best Practice for Project Engineering in Investment Projects

This section discusses best practices existing in literature for investment type of projects. The section is the theory part of the study and it discusses practices and models of project business' to improve a design process in investment projects. The models introduced in this section are from various fields of project business' where successful design process is an important phase of the project. The perspective in this section is derived from the findings of the current state analysis in section 3.

Section 4.1 discusses the characteristics of project engineering by introducing different types of a project and their risk handling. Section 4.2 specifies the concept of design process from chemical and mechanical engineering literature's point of view. Section 4.3 explains the critical path method that is widely used in schedule planning to recognize the most important tasks in the project. Section 4.4 discusses ideas of sharing and learning culture in companies whose business is research and design oriented. The findings in current state analysis part of this study indicated that many challenges in projects of the case company are related to collaboration between different stakeholders. Section 4.5 summarizes the theory part of this study.

4.1 Characteristics of Project Engineering in Investment Projects

Success of the project in investment type of projects is depended on staying on schedule, budget and meeting the quality requirements. It requires good relationships inside the project team and parent organization. Another measurement is quality and usefulness of the delivered project that can be measured with client satisfaction (Pinto and Mantel Jr. 1990: 270). As it was introduced in the current state analysis of this Study, the case organization applies the LABC project model tool to follow and measure the investment project.

Managing the project usually means managing risks along with the project plan. Risk is something that is already known, but not yet realized. Other similar threats in a project are changes and deviations. Changes are threats that are acted against after the realization as risks can be reduced proactively beforehand. Deviations recognize a larger amount of situations than normal risk or change would do. Deviation can be positive, negative, large or small (Hällgren & Maaninen-Olsson 2005: 18). The Data 1 of this study was summarized in the Table 7 that introduced challenges that had realized in the studied case projects.

Some typical investment projects are, for example: *Regulatory compliance projects* that are required by government or other legislator due to environmental or other reason. Government can change the demands on plant safety, emissions or product specifications. Plant can then be forced to carry out the project or be shut down in a certain period of time. *Cost-reduction project* are implemented when seeking lower costs in plant operation. For example *preventive maintenance* is a typical cost-reductive action where plant is kept efficient by replacing equipment or repairing them on time. *Growth projects* are investment projects that seek to give returns to the invested capital. These projects can be expansions to existing plant or so called *revamp or debottlenecking projects.* Entirely new investment projects can be called *Grassroots projects.* Before any of these projects can be designed, a large amount of information about the existing plant and site is needed (Sinnot and Towler 2009:377). In the case company's power plant where the three studied investment projects were implemented the information has to be searched from old drawings that have to be verified on site visits before starting the actual design in the target.

Grassroots projects can be designed on an empty site without comparative simulation to existing plant. However, their share of typical investment projects is less than 10% (Sinnot and Towler 2009: 377). The next section discusses the design process in investment projects from the perspective of different fields of engineering.

4.2 Design Process in Investment or Research and Design Projects

A typical starting point for design process is identification or proposal of the need. The need can arise for example from the will of the marketing organization to increase sales or other demand for creating something new. The overall objective and requirements should be clear for designer before starting work. From the requirements it is important to recognize the parts that are desirable, but not necessary.

Sinnot and Towler (2009: 4) suggest that designer should always follow the requirements critically and evaluate them as the design progresses. It is important for designer to communicate with the stakeholders that define the requirements and refine them through discussion if possible. Also when giving specifications to other stakeholders, it is important to understand the effects of given restrictions to next stakeholder’s work. The previous was also recorded as the Project Challenge no. 1 in Data 1 (Table 7). Well-planned specifications that are written in mutual understanding with other stakeholder’s, define successful design borders for every designer to work. (Sinnot and Towler 2009:4).

Design basis is the most important step in the beginning of the design process. It is a translation of the customer need that defines the problem and design constraints. In the process plant engineering the most common constraints are units that will be used, design codes or instructions, raw materials, surrounding environment and available services that allow the running of the process. (Sinnot and Towler 2009:4). The previous statement from Sinnot and Towler can be related to Project Challenges 4 “*Communication between the project organization and the power plant”* and 7 “*Specification requirements and commissioning practices…”,* that were found in Data 1.

According to Sinnot and Towler (2009:5), a chemical engineering projects are usually some of the following three types, depending on the existing/new ratio in the project. Modifications to existing plant which is usually designed by the own group of experts working on a plant, new capacity to increase plant’s efficiency, which are usually existing design by external engineering company or completely new processes that are developed by plant’s own R&D personnel.

In a chemical engineering it is usually too expensive to build several prototypes to find out the best solution, as in typical product development based business. Therefore, in the field of chemical engineering various design models are used to optimize the plant process before moving on to more detailed design (Sinnot and Towler 2009:6). However, some significant design parts of the project can be pilot tested as it was suggested in Table 7 Best Practice 2 “*Solutions can be tested by building pilot equipment outside the plant area”.*

In a typical process plant project that includes piping system, the process designer can start to estimate the equipment sizes and costs to rule out the most uneconomical process options after process optimization. The proposed basic design is first presented in the process flow-sheet and then in the P&I Diagram that shows the arrangement of process equipment, piping, pumps, instruments, valves and other fittings. The economic evaluation is usually the primary criterion when selecting the different options. After finding an economically reasonable option for the basic design, safety and operational factors are being overlooked (Sinnot and Towler 2009:7).

Next phase after the basic design is the detailed design phase where the equipment and material are defined more specifically. The usual design stakeholders in detailed design phase are mechanical engineering, civil engineering and electrical, instrumental and automation engineering. Process engineering stakeholder provides the basic design data in form of flow-sheet and P&I Diagram to mechanical engineering who start the pre-design. Process engineer also recommends the material used in piping similarly considering the strength and other requirements (Sinnot and Towler 2009:390).

Mechanical engineering determines the piping detail, support and layout design, which is a starting information for civil engineering and electrical, instrumental and automation engineering. In large projects, these detailed engineering stakeholders are sometimes engaged outside the plant company as contractors. Large contractor companies can provide the needed competence at relatively low cost (Sinnot and Towler 2009:7)

In every stage of project’s design process, information about manufacturing, equipment, materials of construction, costs and details of process materials are important. This information can be found from previous projects, literature or experiment. Needed data can also be purchased from contractor. When values are unavailable, the data needed has to measured or estimated (Sinnot and Towler 2009:420). The accuracy of the required data depends on the *level of design*: In the beginning of the investment project rough estimates are sufficient, *the reliability of the design methods*: If the techniques to be used are yet undecided or the *sensitivity to the particular property*: The effects of small errors. Intelligent guesses are sometimes enough when estimating values that have insignificant causes to final result (Sinnot and Towler 2009:424).

The effectiveness of design process can be measured with three variables: *cost, quality* and *time*. *The cost* of design is usually relatively low when compared to material, installation and overhead costs. Figure 10 shows an example from car industry where the cost of design is only 5% of the total manufacturing cost.

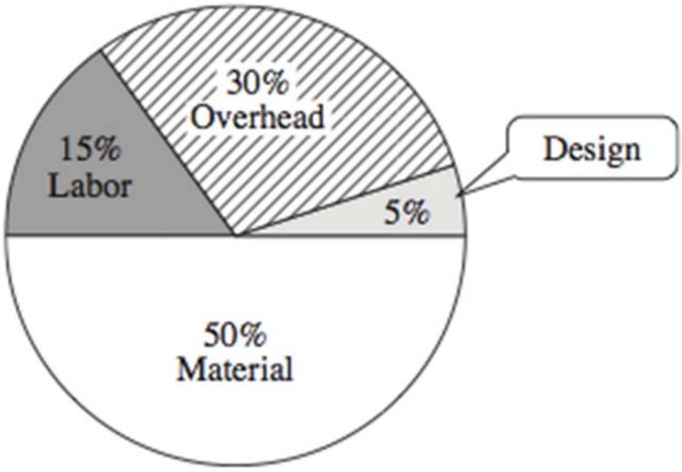


Figure 10. Cost of design in car industry (Ullman 2010:4).

The decisions made in design process can effect enormously to the success and costs of project. However, as seen from the Figure 10, the cost of design is usually under 10% of the total costs of the project. Material, labor and overhead costs are decided in design phase and they define the majority of the costs of the project. This proves that the design process with its needed resources should be carefully thought in the pre-planning stage of the project where project schedule is prepared as it was proposed in the Table 7, Best Practice 5. Extra investment to design costs can give great savings later in the project or vice versa.

The costs committed early in the design phase are spent later in the purchasing phase. In a typical manufacturing project 75% of the costs are already committed in the conceptual design phase as can be seen in Figure 11, which shows the relationship of the third variable *time* and costs committed in a design process. The X-axis presents the time or the schedule of a project. Y-axis presents the costs of the project budget committed.

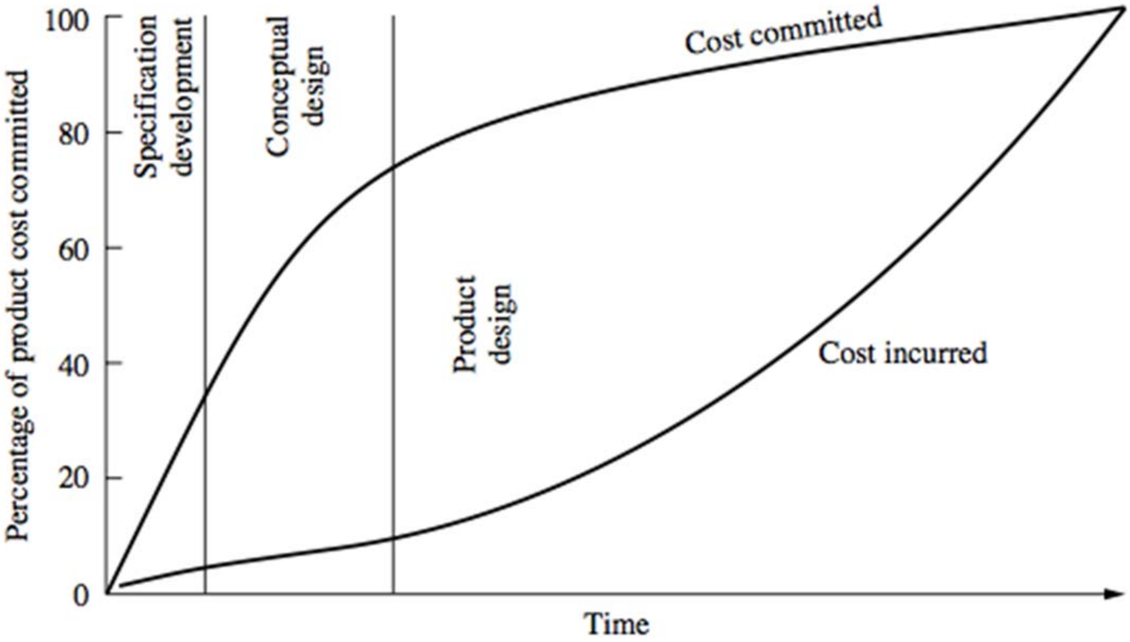


Figure 11. Commitment of costs during design process.

Time is also affected by the decisions made during the design process. Making changes is normal in an iterative design process to find the best possible solution. However, the changes should be executed as early as possible in the design phase. That requires a lot of engineering effort in the beginning of the design process but decreases the more expensive “firefighting” –type of design where changes have to be made in documentation or hardware. (Ullman 2010: 3-7).

There is often sparse knowledge of the design problem in the early phase of the design process. During the design process the knowledge increases but the freedom to change the design decreases. This can be called the paradox of design process which is shown in Figure 12. The X-axis presents the time consumed in the design process of the project. The Y-Axis presents the percentage of knowledge about the design problem and the freedom to change the design.

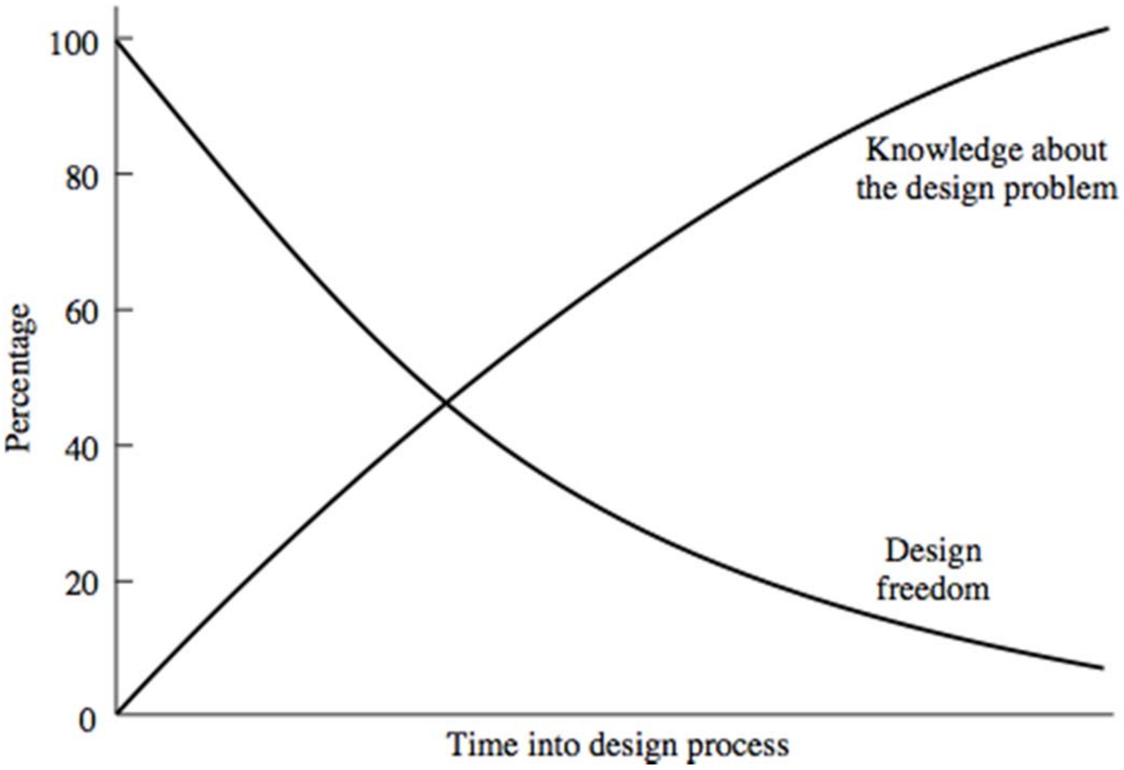


Figure 12. The paradox of the design process.

The Figure 12 illustrates the paradox of design process. The interview results in previous section support the theory of paradox of design process. In the beginning of the project there usually is only a goal that has to be reached by fulfilling cost, schedule and quality requirements set for the project.

Therefore it is important to learn as much about the design problem as possible as early as possible during the design process (Ullman 2010: 19). Ullman (2010:20) explains the design paradox as: “The more you learn the less freedom you have to use what you know”.

As the project progresses the knowledge about the design problem increases and certain technical solutions have to be chosen to give starting information for different design stakeholders. This decreases the freedom to make changes in design, as they would threaten the project schedule. However, the paradox is that these steps back could increase the quality or decrease the overall cost of the project. The conclusion from interviews was that all the possible knowledge should be gained as early as possible in the project by scheduling more design effort in the beginning of the project.

Third variable, *the quality* in mechanical manufacturing is typically defined to be in a satisfactory level when the final product or system works as it was required, latest technology is implemented and it lasts as long as it is required. Again, the decisions made during the design process determine the quality.

In a plant engineering environment the design work of the project organization, can be roughly divided in two phases. The first phase is process design that covers the selection and analysis of the process to be used with all necessary sheets and documents. Also the specification and selection of the main process equipment is on process design group's responsibility.

The second phase is plant design, including detailed mechanical, structural, civil and electrical design. According to Sinnot and Towler (2009:11) the project manager is usually a member of process design stakeholder group and responsible of coordinating the project by ensuring that all stakeholder groups involved in the design process complete design on time. In the design instructions of the case organization the phasing of design work is not defined in a detailed level.

In this study, the challenges and best practice that were found from the analyzed case projects and their design processes are familiar to literature related to project engineering and design processes. Knowledge from literature considering design processes in investment projects was studied to find best practice. When project schedule and design process is being planned in the project planning stage, the critical path method is used to find the most important tasks from project path. Next section introduces the critical path method.

4.3 Critical Path Method in Investment Projects

Critical path method is widely used method that aims to recognize the critical activities in the project. Critical path defines the completion time of the project and therefore it needs to be identified so that project managers can focus on it (Zammori et al. 2009:278). When defining the critical path, the project must be broken in to project parts to create a list of activities. Best possible categorizing of tasks and possible sub-projects can be achieved when project team and scheduler collaborate. The tasks and sub-projects are then located and sequenced on a logic diagram. At this point the time is not part of the planning (Sandru & Olaru 2013:440-443).

When the activities are sequenced, three questions can be asked: “What other activities must be completed before this activity can start?”, “What other activity can be going on while this activity is underway?” and “What activity cannot start until after this activity is completed or at least underway?” (Klastorin et al 2003).

The next phase is to estimate the durations of different tasks and the sizes of the teams implementing the work. After the durations and amount of resources are estimated together with the logic diagram of tasks, the critical path can be defined (Sandru & Otaru 2013:443-444). Time boundaries for each activity are established by determining the basic computations: “forward pass” and “backward pass”. These time boundaries define early start time, early finish time, late finish time, late start time and critical path. According to Kerzner et al. (2003) early start time is “the longest lapsed time cumulative count of all the paths of activities converging at an event of a forward pass”. Early finish time is “the early start time plus the duration of that activity”. Late finish time is “the shortest lapsed time cumulative count of all the pass activities converging at an event on a backward pass”. Late start time is “the late finish less the duration of that activity” and a critical path is “a group of necessarily related schedule activities which together create the longest duration through the schedule to project completion (necessarily related by construction logic or resource allocation)”.

Float is the time of uncertainty that is related to the path or chain of activities. It expresses the amount of time that early finish time of an activity can be delayed without having an effect to the critical path and therefore the total project. Float provides flexibility to act against deviations and solving problems. Sandru & Olaru (2013:445) explain four types of float that can be used in practice: Total Float, Free Float, independent Float and interfering Float. *Total Float* is “the total amount of time by which an activity may be delayed without affecting the project finish date”. *Free Float* is “the amount of time by which an activity may be delayed without affecting any other successor activity in the path”. *Independent Float* is “the time by which an activity may be delayed without affecting the early start date of any other successor activity in the path nor impacting the latest start time of any other predecessor activity in the path”. *Interfering Float* is ”the available period of time that, if necessary in case of delays, would decrease the amount of float available to successors activities in the path; being in fact the difference between *Total Float* and *Free Float”.* According to Sandru & Olaru (2013:445) Total Float is the most common type of floating used in schedules. Free, independent and interfering floats are not used as often.

Project manager must analyze carefully each task of the project to be able to create the critical path of the project. This requires at least cursory understanding of the tasks involved in the project. Also knowing the people who work in the project as well as the culture of the organization is important. The previous current state analysis recognized challenges and practice related to scheduling in the investment projects of the case organization. These challenges were for example 1, 3, 5, 6, 9 and 10 in the Table 7. Next section discusses the sharing and learning culture in research and design oriented organizations.

4.4 Sharing and Learning Culture in Research and Design Work

Design engineers involved in a certain project often have opinion how various tasks could have been done better during the project. In fact many engineers would like to start from the scratch in the middle of the project when they have more knowledge about the design problem than in the beginning of the project. Further the project and design is progressing, more knowledge about different problems is gained. Sadly, the project schedule rarely allows any back-steps. Therefore, it is very valuable to collect these after-project experiences and improvement ideas to apply them in the future projects. And even more valuable is to share this knowledge openly to help other designers use similar successful solutions or not to make same mistakes in their projects.

Failures cannot be avoided in a complex design process, so it would be easier to think how to learn out of them. Design process often involves development of something that has never been done before. These development phases should be piloted as early as possible to learn from the failures. Typically the products or services that are being piloted, are tried to make as perfect as possible to pass the piloting stage. Pilots should be tested under typical circumstances focusing on failing rather than optimizing the success of the test (Edmondson 2011:55).

Failures can be divided in to the three following categories: preventable failures, unavoidable failures and intelligent failures. *Preventable failures* are predictable operations that are considered as bad failures because they are deviations in routines that can be avoided by sufficient training and support. *Unavoidable failures* are failures in complex systems that often unavoidable. These failures should not be necessarily considered as bad failures because of their educative possibilities. *Intelligent failures* at the frontier can be considered as good failures because they lead into development and growth. Intelligent type of failures can be found for example from pilot testing of systems or equipment where answers are being searched. (Edmondson 2011:50-51).

In a design process of a typical investment project, design failures can be considered as preventable failures. Design failures can be for example solutions that are impossible or very expensive to build. However, the failures in typical design process are usually intelligent failures at the frontier, which can be considered as good failures because of their educative reasons. In a design or a project organization it is important to emphasize the learning culture. This means reporting and analyzing the failures rather than finding responsible persons for them. Failing faster means succeeding faster in discovery business. Leaders in project organization should recognize the three kinds of work for example in design process – routine, complex and frontier and treat the failures occurring in them in required manner which are: detection, analysis and experimentation. (Edmondson 2011: 52)

Improving the sharing and learning culture in technology-oriented companies is also an organizational challenge. Coordinating the collaboration among different units in large companies require organizational planning and its maintenance. Goold and Campbell (2002:5) present six forms of “unit-to-unit links” to evaluate the collaboration of different units.

Shared Know-How measures how well best practice are shared, expertise in functional areas is influenced on and if knowledge pooling is successful in different regions. *Shared Tangible Resources* is a link to evaluate how well resources, such as people and physical assets, are shared and can duplicated effort be avoided. It can also be discussed, if the resources of company can be used to create economies of scale. (Goold & Campbell 2002:5)

Generating economies of scale can also be useful for example in common purchases or negotiating with other stakeholders by *Pooled Negotiating Power*. Strategies in different units of the company can be aligned to create *Coordinated Strategies*. *Vertical Integration* measures if the services of the company can be more coordinated to reduce costs and increase capacity. *New-Business Creation* is possible can by combining the competences from different units to create joint ventures and teams. (Goold & Campbell 2002:5)

In the case organization of this study, the best practice in design process of investment projects could be shared (*Shared Know-How*) more efficiently as it is proposed in Table 7 Challenge 1 “*The effects of certain decisions to the whole design process should be understood more clearly”.* Case company is *sharing tangible resources* in every investment project, as design resources work in a project-by-project basis.

4.5 Summary of Best Practice

Literature of project and design engineering defined best practice related to managing the processes in various types of projects. This section defined the conceptual framework of the study. Findings from literature that were introduced in this section can be used as basis when analyzing the current state of the processes in case company.

Figure 13 summarizes the conceptual framework introduced and analyzed in this section.

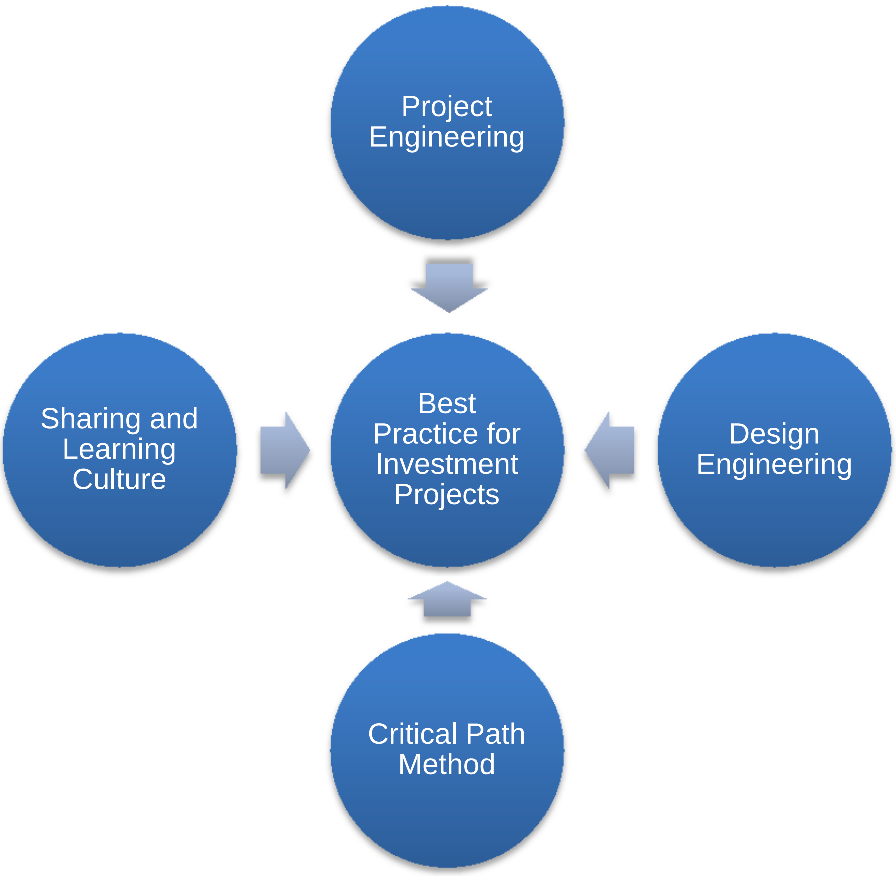


Figure 13. Conceptual framework of the study.

The conceptual framework of this study represents the four elements of a successful investment project requires implementing and understanding. Characteristics of project engineering were studied first to gain general knowledge of the topic. Project engineering includes also schedule and resource planning where critical path method can be categorized. However, the critical path method was studied as an independent part, due to its importance. Characteristics of project engineering described the various natures of a project and explained the importance of preparing against risks.

Secondly, the design engineering section introduced the paradox of design process and explained the design process from the perspectives of chemical, mechanical and construction engineering. The third, critical path method explained the importance of recognizing the most important tasks in the project and method of scheduling the work processes.

The fourth section considering the sharing and learning culture in research and design type of work analyzed the more humane perspective in engineering. Section analyzed the stance to failure and explained practices from literature. Also the role of organization in sharing and learning culture of company was analyzed in this section.

The four elements formed the best practice for investment projects and it was used as a theoretical background when analyzing the current state of the case projects and when proposing improvements to the design process of investment projects.

It is important to study the design problem in the investment project as thoroughly as possible before starting the official design process. Recognizing risks beforehand expedites the actual design process as the most challenging problems can be discussed before the project schedule. Adequate pre-planning also helps to separate the research-oriented design tasks from the typical design process. Research and design tasks should be treated differently depending on how project should react to failures appearing in them. The collaboration and involvement of the stakeholders in the project is as valuable in the beginning of the project as during the project path.

5 Analyzing Best Practice for Investment Projects

In this section the Data 1 from interviews is analyzed and compared to the project instructions of the case company and best practice from the literature. The informants were asked to mark the challenges and best practice from Data 1 to the Figure 15, which presents the LABC model of the case company.

The most typical stakeholders involved in a typical investment project and its piping design process, according to the best practice found from current state analysis and literature, are introduced in Section 5.1. At the end of every sub-section, a table of data and documents is presented to summarize the work of certain design stakeholder. The relationship of the data between the design stakeholders is presented in Table 10. Finally, the analysis is summarized and the tasks of stakeholders and the flow of information are located in chronologic order to illustrate the typical piping design process in Section 5.2.

5.1 Findings of Data 2

The informants were asked to mark the challenges and best practice from Data 1 to Figure 14, which presents the LABC model of the case company. Most of the marked challenges and practice were located in to the design process of the case project. Therefore, the conclusion was that the design process needs to be investigated and better defined. As every case project included piping design, the piping design process was chosen as the focus for building the design process.

Data 1 collected from the current state analysis in Section 3, was analyzed by the informants and compared to the LABC model of the case company. Figure 14 below presents the challenges and best practice located in to the current LABC project model according to the informants of this Thesis. The challenges and actions mapped in Figure 14 were previously summarized in to Table 7. They comprise such challenges as providing information early enough and understanding the effects of decisions. The case project informants were asked to mark the numbers to a paper copy of the LABC project model. The final mapping of the challenges is presented in Figure 14 below.

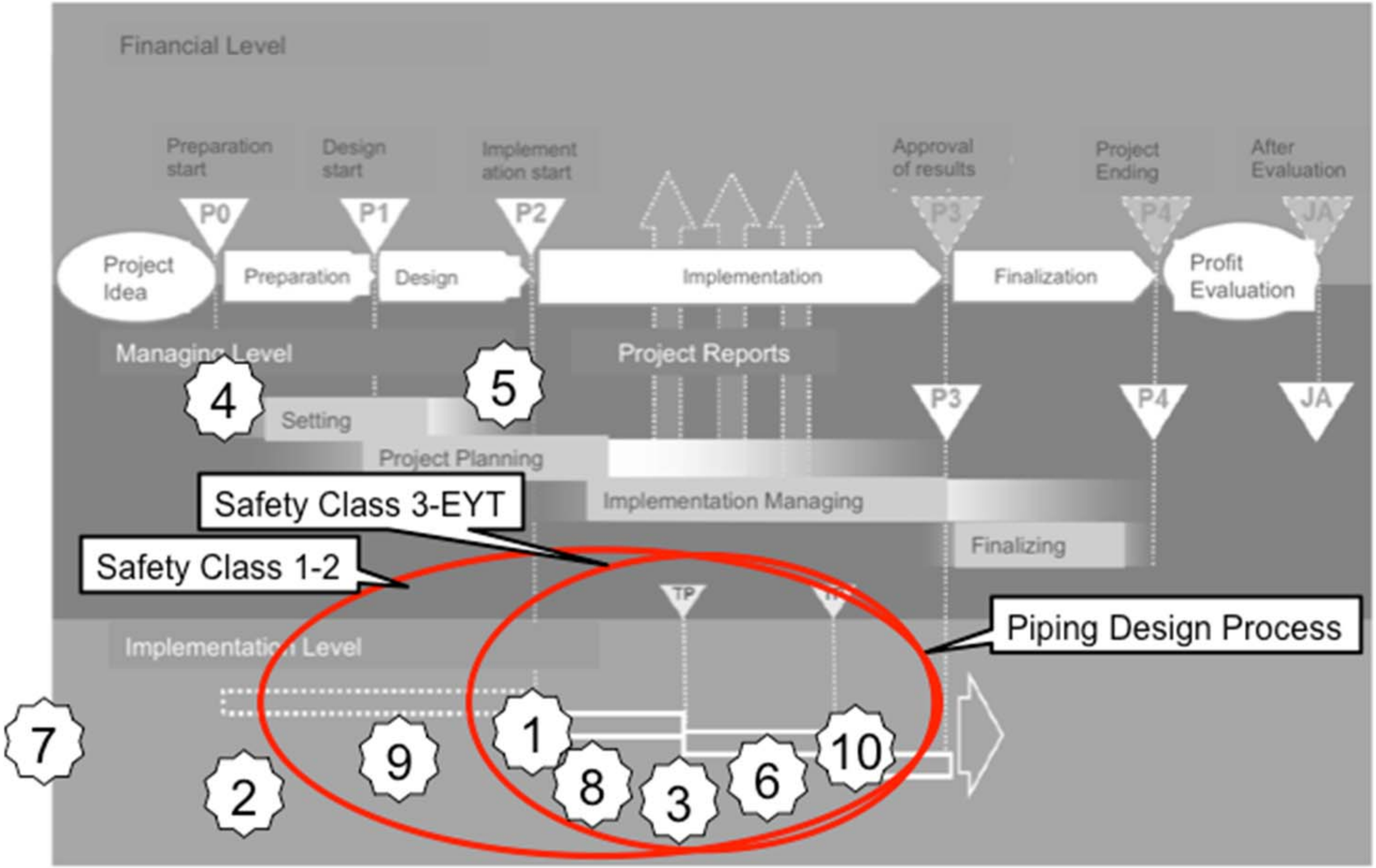


Figure 14. *Challenges and best practice located in the LABC project model. Data 2.*

As it can be seen from Figure 14, most of the challenges of the three case projects are averagely located in to the design and implementation phases where the piping design process is located. The higher the safety classification of the modified construction is, the earlier the design process should begin.

As Data 1 provided challenges and practice from case projects in a general level it was necessary to decide how the issue is treated in Data 2; as a challenge or a practice. The locations of the numbers are depending on whether they are considered as where they are causing challenges or where the practice should be implemented to act against the challenge. For example, challenge 5: “*Not enough design resources”* is a challenge in the actual design process, but its proposed practice; “*The need of resources should be evaluated and reserved in project pre-planning stage”* is located in project planning in the project management level. From similar reasons the challenges 4; “*Communication between project organization and power plant* “and 7; “*Specification requirements and commissioning practices are challenging for new safety equipment*” are located outside the design process even though they are causing challenges to it. Solutions to these challenges are clearly in management level (4) or outside the LABC model (7). *The challenge and practice number 2; “Project includes technical solutions that have to be tested after design”* is located before the design process to propose that the untested solutions should be pilot tested outside the scheduled design process. This would encourage the project to find *intelligent failures*, which were discussed in Section 4.4.

The rest of the issues in Data 1 are related to understanding of the process, collaboration and scheduling that are causing challenges to the design process.

To be able to analyze the reasons for the challenges more thoroughly the design process should be investigated more. As every case project in this Thesis included piping design, the piping design process and its design stakeholders are introduced in the following sections.

5.1.1 Process Design

Process design has the most influence on the technical decisions during the design process of a project. Often the project management has experience from process design and is involved in the early process design phase. The contents of Process Plan and data that process design stakeholder is providing is presented in the Table 8.

Table 8. Process design data and contents of Process Plan.

Process Design	
Process Data	**Process Plan**
Flow information	P&I Diagram
Pipe Material	Process Data Sheet
Design/Operating Pressure	
Design/Operating Temperature	
Pipe Size	P&I Diagram
Safety class	
Line and process instrument codes	
Arrangement of process equipment	
Equipment and Instrument Data	Equipment and Instrument Drawings (Supplier)

According to the best practice from the current state analysis and literature, typical data that process is design is providing are the information on the flowing fluid or gas, size of the new and existing piping, nuclear safety class of the new and existing system, line codes and codes for existing and new process instruments and arrangement of process equipment. The previous process data is usually presented in process and instrumentation (P&I) diagrams as explained in Section 4.2. Material for piping is depending on the flowing fluid or gas and from the surrounding atmosphere Design and operating pressure and design and operating temperature are determined by process design through process analysis.

The previous information is usually provided in process data sheet. Equipment and instrument data are specified by process design to find the best and most economic supplier to meet the design standards. Supplier provides the equipment and instrument data in performance tables and informative drawings. All the previous documents and data are included in official Process Plan, which is approved internally by responsible persons and externally by authority in the needed scope that is depending on the project class and safety class. The final Process Plan serves as a starting information for other design stakeholders, as for example the mechanical design.

5.1.2 Mechanical Design

According to the current state analysis and literature, the aim of the iterative mechanical piping design process is to find optimal routing and supporting plan together with the strength analysis. If necessary, the original pressure, temperature, material or pipe size information should be possible to revise together with process design. The given pressure, temperature, pipe size and safety class information together with installation plan define the quality requirements of the new piping and its equipment and instrumentation.

The arrangement of process equipment is presented in P&I Diagram provided by process design. The arrangement information is utilized to create the layout design for all the new piping and equipment. All the previous design data is presented in various layout, isometric, installation and manufacturing drawings together with the quality and inspection plan. All the previous with final strength analysis results are included in the Construction Plan, which is the official document to be approved by the required inspectors. Construction Plan is the starting information for installation team and bulk material purchasing. Table 9 shows what data the mechanical design stakeholders generate out of the starting information of the process design.

Table 9. Mechanical design data and content of Construction Plan.

Mechanical Design			
Mechanical Data			**Construction Plan**
Pipe Routing & Supporting	Strength Analysis		Isometric Drawings Installation Drawings Manufacturing Drawings Quality and Inspection Plan Strength Analysis
Pipe Wall Thickness			
Design/Operating Pressure		Quality Requirements	
Design/Operating Temperature			
Pipe Size			
Safety class			
Installation			
Arrangement of process equipment			Layout Drawing
Equipment and Instrument Data			Equipment and Instr. Drawings (Supplier)

As it can be seen from Table 9, the mechanical design is using the key data of process design as starting information in mechanical design. Typical investment project in the case company’s power plant includes piping design. The flow chart provided by process design is utilized to generate the routing for pipes and after material information mechanical design calculates the optimal wall thickness for pipes. Pipe size, routing, supporting and wall thickness together with pressure and temperature information are starting information for strength analysis of the piping system.

5.1.3 Quality Control

The responsibility of the quality control is to set the technical requirements and required testing and inspection for the design to meet the required level of quality. Quality control also ensures that the Construction Plan has the required quality and inspection plan completed and that the design is following the regulations set by authority. It is important for quality control to set the requirements on a realistic level to enable the work of design and installation stakeholders. The required level of quality control is dependent on the target. The complete installation is tested according to the quality control plan in Construction Plan. After the test is approved, the work is then accepted by final test report written by third party inspector.

Mechanical design stakeholder should consult the quality control experts when compiling the quality control plan. It is sometimes challenging to choose the optimal testing method for some special construction solutions. Therefore the effort of quality control is needed in mechanical design phase.

The equipment and instruments chosen in the beginning of the project by process design stakeholder need to be accepted by quality control. Therefore the effort of quality control is needed early in the beginning of the P1 phase of the project.

5.1.4 Installation

The installation stakeholders start their work officially after they receive the approved Construction Plan from mechanical stakeholder. However, many projects intend to save time by providing final information for installation stakeholder before the official Construction Plan. To receive the needed information, installation stakeholder must define what information is needed and when. According to this definition, project control must schedule the need of information in the project plan and freeze it. The required information can help the installation stakeholder to for example start purchasing material, pre-fabricate some of the construction or reserve the needed resources beforehand.

The installation stakeholder uses the preliminary information for example to start purchasing bulk material.

5.2 Proposal for Piping Design Process in Investment Projects

Figure 15 describes piping design process in typical investment project of the case company. Beams describe the actual work and a typical “product” of certain design stakeholder. Numbers present the challenges and practice that were found from case project interviews in Section 3, Current State Analysis. The challenge and practice were located in to the design process figure to describe where the challenge and the proposed action should take place.

Challenge 3, “providing starting information early enough”, was clearly located between the work of design stakeholders in the design process. Challenges 6 and 2 were considering mostly the responsible design stakeholder and therefore they were located on the work process. Challenge 6, “Purchasing practices are not clear” was a challenge for process design stakeholder. Challenge 2 “technical solutions that have not been used in the power plant before” was a challenge for mechanical design stakeholder. Challenges 9 and 10 were related to the acceptance of official documents.

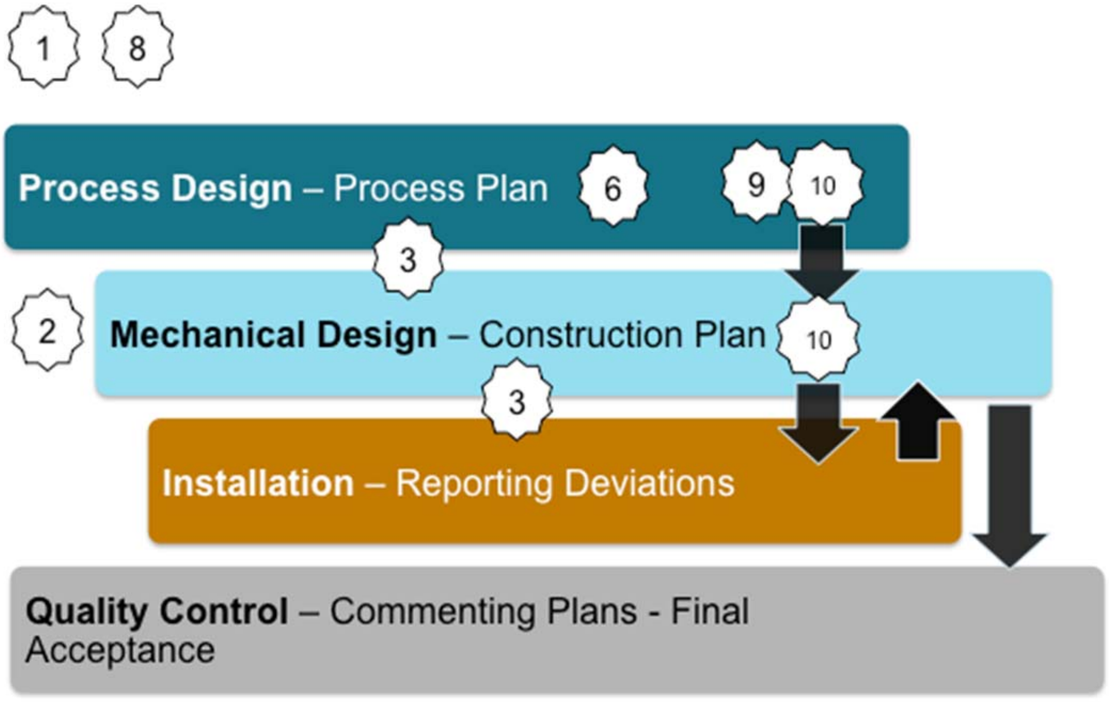


Figure 15. Piping design process with the challenges and actions from table 7 added.

Arrangement of the beams in Figure 15 presents the possibilities of overlapping during the design process. Next stakeholders can comment and collaborate the design work of the previous design stakeholder. This secures the fluency design and prevents any breaks in design process, which could happen if the stakeholders would be operating only through official document flow. Beam of mechanical design continues after the release of Construction Plan, which illustrates the after engineering phase along with the installation phase. In this phase the possible deviations in the original design can be acted on and redesigned.

Challenges 1,2,4,5,7 and 8 where categorized as challenges to Project Management. The challenges were related to decision-making, communication and resources. Challenge 3 "Design stakeholders are unable to provide starting information to each other early enough, which causes breaks in design process" was the main challenge between design stakeholders. The design process should be overlapping so that the flow of information and design remains fluent.

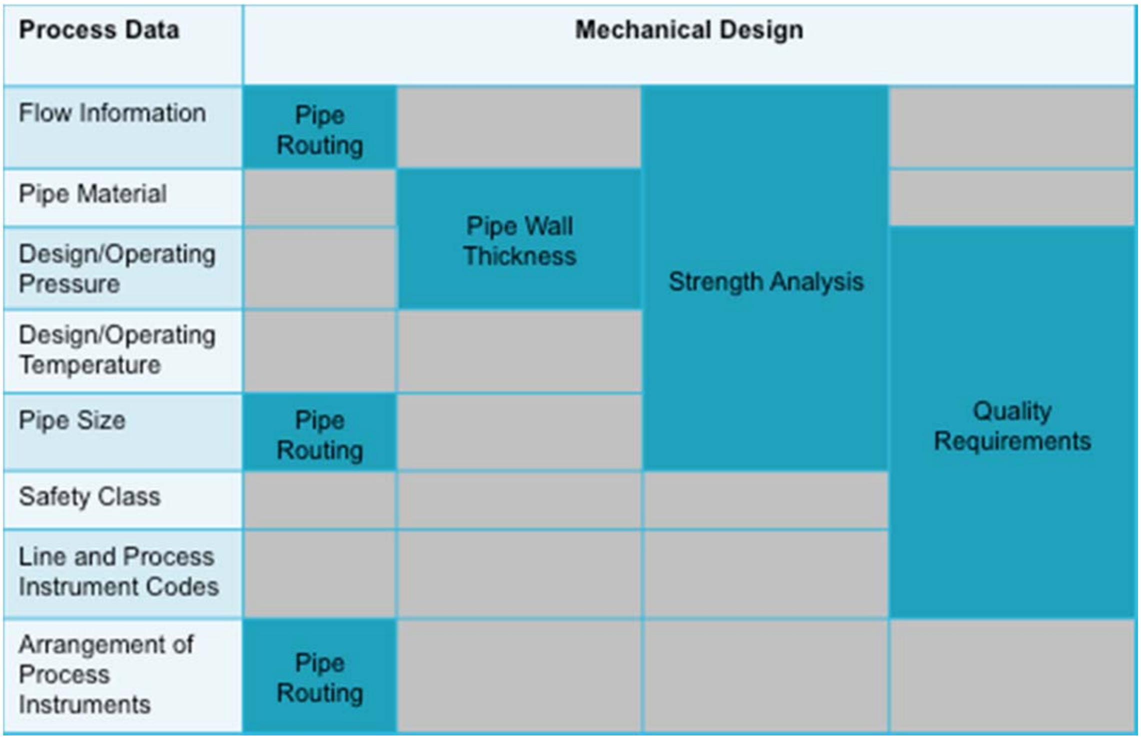
Challenge 6 was the main challenge in design work for process design stakeholder. Specifying the equipment and preparing the purchasing for project was seen demanding because of the increasing demands in requirements by the customer and authority. Challenge 2 was the main challenge for mechanical design. Designing solutions that were not tested in the plant facilities before was challenging, as the solutions were not allowed to threat the nuclear safety. Proposed action was to build pilot equipment.

Challenge 9, “Authority acceptance of documents delays project schedule” was located in to the release of Process Plan. The official Process Plan created by process design stakeholder has to be approved by authority before it can be released to other design stakeholders. Often the authority was overloaded with work and the approval was delayed also delaying the project. Proposed action according to the case project interviews was to increase collaboration with authority earlier in the project. Then the project and the schedule could be proposed to authority who is able to reserve resources.

Challenge 10, “Internal acceptance of documents delays project schedule”, was located in the release of Construction Plan. Mechanical Design stakeholder produces the Construction Plan, which operates as a grounding document for installation work. Approved Construction Plan opens the codes that are used in installation work, which are needed at the power plant always when anything is installed. The Construction Plan is approved by responsible persons in case organization and power plant. Sometimes due to lack of resources or large amount of Construction Plans to be approved, the approval is delayed as well as the start of installation work. According to the interviews in Section 3, the proposed action in to challenge 4 was to name one responsible person from the personnel of the power plant who is aware of the project and is able to oversee the approval round.

Process design stakeholder gives the framework of design to mechanical design stakeholder. Table 10 describes the effects of decisions in the process design to mechanical design. The effects of decisions are important to understand, especially if there are changes in the original process data.

Table 10. The relationship of process data and mechanical design.



Process Data	Mechanical Design			
Flow Information	Pipe Routing		Strength Analysis	
Pipe Material		Pipe Wall Thickness		
Design/Operating Pressure				Quality Requirements
Design/Operating Temperature				
Pipe Size	Pipe Routing			
Safety Class				
Line and Process Instrument Codes				
Arrangement of Process Instruments	Pipe Routing			

As it is presented in Table 10, the pipe routing in mechanical design is based on flow information, pipe size and the arrangement of process equipment and instruments that are received from process design. These three pieces of process data are usually presented in P&I Diagram and they can be used by mechanical design to estimate the preliminary length of piping system.

Flow information includes the information of flowing material, which together with pipe size, affects to the strength analysis of piping system that is performed by mechanical design stakeholder. Other important factor to the strength of piping system is the pipe wall thickness that is defined by pipe material and pressure. Process design stakeholder defines pipe material and design pressure in process data sheet.

To be able to finalize the piping design, mechanical design stakeholder also needs the design temperature and safety class of the piping system from process design. Design pressure, temperature, pipe size and safety class define the quality requirements that are set for the purchasing, manufacturing and installation of the piping system. The final coding of the lines and instruments are also presented in the quality requirements.

The workflow in the piping design process is presented in Figure 15. The simplified design process illustrates the tasks of design stakeholders in proposed order. The design stakeholders described in the workflow are process design, mechanical design, installation and quality control.

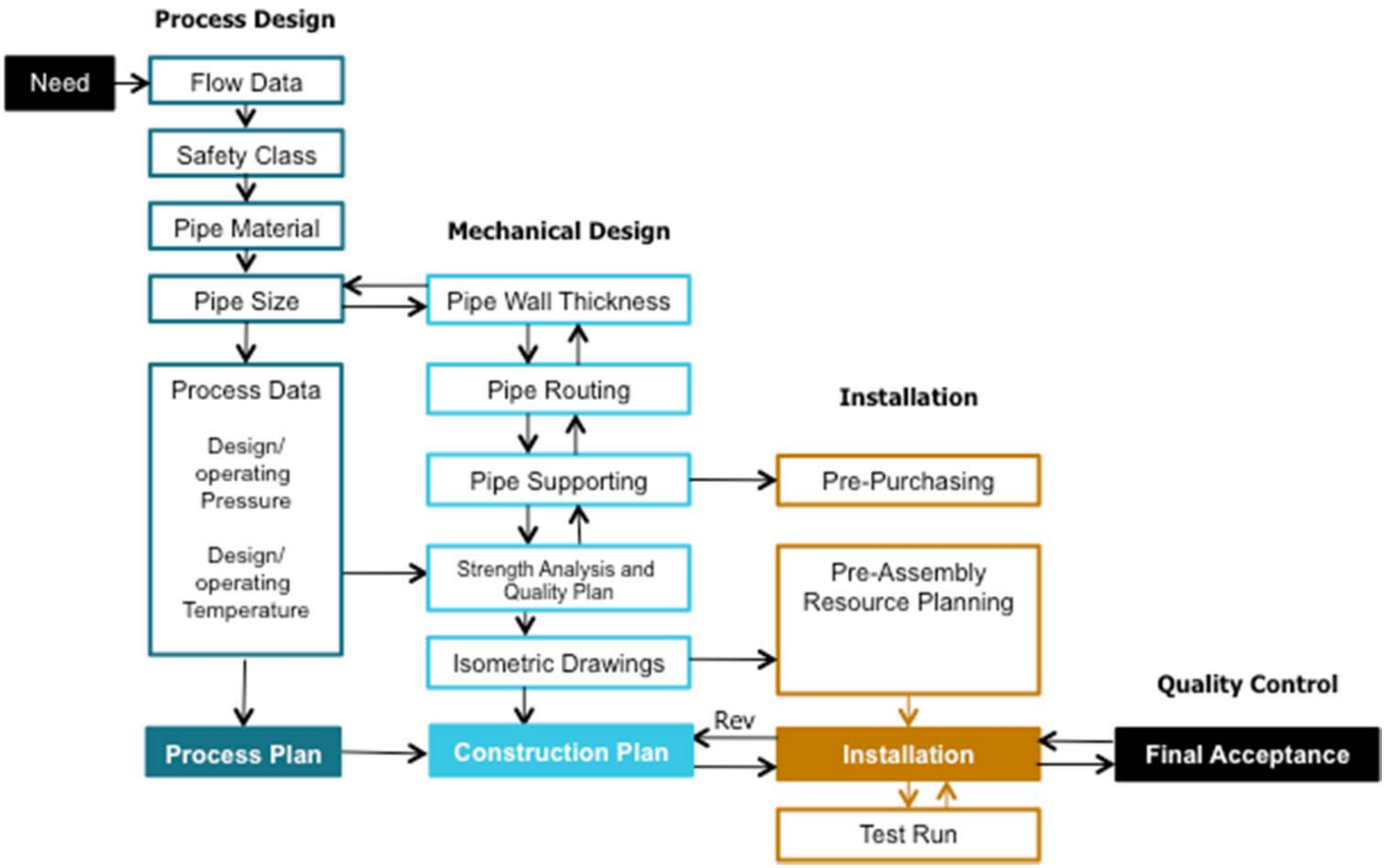


Figure 16. The workflow of the piping design process.

The workflow in the proposed piping design process starts from the need. The *process design* stakeholder defines the flow data and safety class defines the pipe material, which usually defines the pipe size of the piping system that is being designed. *Mechanical design* stakeholder can start the preliminary design already from this stage by defining the preliminary wall thickness. However, to be able to define the wall thickness, there has to be a process design stakeholder's preliminary estimation of the design pressure and temperature, which can be estimated from the flowing material and the purpose of the piping system.

The mechanical design is an iterative process where the preliminary routing and supporting design of the piping system is being analyzed in strength analysis. The routing and supporting design is repeated until the accepted best solution is found (See Figure 1). The basis of the mechanical design is the Process Plan produced by process design stakeholder. The final product of mechanical design stakeholder is the Construction Plan. The entirety that is constructed is explained in the Construction Plan. Construction Plan also consists of manufacturing and installation drawings, the technical analysis and quality control plan.

The *installation* stakeholder can start preliminary purchasing in the proposed workflow after mechanical design stakeholder has evaluated the bulk material amounts after preliminary routing and supporting design. After the mechanical design stakeholder has produced drawings, installation stakeholder can start final resource planning and preliminary installations of the construction. The approved Construction Plan is the official starting information for installation stakeholder, but overlapping of the work process can be increased by the previously proposed actions.

After successful test run of the new system, *quality control* stakeholder approves that the installation is following the instructions of Construction Plan. Quality control also consults and comments on each task of the piping design workflow if necessary.

6 The Proposed Piping Design Process

This section consists of two sub-sections. The previously proposed piping design process is evaluated in Section 6.1 and refined in the final proposal in Section 6.2.

6.1 Evaluation of the Proposed Design Process

Studying past and on-going projects can give important information for design stakeholders when making decisions for future projects. Recording the best practice and common failures preserve and improve the continuity of company’s competence. Three projects were benchmarked in this study to save the knowledge from very experienced project managers and engineers. This knowledge can be transferred to a new generation of project managers and engineers in form of this Thesis. The most efficient way of learning is understanding of the relationship between theory and practice through experience (Tunstall 2006: 338).

In the previous section it was recognized from the Data1 of current state analysis and Data 2, best practice analysis, that the tasks of different design stakeholders should be understood more clearly to increase the collaboration in piping design process. The piping design process was used as an example in this Thesis as every case project included new piping system. The design stakeholders were introduced and their tasks and documents were summarized in Tables 8 and 9. Table 10 showed the relationship of the decisions in the piping design and Figure 16 proposed a typical workflow of a piping design process. The following section introduces the final proposal of the piping design process of an investment project.

6.2 Final Proposal

The final proposal of the piping design process was build after summarizing the tasks and their relationships of different stakeholders in piping design process with the task workflow.

Figure 17 summarizes the Table 8 “Process data and documents”, Table 9 “Mechanical data and documents” and Table 10, “The Relationship between process data and mechanical design. Also the piping design process figures 15 and 16 are applied in the final proposal of the design process.

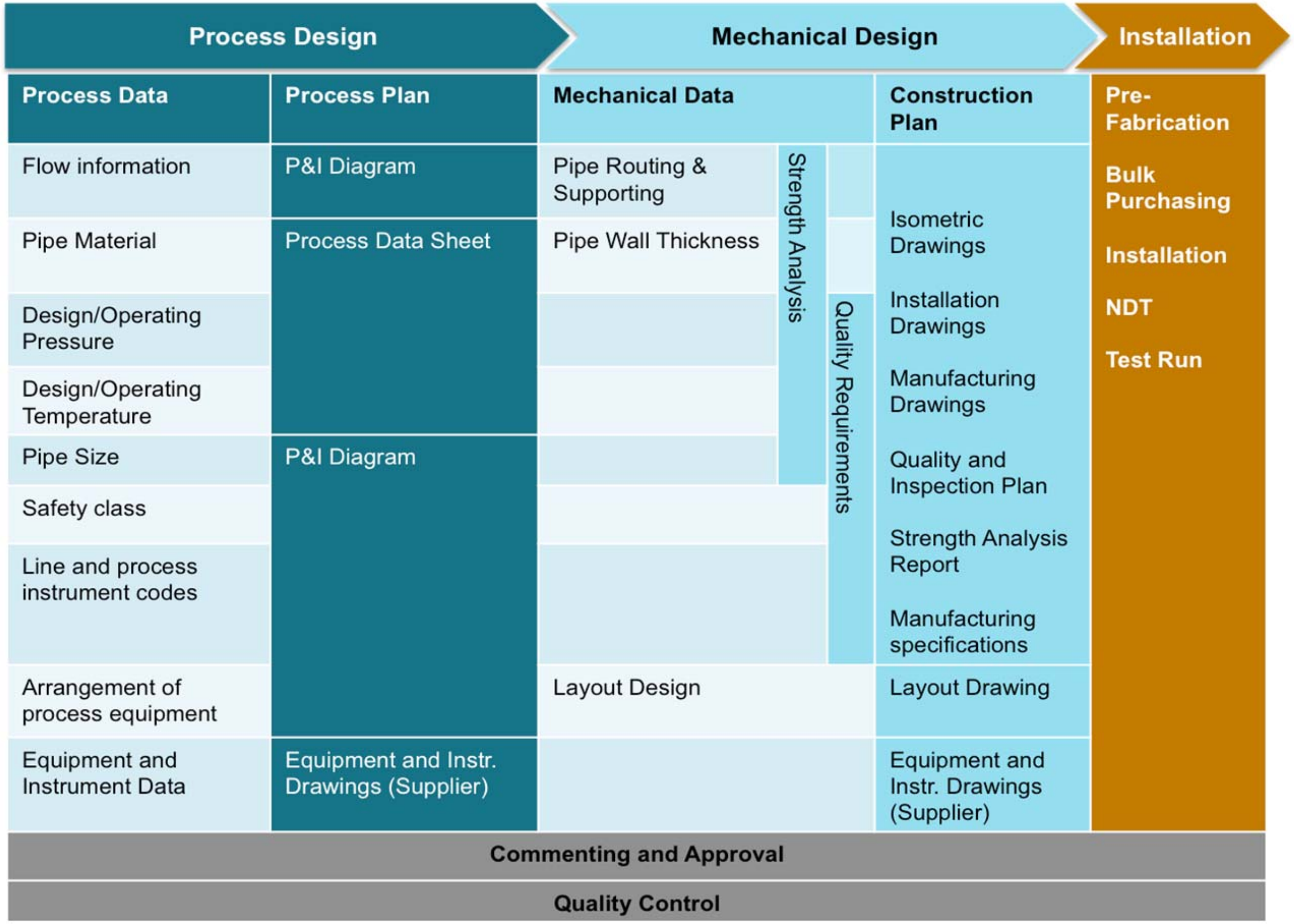


Figure 17. *Final proposal of the piping design process in typical investment project.*

Figure 17 combines the tasks and documents of design stakeholders in piping design process. It also shows the importance of commenting by quality control stakeholder during the design process. Together with the Figure 16, *the workflow of the piping design process*, it can be easier to understand the piping design process in investment projects of the case company. The findings from the current state analysis of this study indicated that there was a need to describe and visualize the piping design process in order to increase the collaboration and understanding of the stakeholders of the process.

7 Discussion and Conclusions

This section summarizes the study and discusses the outcome. Section 7.1 summarizes the study on a general level and Section 7.2 analyzes the outcome on a more detailed level. Section 7.3 discusses the implications of the outcome and its benefits, as well as its implications on the practical and managerial level. Section 7.4 analyzes the reliability and validity in this study.

7.1 Summary

Focus of this study was to improve the design process of the investment projects of the case organization. The objective was to conduct a multiple case project analysis to find the challenges and best practice of three case projects that case organization had implemented to the power plant of the case company.

The investment projects in the nuclear power plant of the case company are often challenging as the original technology is decades old and the new investment projects include technical solutions have never been built before. As the new projects are being built on an existing power plant, it takes significant amount of time to study the environment in the site and search the history related to the existing process in form of plans and drawings. The case company is supporting a safety culture where continuous improvement is required from both, the employees and the technical process. Safety is being constantly improved by training and investing in better technology. New investment projects represent the common efforts of two organizations: the line organization of the power plant and the expert organization of the technical support unit that was the case organization in this study. The case organization is responsible of developing the technology of the power plant of the case company through various investment projects.

The research approach in this study was a multiple case study. Multiple case study was conducted by choosing three case projects that could be defined as investment projects done in the power plant. Studying the case projects was part of the current state analysis of this study. The study analyzed three case investment projects implemented in the power plant by the case organization. Members of the case projects were interviewed to find current challenges and best practice in the projects of the case organization. The challenges and best practice were categorized and located in to the current project model of the case company.

Based on the current state analysis, it was found that most of the challenges and best practice belong to the design process of the investment project. It was derived from the multiple case analysis that many of the challenges in the design process were related to the fact that the design process itself was not clear enough for the design stakeholders.

Thus, the design spiral with an analytical approach (Figure 1.) for example, often does not have sufficient amount of repetitive circles (analysis, synthesis, appraisal and feedback). Therefore, the design process was taken into closer examination to map the challenges and propose improvements to it. As every of the three case projects basically included new process piping system, the piping design process, the tasks and the required information of design stakeholders were visualized to clarify the process. In addition to the needs of the actual design stakeholders such as mechanical and process design, the needs of installation and role of quality control were also mapped in the piping design process.

Thus, the improved design process contains important additions. It helps to understand the needs and processes of other design stakeholders in the design process to be able to provide right information when needed. The proposed piping design process also helps to locate the challenges and practices and align them to certain tasks. The proposed piping design process applies the best practice from multiple case studies and should lead to increased collaboration between the design and installation stakeholders during the design process, thus also helping the projects keep on schedule.

7.2 Outcome

Outcome of this study is an improved description of piping design process with a collection of challenges and best practice in a typical investment project in case organization. The challenges and best practice can be located in to the typical piping design process that was proposed in this study. The current LABC project model only gives a general definition of the design process because it is designed to serve several different types of projects.

It was clear from the beginning that there was no need to describe the piping design process in a too detailed level, as every investment project is different. However, the basic elements in the piping design process are very often the same, as they were in the case projects. The workflow of the design process was described together with the tasks to help project members foresee the coming tasks in the project.

The visualized design process can help the designers to determine the current state of the design process in investment projects and estimate the remaining workload because to the improved visibility of remaining tasks. The design process defined in this study with the association of the different tasks can be applied to piping design process in the future. As piping is categorized as pressure equipment, the piping design process proposed in this study could also be applied with minor modifications when designing other pressure equipment to the power plant.

7.3 Implications

On a practical level in an investment project, the design stakeholders should communicate more and understand the effects of their decisions. Design stakeholders should demand decisions from project managers to freeze starting information early enough. The multiple case analysis in this study showed that the peak in amount of design work was located or is estimated to appear after the P2 decision in every case project. The challenges and best practice introduced in this study can give useful tools to force the location of design peak before P2 decision as it is instructed in LABC model.

This study helps to understand the design process of piping systems. The source of starting information and effects of own decisions are important to understand when working in tightly scheduled investment projects. The proposed piping design process in this study helps the design engineers to locate their tasks in the process.

Design stakeholders should also bring up the risks and problems actively to project management to avoid their escalation. Design engineers confront many of the practice and challenges found in this study along the years they work in the case organization. It would be useful to continue monitoring the challenges and best practice in future projects with design stakeholders introduced in this study, as well as other participants in investment projects.

According to the findings of this study, project management should understand and be aware of the work of every design stakeholder in the design process. It is important for project manager to form a holistic view of the whole project to be able to make right decisions at the right time. The leading style of project manager should be systematic, obedient and logical throughout the project.

The budget and the schedule of the project must be acceptable to financial management but also possible for the design stakeholders to implement. This balancing requires skills from project management as well as years of project experience.
The investment projects are often long-lasting efforts that should be divided into smaller sub-projects that aim to solve certain challenges. Dividing the project in smaller pieces enables the project employees to celebrate small victories. This gives the project employees a feeling that the project is advancing and helps them to remain motivated.

7.4 Reliability and Validity in This Study

To secure the *reliability* in this study, the interviews were conducted to three different case projects. Data was collected from different sources; interviews and databases. Interview findings were collected, verified with the informants and then categorized. The categorized data was used to build a model of the typical design process.

Reliability in this study was also secured by using two different interview methods in each case at two different points of time. Also, theories from other business areas were studied to find similarities with this Thesis' business problem. Data was also collected in different points of time during the research schedule. Critical self-awareness was used to evaluate the output as the researcher was closely involved in the studied cases.

To improve the *validity* in this study, data collection phase and analysis were described as detailed as possible. The data from the interviews was checked by respondents and instructors after interpretation and summarizing. Detailed reporting was emphasized and prejudice in interviews was avoided. The interview themes were built based on the best practice taken from literature, as well as the researcher's own experience in a particular topic and discussions with co-workers.

Finally, the researcher has worked with the interviewees in the case company for three years as an employee of the case organization and also participated in all three case projects as a mechanical design engineer. Thus, the researcher’s level of knowledge about the research topic could be considered sufficient to ensure credibility in the research. The challenges that were dissected in the current state analysis were also familiar to the researcher and the study itself has helped to understand the whole design process even better. It has also helped to understand the decision making process in LABC project model. The researcher has also gained four years of experience earlier from a similar field, which can also be considered as an improvement to the objectiveness of this study.

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Questions – DATA 1

1. What where the strengths of the project?

    -What practice from the previous projects where applied in this project?

    -What practice of this project could be applied in the future?

2. What where the biggest challenges/weaknesses of the project?

    -What where the biggest challenges in the design process?

    -What challenges from previous projects where recurring?

3. How was the project progressing compared to the LABC model?

    -How did the design work distribute between P1-P2-P3 decisions? Is there hourly data available?

Questions – DATA 2

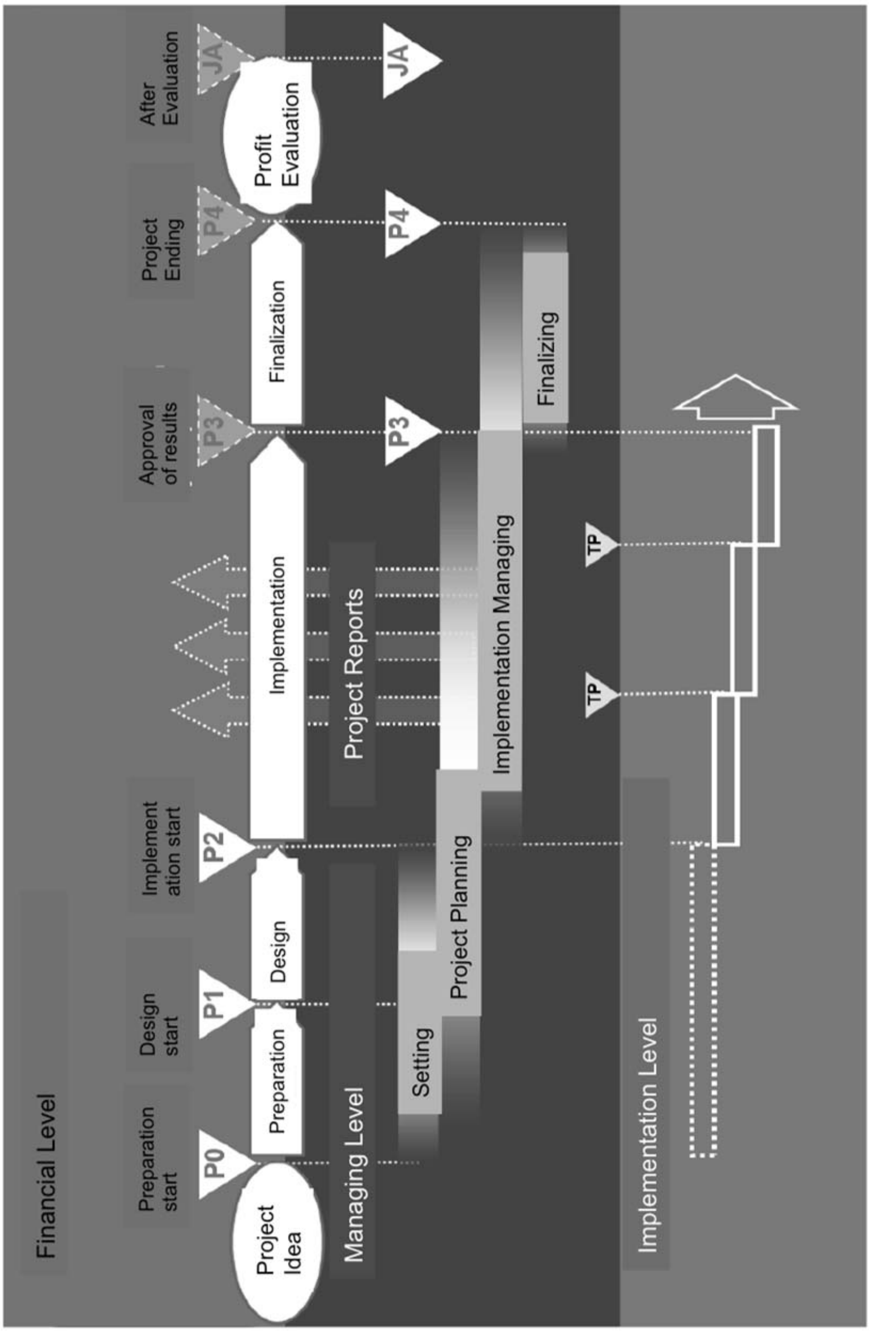
1. Please mark the challenges and practice of previous questionnaire in to the Figure of LABC model or to the Figure of typical design process.

   -Use the numbers from the table
   -You can comment the summarized table and the marking to the paper or by e-mail.

	Project Challenge	**Best Practice**	**Case**
1	The effects of certain decisions to the whole design process should be understood more clearly.	Collaboration between design stakeholders, mapping the design process, “Freezing points”	B, C
2	Project includes technical solutions that have to be tested after design.	Solutions can be tested by building pilot equipment outside the plant area.	A, B
3	Design stakeholders are unable to provide starting information to each other early enough, which causes breaks in design process.	Design process must be phased so that each stakeholder has enough time to provide information to next designer.	A, B
4	Communication between project organization and power plant.	Naming responsible person from power plant, Monthly meetings, Owner or manager from Plant personnel	A, C
5	Not enough design resources	The need of resources should be evaluated and reserved in project pre-planning stage.	A, B
6	Not enough time to prepare the purchasing, Purchasing practice are unclear.	Using a Purchase Engineer	A, B, C
7	Specification requirements and commissioning practices are challenging for new safety equipment.	Purchasing practices and specification requirements should be more standardized	B,C
8	Handling a large amount of documents consumes management and design resources	Use of extranet or sharepoint, Using Project Assistant	C
9	Scheduling the authority acceptance round of documents	Presenting the project and schedule to help the authority prepare their resources. Approx. 3 months	A
10	Scheduling the internal acceptance round of documents	Responsible person from power plant follows the acceptance. Electrical acceptance.	A, B, C

Summary of the answers

LABC model


Financial Level
Managing Level
Implementation Level
Preparation start
Design start
Implementation start
Approval of results
Project Ending
After Evaluation
P0
P1
P2
P3
P4
JA
Project Idea
Preparation
Design
Implementation
Finalization
Profit Evaluation
Project Reports
Setting
Project Planning
Implementation Managing
Finalizing
P3
P4
JA
TP
TP

Typical piping design process