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Developing a Concept Enabling Capture of Inputs and Outputs of a Piping Flexibility Analysis Process during Plant Design Projects

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In the course of a 13-year professional career that began with familiarizing myself with the concept of piping engineering, I have come across many professionals and individuals who have helped shape my career and attitude towards self-development. Today, as a Lead Stress Engineer in the case company, I am still seeking for improvements and knowledge that may help enhance my efficiency and productivity as a team player. The decision to undertake a course in Industrial Management came from an interest in understanding the role of project management in plant design projects. This programme has enlightened me and helped answer some of the questions that have arisen during projects.

In that regard, I would like to thank Metropolia University for the opportunity and the team of lecturers for their unconditional supports and guidelines. I would like to express my sincere gratitude to my supervisor Dr. Thomas Rohweder and Senior Lecturer, Sonja Holappa for providing their guidance and comments throughout the course of the research. A special thank you to my classmates for the unforgettable experience and their constructive feedback throughout the programme.

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A well-organized concept is necessary to enhance capture of inputs and outputs between teams during plant design projects, to minimize delays in the process and facilitate team-working and knowledge management. The objective of this thesis was to develop a concept enabling capture of mutual expectations of inputs and outputs between the Strength Calculation and Stress Analysis (SCSA) and Piping Design teams during the flexibility analysis of critical piping.

An applied action-based qualitative research approach involving triangulation was used to collect data for this study. The techniques used to collect data included in-depth one-to-one interviews, workshops, and internal documentation. Data was analyzed by categorization into key focus areas, corroboration based on similarities in responses and percentage of agreement among key stakeholders. The study was undertaken by first conducting an analysis of the current inputs and outputs exchange practices. Several strengths and weaknesses emerged from this analysis. Then, a literature review provided best practices, tools, and strategies necessary to resolve key weaknesses in the process. The literature review served as a foundation for the creation of the conceptual framework (CF). Finally, an initial proposal of the concept was created based on key focus areas of the current state analysis (CSA), CF and several suggestions from key stakeholders.

The final version of the concept consists of key elements such as involving stakeholders at the early stage of projects to capture their needs, defining roles and responsibilities to enhance ownership of tasks, applying effective communication practices to improve exchange of information, empowering through coaching and monitoring to close skill gaps. It also includes tools such as the flexibility analysis follow-up list, the role and responsibility (RACI) matrix and flexibility analysis inputs checklist. The combination of these elements and tools does not only enable capturing of inputs and outputs but also allow improving cooperation between the teams.

The concept developed in this thesis provide the case company with a well-organized approach of capturing inputs and outputs during a flexibility analysis process. It is a co-created effort and has been recommended for a strategical implementation within the case company.

Keywords	Plant design, piping design, flexibility analysis, stress calculation, inputs, outputs

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1 Introduction

The design of process plants is a team effort involving different engineering departments: mechanical, piping, process (chemical), instrumentation, electrical, controls, materials and project. It also requires considerable cooperation between teams, a systematic planning of each phase, as well as good coordination and management. A project will rarely be successful if the team of people responsible for its delivery cannot work together (Pollack and Matous 2019).

The case company's objective in every project is to help its clients build plants that meet the process requirements and client specification and that operate in a safe reliable manner by minimizing costs. This implies the stakes are always high in every project and the outcome depends to some degree on teamwork. In the post-industrial era, team and project work has developed into the preferred mode of organizing work in many companies and public institutions (Buch and Andersen 2015). However, there are numerous challenges that arise from the interaction of cross-functional teams. There is not one single approach on how to best tackle the challenges, but some can be mitigated with appropriate steps.

One of the most important aspect of a process plant design is its layout and piping design. Therefore, it is critical to design a process plant so that equipment, piping systems, instruments, electrical systems, electronics, computers and control systems can all fit without disrupting the maintenance and operation of such a facility. The responsibility of achieving a proper design of the piping system lies with the Piping Engineering discipline. It is important to reiterate that Piping Engineering is not a standalone activity. In order to successfully accomplish the process and finish all engineering aspects, Piping Engineers need to depend on other disciplines in terms of inputs and outputs. In the process of designing a piping system during a plant design project, many inputs are required from other disciplines and inputs are simultaneously provided to other disciplines as outputs from the Piping Engineers. In addition, there are also outputs generated by Piping Engineers that are required for procurement, erection and fabrication of the piping system.

This interdependence between disciplines in plant design is key to project planning and execution. The complex task of designing and building process plants is undertaken in several phases – design, engineering, procurement and construction. The design phase itself consists of conceptual design, design study and detailed design. The scope of the mutual inputs and outputs exchange practices between the Strength Calculation and Stress Analysis, and Piping Design teams is limited to the design and engineering phases where the whole exchange process takes place.

1.1 Business Context

The case company in this thesis is an international engineering, design and advisory company within the fields of energy, industry, infrastructure and information technology. As a result of a recent merger, the case company has become the biggest company in its sector in the Nordic region. Services include management consulting, engineering, project implementation, operations support and environmental consulting.

The company serves clients through a variety of sectors including the process industry sector. The process industry sector is searching and developing solutions to solve the challenges related to overall efficiency and sustainability. The case company supports the global process industry in Pulp & Paper, Chemicals, Biobased solutions and biorefining, Mining & Metals, Food and Beverage as well as other process industries. Moreover, the process industry sector delivers solutions for complex new investments projects and rebuilds of existing plants. Offerings in this sector cover the whole lifecycle and value chain of the clients' business. Prior to the merger all services in the process industry sector were under the Industry Business Group (IBG). This group is now referred to as the Process Industries Division.

One of the key services provided by the Process Industries Division is project implementation. Whether the client is looking for a sharp or independent advice on a new investment or is seeking a partner for a complex plant rebuilt, the process industries division can be relied upon. The offerings in plant design cover the full project lifecycle which consists of the following basic steps: Design, advanced 3D modelling and process simulation, controls engineering, fabrication and assembly, installation and start up.

In order to carry out this entire process efficiently and within the time schedule, the case company and Process Industries Division rely on world-wide teams of talented and experience experts. In Finland, the Process Industries Division consists of the Mechanical and Piping department, as well as other departments. In the Mechanical and Piping department, the Strength Calculation and Stress Analysis (SCSA) team works in close cooperation with the Piping Design throughout the full lifecycle of plant design projects.

1.2 Business Challenge, Objective and Outcome

In plant design projects, the Strength Calculations and Stress Analysis (SCSA) team cooperate intensively with internal Piping Design teams in Finland and abroad depending on the project. The SCSA-team consists of approximately eleven people in Finland. The number of engineers assigned to a project from each team often depends on the size of the project, their location and expertise. However, the frequent involvement of the case company in meeting clients' needs locally and globally means every team member is often involved in more than one project at a time.

For this cooperation interface to be efficient, mutual expectations, that is, each other's inputs and outputs must be agreed at the project planning stage and as the project evolves. The downsides of missing a set of inputs or not understanding the type of outputs to provide and at what project phases can be detrimental and may lead to delays in execution and delivery.

Despite a long history of providing plant design solutions to its clients, the case company does not have a conceptual way of capturing expected inputs and outputs within the Mechanical Engineering and Piping department in Finland.

Therefore, the specific objective of this study is *to develop a concept enabling capture of mutual expectations of inputs and outputs between SCSA-team and Piping Design team.*

Consequently, the outcome of this thesis is a concept for the inputs and outputs capture.

1.3 Thesis Scope and Outline

The study covers a small SCSA-team of about eleven engineers responsible and capable of simultaneously handling a reasonable amount of strength calculations and stress analyses in numerous projects within the Process Industries Division in Finland. Unlike the SCSA-team, the Piping Design team is much bigger in size but is also based in Finland. In the course of a plant project implementation, these two teams exchange information in the form of inputs or outputs to ensure the flexibility of piping through a flexibility analysis, strength of components and fittings through strength calculations, strength of non-standard components, tanks, silos, pressure vessels, steel structures and so on through Finite Element Analysis. However, the scope of this study is limited to *Flexibility Analysis* of Piping, also commonly referred to as *Stress Analysis*.

The study utilizes data from a limited number of respondents with many years of work experience and who have been involved in hundreds of projects altogether. However, the study does not rely on existing documents on the flexibility analysis process within the company due to their non-existence. The data is collected using a qualitative method through in-depth interviews of the stakeholders, information gathered from a workshop and the Process Industries Division internal strategy documents.

This study is written in seven sections. The Introduction is followed by Section 2, which explains the research plan of this thesis. In this section, the research approach is explained, a research design and data plan presented.

Section 3 describes the current inputs and outputs exchange practices between stakeholders and identifies the strengths and weaknesses. Following this, Section 4 focuses on best practices of project inputs and outputs expectation capture from relevant literature. A valuable conceptual framework (CF) is derived to help develop solutions in Section 5. Section 5 is built on the outcomes of sections 3 and 4 and describes the steps undertaken to develop a concept enabling capture of mutual expectations of inputs and outputs.

The concept developed in Section 5 is piloted and validated in Section 6. The final section of this thesis provides the conclusions with an executive summary and managerial implications along with an evaluation of the thesis and some final words.

1.4 Key Concepts

The keywords and concepts used in this thesis include the following:

Piping Flexibility Analysis (Pipe Stress Analysis): A piping flexibility analysis predicts stresses in piping and loads on equipment resulting from thermal gradients, thermal transients, weights, pressure, and bolt-up strain. This kind of study is typically required for piping that experiences high temperature fluctuations, or for long pipe runs such as hot piping to coolers or headers.

Piping Engineering: Piping Engineering is a specialized discipline of Mechanical Engineering which covers the design of piping and layout of equipment and process units in the Pulp and Paper, chemical, petroleum and hydrocarbon facilities as well as other process industries.

Flexibility Analysis inputs: Data, documents and information required to initiate a flexibility analysis process.

Flexibility Analysis outputs: Data, documents and information provided by the Stress Analysis Engineer during the flexibility analysis of critical piping.

2 Method and Material

This section outlines the methods and materials this thesis is based on. It first presents the criteria for a high-quality research and for observing good scientific practice and then proceeds to describe how high quality has been ensured in this thesis.

Accordingly, this section explains the research approach used in undertaking the study as well as the justification for using this approach. It then introduces the Research Design in the form of a flow diagram on how the study was conducted. Next, it explains how data was collected and provides details on the data collection rounds as well as types and significance of the data. Finally, this data information is all presented in a matrix form as a Data Plan.

2.1 Research Approach

A variety of ways exist for carrying out a high-quality research depending on the nature of research problem or issue being addressed and the consumers or audience of the study. In business and management research projects, two research approach models can be distinguished. One is basic research that is undertaken with the sole purpose of understanding some processes and their outcomes without laying much emphasis on its practical applications. The other one is applied research that is direct and offers immediate relevance to the managers, addresses important issues and is easy to understand and implement (Saunders et al 2012: 8). This research explores the challenges facing a department in an organization and involves improvements in specific areas. In addition, it aims at finding immediate solutions by relying heavily on those directly involved. This implies the need for an applied research to carry out the study in this thesis.

2.1.1 Applied Action Research

An applied research itself can be undertaken as a case study, action research and so forth. A research can be undertaken in many ways within each label with prescribed procedures and philosophical foundations which are not relevant to this study. Therefore, procedures and philosophical background will not be discussed in this thesis.

In this thesis, the applied *action research approach* was selected, for which information is collected by a qualitative method to explore the business challenge. This type of research produces functional and practical solutions, combines development and research, and is conducted in organizations in order to improve operations (Kananen 2013: 20-21).

A qualitative research was used in order to gather data for this thesis. It is characteristic of qualitative research that the study is conducted in a real-life context, striving to collect, integrate and present data from a variety of sources of evidence (Yin 2009). This research approach is suitable for this thesis because, on the one hand this research is exploratory in nature. On the other hand, it provides insights into the problem in a real business context and helps gain understanding of underlying viewpoints of stakeholders. The chosen methods of generating data for this study were in-depth interviews of the stakeholders as well as a strategy document of the Industry Business Group and a memo from a 2018 workshop held when the case company was finalizing a transformation process. The one-to-one interview approach allows key topics to be covered with the flexibility to ask follow-up questions which explore the underlying reasons and opinions of the participants based on their experience working in the field.

2.2 Research Design

Figure 1 below shows the research design in the form of a flow diagram and presents the different phases of this research process.

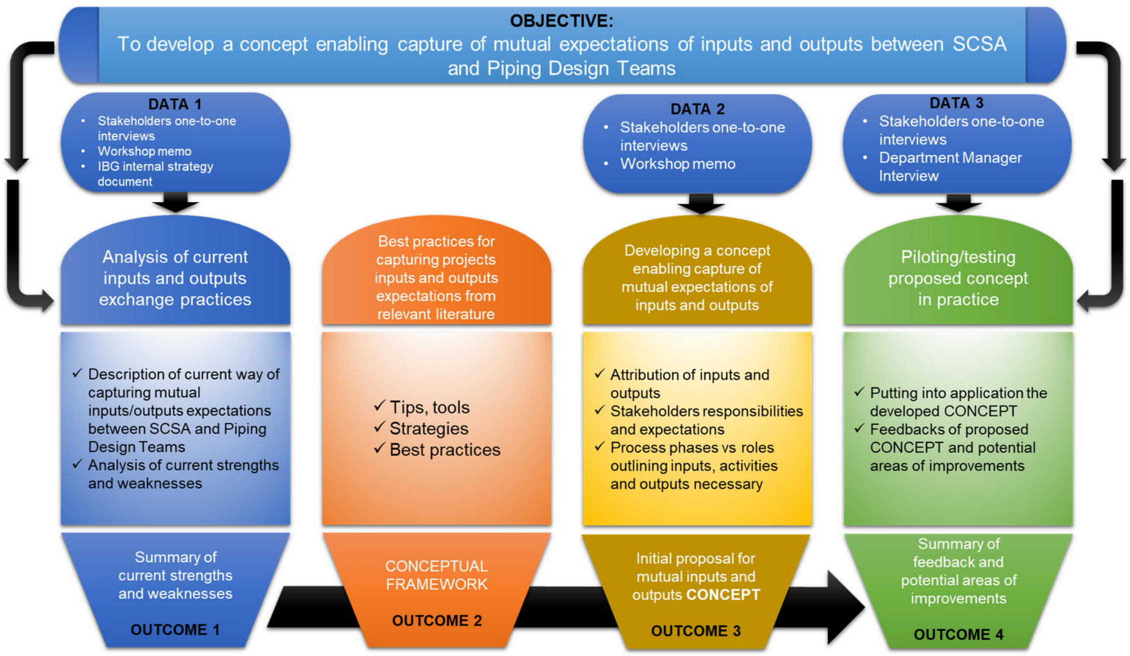

Figure 1. Thesis research design flow diagram.

As shown in Figure 1, this study was conducted in four major phases that follow a strict logic sequence in order to achieve the objective of this project. As a result, the next four main sections of this thesis were produced, i.e. Sections 3, 4, 5 and 6. Each phase consisted of various objectives and led to a specific outcome. For this project, the current state analysis comes before the literature review because mutual inputs and outputs exchange practices between the two internal teams involved is an ongoing process within the case company. This process has been running for many years and it must first be understood prior to providing solutions on how to improve it. The strengths and weaknesses are highlighted in the current state analysis and only then a literature review provides the best practices and tools to help achieve the final outcome.

Consequently, with the objective of the thesis in mind, the first phase of the thesis was to analysis the current state of inputs/outputs exchange practices between the SCSA and the Piping Design teams. This phase is presented in Section 3 and gives a detailed description of the process while highlighting it strengths and weaknesses. Data 1 provided the necessary input for this phase.

The second phase was the literature review in search of tips, tools, strategies and best practices for capturing project inputs/outputs expectations. This phase is presented in section 4 and gives a summary of the best practices suitable for this study. The outcome of this section was a conceptual framework that served as a foundation in building the concept in Section 5.

In the third phase of this thesis, a concept enabling capture of mutual expectations of inputs and outputs expectations from both teams was developed. This phase is presented in Section 5 and outlines a summary of the developed concept. Data 2 provided the necessary input for this third phase.

The final phase of this thesis involved putting into practice the developed concept. In the process of piloting the proposed concept areas of improvements were detected and material gathered through feedback. This phase is presented in Section 6 and gives a summary of feedback and potential areas of improvements. Data 3 provided the necessary input for this final phase.

As depicted in Figure 1, this thesis used triangulated data, collected at three phases of the project. This approach enabled involvement of relevant stakeholders, a comprehensive understanding of the business challenge and validation from various sources, thereby making the result of this thesis bias free.

The first three outcomes shown in Figure 1, each played a crucial role in building the final outcome of this thesis. First, outcome 1 resulted in a summary of weaknesses and strengths identified during the current state analysis. Then, based on weaknesses, tools, strategies and best practices were gathered from existing literature and outcome 2 resulted in a conceptual framework. Finally, an initial concept was built based on the framework and guidelines from relevant stakeholders as outcome 3 and the final outcome of this thesis.

2.3 Data Plan

Figure 2 shows the triangulated data collection matrix of this study and illustrates the different data collection methods used to achieve the ultimate goal of this qualitative study. The chosen methods of generating data were in-depth one-to-one interviews of relevant stakeholders, the then Industry Business Group (IBG) and now Process Industries Division internal strategy documents and available memos from a 2018 workshop.

	CONTENT	SOURCE	INFORMANT	TIMING	OUTCOME
DATA 1 Analysis of current inputs/outputs exchange practices	✓ Description of the current way of capturing mutual inputs/outputs expectations between SCSA-Team and Design Team ✓ Analysis of current +/-	✓ Stakeholders one-to-one theme interviews ✓ Memos from SCSA team workshop ✓ Industry Business Group Strategy document	✓ Senior Project Engineer ✓ Lead Project Engineer ✓ Lead Stress Engineer ✓ Senior Piping Design Engineer ✓ Senior Mechanical Engineer ✓ Senior Stress Analysis Engineer	JANUARY 2020	✓ Summary of identified strengths and weaknesses
DATA 2 Developing a concept enabling capture of mutual expectations of inputs and outputs	✓ Description of mutual inputs/outputs ✓ Stakeholders' responsibilities and expectations ✓ Project phases vs roles outlining inputs, activities and outputs necessary	✓ Stakeholders one-to-one theme interviews ✓ Industry Business Group Strategy document	✓ Line Manager ✓ Lead Project Engineer ✓ Senior Project Engineer ✓ Lead Stress Engineer ✓ Chief Piping Design Engineer ✓ Senior Mechanical Engineer ✓ Senior Stress Engineer ✓ Senior stress Engineer	MARCH 2020	✓ Initial proposal of mutual inputs and outputs CONCEPT
DATA 3 Piloting proposed concept in practice	✓ Putting into application the developed concept ✓ Feedback on proposed concept and potential areas of improvement	✓ Stakeholders one-to-one theme interviews	✓ Line Manager ✓ Lead Stress Engineer ✓ Lead Piping Designer	MARCH-APRIL 2020	✓ Summary of feedback and potential areas of improvements

Figure 2. Thesis data plan matrix.

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As seen in Figure 2, information presented focuses on the three phases of the study that required data collection and whose outcomes are crucial in building the final outcome of this thesis. Therefore, some of the content of Figure 2 is similar to that already presented in Figure 1. However, the matrix shows additional information, particularly the quality and depth of the data collection approach. This study relied on experienced engineers from the SCSA and Piping Design teams as informants with many years of experience on their resume and in-depth knowledge of the inputs/outputs exchange practices between both teams.

During the transformation period of the case company that started in 2016, the then IBG put in place a new strategy which was in line with the overall strategy of the case company. Among actions that required implementation included the development of new approaches and tools that will help save time and cost, as well as improve quality and efficiency. Developing a concept aimed at improving inputs/outputs exchange practices certainly falls in this category. This explains why the IBG internal strategy document was used as a source, thereby validating the initiative and putting the objective of this thesis in line with the case company's strategy.

The second source of data collection was in-depth interviews of relevant stakeholders, which is particularly pertinent to this study. Participants were chosen from both teams based on their work experience and in-depth knowledge in plants design projects' inputs/outputs exchange practices. Besides, the work experience of the participants in their respective fields ranged from 12 to 26 years and altogether have been involved in hundreds of projects. One-to-one in-depth skype interviews were prioritized but in cases where it was not possible due to the participant's schedule or location at the time, an Email in-depth interview was opted for instead. However, in both cases questions were systematically formulated prior to the interviews while allowing some flexibility to ask follow-up questions. Data collection was done by recording and taking notes.

The third source of data collection was a memo from a 2018 workshop that was held at the time the case company was finalizing the transformation process and the department has been placed under new leadership. The newly appointed line manager hosted a workshop aimed at bringing the SCSA team together and defining a new team approach. During this workshop a list of inputs/outputs expectations between SCSA and Piping Design teams was established, targets of the IBG inner strategy discussed and responsibilities attributed to some team members.

Table 1 below details the data collection sources, types, content and the respective objectives of each at the three different data collection phases of this thesis.

Table 1. Utilized project data type.

Data 1	***Content***	***Data Source***	***Data Type***	***Objective of Analysis***
Current state Analysis (CSA)	Review of past and current mutual inputs and outputs exchange practices	Stakeholders one-to-one interviews	Skype recorded interviews	Evaluation of strengths and weaknesses of the mutual inputs and outputs exchange practices
		Process Industries Division Strategy and guidelines material	PPT presentation	Clarification of case company's and business group's current strategy and required actions
		Workshop memo	Text documents	To clarify inputs, outputs and phases of the exchange practice
Data 2	***Content***	***Data Source***	***Data Type***	***Objective of Analysis***
Proposal Building	Description of a step-by-step approach on how to best capture mutual expectations of inputs and outputs	Stakeholders one-to-one interviews	Skype recorded interviews	To create an initial proposal based on weaknesses (CSA), element of conceptual framework (CF) and input from key stakeholders (Data 2)
		Workshop	Text documents	To gather Flexibility Analysis Requirements: Inputs and outputs at various phases of the Flexibility Analysis Process
Data 3	***Content***	***Data Source***	***Data Type***	***Objective of Analysis***
Piloting proposed concept in practice	Review of the proposed adjustments and feedback	Stakeholders one-to-one interviews	Skype recorded interviews	To gather feedback for further improvement of proposal

As shown in Table 1, each set of data collection focused on a specific content, data source and type. Each data collection phase also included an objective, thereby allowing a systematic approach to the research process. In this thesis an overview of data 1, 2 and 3 is presented in detail in Section 3, 5 and 6 respectively.

This completes the Project Plan and Material section of this thesis. The next section focuses on carrying out a Current State Analysis of mutual inputs/outputs exchange practices.

3 Current State Analysis of Mutual Inputs/Outputs Exchange Practices

This section describes the current state of mutual exchange practices of inputs and outputs between the SCSA and Piping Design teams during design projects of process plants in the case company. The section starts with a brief overview of Data 1 and then proceeds to presenting the results of the analysis of the current exchange practices between both teams within the Mechanical and Piping Engineering department in Finland.

3.1 Overview of the Current State Analysis Data Collection Stage, Data 1

The three methods used in generating data for the Current State Analysis (CSA) have been presented in Section 2 of this thesis. These methods included in-depth one-to-one interviews of relevant stakeholders, IBG internal strategy document and a memo from the SCSA team 2018 workshop. Table 2 shows the participants of the one-to-one interviews, interview type, job title of participants, topic discussed and date of interviews.

Table 2. Details of interviews and discussions in Data 1.

Participants	Data type	Title / years of experience	Topic	Date
Data 1: Current State Analysis (Interviews)				
Respondent 1	Skype interview	Senior project Engineer (20 years in the field)	CSA review from **Piping Design Team** perspective	9.1.2020
Respondent 2	Skype Interview	Lead Project Engineer (26 years in the field)	CSA review from **Piping Design team** perspective	13.1.2020
Respondent 3	Skype interview	Lead stress Engineer (15 years in the field but 3 years performing flexibility analysis)	CSA review from **SCSA Team** perspective	14.1.2020
Respondent 4	Email interview	Senior Piping Design Engineer (13 years in the field)	CSA review from **Piping Design Team** perspective	16.1.2020
Respondent 5	Skype interview	Senior Mechanical Engineer (12 years in the field)	CSA review from **SCSA Team** perspective	29.1.2020
Respondent 6	Skype interview	Senior Stress Analysis Engineer (13 years in the field)	CSA review from **SCSA Team** perspective	30.1.2020

As seen in Table 2, six experienced senior engineers were selected to give an insight of the current mutual inputs and outputs exchange practices. In order to consider a diversity of viewpoints, three senior Engineers were interviewed from each team. Five out of the six interviews were conducted and recorded via skype. The sixth interview was conducted through emails due to the respondent unavailability for a one-to-one skype interview. Interviews were conducted during working hours and lasted from 45 to 60 minutes. In addition to one-to-one interviews, two other sources of data were used for this phase of the study. These sources included internal documents mentioned and discussed in Section 2 of this thesis. Table 3 shows the other sources of data analysed for the current state analysis.

Table 3. Internal documents used in current state analysis, Data 1.

Document Number	Data type	Document Name	Description	Date
Data 1: Current State Analysis (Internal documents)				
Doc 1	PPT presentation	Process Industries Division Strategy guidelines material	Strategy in relation to teams' interaction, data sharing, saving documents and reporting	Accessed 19.12.2019
Doc 2	Text documents	Workshop memo	Types of inputs and outputs, how and when to deliver them	Accessed 16.1.2020

As seen in Table 3, this study also relied on internal documents relevant to the research topic. The main documents included the IBG internal strategy document and a memo from a 2018 workshop. These documents were accessed and printed from the case company's data bases. Table 3 also presents a brief description of the contents of each document.

In order to capture the current state of inputs and outputs exchange practices during a piping flexibility analysis, a systematic approach was utilised to conduct the interviews and analysed the information obtained. First, documents were analysed to capture the requirements of a flexibility analysis and to confirm the objective of this study was in line with the case company's strategy. Second, four phases were identified, and questions categorized into respective phases in order to carry out an in-depth study of each phase. Third, the process was summarized into a flowchart based on information collected in the form of Data 1. Finally, the information gathered was used to produce the following sub-sections which include the workflow of the process, the findings and summary of the analysis.

3.2 Workflow of Current Inputs and Outputs Exchange Practices

During the analysis of the current state, four phases were identified - initiation, modelling, analysing (problem-solving) and reporting phases. These phases represent stages involved from the moment all initial data is gathered, critical pipelines identified by the Piping Designer and sent to the Stress Analysis Engineer for a flexibility analysis, until all problems regarding the piping system are solved and reported through intensive co-operation between both engineers or teams. During these phases, different types of inputs and outputs are exchanged, and solutions are provided.

Results of the analysis of the current inputs and outputs exchange practices for piping flexibility analysis between the SCSA and Piping Design teams are presented in the form of a Flexibility Analysis process flowchart. Figure 3 shows a summary of the process map which was derived based on data collection at this stage. Therefore, the case company did not have a process map at the time this study was conducted.

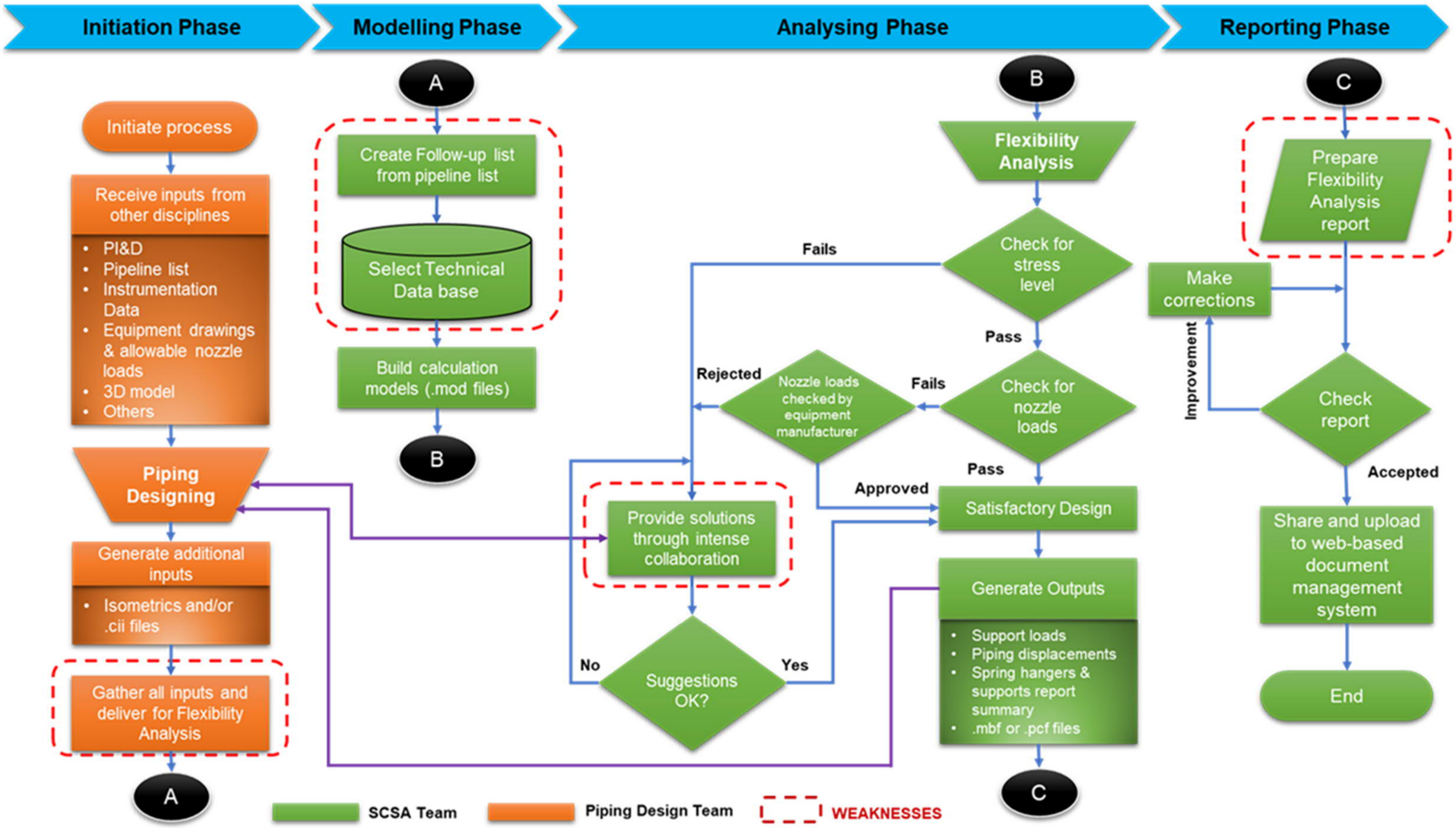

Figure 3. Workflow of current inputs and outputs exchange practices between SCSA and Piping Design Teams - Flexibility Analysis Process.

As seen in Figure 3, the process consists of four phases, each of which involves different exchange activities. The current state analysis revealed weaknesses and strengths in some specific areas of the process. While identified areas of weaknesses have been highlighted in Figure 3, strengths and weaknesses are presented in detail in the next four sub-sections describing each phase of these exchange practices.

3.2.1 Initiation Phase

Figure 4 shows the flowchart of the initiation phase and highlights the identified weaknesses and strengths of this phase.

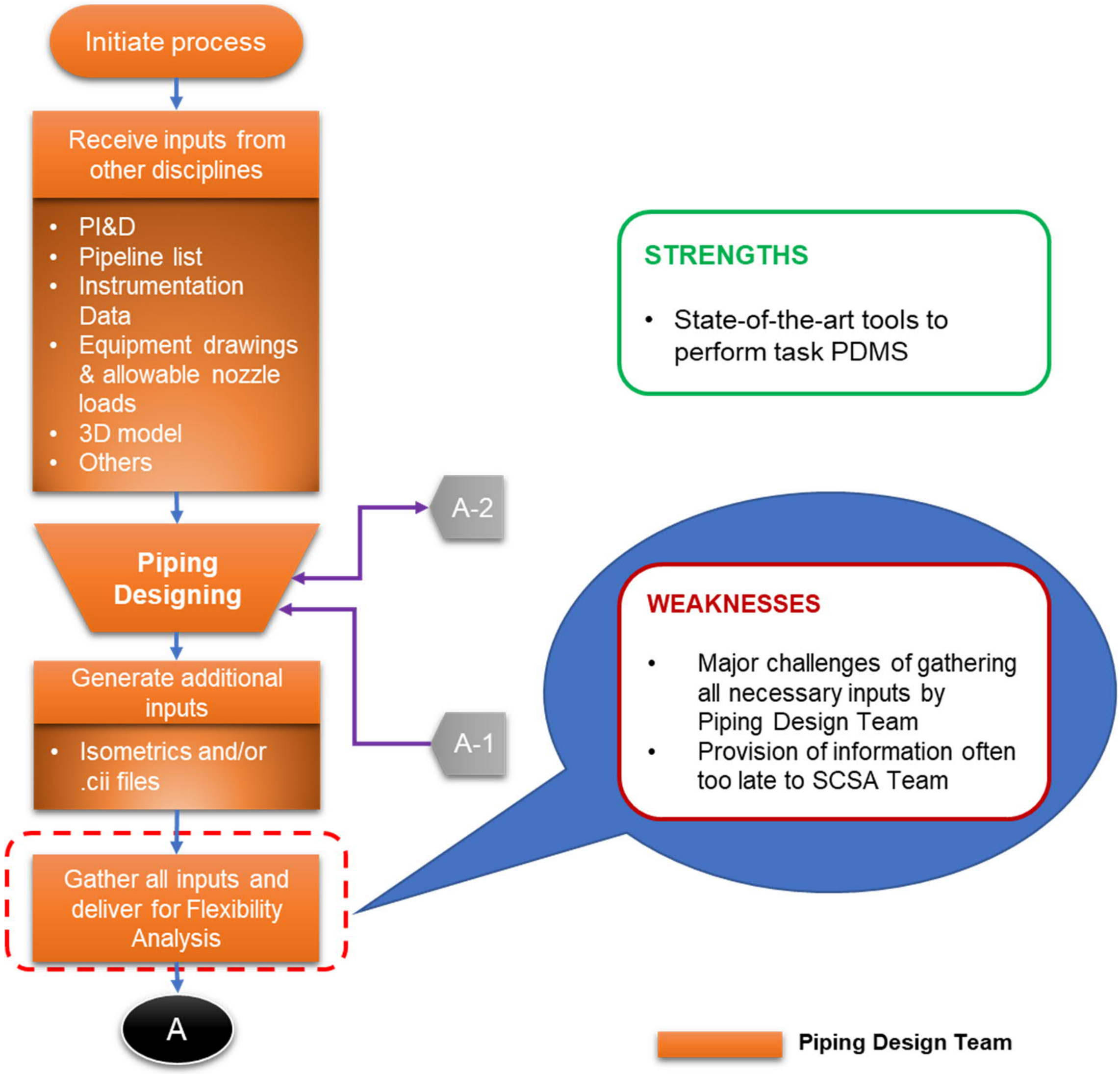

Figure 4. Strengths and weaknesses in the Initiation Phase.

As seen in Figure 4, the owner of the task in this phase is the Piping Designer or Piping Design Team. The main weakness involves major challenges in gathering all necessary inputs to transmit to the SCSA Team for a flexibility analysis. This is also the main reason why there is often a delay in providing all necessary information or requesting for a flexibility analysis. The in-depth analysis of the initiation phase also revealed some strengths including the availability of state-of-the-art tools for 3D modelling such as PDMS.
In the Initiation Phase, critical pipelines are identified, inputs are gathered, and the flexibility analysis process is planned. This phase has proven to be the most challenging in this exchange practice. The lack of the right information at this phase often plays a crucial role in the late delivery of inputs to the SCSA team. Even though both teams agree that the Piping Designer is the owner of inputs for the Stress Analysis Engineer, it is important to emphasize that some of those inputs come from other disciplines. Most often, the information at the early stage of this phase is preliminary, assumptive or based on previous similar projects.

This phase is the beginning of an intense process of collection of data by the Piping Design team to transmit to the SCSA team for flexibility analysis. In general, this process follows procedures used in plant layout and piping design, which is a complex task and consists of several stages, all of which would not be discussed in this study. The first stage of designing a process plant that produces the first important input document is the design study stage. During the design study stage preliminary routing of major pipelines take place. The outcome of this stage is a final plot plan and a preliminary Piping and Instrumentation Diagram (P&ID). The P&ID shows the piping, process equipment, instrumentation and control devices as well as references to detailed drawings of equipment. Moreover, the P&ID serves as the primary reference document in communication between all engineering and design disciplines involved in plant designing project.

The next step is to create a three-dimensional model (3D model) of the process plant using the plot plan, P&ID and other information available at this stage. In order to create this type of model, the case company possesses advanced computer hardware and 3D modelling software such as PDMS and AutoCAD plant 3D. The preliminary 3D model is then used in the detailed design and engineering phase of plant designing by the Piping Design Engineers for pipe routing. A 3D model contains all components of a plant including piping, equipment, fittings, control stations and support structures. During the detailed engineering and design stage, piping isometrics drawings known as “Issued-For Design (IFD)” are generated for stress analysis. In some cases, micro files (.cii files) that can be imported to the stress analysis software are generated from the 3D modelling software at this stage.

The other set of inputs generated during the initiation phase is the code compliance and piping material specifications. Pipes and piping components are normally designed to meet the requirements of the national standards. Therefore, the code that governs the design of piping systems for plants is often selected based on the future location of the plant or agreed by the client and contractor, in this case the case company. While selecting the design code is straightforward, specifying appropriate materials for the pipes is often a time-consuming task. The Piping Material Engineer (PME) is responsible for carrying out this task. The PME is also responsible for selecting the PED (Pressure Equipment Directive) class for each line on the P&ID and developing an initial listing of all pipelines. This initial list of all pipelines is often referred to as the *pipeline list.* In order to define the purpose, design, and operating conditions of each pipeline, the PME needs to work with the Process Engineer and later with others including the vendors to satisfy the requirements. The *pipeline list* contains information such as piping outside diameters, wall thicknesses, materials, flow substances, PED classes, design and operating conditions (design temperatures and pressures, operating temperatures and pressures). In some cases, insulation thicknesses and densities of the flow substance may be included in the *pipeline list* or provided separately.

The information presented so far in this phase is not only inputs for the flexibility analysis of piping systems but also inputs for the pipe routing. According to Respondent 1, the procedure of identifying critical pipelines requiring a flexibility analysis begins with available information on piping standards, dimensions and PED classification. Respondent 1 explained that sometimes the process department provides a list of pipelines containing the PED classification of each pipeline. Based on this information and available guidelines within the case company, critical pipelines requiring a flexibility analysis are identified. When asked whether it was easy to obtain this information, Respondent 1 insisted that it was often difficult to obtain this information at the early stage of the project.

3.2.2 Modelling Phase

Figure 5 shows the flowchart of the modelling phase and highlights the identified weaknesses and strengths of this phase.

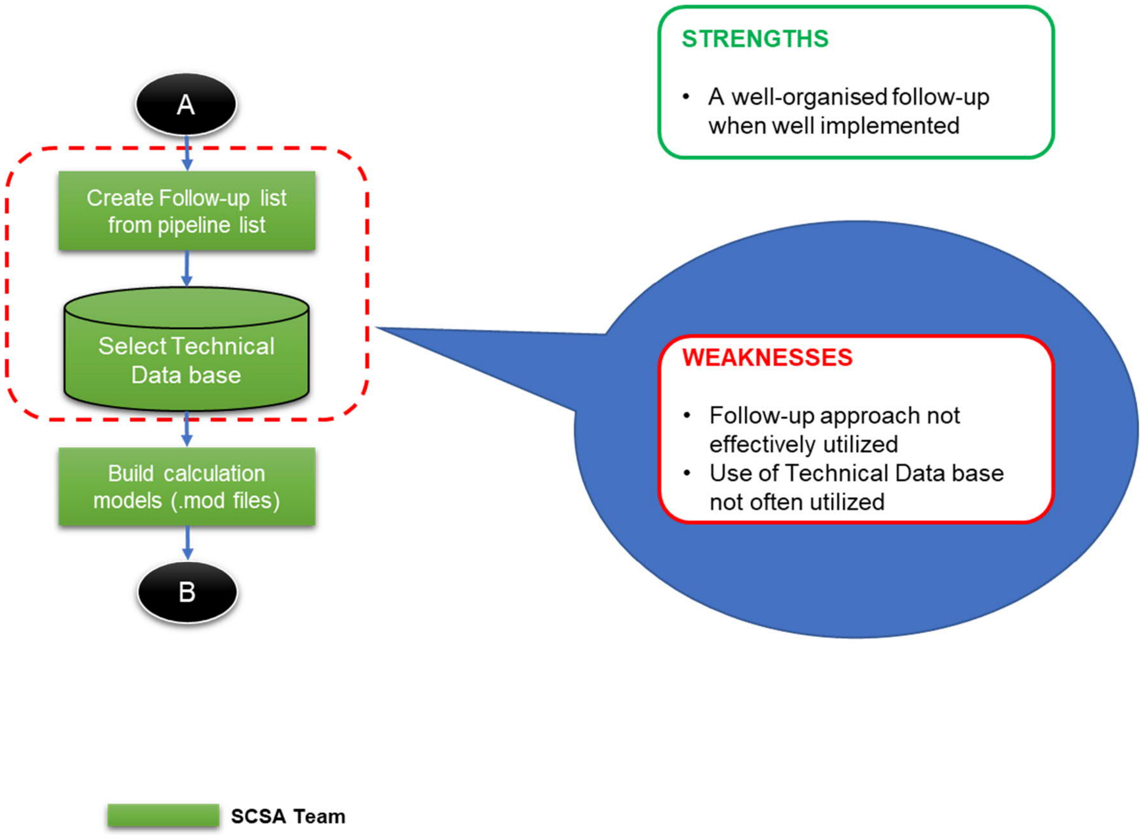

Figure 5. Strengths and weaknesses in the Modelling Phase.

As seen in Figure 5, the owner of the tasks in this phase is the Stress Analysis Engineer from the SCSA Team. This phase begins with creating and selecting tools aimed at facilitating the follow-up of activities during the flexibility analysis. The analysis revealed strengths and weaknesses in the follow-up approach.

The initiation phase is followed by the modelling phase where pipelines are divided into packages and available data is transformed to stress analysis models.

A stress analysis model must have boundaries to ensure accurate flexibility analysis results. Therefore, each calculation package must include a pipeline or group of pipelines from a reference anchor connection point to another. A reference anchor connection point can be a nozzle connection such as a connection to an equipment or pump, or a fixed support. This process marks the beginning of the modelling phase.

The next step is to simultaneously create a *flexibility analysis follow-up list*, which is a term used internally. For simplification purposes, a flexibility analysis follow-up list is often created by adding a few columns to the pipeline list. The new columns often include information such as package number, Piping Designer of each pipeline or package, Stress Analysis Engineer of each package, date of delivery of isometrics drawings for flexibility analysis, flexibility analysis status and a comment section. The status of the flexibility analysis is itself abbreviated in three letters, where M, A, R stand for Modelled, Analysed and Reported, respectively. The main purpose of this follow-up list is to keep track of the flexibility analysis process. It also allows everyone involved to easily follow the process, be aware of the status of the analysis as well as the people directly involved in the design and flexibility analysis of each line and package. In addition, it allows the lead Stress analysis Engineer, who is also the owner and creator of the follow-up list, to manage the process effectively.

The *flexibility analysis follow-up list* is accessible to all the Stress Analysis and Piping Design Engineer involved in that project. However, the list is mainly another source of communication and keeping track of the process. This way of keeping track of the process has earned a lot of praise from the top management and both teams agree on its effectiveness when properly used.

Once packages and the flexibility analysis follow-up list are created, the Stress Analysis Engineers begin building calculation models within the stress analysis software. Building a calculation model is a systematic and carefully executed step-by-step approach. First, every important data such as the piping calculation code, design data, pipe section dimensions, materials, are input into the stress analysis software. Second, coordinates are input into the system based on the piping geometry using isometrics drawings or micro files. Finally, in the process of building the model support types, valves and instrument weights and other element types are added accordingly.

Two identified approaches are used within the case company's Mechanical and Piping department to create a calculation model for a flexibility analysis. The first approach consists of using piping isometric drawings generated for analysis and all other required inputs from other disciplines discussed in the initiation and planning phase. The second approach consists of importing .cii files generated from the 3D model in the previous phase to the stress analysis software. The SCSA and Piping Design teams agree that transferring files and data from PDMS to CAEPIPE is not suitable for every pipeline. According to Respondents 5 and 6, the second approach works better with simple piping but have proven to be time consuming for complex piping. The explanation given was that files were often transferred with many nodal points, some of which intersected. In addition, valves and instruments were missing, design data, piping sizes, insulation thicknesses, specific gravities and other design parameters needed to be adjusted. Surprisingly, Respondent 3 finds the second approach more efficient sometimes especially in cases the Piping Designer finds it time consuming to print preliminary isometric drawings at the initiation phase of this process. However, Respondent 3 reiterates the importance of having isometric drawings at some point to double check. While the first approach is systematic and is based on the Stress Analysis Engineer's ability to use the coordinate system from isometric drawings and other available inputs to create the model within the flexibility analysis software, the second approach relies on the quality of the file and the amount of accurate information that can be extracted from the 3D model. Presently, the quality of the .cii files do not allow both teams to rely only on these files to create calculation models but mostly on generated isometrics. Once the models are ready, the next phase is to analyse the model.

3.2.3 Analysing Phase

Figure 6 shows the flowchart of the analysing phase and highlights the identified weaknesses and strengths of this phase.

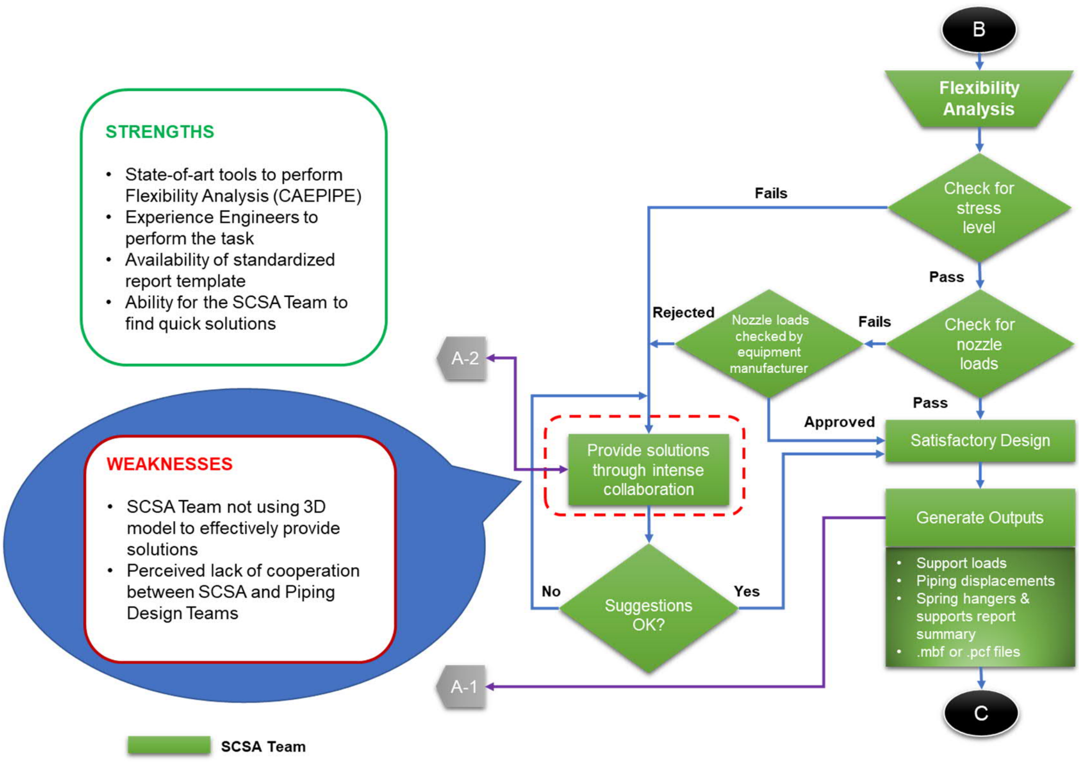

Figure 6. Strengths and weaknesses in the Analysisng Phase.

As seen in Figure 6, the owner of the main tasks of this phase is the Stress Analysis Engineer from the SCSA Team. There is also intense collaboration involved between the Stress Analysis and Piping Design Engineers throughout this phase. This phase is the most intense and time consuming in terms of activities involved. While the in-depth analysis of this phase revealed a strong foundation of the process, it also exposed a few weaknesses related to cooperation and use of 3D view model by the SCSA Team.

The modelling phase is followed by the analysing phase where calculation models are analysed for stresses, displacements and loads. This phase also includes intensive collaboration and interaction between SCSA and Piping Design teams.

The analysing phase is the most important in ensuring that piping designed is flexible, stress levels, displacements and nozzle loads are kept within acceptable limits. Moreover, this phase also ensures all high support loads are considered when designing secondary steel supports, and that spring hangers and supports are designed accordingly. The outcome of these phases also sets the standard of the quality of the final phase of this process as well as its potential approval by the Notified Body (NOBO) in cases where official approvals are required. When the piping is finally installed at the site and all the processes are running accordingly, it enhances the client's satisfaction. Therefore, it is important that this phase is carefully executed, checked and double checked.

Designing and analysing piping requires not only skills but the right tools to perform these activities. The case company provides its Engineers with state-of-art tools that allows Designers and Stress Analysis Engineers to effectively design and simulate piping flexibility. When asked about the strengths of the modelling and analysing phases, Respondent 3 pointed out the availability of the state-of-art tools. While the Design team uses tools such as PDMS, AutoCAD plant design to design 3D piping, the SCSA team uses CAEPIPE to model and perform flexibility analysis of simple and complex piping systems. Main users have been assigned for each tool whose responsibility is to make sure every user is aware of the availability of the latest version and can request for its installation. They may also contact the software providers to report problems related to the usage or flaws in the software.

Once the calculation model is created with the right design parameters, the next phase is to analyse the piping system for stress and load to ensure that the pipelines are not overstressed (both under installed and operating conditions) and are adequately supported. Piping systems need to be flexible enough to allow for thermal expansion. Pipe stress analysis also calculates loads and stresses on equipment nozzles and these loads need to be compared to existing standards and codes or provided to the equipment manufacturer to ensure that they are within acceptable limits. More often, it is a complex and challenging procedure. According to Respondent 3, the knowledge of understanding and finding solutions to complex piping systems requires many years of experience performing piping flexibility analysis, as well as in-depth knowledge of thermal expansion theory. Therefore, analysing piping systems and providing accurate solutions requires a particular set of skills. Fortunately, the case company relies on Stress Analysis Experts with many years of experience and the problem-solving phase even though challenging is often well handled. The availability of an effective and up-to-date stress analysis software also enhance results.

After running the analysis and spending some time solving problems, solutions are presented the solutions to the Piping Designer. These solutions are considered outputs for the SASC team but become inputs to the Piping Design team as this information is required to improve the Piping design. Solutions, suggestion or comments can be presented in different ways depending on the location and availability of the Piping Design Engineer, urgency of the matter or the need to avoid any misinterpretation of the solutions presented. The first and recommended approach is to present most of the solutions via a skype call and presentation tools. This approach allows the Stress Analysis and Piping Design to systematically go through the solutions and more often it speeds up the process. When a skype call is not possible, solutions are often presented in pdf format, sent to the Piping Designer via email as attachments and saved to the technical data base selected at the initiation phase and the Flexibility Analysis follow-up list revised accordingly. Both teams agree that a close collaboration is very important at this stage and both approaches should be used often. However, almost every respondent pointed out a few cases when they have witnessed poor collaboration. When ask about the strength and weaknesses of the inputs and outputs exchange practices, Respondent 1 expressed the need of a close collaboration. According to Respondent 1, there have been cases where pipelines are sent for calculation and came back with a simple comment from the Stress Analysis Engineer. The comment read “the pipeline does not work”, meaning the pipeline was not flexible enough, but without any suggestions on how to improve the piping flexibility.

In the process of providing solutions to the Piping Design Team, the Stress analysis engineer must have access to the 3D-model. Piping Design Engineers need a state-of-the-art 3D modelling software in order to effectively create pipelines routing in a neat, orderly and symmetrically manner while keeping in mind the future need of the plant. The case company provides 3D-modeling software such as PDMS, AutoCAD Plant 3D and

3D model review software such as Navisworks. While it is not a requirement for Stress Analysis Engineers to have skills in 3D modelling, it is beneficial to be at least able to navigate around 3D models and use a set of basic tools. This allows the Stress Analysis Engineer to follow-up closely the pipe routing process, compare the calculation models to the existing 3D model, make suggestions based on the available space within the 3D environment and locate support where they can be designed. Most of the Respondents from the SASC team admitted to being able to access and navigate around a 3D model environment in real-time. However, when asked about their best experience working with a Stress Analysis team, Respondents 1 and 2 pointed out their respective experience working with Stress Analysis team of the case company's main competitors in Finland. Respondent 2 emphasized that the ability of the Stress Analysis Engineers to have skills in 3D modelling was particularly beneficial. The skills set of the Stress Analysis Engineers in 3D modelling allowed them to make suggestions by routing pipes directly from the 3D-model. Respondent 2 also agreed that this is not the responsibility of the Stress Analysis Engineer and it may seem they are performing the Piping Design Engineer task of routing pipes.

Finding ways to route pipes in a space limited environment is not always the only challenge in the analysing phase. As discussed previously, a piping system does not only need to be flexible enough but loads to its connection to equipment such as tanks, pressure vessels, turbines, pumps must be within allowable limits. On the one hand, it is easier to provide solutions to the Design Team when allowable loads are provided in the initiation phase or at some point during the project. This allows minimizing nozzle loads at this phase without worrying about the extra work required in cases they were not approved by the equipment manufacturer. On the other hand, the availability of local standards, previous projects materials and experience of the SCSA team allows the Stress Analysis Engineer to minimize nozzle loads to reasonable values before sending them for approval to the equipment manufacturer. According to the SCSA team, nozzle loads are often approved when sent to the equipment manufacturer.

Support loads are also crucial at this phase for the design of secondary steels structures that are used to support pipelines. Failure to use the right profile in designing secondary steel structures may result in costly damage at the site during operation. The Stress Analysis Engineer provides outputs to the Piping Design Engineer that become inputs for the design of primary and secondary supports. This exchange of inputs and outputs also involves two approaches. The first and faster approach is to print a preliminary support loads summary report from the stress analysis software. This software allows printing a support load summary per node numbers. Therefore, adding a visual print of node number is as important when sending this information. However, the Piping Design team considers this approach cumbersome especially when the piping system consists of many nodal points. The second approach is to first prepare a pdf format of a rendered 3D model of the calculation model from the stress analysis software. Then a document is created by taking a screen shot of support load tables and pasting them to the 3D model in a way that maps the support and their corresponding table. Even though this approach can be time consuming, both teams agree is the most effective and efficient.

As the project evolved, the process of mutual inputs and outputs exchange practices intensifies, updates are made during meetings with the stakeholders and client, problems are raised, and decisions are made on how to proceed. Unfortunately, the SCSA team is often not invited to attend those meetings even when those are directly related to the results of the team's work. When asked about why the SCSA is not often invited to meetings, Respondent 3 answered that no one seems to take flexibility analysis seriously. Respondent 3 argues that an explanation from someone who understands the physics of the process could sometimes save time and clarify phenomena that are often confusing to the project management or client.

The next step of this phase is to agree on the final routing of the pipe with both teams and the project management. This step also involves updating all the valves and instruments weights, making sure the stress analysis model, support types and support locations are according to final isometric drawings. In some cases, a .mbf file is sent to the Piping Designer by the Stress Analysis Engineer to map the calculation model to the 3D model making sure that these two are identical. Where the piping system includes spring hangers and support, a final hangers report summary is sent to the Piping Designer. Values from this report are used as inputs within an intelligent piping support design software LICAD and support drawings to scale and materials are generated automatically.

The final step of the modelling and analysing phases is to combine all this information into a final flexibility analysis report. The next phase describes the reporting phase of the current mutual inputs and outputs exchange practices between the SCSA and Piping Design teams.

3.2.4 Reporting Phase

Figure 7 shows the flowchart of the reporting phase and highlights the identified weaknesses and strengths of this phase.

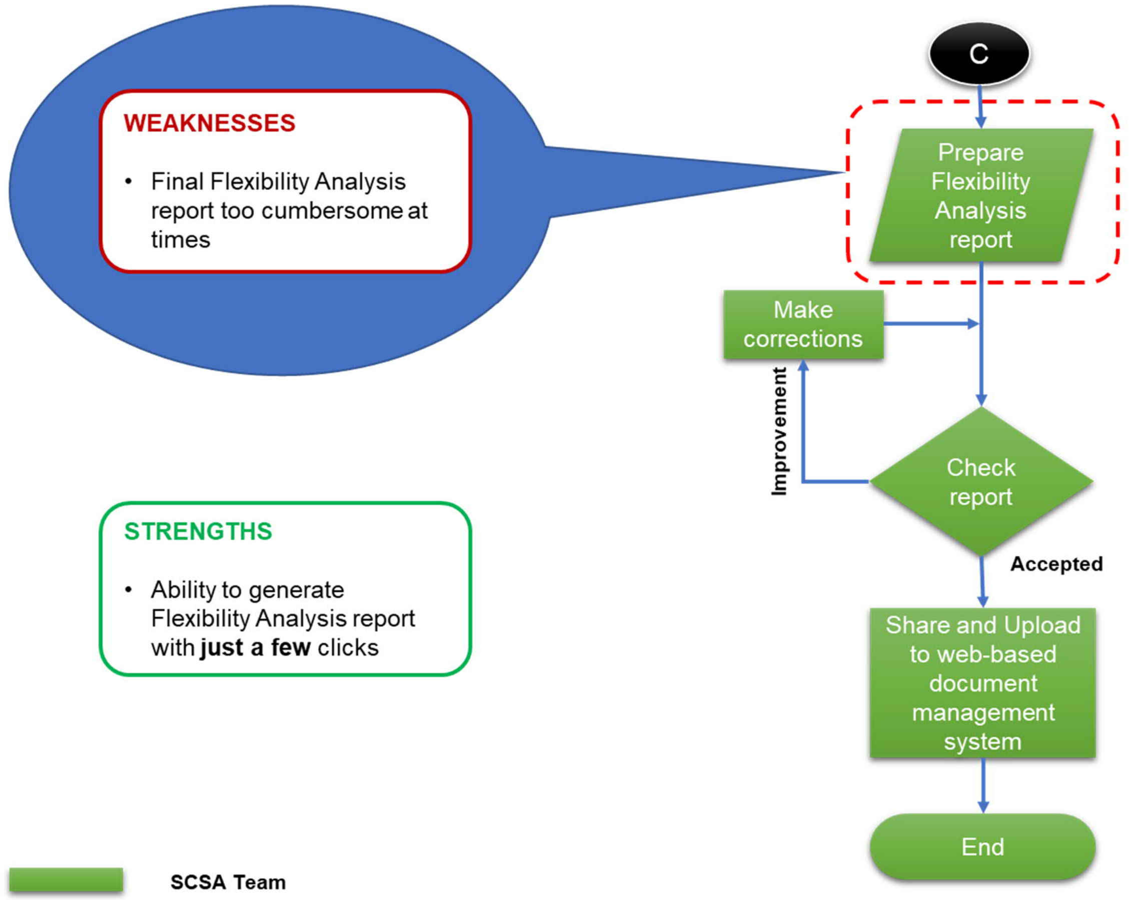

Figure 7. Strengths and weaknesses in the Reporting Phase.

As seen in Figure 7, the owner of the tasks in the reporting phase is the Stress Analysis Engineer from the SCSA Team. In this phase, the flexibility analysis report is prepared, checked and finalized. Despite the ability to generate reports in remarkably easy steps, the analysis of the reporting phase revealed a minor weakness related to the size of the report, which is perceived too cumbersome at times.

Before the transformation process began in the case company in 2016, many ways of reporting a flexibility analysis were used. A quick look at previous reports confirms that reports were customized depending on Stress Analysis Engineer, local office or project. However, in 2018 during a workshop supervised by the SCSA team line manager, one of the actions undertaken was the development of a new flexibility analysis template. This template was going to serve as the basis for all projects unless otherwise requested by the client. The template has been developed and improved since then and has served as the benchmark in many projects. When discussing the strengths of the reporting phase, Respondents 3, 5 and 6 highlighted the availability of this template. According to

Respondent 3, the ability to use this template in every next project by making all the necessary changes within the template has been very effective in saving time.

The flexibility analysis report template consists of a cover page, a list of inputs for the flexibility analysis, a theoretical part and information considered important for the report. The cover page presents information such as name of issued company and client, the project name, number, list of calculated pipelines, contents of report, names of the author and persons responsible to check, approve and issue the report. The second page presents a summary of the inputs that were used in the stress analysis. Some of such inputs include the piping flexibility analysis code, piping flexibility analysis software and version, pipelines number and PED class. Information on this page also include load cases, piping material, design pressure and temperature, insulation thicknesses, flow substance, specific gravity of flow substance, corrosion allowance, a summary of the result of the stress levels and the status of nozzle loads calculation (approved by manufacturer or checked according to existing standard). The next pages of the template offer a brief overview of the theory behind flexibility analysis, formula used in sustained, expansion and occasional load cases. The rest of the template presents tables such as nozzle loads summary, support loads summary tables used for large diameter pipelines or pipelines with high support loads, hanger report summary for pipelines that include spring hangers and supports. The final page of the template contains the conclusion reserved for the summary of the flexibility analysis report.

The appendix section of a flexibility analysis consists of CAEPIPE print outs. Among the helpful features in CAEPIPE includes the interactive and organized screen. This allows the user to generate the result of a flexibility analysis in pdf format by a single keypress that takes them through available results. However, this can generate hundreds of pages of report depending on the size of the piping system calculated. Respondent 2 pointed out the need to simplify this part of the report, but Respondent 3 disagrees. According to Respondent 3, a flexibility analysis report is not addressed to the Piping Designer but to a Notified Body (NOBO) whose responsibility is to check and approve the calculation. Therefore, the target of the report is NOBO and Respondent 3 insisted that their expertise gives them a clear understanding of the content of the report.

Most of the information presented in a flexibility analysis report has either been received as inputs at the initiation and planning phase of this process or has been provided as outputs throughout the analysing phase. Consequently, a flexibility analysis report should be considered the outcome of a team effort between the SCSA and Piping Design team. A Notified Body (NOBO) may also be required to check and approve the final flexibility analysis report. This phase sometimes exposes the inconsistencies between the Stress Analysis and Piping Designing, showing one more time why the corporation between both teams requires special attention.

To ensure accuracy in execution and reporting, a flexibility analysis is prepared and issued by the author of the stress analysis calculation. Then it is sent to another member of the SCSA team for checking and is finally approved by either the line manager, project manager or someone else assigned in the course of the project to carry on this task. Once the report is checked, it is sent back to its author for either further improvements and adjustments or finalization. Finally, the flexibility analysis model and report files are uploaded to an official location where all official documents of the project are shared.

3.3 Key Findings from the Current Inputs and Outputs Exchange Practices

The current state analysis of mutual inputs and outputs exchange practices between the SCSA and Piping Design teams revealed several findings that are relevant to this study. Several strengths and weaknesses were identified and are summarized in Figure 8.

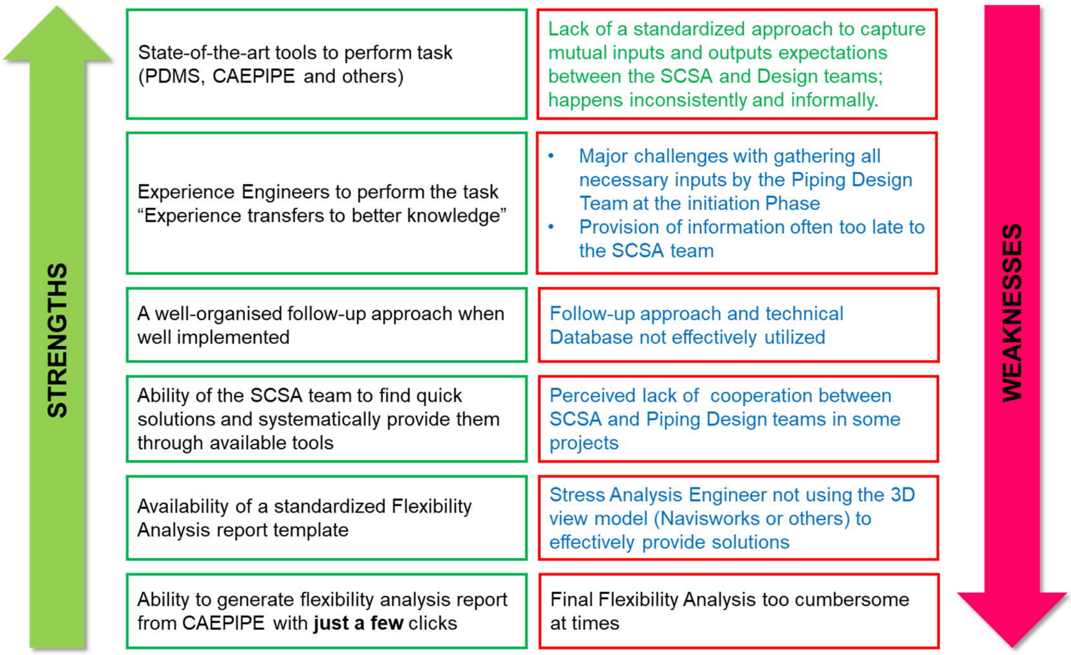

Figure 8. Summary of strengths and weaknesses of inputs/outputs exchange practices

As shown in Figure 8, several strengths which have been key in sustaining this process emerged from the analysis despite the absence of a conceptual way to capture inputs and outputs expectations between the teams. Interestingly, these strengths emerged from the available tools and skill sets of the stakeholders. Both teams were found to be equipped with state-of-the-art tools allowing them to perform their respective tasks. The teams were also found to have the necessary experience and skill sets to provide quick solutions. Other strengths included the availability of a flexibility analysis report template, ability to effortlessly generate reports from the stress analysis software and a well-organized follow-up approach when well implemented.

Many weaknesses that are of particular importance to this study were also revealed. First, the study confirmed that the case company does not have a standardized approach or concept for capturing mutual expectations of inputs and outputs between the SCSA and Piping Design teams in Finland for piping flexibility analysis. Many different approaches were identified throughout the analysis, some more effective than others depending on the project.

Second, the findings revealed that the most significant challenges occur at the initiation phase. These challenges involve identifying the primary owners of the inputs and gathering all the necessary information to transmit to the SCSA team for flexibility analysis. This may explain in part why information is of-ten provided too late to the SCSA team.

Third, despite the availability of an effective follow-up approach, the findings revealed that most often, it was either poorly implemented or not used at all. The same result was found for the use of technical data bases for sharing inputs and outputs throughout the life cycle of projects.

Finally, the study also revealed different viewpoints between the SCSA and Piping Design teams concerning certain aspects of the exchange practices as well as between members of the same team. However, everyone agreed on the importance of improving cooperation due to a perceived lack of cooperation between both teams during some major projects and in general. In addition, the study also revealed a perceived lack of commitment in using the 3D view model by the Stress Analysis Engineer in some projects when providing solutions requiring effective use of space or specific locations. This perceived lack of cooperation tends to hinder communication, undermine each other’s expectations and create confusion around certain roles and responsibilities.

The weaknesses selected for development are highlighted in blue. The reason for choosing these weaknesses has to do with their respective impact on the process. The five weaknesses were identified in the first three phases of the exchange practices during which all inputs and outputs are exchanged. The areas of identified weaknesses play an important role in the outcome of the process and are relevant to developing the final outcome of this thesis. This explains the reason behind adding the major weakness to

Figure 8 and highlighting it in green. Moreover, these weaknesses have an impact on the efficiency of the process and overall performance of the teams as was pointed out in the description of the current inputs and outputs exchange practices.

This completes the Current State Analysis section of the mutual inputs and outputs exchange practices between the SCSA and Piping Design teams during a flexibility analysis. The next section focuses on a literature review to identify best practices, strategies and tools to help find solutions to highlighted weaknesses. The outcome of the next section is a conceptual framework.

4 Best Practice on Capturing Project Inputs and Outputs

This section reviews existing literature related to the key findings of the current state analysis in Section 3 of this thesis. First, an overview of the critical factors for project success is presented to assess factors that are perceived to define success in project implementation or in the project life cycle.
Second, useful techniques and tools necessary for collecting stakeholders' requirements to achieve project objectives are presented. Third, a general concept of key aspects related to cross-functional communication of teams for capturing exchange of information is reviewed in order to understand factors that enhance efficiency in a project. Fourth, effective training and development approaches are reviewed in order to gain knowledge on factors that can enhance skills sets and improve performance among team members.

Finally, a conceptual framework outlining the strategies and tools required to best capture mutual expectations of inputs and outputs throughout a project life cycle, as well as improving interaction between the teams is presented.

4.1 Overview of Project Success Factors and Criteria

The use of projects in organizations has emerged as a trend over the last several decades (Papke-Shields and Boyer-Wright 2017). Firms that are set up around projects are often referred to as project-based firms (Gann and Salter 2000). The fundamental business practice of these firms is to deliver projects for their customers and complete them under tight schedules.

> *Project managers are the new strategic leaders, who must take on total responsibility for project business results. Defining and assessing project success is therefore a strategic management concept, which should help align project efforts with the short- and long-term goals of organization. (Shenhar et al. 2001)*

According to the Project Management Institute (PMI), a project is a temporary endeavor undertaken to create a unique product, service or result. The temporary nature of a project indicates a definite beginning and end. The end is reached when the objectives of the project have been achieved or when it is terminated because its objectives cannot be met, or when the need for the project no longer exist. As a result, a project could be declared either successful or unsuccessful depending on whom you ask or on the criteria under consideration. Moreover, success as an end result has always been the goal of every business activity. Therefore, it is highly important for organizations to be successful in their businesses in order to survive in competitive business environments such as the Engineering consulting.

Successful projects have often been perceived to be those that meet time, budget and performance goals (Shenhar et al. 2001; PMI 2017). This explains why some authors have focused on developing frameworks for assessment of project success for strategic management and top-level decisions on project selection and project initiation. However, others agree that there is more to project success than meeting time and budget (Fortune and White 2006; Jari et al. 2013; Davis 2014).

The search of critical success factors (CSF) in project management began as early as in the 1960s (Fortune and White 2006). Since then many practitioners and academics have attempted to define project success (Jugdev and Müller 2005; Turner and Zolin 2012). Others have published lists of factors while relating them to specific problem areas or activities and in some cases, pointing out their applicability to specific types of projects (Pinto and Slevin 1987; Pinto and Slevin 1988a; Pinto and Slevin 1988b). Pinto and Slevin (1987) summarized five attempts by different researchers to determine critical factors for project implementation. They found the absence of a clear consensus between the authors but determined some similarities in their study while attempting to isolate some CSF based on a comparative analysis of conceptual models developed by the five researchers.

The lack of a consensus between authors on what constitute the critical success factors demonstrates that it is not good practice to rely on only one single approach to assess the success of a project. The three most cited success factors in literature are: have clear and realistic objectives; the importance of a project receiving support from top management; and producing an efficient plan (Fortune and White 2006). These three factors lie within the scope of project management and indicate that project management plays a role in project success. However, availability of other factors outside the direct control of the project manager as presented by Pinto and Slevin (1987), Muuns and Bjeirmi (1996) demonstrate the importance of other factors. Fortune and White (2006) pointed out that project management is only a subset of a project. This also reinforces the claim that the project manager should not be the only viewpoint and path to success (Davis 2014).

Davis (2014) conducted a literature review on the evolution of project success since the 1970s. According to the study, the focus of early studies on success was mainly on the operational sides, tools and techniques and omitted communication with the customers. During this early period project success was assessed at the implementation stage. Then the viewpoint evolved to a close examination of the technical aspects of the project and its relation to the client organization. This second phase of studies often omitted the planning phase and linking a project to strategic management and organization. However, studies began to recognize the importance of success as perceived by various stakeholders. This phase in the literature was marked by the development of CSF frameworks and the importance of success being dependent on internal and external stakeholders.

The 21st century studies on projects success are more stakeholder focused with project success being dependent on the project life cycle (short goals) and not on the wider organization (Turner and Zolin 2012). Davis (2014) concludes that perceptions of success by stakeholders are significant, as are the perceptions of important criteria and actual performance.

Figure 9 below shows results of the analysis of success factors across stakeholder groups from Davis (2014) empirical study. The research approach allowed a theme to be only cited when two or more stakeholders recognized it as a critical dimension to project success.

Analysis of success factors across stakeholder groups.

Success factor theme	Project manager	Client	Sponsor	Owner	Executive	User etc.	Project team
1. Cooperation/collaboration/consultation/communication	1	1		1		1	1
2. Time	1	1	1			1	
3. Identifying/agreeing objectives/mission	1				1		1
4. Stakeholder satisfaction (quality)	1	1				1	
5. Makes use of finished product/acceptance		1				1	1
6. Cost/budget	1	1				1	
7. A project manager competencies and focus	1		1				
8. The project delivering the strategic benefits	1		1				
9. Top management support/executive commitment	1				1		

Figure 9. Analysis of success factors across stakeholder groups (Davis 2014).

As seen in Figure 9, the main dimension common to most stakeholder groups was communication. The project manager, client, owner, user and project team perceived communication as one of the key factors to success. This echoes findings in the success factors in literature, whereby communication was seen to be significant. The second dimension common to most stakeholder groups was setting and meeting a schedule, which all fall under time. The next most reoccurring success factors among stakeholder groups were identifying project objectives, stakeholder satisfaction and making use of finished product. The result also revealed a clear disparity in perception of project success between the project manager and the project team. Two success factors emerged common to both groups: communication and identifying/agreeing objectives/mission. This further reinforces the importance of involving stakeholders at the early stage of a project to assess what constitutes process success and agree on success criteria.

This concludes sub-section 4.1 whose objective was to present how project success is described in different literature and how it is perceived by different stakeholder groups. In addition, the sub-section presented why it is important as a strategy in project implementation to involve stakeholders at the early stage of a project to assess what constitutions project success and agree on success criteria. The next three sub-sections (4.2, 4.3 and 4.4) focus on best practices, tools and techniques on how to effectively capture project and stakeholder needs and requirements, which are considered inputs and outputs in this thesis.

4.2 Capturing Project Technical Requirements

Collecting requirements for a project is a very important part in its implementation. Poor requirements management processes have been identified as one of the reasons of project failure (Kumar 2006). Research studies on new product development, especially in the Information Technology industry, continue to point to poor handling of product requirements as one of the major causes of project failure. However, project failure cannot be associated only with issues in establishing requirements.

4.2.1 Stakeholder Need and Requirements

According to PMI (2017), the collection of requirements is the process of determining, documenting, and managing stakeholder needs and requirements to meet project objectives. Consequently, the first step in collecting requirements is to identify stakeholder needs. The second step include documenting the needs and requirements and then finally manage them throughout the project life cycle to meet the project goal. This process has a broader application and often provides the basis for defining product scope and project scope. For the purpose of this study, requirements are limited to the data or information needed to perform a flexibility analysis as well as outputs from the analysis.

Traditionally, projects consist of five major phases: Initiation, Planning, Execution, Monitoring and controlling, and closing. Misch (2010) points out that requirements management focuses on the planning phase. In the initiation phase key stakeholders are identified and consulted on their needs, prime expectations as well as expected business value generated from the project (Misch 2010). This reinforces the argument that requirement issues should be addressed very early in the project life cycle (Kumar 2006; Burek, 2008; PMI 2017). According to Kumar (2006), poor requirements lead to design issues that are more difficult and expensive to fix after the project development is underway.

A project consists of many types of requirements and approaches to capture them. Thus, before initiating an actual capturing of requirements, a requirement gathering process must be developed (Jonasson 2007). PMI (2017) proposes different techniques to gather requirements which are all relevant depending on the time and place. However, it is considered good practice for the project team to spend some time upfront determining the right approach for the specifics of a project. Some of the data gathering techniques include but are not limited to the following:

Workshop – This technique consists of bringing together stakeholders of different function with expertise on a subject matter to find out about their cross-functional needs and expectations. It is done through an interactive discussion guided by a moderator.

Benchmarking – This technique involves comparing actual practices to those internally from same organization or externally from other organizations to identify best practices.

The Inputs, Tools & Techniques, Outputs (ITTO) process chart is a simple tool that can be used to map the collect requirements process. The ITTO process chart illustrates the way on how to accomplish the goal of a process. Inputs can be referred to as the documents or information needed to accomplish a specific goal. The tools & techniques represent the tools and techniques that are used to accomplish the goal and the Output is the goal itself. PMI (2017) is divided into many knowledge areas, each of which consists of many processes. These processes are divided into inputs, tools and techniques, and outputs.

4.2.2 Significance of defining roles and responsibilities

A process map, like the one presented in section 3 of this thesis, helps identify the actual tasks that are being accomplished and the individuals who perform those tasks. However, it fails to identify the problems that go beyond the processes such as someone refusing to take ownership or a confusion on who is responsible (Jacka and Keller 2009). Projects often require the involvement of many people as well as several departments. As a result, questions on who is in charge often arise throughout the implementation process of a project. Moreover, people often struggle against one another to accomplish a task and in some cases, nobody will take ownership or make a decision. Therefore, it is important that roles and responsibilities of individuals involved in the process are further clarified in order to avoid this kind of ambiguities (Smith et al. 2005).

Role clarity can easily be compromised particularly within cross-functional teams. First, when tasks become complex and employees work on several teams. Second, when employees work on several teams and must report to several managers (Wong et al. 2007). Henderson et al. (2016) in their empirical research on the centrality of communication norm alignment, role clarity, and trust in global project teams uncovered the importance of role clarity on the project satisfaction and performance on individual members in global project teams. On the one hand, effective communication norms help establish and sustain role clarity and interpersonal trust. On the other hand, interpersonal trust among project team members helps sustain communication norm alignment and role clarity (Henderson et al. 2016). Other organizational researches have also demonstrated that role clarity enhance both performance (Bolino and Turnley 2005) and satisfaction (Moynihan and Pandey 2007).

A useful tool that is often used to isolate responsibility issues within a process, department or cross-functional teams is the Responsibility Assignment Matrix, often referred to as RACI Matrix. Unlike a process flow diagram, the RACI Matrix is a visual representation of the role of individuals within the process. RACI stands for Responsible, Accountable, Consulted, and Informed. This chart identifies the roles of all stakeholders from all participating departments (PMI 2017). This chart also serves as a baseline for the communications plan by specifying the receiver of information, the frequency, and other details (Friedman 2008). When well implemented and used, the RACI Matrix can eliminate misunderstandings about each person’s role, reduce duplication of effort, and help build consensus within the team (Jacka and Keller 2009).

Responsibility Charting is a technique for identifying function areas where there are process ambiguities, bringing the differences out in the open and resolving them through a cross-functional collaborative effort. (Smith et al. 2005)

The RACI tool is a simple tool and can be applied to either broad or specified issues. However, role and responsibilities clarity does not end after completing the responsibility charting process. The activity must be an ongoing process as the process evolved as roles and responsibility can change due to unpredictable circumstances. Figure 10 below shows a blank sample of a RACI Matrix in the form of a grid.

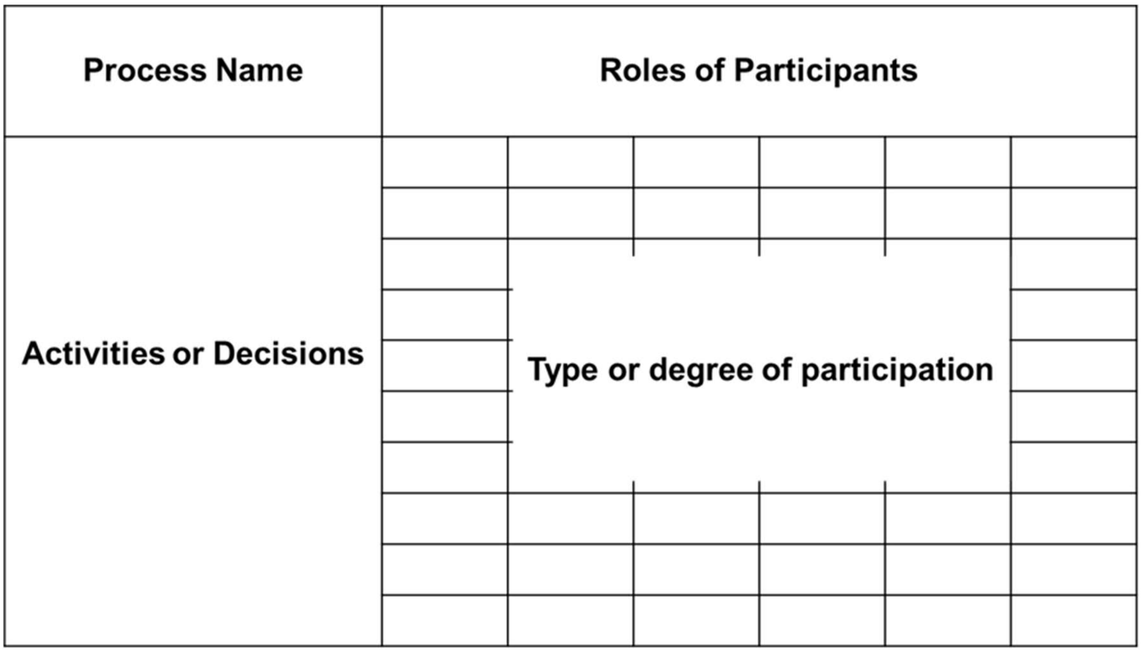

Figure 10. RACI Matrix (Jacka and Keller 2009, p.257).

As seen in Figure 10, the matrix consists of activities or tasks on the left-hand side and the functional roles across the top. While the functional roles are the positions of the individual or person accomplishing an action or task, the activities are the key steps in the process. The third area of the Matrix constitutes the role and degree of responsibility for each individual. Four level of participation are identified that correspond to the four letters of the word RACI: Responsible, Accountable, Consult, and Inform.

Responsible (R) – The individual who actual does the work or the doer. Responsibility can be shared depending on the complexity and volume of the task.

Accountable (A) – This individual is accountable and bears responsibility for the correct completion of the task. It is the individual with yes-or-no authority and veto power. Only one individual can be Accountable.

Consult (C) – This include the individual or groups that is to be consulted before the process can be move forward, generally prior to the final decision or action. The most important characteristic of this activity is its two-way communication. In a check request process, the review by the first- and second-level reviewers represent two Consults per activity.

Inform (I) – This represent the individual or group who is informed while the activity is occurring or afterward but is not required to be part of the process. The characteristic of this exchange is that it is a one-way communication.

4.3 Cross-Functional Communication

A cross-functional team is a workgroup made up of employees from different functional areas within an organization who collaborate to reach a stated objective. Increasingly, many modern organizations incorporate teams from among several department areas to achieve specific goals. This is especially common in project-based organizations, where the work of a project is carried out by a project team which consists of people from different teams with precise subject matter knowledge or with the required skill set. Realization of projects requires appropriate management, which is of particular importance for success implementation (Muszynska 2015). Many authors have described critical factors in successful project implementation (Pinto and Slevin 1987; White and Fortune 2002). Despite the absence of a clear consensus among studies on what constitute a project important success factors, it is possible to spot similarities or patterns between them. A few critical success factors seem to emerge more frequently in previous studies and among them is communication.

Pinto and Slevin (1987) in their study on critical factors in successful project implementation isolated some critical success factors for project implementation, based on a comparative analysis. The analysis resulted in a list of critical factors that included communication among others. Since then this list has been widely referenced or used in project management studies (Fortune and White 2006; Jari et al. 2013; Davis 2014). Thus, the need of adequate communication channels is extremely important in creating an atmosphere for successful project implementation. Communication is not only essential within the project team itself, but between the team and the rest of the organization as well as with the clients (Pinto and Slevin 1987). Moreover, communication in this context refers not only to feedback mechanisms, but also to the need of exchanging information with both team members and the rest of the organization concerning project goals, changes in policies and procedures, status report and so forth.

Cross-functional design teams consist of members from different departments within an organization, which have different working cultures, and use a variety of information systems. These individuals may also possess different skills sets, understanding and opinions on how to embrace the available communication tools. They may also have different perceptions for specific means of communication. Communication itself has always been part of organization practices and is unavoidable in a function organization. However, effective communication is avoidable (Ivancevich et al. 201).

Effective communication is an essential aspect of teamwork in cross-functional teams (Otter and Emmitt 2007; PMI, 2013b;). According to PMI's Pulse communications research, effective communication leads to more successful projects, allowing organizations to become high performers. Such organizations were found to be able to complete 80 percent of projects on time, on budget and meeting original goals. Moreover, effective communication enables the project team to clearly understand each other's views, intentions, to explicitly determine the rights, responsibilities and benefits, and to facilitate teamwork (Otter and Emmit 2007). Poor communication, on the other hand, may not only put project outcome at risk (Muszynska 2015; PMI, 2013b) but also impacts relationship building among team members.

4.3.1 Stakeholder Interaction

Most of the complex projects involve a large number of stakeholders (Müller and Turner 2007). Project stakeholder theory has been studied in previous research work since its introduction by Freeman (2010) in the first edition of his book, *strategic management*, published in 1984. The definition that is of interest to this study views project stakeholders as organizations or individuals who can somehow affect achievement of the project's objectives or are affected by the achievement of the project objectives (PMI 2017). Thus, stakeholders play an important role and ignoring them may lead to a project failure.

The need for a quick solution approach to problem solving within organizations has given rise to flatter organizational hierarchies, where problems can be solved by employee teams. This approach has proven to enhance organizational effectiveness. Accordingly, stakeholder interaction plays a critical role in achieving organizational effectiveness. In project-based organizations, project teams are built for the implementation of the project. As a result, a communication network or channel emerges, depending on the purpose and degree of centralization of a given team.

According to Ivancevich et al. (2014), two common team communication networks include the *Wheel (or Star) Net* and the *All-Channel Net*. While the earlier results in fewer errors with routine or less complex problems, it has a potential of lowering morale among team members. The latter is often used in teams requiring higher creativity and diverse perspective with team generally reporting higher morale and job satisfaction. In projects involving multiple stakeholders, the more realistic view of a communication process is that involving multiple communications channels occurring simultaneously (Richardson, 2010; Ivancevich et al. 2014).

4.3.2 Managing Collective Communication

Design teams are most effective as a collective bunch when all members use available communication media as agreed at the beginning of a project. However, managing collective communication can be a challenging task even for managers of design teams. First, the use of electronic tools for communication requires a certain set of skills. Second, the skills gap between participants of a project in using certain communication tools may impact operations and individual satisfaction.

PMI (2017), presents two important aspects of communication in a project. On the one hand, communication planning which attempts to integrate the communications requirements needed by the project stakeholders and technology utilized for communications. It involves answering questions such as – (1) Who needs what information? (2) When will they need it? (3) How will it be given to them and by whom? On the other hand, communication channels are another factor that must be managed collectively. This involves the connections between communicators in a project and the number of channels is proportional to number of stakeholders in a project. Thus, the greater the number of stakeholders in a project, the more channels and hence the more complex communication issues become (Daim et al. 2012).

Based on these aspects, the project manager should opt for written and formal communications methods. PMI (2017), outlines the content recommendations for this plan. This process starts with choosing a formal communication method for the selected stakeholder group. Some formal options include but are not limited to periodic status report, progress review meetings, kickoff meetings, formal presentations to various stakeholder groups, role responsibility and so forth. Once the stakeholders have been identified the next step requires discussions with them on what and how they wish to receive project communications. This documentation step would include specifics such as recipient, who is responsible for the delivery of the communication, what (output content of the communication), location (where the item would be stored prior to distribution), when (calendar delivery time), media (preferred media for delivery), focus (indication of the communication focus).

4.3.3 Recommended Communications Practices and Tools

The use of Information Technology (IT) tools by members of design teams has been growing in recent years. These tools allow to electronically generate, collect and update design information effectively. Effective design teams use a mix of synchronous and asynchronous communication (Otter and Emmitt 2007) to distribute generated design knowledge among design team members for progress of design (Otter, 2005). Otter and Emmitt (2007) defines synchronous communication as the use of face-to-face means like meetings and dialogues to communicate at the same place and time, as well as the use of electronic means of communication such as video conferencing and messenger services at different places at the same time. Conversely, asynchronous communication is the use of postal mail and paper delivery, as well as electronic means to communicate at different time and mostly at different places.

In the early design stages, synchronous, face-to-face communication in form of dialogues and team meetings is often used, especially when there is a need to reach consensus on the agenda. Asynchronous design team communication, on the other hand might be appropriate for effectiveness when overviewing, assimilating design information, exchanging and sharing information (Robert and Dennis 2005) with the purpose of avoiding miscommunication as well as design failures.

Thus, dialogues and team meetings are the most widely used form of synchronous communication. During the design process when detailed design discussions are conducted, participants commonly resort to dialogues. On the other hand, when there is a need to discuss and understand the interpretation of the object to be designed by the designer, reach consensus about the design (Robert and Dennis 2005) exchange knowledge and experience, review, plan and evaluate progress, participants resort to team meetings. Based on this, it is safe to conclude that synchronous communication is more effective for reaching consensus in a team than asynchronous communication (Otter and Emmitt, 2007).

Figure 11 below present a summary of means of communication with reference to their ease of use, feedback, interaction, overview, informal and formal nature and their status.

Means of communication	Ease of use	Feedback	Interaction	Overview	Informal	Formal	Status
Dialogue	x	X	X	-	x	x	x
Group meeting	-	X	x	x	-	x	x
Informal meeting	-	X	X	-	x	-	-
Telephone	X	X	X	-	x	x	x
Facsimile	x	-	-	-	-	x	X
Postal mail	-	-	-	-	-	X	X
Project dossier	x	-	-	x	-	X	x
Email message	X	X	x	-	x	x	-
Messenger service	X	X	X	-	x	-	-
Video conference	x	X	X	x	-	X	x
Outlook calendar	X	-	-	X	-	X	-
Computer network	x	-	-	-	-	x	-
Project Website	X	X	-	X	-	X	X

X = high level, x = average level, - = low level

Ease of use = the interface of the means with the user(s) is simple and easy
Feedback = direct feedback of the receiver to the sender
Interaction = immediate repeated feedback between sender and receiver
Overview = the information collected is complete and can be viewed in total
Informal = without restrictions or rules
Formal = with restrictions and rules to follow
Status = the status of stored information; new, updated, final

Figure 11. Properties of synchronous and asynchronous means of communication (Otter and Emmitt 2007).

As seen in Figure 11, some means of communication appear to be easy to use, allow a direct feedback mechanism, possible interaction and overview of information in a higher level than others. This provide options and a grading scale for the means of communication from high to low in terms of value to the design team. However, it is important to emphasize that this mapping is theorical but the significance of the highly rated means of communication has been reinforced by recent research works (Ivancevich et al. 2014).

Organizations employ different communication media within the organization among co-workers, and outside the organization, with customers and vendors. Communication media contrast in their information richness as shown in Figure 12. Otondo et al. (2008) associated media richness with communication effectiveness. The choice of medium does not only depend upon the richness of the medium and the equivocality of the task (Daft and Lengel 1986) but also on the complexity of the task (Sheer and Chen 2004).

Source: Adapted from Robert H. Lengel and Richard L. Daft, "The Selection of Communication Media as an Executive Skill," *Academy of Management Executive* 2, no. 3 (1988), pp. 225–32.

Media	Richness	Example	Benefit
Face-to-face	Very high	Ask supervisor for a raise.	Ability to adjust message according to real-time feedback.
Telephone conversation, video conference	High	Meeting with virtual group members.	Efficient, less costly, and less time-consuming than traveling to central location.
Memos, letters, faxes, personalized e-mail, voice mail	Low	Communicate a customer service policy to customer.	Efficient and cost-effective way to communicate routine information.
General e-mail, financial reports, flyers, bulletin boards, computer reports	Very low	Annual report to shareholders.	Standardized information for large audience.

Figure 12. Common communication media in the 21st century (Ivancevich et al. 2014).

As seen in Figure 12, face-to-face communication, telephone conversation and video conference are high in richness. All these forms of communication are in 'real-time' and allow on-the-spot feedback. In addition, it allows a considerable amount of information to be exchanged in the process. In contrast, e-mail is low in richness, especially when related to a general population (a department, an entire project team and so forth). The low richness of this type of communication is because feedback is not likely to occur (Ivancevich et al. 2014), information could easily get lost in the process and may not reach the recipient or may take time to reach the recipient.

4.4 Knowledge and Skills Emphasis

In a global competitive environment, organizations strive to differentiate themselves from others on the basis of skills, knowledge and motivation of their workforce. Improved capabilities, knowledge and skills of a workforce have proven to be a major source of competitive advantage (McKinsey 2006). In order to achieve this, organizations use training and development programs that are often designed and controlled by the human resources due to their financial impact. In this context, employee training refers to programs enabling workers acquire new information, skills or professional development opportunities (Elnaga and Imran 2013). Employee development on the other hand refers to activities that help acquire new knowledge or skills for the purposes of personal growth (Aguinis and Kraiger 2009).

Aguinis and Kraiger (2009) reviewed training and development literature since 2000 in their study *benefits of training and development for individuals and teams and organizations, and society*. As the basis of their study, they reviewed about 600 articles, books and chapters published in psychology, human resource management, instructional design, human resource management, human factors, and knowledge management. This study found that training related changes resulted in improved job performance. Other benefits of training included variables that are also directly related to performance such as innovation and tacit skills, adaptive expertise, technical skills, cross-cultural adjustment, and indirectly such as empowerment, communication, planning and task coordination in teams. These performance related benefits were all recorded at individual and team level.

Organizations spend billions in training every year (Aguinis and Kraiger 2009; Salas et al., 2012). However, only properly and well-designed training works (Salas et al. 2012). In addition to well-designed training, continuous learning and skill development are impactful and are a common practice in many organizations. Thus, well-designed training can enhance individual productivity and performance (Nikandrou et al. 2008; Salas et al. 2012). It is important to emphasize that training alone is not the only factor which employee performance is dependent on. Employee performance depends on other factors such as job satisfaction, knowledge, management. However, there is an interdependence between training and job performance (Aguinis and Kraiger 2009) and a direct link between training and productivity (Nikandrou et al. 2008).

The purpose of training should not only be regarded as enhancing individual skills or performance. Training can also be used to provide individuals with skills that can be applicable when working with other team members. The fast-growing pace of technological development and changes in work requirements present organizations with constant changes and challenges to provide their employees with the proper training as well as development programs. Effective training programs allow employees to equip themselves with the necessary knowledge, skills and abilities to achieve team and organizational goals (Elnaga and Imran 2013). More effective training is hence needed to help employees acquire new skills required due to new technological advancement, as well as to gain full skills and competencies required to perform a certain task or job that may improve the performance or effectiveness of a team.

Elnaga and Imran (2013) in their study on *the effect of training on employee performance* concluded that because one of the main purposes of every training is to add value to the performance of the employee, organizations should design training programs with clear goals while taking into account the particular needs of the individual and firm. They also found that training is required wherever there is a deficit in performance and will enable close the gap between actual and desired employee performance. Moreover, training plays an important role in elevating the competence of new as well as current employees.

Training in organizations can be done through formal and informal methods (Cooper and Robertson 2004). Formal methods take place through well-designed training and development activities, where the content and objectives are well-defined to the learner (Cooper and Robertson 2004). Unlike formal methods, informal training or learning activities are often unstructured (Borman et al. 2003) and most often initiated by employee themselves. This type of activities includes but are not limited to on-the-job learning experiences, self-managed learning and exchange of information aimed at improving knowledge and skills. Although most of the spending is often allocated to formal training and development methods by organizations, research demonstrates that most of the learning in organizations is achieved through informal methods (Borman et al. 2003; De Grip 2015). While informal training is more important to employee performance than formal learning (De Grip 2015) and knowledge sharing at the workplace enhance productivity, the skills acquire informally are often not evident to other employers. Moreover, the economic literature on informal learning remains underdeveloped.

On-the-job training is widely used in organizations and has proven effective for practical tasks. Employees with more on the job experience always tend to have a better performance due to increase skills and competencies at the job. This type of training, widely considered informal, requires an experienced employee or manager to serve as a mentor passing on new knowledge or specific skills to a new employee through instructions or demonstrations. The use of job experts as instructors, monitors or coaches, fewer expenditure for planning and design, and absence of a training cost makes this type of learning more beneficial (Borman et al. 2003) as compared to formal training.

In order to effectively capture mutual expectations of inputs and outputs of teams in projects, specific individual skills are required. The lack of specific technical skills or knowledge will lead to delays or errors in execution which often have an impact on cost and reputation of the organization. Therefore, it is important that the skill gap is closed through training, coaching and empowerment within teams. In order to achieve this both formal and informal learnings are important as has been demonstrated by this sub-section. In summary, training improves individual, team and organization performance and productivity as well as tacit, technical and strategic skills. The next sub-section describes some of the best practice on how to keep track of flaws in the process and ensure a continuous improvement.

4.5 Performance

Performance measurement of project-related activities has been widely researched in project management literature. Performance measures can be used for multiple purposes and different individuals, teams and organizations have different purposes. Although studies have attempted to isolate the purpose managers in specific industries have to measure performance, the main reason is to improve performance (Behn 2003). Other reasons for using performance measurements include but not limited to evaluating, controlling, budgeting, motivating, promoting, and learning, and are often aimed at achieving the ultimate purpose which is to improve performance.

Despite the multidimensional nature of project and its performance (Shenhar et al. 2001), project evaluation still widely revolves around cost or budget and schedule as the principal ways of evaluating performance in organizations (Shenhar et al. 2001; Hughes et al. 2004; PMI 2017). In the previous sub-sections, it has been demonstrated that an overwhelming majority of researches support the hypothesis that to ensure project success, project managers should initially identify all individuals or group that have the potential to affect the work in progress. These individuals or groups have been identified as stakeholders.

While cost and schedule provide objective metrics to measure performance or project success, other aspects of a project that might be subjective but have an important impact on perceptions of project success (Hughes et al. 2004), including stakeholder satisfaction. Stakeholder satisfaction is a leading indicator of use and adoption. It is considered as a pre-project fulfillment of stakeholders in the actual performance which are measured at different project stages (Oppong et al. 2017). Stakeholder satisfaction has also been identified as a key success factor by Pinto and Slevin (1987), Fortune and White (2006), Davis (2014) and other researchers. Moreover, stakeholder satisfaction also emerged as one of the most perceived success dimensions among different stakeholder groups in Davis (2014). Therefore, if teams and organizations neglect the importance of stakeholder expectations, they risk not meeting a very important success criterion.

The most cited instruments in literature to assess project success is a quantitative survey diagnostic behavioral instrument by Pinto and Slevin (1987). Davis (2016) created an adapted method by using the project success dimensions from Pinto and Slevin’s (1987) instrument formed interview questions to investigate perceptions of project success. Hughes et al. (2004) demonstrates the value of a project success assessment instrument that focuses on attributes outside the traditional objective metrics of cost and schedule. This instrument is also based on a survey and may be helpful to engineering managers to identify important success metrics before the start of a project as well as evaluate the level of success achieved once the project is complete.

Therefore, some best practices of method used in measuring stakeholder satisfaction include stakeholder satisfaction surveys, interviews and focus groups. Interviews allow to gather feedback from individuals who can impact a process or project. This method should be used to gather both negative and positive input in a controlled environment. On-to-one interview is also efficient to gather information that cannot otherwise be obtained in a public setting during open group meetings.

In conclusion, the most appropriate criteria for a project success are its objectives. The degree to which the objectives of a project are met will determine its success or failure. Therefore, when measuring the success of a project, the objectives of all stakeholders should be considered throughout the life cycle of the project and that includes assessing stakeholder satisfaction with pre-defined measurements methods. However, it is better to have a key measure that can be monitored and important to ensure that the measurement system is focused on continuous improvements.

4.6 Conceptual Framework of This Thesis

During the current state analysis, carried out in Section 3 of this thesis, of mutual inputs and outputs exchange practices between the SCSA and Piping design teams throughout the course of a piping flexibility analysis process, weaknesses emerged that could not be classified under one single topic. Issues were revealed that relate to gathering and delivering of inputs, skill gap and a perceived lack of cooperation between the teams involved. Consequently, the framework shown below in Figure 13 was established and consists of different dimensions such as determining project requirements (Burek 2008; PMI 2017), effective communication management (Otter and Emmitt 2007), knowledge and skill emphasis (Aguinis and Kraiger 2009) as well as other supporting elements.

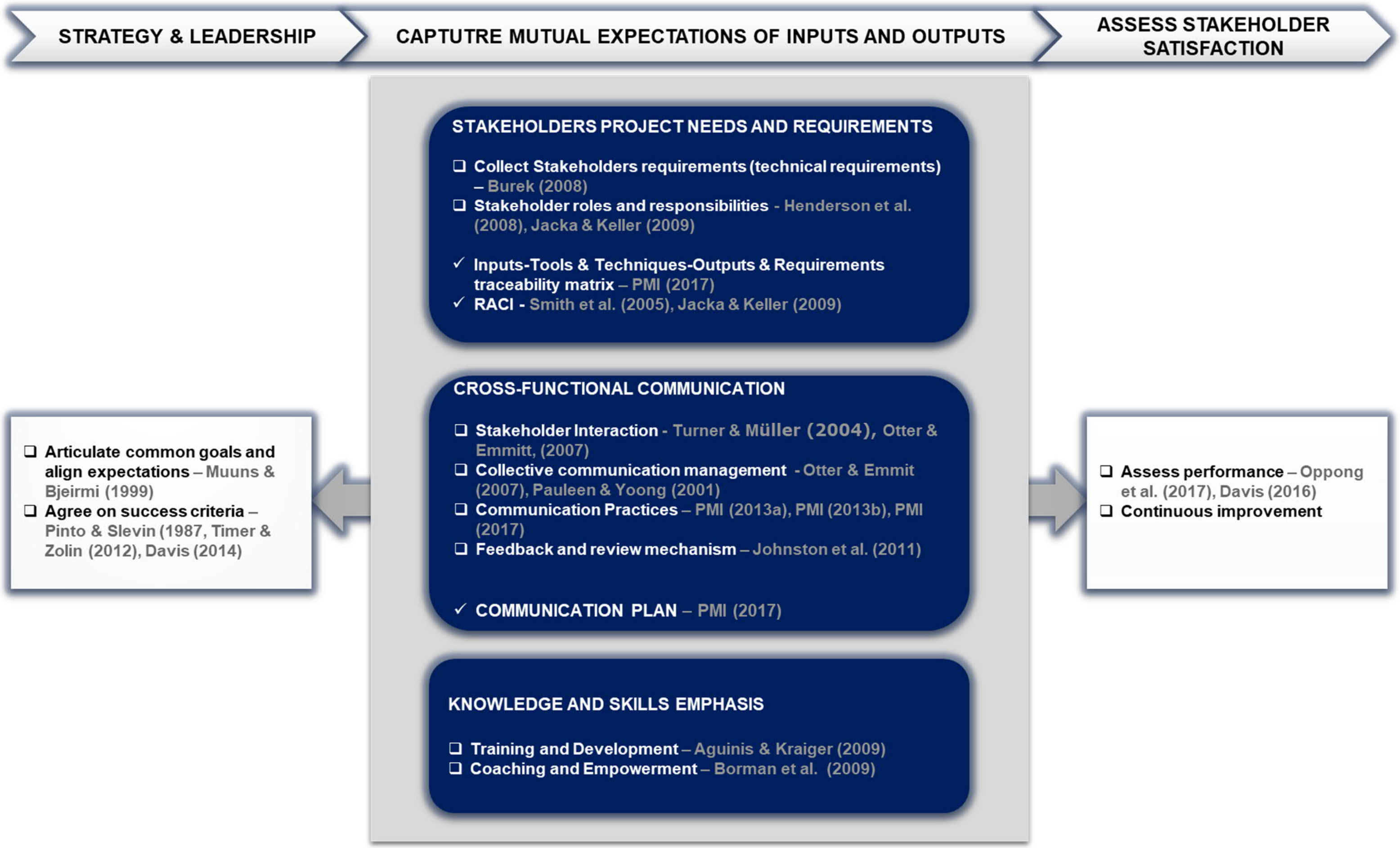

Figure 13. Conceptual framework for enabling capture of mutual expectations of inputs and outputs.

As seen in Figure 13, the conceptual framework is divided into three components: a core and two supporting components. The core component itself is divided into three elements that are directly related to the objective of this thesis and enabled finding best practices in relevant literature that provide solutions to the weaknesses selected for development in Section 3 of this thesis. This major component starts with best practices in capturing stakeholder needs and requirements which provided strategies and tools to finding solutions to difficulties in gathering flexibility analysis inputs by the piping design team as well as their late provision to the SCSA team. Then, cross-functional communication which includes stakeholder interaction, best communication practices and tools enabled establishing best practices in improving cooperation and as a result provide the basis to effectively capture not only inputs but outputs during the analysing phase of the flexibility analysis. Finally, the third element includes knowledge and skill emphasis focused on training and development practices. This element was aimed at tackling skill gap related issues between individuals and enabled finding best practices to help close the gap.

The first supporting component of the conceptual framework consists of strategy and leadership and involves articulating common goals and agreeing on success criteria. This component is not directly linked to the objective of this thesis but is required in interaction of teams. Cross-functional teamwork requires drivers or enablers in order to advance collective decisions making (Munns and Bjeirmi 1996). Therefore, assessing success and defining success criteria is crucial in the process, hence its inclusion.

The second supporting component involves performance assessment and is focused on specific dimension such as assessing stakeholder satisfaction, a measurement that is inclusive and allows continuous improvements.

This Section has developed the idea that capturing stakeholder mutual expectations of inputs and outputs in projects is directly related to how teams are collectively managed. Best practices of ensuring a successful project through capturing of inputs and outputs include the importance of gathering stakeholder needs and requirements, defining roles and responsibilities, communication planning, employee empowerment and training as well as ensuring top management commitment, assessing stakeholder satisfaction and ensuring continuous improvements.

This completes the literature review which generated best practices, strategies and tools for capturing project inputs and outputs based on weaknesses selected for development in Section 3 of this thesis. The next section focuses on building an initial proposal of a concept on capturing mutual expectations of inputs and outputs between the SCSA and

Piping Design teams throughout the course of the flexibility analysis process in projects. The outcome of the next section is an initial proposal of the concept.

5 Building Proposal of a Concept for Capturing Mutual Expectations of Inputs and Outputs for the Case Company

This section merges the results of the current state analysis and the conceptual framework towards the building of the proposal using Data 2. A brief description of the CSA and CF stages is first given as background. An overview of the proposal building stage is first presented followed by a systematic step-by-step description on how the proposal building was conducted.

In Section 3, the current state analysis of mutual expectations of inputs and outputs between the SCSA and Piping Design teams in the course of piping flexibility analysis during plant design projects revealed several strengths and weaknesses. The availability of state-of-the-art tools provided by the case company, a competent group of engineers capable of solving complex tasks, availability of an effective follow-up approach and report template emerged among the strengths during the CSA. On the other hand, weaknesses were found, and the main weakness was the absence of a single standardized concept for capturing mutual expectations of inputs and outputs between the SCSA and Piping Design teams. Other weaknesses included a perceived lack of cooperation between both teams, difficulties of gathering inputs at the initiation phase of the flexibility analysis process by the Piping Design team, provision of inputs often too late to the SCSA team, an effective follow-up approach often neglected and final reports sometimes perceived as too cumbersome.

Existing literature was searched in Section 4 of this thesis for finding solutions to the four key weaknesses identified in the CSA. These weaknesses emerged from different stages of the flexibility analysis process as well as from different aspects of the inputs and outputs exchange practices. As a result, a conceptual framework tackling different dimensions of the process was created while still focusing on enabling capture of mutual expectations of inputs and outputs between the teams.

In order to address the issue related to difficulties in gathering inputs at the initiation phase by the Piping Design team, a literature review on capturing stakeholder needs and requirements in projects was conducted. As a result of this review, tools and techniques that are helpful in establishing a requirements documentation and a requirement traceability matrix emerged. Next, a review on cross-functional communication helped understand the challenges in cross-functional teams to establish effective cooperation practices. This review enabled establishing best practices on how to enhance effective communication practices, manage collective communication and select the appropriate media based on task, project set-up and project implementation phase. This review was aimed at addressing the perceived lack of cooperation issue, lack of commitment in utilizing an effective follow-up approach and as a result solidify the capture of mutual expectations of inputs and outputs. Then, the importance of training and development was reviewed to address knowledge and skills emphasis. This was aimed at addressing a skill gap within teams in not only exploiting certain capabilities to provide solutions but also in helping newly hired acquire certain skills. Different training and development methods emerged including formal through well-designed training and informal through on-the-job learning by coaching, empowering and mentoring. Finally, project success factors were reviewed as a supportive argument to why stakeholder perception matters in defining project success criteria. These supporting elements were aimed at addressing leadership and assessing performance in order to strive for continuous improvement now and beyond this thesis.

5.1 Overview of the Proposal Building Stage

The proposal building for a concept enabling capture of mutual expectations of inputs and outputs between SCSA and Piping Design teams was conducted methodically. First, several relevant stakeholders were involved through a workshop and one-to-one skype or email interviews. This approach allowed capturing different viewpoints, ensured a co-creation effort and resulted to suggestions for the proposal which are discussed in detail in sub-Section 5.2. Second, suggestions were categorized according to key focused areas from the current state analysis and conceptual framework of Section 3 and 4 respectively. Finally, suggestions were then prioritized based on their frequency of occurrence in interviews as well as their relevancy to the objective of this thesis, thereby allowing the proposal building to be not only unbiased but based on a co-creation effort.

The methods used in generating data for the proposal building stage have been presented in Section 2 of this thesis. These methods included in-depth one-to-one interviews of relevant stakeholders. In addition to interviews, a workshop was conducted to create a flexibility analysis checklist which emerged as an important document and is the output of a flexibility analysis requirements collection process. Table 4 shows the participants of the one-to-one interviews, interview type, job title of participants, topic discussed and date of interviews.

Table 4. Details of interviews and discussions in Data 2.

Participants	Data type	Title	Topic	Date
Data 2: Initial Proposal Building (Interviews)				
Respondent 7	Performance review one-on-one meeting	Line Manager	Proposal Building from **Piping Design Team** perspective	11.3.2020
Respondent 8	Skype Interview	Lead Project Engineer	Proposal Building from **Piping Design team** perspective	30.3.2020
Respondent 9	Skype interview	Senior Project Engineer	Proposal Building from **Piping Design Team** perspective	2.4.2020
Respondent 10	Skype interview	Lead stress Engineer	Proposal Building from **SCSA Team** perspective	6.4.2020
Respondent 11	Email interview	Chief Piping Design Engineer	Proposal Building from **Piping Design Team** perspective	7.4.2020
Respondent 12	Skype interview	Senior Mechanical Engineer	Proposal Building from **SCSA Team** perspective	8.4.2020
Respondent 13	Skype interview	Senior Stress Analysis Engineer	Proposal Building from **SCSA Team** perspective	9.4.2020
Respondent 14	Skype interview	Senior Stress Analysis Engineer	Proposal Building from **SCSA Team** perspective	14.4.2020

As seen in Table 4, participants of the data collection (Data 2) for the proposal building differed slightly from those of the CSA. However, this stage also relied on input from key stakeholders and considered a wider range of viewpoints.

In order to make sure the overall proposal building was a co-created effort; a systematic approach was utilised to conduct the interviews and analysed the information obtained. First, the results of the findings of the CSA were presented to every participant prior to the interview in order to help the participants familiarize themselves with the results of the CSA and questions, as well as give them time to think over the suggestions, and if necessary provide them in writing. Second, questions were categorized into the CSA focus areas with emphasis on key elements of the conceptual framework. Third, follow-up questions were asked for clarification or elaboration thereby giving participants enough flexibility to elaborate, explain and give examples as well as avoid misinterpretation. Finally, suggestions were categorized into groups due to an apparent consensus among stakeholders on the direction and content of the solutions.

5.2 Findings of Proposal Building Data Collection Stage, Data 2

The proposal building stage was very fruitful. A number of useful suggestions were made by stakeholders on how to improve the weaknesses from the CSA while focusing on key areas from the CSA and CF. Suggestions that emerged are presented in Table 5 below and represent the core of the proposal building of this thesis.

Table 5. Key stakeholder suggestions for proposal building (Data 2) in relation to findings from CSA (Data 1) and the key elements CF.

	Key focus area from CS (from Data 1) *or/and the element of CF*	*Suggestions from stakeholders, categorized into groups (Data 2)*	*Description of the suggestion*
1	Major Challenges with gathering all necessary inputs by the Piping Design Team	a) Develop a requirement document in the form of inputs checklist b) Include a requirement traceability matrix c) Define roles and responsibilities at the initiation stage	The Senior Project Engineer, Respondent 9 of the Piping Design team suggested to prioritize process data requiring flexibility analysis and providing them at the early stage. He argued that the checklist was good as a tool that not only gives all the necessary requirements to carry out piping flexibility analysis but will also be a good initiating tool for the newly recruited younger Designers.
2	Provision of information often too late to the SCSA Team	a) Involve stakeholders early on b) Schedule flexibility analysis early and initiate cooperation between lead Engineers from both teams c) Define roles and responsibilities	The Lead Project Engineer, Respondent 8 of the Piping Design team suggested the Lead Piping Design Engineer, in collaboration with the Lead Stress Analysis Engineer, schedule flexibility analysis at the early stage of the project. In case there is not information available at the early stage, agree on preliminary data based on previous projects, for example.
3	Follow-up list often neglected despite its potential as a good communication tool	a) Make the Follow-up list a benchmark and communicate its importance b) Assign as responsibility to the Lead Stress Analysis Engineer	The Line Manager, Respondent 7 of the SCSA team suggested to make the Flexibility Analysis follow-up list the benchmark of the follow-up process; and suggested applying the approach to all future projects unless otherwise recommended.

		c) Communicate its importance to the Piping Design Team and to achieving process success	
4	Exchange of information not done through technical database	a) Redefine information sharing rules b) Communicate it to relevant stakeholders	Both teams suggested to redefine information sharing rules by aligning information sharing to the Process Industries Division strategy.
5	Perceived lack of cooperation between SCSA and Piping Design Teams	a) Schedule meetings between both teams b) Promote cooperation c) Use the most effective communication tools (face-to-face meetings, skype/teams calls) and emails as a second option d) Provide the necessary feedback and including critical	Members from both teams suggested to improve cooperation through meetings (kick-off and follow-up meetings), effective use of communication tools, building interpersonal relationships and networks during projects as well as embracing the concept of **"us"** toward team success rather than **"us and them".**
6	Stress Analysis Engineer not using 3D view model to provide solution	a) Close the skill gap by learning and coaching b) Plan formal training in performance review meetings and	The Line Manager, Respondent 7 suggested to close the skills gap through personal initiative by bringing forward any trainings that are required in our respective jobs; and suggested that the every person should be made responsible and feel empower to coach or monitor any other colleague who is willing to learn.

As seen in Table 5, the suggestions were made in relation to key CSA focus with emphasis to elements of the conceptual framework. Suggestions from stakeholders were then categorized into groups and a description of each suggestion is presented separately in another column of the table. These descriptions were either from one or a group of respondents whose suggestion was explicit and covered a wider range of the key focus area. The suggestions are discussed below in detail.

5.3 Flexibility Analysis Inputs Checklist

The different challenges related to gathering inputs by the Piping Design team at the initiation phase of the inputs and outputs exchange practices emerged as one of the major weaknesses during the CSA in Section 3 of this thesis. During the literature review in Section 4, the importance of involving key stakeholders at the early stage of a project in order to effectively capture stakeholder needs and requirements was established. In addition, important tools and techniques emerged from this review. This resulted to a key element of the CF which became a focus area during the second data collection stage (Data 2) of this thesis.

This thesis focuses on technical requirements in the form of inputs and outputs generated for and from piping flexibility analysis during an intense exchange process between the SCSA and Piping design teams. The workshop conducted in 2018 and described in Section 2 of this thesis resulted in a list of inputs and outputs for the flexibility analysis. However, this list fell short in its application and importance to the SCSA and Piping Design teams. Consequently, the need for a document that could be beneficial to both experienced and any newly hired engineers was raised. There was a clear consensus among Respondents from the Piping Design team on the need for a flexibility analysis requirements document. This document is particularly beneficial to the Piping Designer as it lists all the inputs that are required for a flexibility analysis. According to one of the Lead Project Engineers:

> *A flexibility analysis requirements document is a good idea. It is not enough that an input file is generated from a 3D program. Weights of valves and other components must be known. Moreover, young designers may not have the information that they need and with a flexibility analysis requirement document all stakeholders/participants can be sure flexibility analysis inputs is provided accordingly. (Respondent 8)*

Respondent 9 agreed that a list providing all necessary flexibility analysis documents is useful. According to Respondent 9, process data for piping requiring a flexibility analysis must be prioritized at the beginning of the piping design phase and this information must be frozen without further changes until the end of the project. The flexibility analysis requirements document was attributed the name “checklist” which is already a well-established expression within the Mechanical and Piping Department of the case company. The availability of a checklist will help improve the process of gathering inputs. First, the checklist allows everyone involved in a project understand the importance of the inputs data for a flexibility analysis process. Second, it provides information on the type of inputs, its source and owner thereby enabling its traceability especially for newly hired or young Design Engineers. Finally, it will help establish a benchmark for the process of the gathering inputs. Respondent 7, the SCSA line manager agreed to communicate importance of the checklist together with other elements of the concept to all stakeholders and prioritize its application.

Previous attempts to create a checklist have not materialized. While a version of a checklist exists in the SCSA team database, the list falls short to capture explicitly flexibility analysis inputs and their traceability. Moreover, its availability is not known by those who need it most, i.e. the Piping Design team and its Engineers. Respondent 14 eloquently pointed out as follows:

> *The new checklist does not only provide a solution but also a tool that could be useful immediately as well as shared or printed. (Respondent 14)*

The reason behind the late provision of inputs to the SCSA team was also found to be associated to the difficulty in gathering inputs as well as the lack of involvement of all stakeholders at the early stage of projects. This element will be discussed in detail in the next sub-section when presenting the second element of the initial proposal building.

In order to create an effective flexibility analysis inputs checklist, the inputs, tools & techniques, outputs tool mentioned in Section 4 of this thesis was used. Figure 14 shows a flow chart of the process that was used to establish a flexibility analysis requirements or inputs checklist.

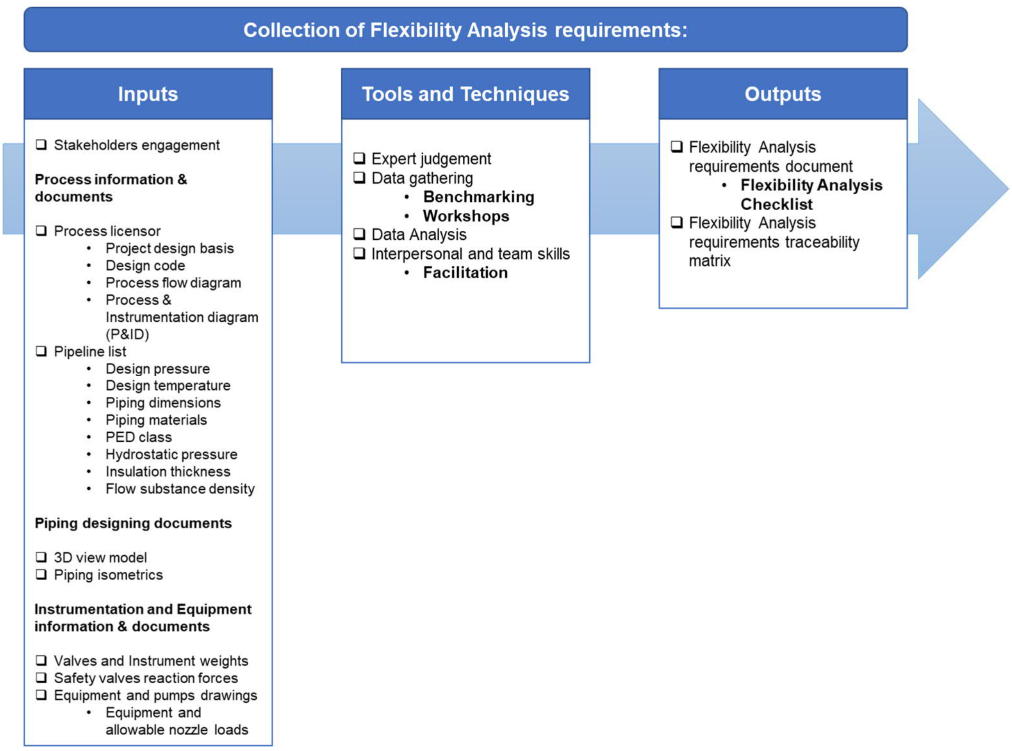

Figure 14. Collection of Flexibility Analysis Requirements.

As seen in Figure 14, inputs of the process consisted of stakeholder engagement, Process information and documents, Piping designing documents, instrumentation, equipment information and documents. All this information is required and must be made available at the early stage of any project involving critical pipelines requiring a flexibility analysis check. Almost every respondent who has been directly involved in gathering this sets of inputs agreed that it is not an easy process but argued in favour of a checklist to improve the process. Tools and techniques used in this process included expert judgment, data gathering techniques such as benchmarking and workshop, data analysis and team skills. These tools and techniques led to the outputs of this process as shown in Figure 14 and allowed to establish a preliminary version of the checklist presented in Appendix 1 of this thesis. The checklist consists of all necessary inputs required to perform a piping flexibility analysis. It also includes phases of the process, owners of inputs, the type of documents or files. In addition, it allows the user to use it to check in boxes as a reminder of inputs that have been delivered and those that are still missing as well as a date when the input was delivered. Appendix 2 on the other hand presents the tools, techniques and activities connecting inputs and outputs of the flexibility analysis process.

5.4 Clearly Define Roles and Responsibilities

The provision of information often too late to the SCSA team to initiate a flexibility analysis of critical piping emerged as a weakness during the CSA in Section 3 of this thesis. This issue was often link to lack of effective communication in the literature review in Section 4 of this thesis as well as to not involving stakeholders in the early stage of project implementation process. Stakeholder interviews while collecting Data 2 of this thesis confirmed the interconnection between poor communication, not involving stakeholders and late provision of flexibility analysis inputs.

The CSA analysis revealed one major weakness in the provision of inputs to the SCSA team often delayed. This major weakness was compensated by strengths in the process such as the availability of state-of-the art tools and experienced employees who can provide quick solutions under immense pressure. Despite this important advantage in the process, respondents argued that a better approach is still needed, as see below.

> *We cannot solve flaws in the process with effective tools and talent alone. Being able to work under immense pressure may be beneficial but not a sustainable advantage for the flexibility analysis process. (Respondent 12)*

Respondent 12 argued that although building from the strengths of the inputs and outputs exchange practices should be the core of improvements, the focus must be on minimizing the delays in initiating the flexibility analysis process. According to Respondents 8, 9, 10 and 12, solutions to the late provision of information to the SCSA team must start with a well-presented flexibility analysis checklist, followed by involvement of stakeholders at the early stage of the project that include critical piping requiring a flexibility analysis.

When asked what should be done to avoid the delay of the flexibility analysis process, Respondent 8 suggested that the Lead Piping Design Engineer must schedule flexibility analysis of critical piping at the early stage. In addition, it is important that the SCSA team request for critical piping through their Lead Engineer. However, as the CSA and proposal building interviews revealed, this process lacks an effective communication scheme that involves all stakeholders at the early stage of the project implementation process. Respondent 9 explained that in order to prepare the correct information for flexibility analysis, the Piping Design team need information from the process team regarding piping size, pressure class, material type, insulation type and thicknesses, valves and instruments weights and lengths. Most often guessing based on previous projects has been the solution when this information is unclear or still open for discussion at the early stage of the project. According to most respondents from the Piping Design team, using assumptions based on previous projects is often not enough. However, the SCSA team argued that it is better to initiate the process based on assumptive information rather than delay the process because starting the process from scratch is more time consuming than correcting existing flexibility analysis models. Despite this slight disagreement, both teams agreed on a set of solutions that could help minimize the delay and improve effectiveness of the process.

This stage of the process must involve clearly defining roles and responsibilities. Role clarity is important at the early stage so that all participants are aware of who oversees a task, whom to contact if information is needed, who has a veto or approval power and so forth. This also marks the beginning of clear communication scheme that is presented in detail in the next sub-section. Therefore, in order to minimize the delay of inputs to the SCSA team, well-defined cooperation scheme must be established that involves role clarity, involvement of stakeholders as well as effective communication. It may seem out of context to associate delay of information to role clarity, involvement of stakeholders and effective communication. However, this connection is not only supported by Section 4 of this thesis but one of our Chief design Engineers passionately emphasized the following:

The success of our inputs and outputs exchange practices depends on team effort. This consists of how we think as a team, how we interact during projects, how aware we are of each other's responsibilities, how familiar we are with our processes and how effectively we communicate our needs, inputs and outputs. (Respondent 11)

Role clarity not only helps avoid disputes over ownership of tasks or decision making but also plays a critical role on project satisfaction and performance on individual members at different stages of a project implementation. In order to define roles and responsibility the proposal building stage of this thesis relied on the RACI matrix which has been explicitly presented in the literature review (Section 4) of this thesis. The letters of the R.A.C.I. abbreviation stands for Responsible, Accountable, Consulted and Informed. Although the meaning of these expressions have been presented in detail in Section 4 of this thesis, it is important to briefly introduce each letter of the RACI matrix: Responsible implies the doer of the task; Accountable refers to who is responsible for the correct completion of the task (Owner of the work); Consulted refers to individual or groups that should be consulted before final decision or action (Give input and may also provide resources); Informed refers to the individual or group that should be informed while the activity is occurring or afterward. Figure 15 shows a simplified RACI matrix in a typical flexibility analysis process from a small-scale project.

R = Responsible – The Doers

A = Accountable – Owner of the Work

C = Consulted – Give input/provide resources

I = Informed – Require Updates/Progress

	Project Manager	Line Manager (SCSA team)	Lead Stress Engineer	Lead Piping Design Engineer	Stress Analysis Engineer 1	Piping Design Engineer 1	Equipment Manufacturer	Line Manager (Piping Design team)
Gather Flexibility Analysis INPUTS	C			R/A		R		
Create a Flexibility Analysis Follow-Up list			R					
Agree on Technical Database			R	R				
Organize process into calculation packages			R					
Create calculation models (.mod files)			R		R			
Provide solutions and Flexibility Analysis OUTPUTS	C	I	R/A		R			
Check Equipment loads	A		I					R
Prepare Flexibility Analysis Reports			R		R			
Check flexibility Analysis Reports			R		R			
Approve Flexibility Analysis report	I	R						

Figure 15. Roles and responsibilities matrix of a small-scale project.

As seen in Figure 15, the RACI matrix can be created and adjusted depending on the scale of the project and the number of stakeholders involved. However, it is important to involve stakeholders when defining roles and responsibilities to avoid disputes over roles and ownership of tasks. The RACI matrix includes tasks of the flexibility analysis process presented in the CSA (Section 3) of this thesis but can also include individual inputs since ownership of inputs is spread all over the Piping and Mechanical Engineering department.

As depicted by Figure 15, it is important that key stakeholders are involved, and their roles clarified. When asked the most noticeable aspect of the RACI matrix, most Respondents agreed that it was a simple tool and a quick overview of the properties of the matrix made it easy to follow. However, everyone agreed that roles and responsibilities most be discussed in a formal setting such as a kick-off meeting to avoid misunderstanding.

5.5 Effective Communication Practices

The previous two elements of the proposal building stage focused on gathering inputs, involving stakeholders and defining roles and responsibilities. Other weaknesses that emerged from the CSA were linked to either not effectively using available tools or resources such as the flexibility analysis follow-up approach and technical databases for exchange of information or a perceived lack of cooperation between the SCSA and Piping Design teams. When conducting a literature review in Section 4 aimed at finding best practices in relevant literature, it emerged that lack of effective communication was at the helm of these issues. The second set of data collection (Data 2) of this thesis confirmed that stakeholders perceived the weaknesses of the inputs and outputs exchange practices as directly or indirectly related to lack of effective communication practices.

Tools already presented earlier such as the flexibility analysis checklist, role and responsibility (RACI) matrix are themselves considered interaction tools. These tools provide information to different stakeholders and establishes a link of communication. While these tools are not a direct solution to lack of effective communication practices, the flexibility analysis follow-up list provide a basis for exchange of information throughout the flexibility analysis process from the modelling phase until the reporting phase.

5.5.1 Flexibility Analysis Follow-up List

A flexibility analysis follow-up approach has proven to be effective in previous projects when effectively applied. Therefore, many in the case company and among respondents of Data 2 are familiar with this approach. The flexibility analysis follow-up approach is based on a flexibility analysis follow-up list which is often created from the pipeline list. This list establishes a platform of communication between the Stress Analysis Engineers and Piping Designers. Respondent 9 stated the following:

> *In my opinion, a follow-up list together with a P&I diagram and pipeline list are the most important documents for Piping Designers. In many projects, it has been possible for many disciplines (Process, Piping Design, Instrumentation and Stress Analysis) to use this type of list. It is the only efficient way to allow information from all stakeholders. Hopefully this approach can be standardized. (Respondent 9)*

Respondents 8 and 13 agreed that a follow-up list is a good idea even though they have never used list before. According to Respondent 8, designating a Designer can be an extra boost to the job. However, time may be wasted if the Designer cannot easily follow-up previous work or understand at what stage the flexibility analysis process is. A follow-up list gives the newly designated Designer a platform to work with, in addition to a face-to-face introduction to the project.

In an ongoing project where the follow-up approach is being effectively used, the approach has received a lot of positive feedback, including from a Piping Design team of the case company that is based in China. Respondent 7 suggested that this approach become the benchmark for monitoring the progress of the flexibility analysis process, and there seems to be a clear consensus among stakeholders when it comes to the flexibility analysis follow-up list. Figure 16 shows a version of the flexibility analysis follow-up that was created and used in a local project in Finland.

	A	B	C	D	E	G	H	J	K	M	N	P	S	V	W	AB	AC	AD	AE	AF	AG
1	NEW / OLD	Line ID	Flow substance	Flow substance descr.	Pipe class	Chemical class	Insp. class	Temperature	Temperature (Des)	Pressure	Pressure (Des)	Line DN	PI-diagr. nr	Content density	Test pressure	To be analysed	Stress report package	Stress report number	Designer	Delivered for calculation	Calculation satatus: M=modeled, A=analyzed, R=reported
2																					
3	NEW	212062-1120	GMA4	MAAKAASU	E25C1B	G1	I	20	(60)	4	(4,8)	100	10000040248	0.1	6,9 barg	Y	1		JXS		
4	NEW	212062-1121	GMA4	MAAKAASU	E25C1B	G1	II	60	(75)	4	(18)	100	10000040248	0.1	25,7 barg	Y	1		JXS		
5	NEW	212062-1122	GFA	HAPAN KAASU	N25C1D	G1	II	60	(155)	4	(18)	100	10000040248	0.1	26,1 barg	Y	1		JXS		
6	NEW	212062-1123	GFA	HAPAN KAASU	N25C1D	G1	II	60	(150)	4	(18)	100	10000040248,10000040385	0.1	25,9 barg	Y	1		JXS		
7	NEW	212062-1124	GFA	HAPAN KAASU	N25C1D	G1	I	60	(155)	4	(18)	50	10000040248,10000040311	0.1	26,1 barg	Y	1		JXS		
8	NEW	212062-1125	GMA4	MAAKAASU	E25C1B	G1	I	20	(60)	4	(4,8)	50	10000040248	0.1	6,9 barg	Y	1		JXS	13/06/2017	
9	NEW	212062-1126	GRP	HÖNKÄ SOIHDULLE	16C1E	G1	I	60	(400)	0.4	(3,5)	50	10000040248	0.8	8,4 barg	Y	1		JXS	13/06/2017	
14	NEW	645562-0300	GFA	HAPAN KAASU	N25C1D	G1	II	60	(155)	4	(18)	100	10000040294,10000040248	0.1	26,1 barg	Y	1		JXS		
15	NEW	645562-0326	GFA	HAPAN KAASU	N25C1D	G1	II	60	(155)	4	(18)	80	10000040294	0.1	26,1 barg	Y	1		JXS	13/06/2017	
16	NEW	645562-0327	GRP	HÖNKÄ SOIHDULLE	16C1E	G1	I	60	(400)	0.4	(3,5)	80	10000040294	0.8	8,4 barg	Y	1		JXS	13/06/2017	
18	NEW	645562-0328	GFA	HAPAN KAASU	N25C1D	G1	II	60	(155)	4	(18)	100	10000040294	0.1	26,1 barg	Y	1		JXS	13/06/2017	

Figure 16. Flexibility Analysis follow-up list - Simplified version (Source: Case company).

As seen in Figure 16 the list has been created from the pipeline list which is an input document for the flexibility analysis process. In order to create a follow-up list, a few columns are added to an existing pipeline list and in Figure 16 added columns are highlighted in green. This version of the list is a more simplified version because it was created for follow-up between one Stress Analysis Engineer and one Piping Designer. Therefore, it is important to emphasize that this was a small-scale project. In projects involving more stakeholders, it was suggested to add extra columns such as a comment section which allows to leave a detailed description of the state of the flexibility analysis. This could include issues causing a delay, missing information or a detailed explanation of the status of the calculation.

The Stress Analysis Engineer is responsible to update or revise the list based on an agreed schedule which can be daily or weekly. Other stakeholders then check the status of the flexibility analysis process and in return provides missing information or stay updated without having to contact the Stress Analysis Engineer. It also provides information on the Piping Designer or Stress Analysis Engineer of each critical pipeline, thereby helping to further clarify roles and knowing whom to contact if needed. However, it is important to reiterate that stakeholders are not dependent solely on this approach for updates or as the only communication tool. This is one of many communication tools used but its efficiency has been proven in practice and everyone agrees its application should by all.

5.5.2 Selection of a Technical Database

A flexibility analysis follow-up list is not useful if it is stored in a location that is only accessible by its creator. Other stakeholders must and should be able to easily access the list and edit it without altering any important aspect of the list. This give rise to the need and importance of a technical database. A technical database is not only critical to the flexibility analysis follow-up list but for sharing flexibility analysis inputs and outputs. Moreover, it helps keep track of all-important documents, involving piping flexibility analysis, shared throughout the life cycle of the project. The use of such databases was also highlighted in the IBG internal strategy document used in the first the data collection stage (Data 1) of this thesis, thereby aligning the choice of communication tools to the case company strategy.

During the CSA, a perceived lack of cooperation between the SCSA and Piping Design teams was associated to many shortcomings of the inputs and outputs exchange practices. One of the shortcomings was not often utilizing available technical databases. When asked why the use of a technical database was so critical to the process, one of the Chief Design Engineers replied as follows:

> *I believe this is a key point to improving cooperation. A well-defined database agreed at the beginning of the flexibility analysis process will save time and avoid unnecessary errors or misunderstanding. (Respondent 11)*

The use of databases has been a common practice within the case company during projects implementation. The absence of strict database rules or a well-defined strategy has often led to the use of personal work computers to safe documents. However, advancement in technology and the case company internal strategy has given rise to more innovative ways of exchanging information. Both teams agreed to the use of technical databases for exchange of information but suggested making the rules clear to all stakeholders. During interviews it emerged that many are already transferring to the use of technical databases because of their simplicity.

Nowadays, data can easily be synchronized from a source such as a personal storage disc to a target data storage location such as a technical database (cloud storage) and vice versa. This way individual could still be able to use their local storage and then automatically back up data to the cloud or a technical database. However, it would require some basic training which is available and free within the case company. According to respondent 14, it is more beneficial personally and as a team to rely on technical data base. First, it is effective because it is not only a way of sharing documents and data, but it allows information to be saved for future use. Second, information in technical databases is often easily accessible and will eliminate waste related to the slow process of exchanging vital information through emails. Finally, it provides and unlimited amount of storage space which is often needed to run huge flexibility analysis calculations or to save calculation and 3D view files.

5.5.3 Preferred Communication Media, Meetings and Frequency

Effective communication cannot be complete without a selection of means of communication that are effective and up to date. A perceived lack of cooperation between the SCSA and Piping Design teams emerged as a major weakness during the CSA in section 3 of this thesis. This weakness was associated to various factors including the way both teams interact during projects. In Section 4, a literature review provided best practices on how to improve stakeholder interaction in cross-functional teams. It emerged that interaction between individuals in cross-cultural teams can be improved through effective communication management which involves a selection of effective means of communication among other things. Based on this information, questions were asked to relevant stakeholders and solutions provided accordingly.

When asked directly what should be done to improve cooperation between both teams, Respondents 8, 9, 11 and 14 insisted on both teams meeting with the goal of refocusing on “us” rather than “us and them” approach. When asked to explain further, they all argued that both teams have struggled to solve disagreements in the past. The perception has been that everyone is looking in their own direction when the goal should be looking in the same direction. One of the Chief Designers eloquently stated the following:

> *The goal should be for everyone to think ‘our team’. The approach of feeling like you want to help a friend in ‘our team’ lowers the threshold to ask questions. If face-to-face meetings are not possible, use Teams/Skype conference calls. You can share your monitor and ask for guidance on the actual design environment. (Respondent 8)*

Emphasis should not only be put on improving team spirit but also on the choice of the communication media as highlighted by Respondent 8. According to Respondent 11, the best way to cooperate is when individuals know each other and recognizes who is involved in a project. One way to establish this kind of basic but important relationships is by using conference calls such as Teams or Skype at the minimum. The Piping Design team suggested that it is always good when the Stress Analysis Engineer is sitting in the same office as the Piping Designers. This facilitates face-to-face meetings and enhances quick relationship building. However, this kind of setups is more and more difficult in this type of industry that involves more and more virtual teams.

The choice of an effective communication media can help save time and establish strong interpersonal connections for future projects. Many good examples were given throughout the interviews with the stakeholders but one in particular stood out. According to Respondent 14, building such networks allow share of information even after the projects that established the network are over. For example, questions may arise during a current project that require some expertise in a certain area. However, Engineer X does not have answers but remembers working in a recent project with Engineer Y who can provide answers or solutions. Engineer X then contacts Engineer Y and a quick solution which is beneficial to ‘our team’ is made available.

Effective tools for communication have been put at the disposal of employees by the case company. These tools are upgraded accordingly based on advancement in technology and the teams are left with the responsibility of making sure everyone uses them. During the second set of data collection (Data 2) of this thesis, stakeholders were asked to select the most effective means of communication based on their experiences and for future recommendation in the inputs and outputs exchange practices. The results of the selected effective means of communication is presented in Table 6.

Table 6. Preferred means of communications.

Flexibility Analysis Phases	Activities	Storage of Data/Documents	Preferred Communications means
Initiation Phase	Stakeholders needs and requirements		Face-to-face: Kick-off meetings, meetings
Modeling Phase + Analysing Phase	Provision of inputs to SCSA team	✓ Selected Technical database ✓ Communicate information to relevant stakeholders	Email + link to documents location
	Create Flexibility Analysis Follow-up list	✓ Selected Technical Database	-
	Create calculation models	✓ Selected Technical Database	-
	Provision of solutions and comments/Discussions by SCSA team	✓ Selected Technical Database	1. Face-to-face, video conference (Teams or/and skype) 2. Emails + link
	Provision of feedback by Piping Design team to solutions and comments	✓ Selected Technical Database	1. Face-to-face, video conference (Teams or/and Skype) 2. Emails + link
	Provision of Outputs	✓ Selected Technical Database	1. Face-to-face, video conference (Teams or/and Skype) 2. Emails + link
	Update of information, changes in project scope and data		1. Face-to-face, meetings
Reporting Phase	Preliminary Report	✓ Selected Technical Database	1. Emails
	Final Reports	✓ Project Database (Web-based document management system)	-
	Revisions		

As seen in Table 6, effective means of communication were selected according to the flexibility analysis process phases and per the major activities involved during the process. Face-to-face interactions, video conferences with Teams and Skype emerged as the preferred means of communication when it came to activities involving discussions and requiring immediate feedback. In contrast, Emails were preferred for activities that were informative in nature, did not require immediate feedback and required keeping other stakeholders informed of the progress. The result of this assessment is in line with best practices involving choice of media for effective communication. Face-to-face interaction, video conferences were media type with a high richness while Emails are attributed a low richness.

5.6 Training, Coaching and Mentoring

Skills emphasis is an important aspect of any engineering profession. The rapid advancement of technology give rise to new engineering tools and new ways of communicating requiring a constant upgrade of individuals skills. Moreover, the case company is constantly in search of new technologies in order to improve efficiency among its employees. This requirement of new skills is not different in the inputs and outputs exchange practices presented in this thesis. Lack of certain skills set, especially those related to accessing piping 3D model by the SCSA team when providing solutions, emerged as one of the major weaknesses during the CSA. A review of best practices in Section 4 of this thesis provided solutions through training and development. The consensus was unanimous among stakeholders during the proposal building interviews that the case company should do more to encourage training and development program.

In recent years, the case company has promoted internal training through learning or training at the job. External training, on the other hand were difficult to sign up for and the reason has always been financially related. According to Respondent 7, it is possible to sign up for any external training but it should be done through personal development programs and it should be a personal initiative as supervisors are not aware of the type of training each individual may be interested in. This information was welcome by most of the respondents despite some suggesting also focusing on learning at the workplace through empowering and coaching. Respondents 8, 10 and 12 offered to help anyone in need of a crash course on how to navigate within the environment of a 3D view model such as Navisworks. According to them, it does not require to be an expert in 3D design to be able to navigate within the environment of a 3D model in order to provide solutions during the flexibility analysis process. However, knowledge related to the use of some commands is required and internal training could be organized under the leadership of those who have volunteered to coach colleagues whenever there is a need.

Coaching, empowering and mentoring also involves taking ownership of these activities when newly recruited young Engineers join the teams. Respondent 8 pointed out that these newly recruits are often left on their own and only receive help when questions arises related to the task they are undertaking. The process of learning is often slow and not effective in this kind of setup. Respondent 11 suggested a well-defined monitoring approach with the support of line managers. This approach will consist of assigning a Senior Engineer with experience in the field as the primary monitor and will oversee the training process. The responsibility of the primary monitor will focus on but shall not be limited to guiding and providing support related to the use of tools, fundamentals of piping designing and working culture within the teams. When presented with the solutions of the respondents regarding the issue of monitoring newly recruited young Engineers, the line managers agreed to provide support to the initiative. Respondent 7, the line manager of the SCSA team also suggested including this in the personal development plan of the monitor and the newly recruited.

5.7 Proposal Draft

The build up to the proposal draft of the concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design team followed a systematic approach. Key suggestions from relevant stakeholders, in relation to the CSA focus areas and conceptual framework emerged. These suggestions were then used in a co-creation effort to develop the initial proposal of the concept whose elements have been discussed in the previous sub-sections (5.3, 5.4, 5.5 and 5.6) of proposal building stage (Section 5) of this thesis. The proposal daft and its elements are presented in Figure 17.

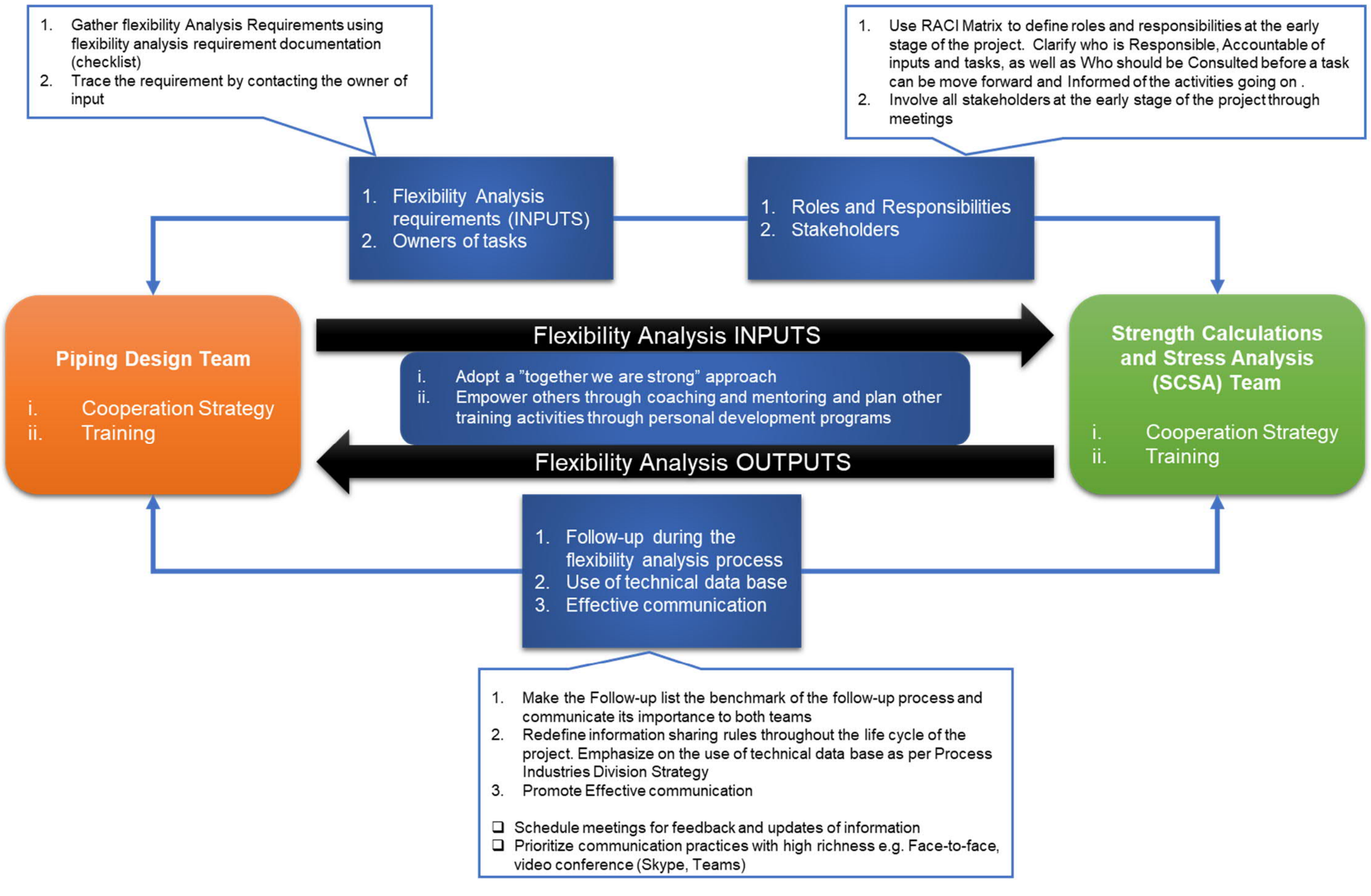

Figure 17. Proposal draft of concept enabling capture of mutual expectations of inputs and outputs between SCSA and Piping Design teams.

As depicted in Figure 17 the initial proposal of the concept combined suggestions by stakeholders in relation to weaknesses that were revealed by the CSA and key dimensions of the conceptual framework. In addition, it also requires building on existing strengths of the flexibility analysis process that emerged during the CSA.

The initial draft of the proposal follows the same sequence as the key dimensions of the conceptual framework presented in Section 4 of this thesis. It also utilizes tools and techniques of the conceptual framework. The objective of this thesis is to develop a concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping design Teams. The two black arrows in the middle of Figure 17 represent the exchange process where it is clearly illustrated which team is the provider of either the inputs or outputs. While the Piping Design team is the sole provider of inputs, the outputs exchange process is owned by the SCSA team but involves a flow of information in both direction until solutions provided by the SCSA team are acceptable. Therefore, the draft proposal does not only depict solutions or improvements but also embodies the inputs and outputs exchange practice.

The first element of the draft proposal is related to solutions on how to improve the gathering of inputs by the Piping Design team for a flexibility analysis. With a newly agreed checklist and a way to trace inputs through their owners, the exchange process will rely on an effective approach to gather inputs and avoid delay of inputs to the SCSA team. This will be in combination with already existing practices that will be complementary to the checklist.

The second element consists of involving stakeholders at the early stage of the process or project and defining roles and responsibilities. The RACI matrix was chosen because of its simplicity and ability to define roles and responsibilities with only a single letter. With well-defined roles and responsibilities, stakeholders will avoid disputes over roles and decision making as well embrace ownership of task. Moreover, it will provide additional information on the right contact person when questions regarding a particular task arise.

The third element touches many dimensions of the draft proposal. First, it establishes the flexibility analysis follow-up list as a benchmark of the follow-up process of the inputs and outputs exchange practice. Second, it requires redefining information exchange rules and that include emphasizing on the use of technical database as an effective way of sharing, saving and keeping track of information during and after projects. Finally, it requires the implementation of effective communication practices to not only improve cooperation but also to capture information and data sharing as well as building interpersonal relationship that can be beneficial to the process.

The final element of the initial proposal of the concept requires continuous training using either formal or informal methods to close the skill gap and help expedite integration of younger newly recruited Engineers. Moreover, it requires embracing the “us” rather than “us and them” approach as both teams move forward to redefining their respective co-operation strategies.

This completes the proposal building stage of this thesis which generated an initial proposal draft as a co-created effort of the concept by relevant stakeholders, for enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams during a flexibility analysis process. The next section focuses on building the final proposal of a concept based on feedback related to the initial proposal from a limited number of stakeholders. The outcome of the next section is the final proposal of the concept.

6 Validation of the Proposal

This section reports on the results of the validation phase and points to further developments of the initial Proposal presented in Section 5 of this thesis. At the end of this section, a final proposal and recommendations are presented.

6.1 Overview of the Validation Stage

This section validates the initial proposal developed in Section 5. The absence of a concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams has been a regular topic of discussion within the case company since defining the objective of this thesis and conducting the first set of interviews. The stakeholders have voiced their support and have been constantly updated on the progress. Consequently, the initial proposal received positive feedback but still need improvements particularly related to the implementation of the proposal.

The proposal building stage in Section 5 of this thesis was created in relation to key focus areas of the CSA. These focus areas included major challenges in gathering inputs by the Piping Design team, provision of information often too late to the SCSA team, effective follow-up approach and technical database often neglected, perceived lack of cooperation between the teams and Stress Analysis Engineer not using the 3D view model to provide solutions. The combination of these key areas with emphasis on elements of the conceptual framework, together with suggestions of relevant stakeholders led to the development of the initial proposal draft.

The validation process itself was planned systematically similar to other sections of this thesis. First, it was agreed to test some aspects of the concept in a medium scale project that started in the fall of 2020. The author of this thesis has overseen the role of Lead Stress Analysis Engineer and has been responsible for implementing some aspects of the concept such as the flexibility analysis follow-up list, the use of technical data bases and effective communication practices. Second, the proposal draft was presented and discussed with the Line Manager of the SCSA team prior to her leave of absence. The proposal draft was also presented to Lead Engineers from both teams for further feedback. Finally, a final proposal of the concept was developed and is presented at the end of this validation section.

The methods used for generating data in the proposal validation stage included feedback through interviews and discussions. Validation was not only achieved through interviewing stakeholders for feedback but also through piloting some aspects of the concept in a medium scale project with the author of this thesis as the Lead Stress Engineer. Table 7 below shows the stakeholders interviewed for the validation of proposal.

Table 7. Details of interviews and discussions in Data 3.

Participants	Data type	Title	Topic	Date
Data 3: Validation of Proposal (Interviews)				
Respondent 15	Discussions/ Emails	Line Manager	Validation of Proposal from Leadership perspective	14.4.2020
Respondent 16	Email Interview	Lead Project Engineer	Validation of Proposal from **Piping Design team** perspective	17.4.2020
Respondent 17	Email interview	Lead Stress Engineer	Validation of Proposal from **SCSA Team** perspective	17.4.2020

As seen in Table 7, the validation of the proposal relied on the Line Manager, the Lead Stress Engineer and Lead Design Engineer from the SCSA and Piping Design teams respectively. The fact that the case company has taken measures due to the spread of the coronavirus meant that most of the stakeholders were working remotely from home. This situation together with the involvement of everyone in many projects also resulted in a new approach of collecting data. As a result, emails or discussions via emails or video conferences were selected as the preferred ways to collect data. The data collection also relied on individuals with leadership roles from both teams for feedback, thereby strategically involving those who will oversee the implementation of the outcome of this thesis.

6.2 Findings of Proposal Validation Data Collection Stage, Data3

The proposal validation stage was very satisfactory. A number of useful suggestions were made by the stakeholders in the direction of improvements aimed at further enhancing capture of mutual expectations of inputs and outputs and facilitating the implementation of the concept. The suggestions and recommendations that emerged are presented in Table 8 below and represent either adjustments that were made in the final version of the concept or the next action reserved for internal implementation, hence out of the scope of this thesis.

Table 8. Key stakeholder suggestions for validation of proposal (Data 3).

	Key focus area from Proposal building and/or Validation	*Suggestions from stakeholders, categorized into groups (Data 3)*	*Description of the suggestion for development*
1	Flexibility Analysis requirements (INPUTS)	a) Further improve the inputs gathering process by involving the Process department b) Engage the Process team as the owner of most of the flexibility analysis process inputs	The Lead Engineers, Respondents 16 and 17 suggested involving the Process team which emerged as a very important stakeholder in the gathering process of flexibility analysis inputs; and suggested striving for a three-way cooperation in the future rather than just a two-way.
2	The Concept as a useful document within the case company	a) For implementation within the case company prepare a *"path to flexibility analysis document"* b) Simplify the concept so that everyone can follow and implement	The Line Manager, Respondent 15 SCSA team suggested that despite enough clarity in the draft proposal, individuals will have an easy task aligning to the concept if a document could be made available in the form of a "path to flexibility analysis" that included a simplified version of the concept.

As seen in Table 8, the validation of the proposal did not receive feedback requiring changes in the core of the draft proposal presented in Section 5 of this thesis. On the contrary, it received a strong validation from the stakeholders. The Line manager endorsement was related in a statement as follows:

> *I am satisfied with the proposal and I am particularly glad that it was done in a good team spirit. I have followed the progress and discussed with others who have shown their excitement and willingness to contribute on producing something that can be helpful to all. In this concept we have achieved just that but there is room for improvement and the next step should be to produce a document that will help the implementation of the concept within the department. (Respondent 15)*

The Lead Engineers from both teams agreed and argued further that because it has been a co-created effort, there is not much that can be added to the concept itself except suggestions for further improvements.

The piloting of the concept in a medium scale project was initiated by the Line Manager of the SCSA team by selecting the author of this thesis as the Lead Stress Engineer to oversee the flexibility analysis process. While the project is still ongoing, some aspects for the draft proposal have received strong validation through positive feedback. The use of a flexibility analysis follow-up list, exchange of information through a technical database, presentation of solutions and instant feedback have allowed the process to move on at a satisfying pace. The Piping Design team located in China, the SCSA team and project management team located in Finland have all given positive feedback to the process. When wrong data was used in January 2020, the organized elements of the concept helped mitigate the impact of the errors and quick solutions were provided, thereby avoiding delays in the process. Although the scope of this thesis was limited to the inputs and outputs exchange practices between teams in Finland, piloting of some aspects of the concept has demonstrated that this concept can be adapted in projects involving virtual teams working from different countries.

6.3 Developments to the Proposal Based on Findings of Data Collection 3

As already stated, the initial proposal of the concept developed in Section 5 of this thesis received a strong validation from key stakeholders. However, the initiation phase of the flexibility analysis process involving gathering of inputs by the Piping Design team was the focus of the stakeholders due to the dependence of its effectiveness on another team, i.e. the Process team. The Process team has been identified throughout this thesis as a key stakeholder of the flexibility analysis process. Consequently, developments on how to improve the gathering of inputs by the Piping Design team and the implementation of the final proposal of the concept internally emerged as the key findings of Data collection stage, Data 3.

6.3.1 Involve the Process Team

The process department is a vital stakeholder in piping engineering and in plant design projects. Although the inputs and outputs exchange practice during the flexibility analysis of critical piping is often between the SCSA and Piping Design teams, the gathering of inputs is dependent to some extent on the Process team. This team is responsible for providing most of the information required by the Piping Design team to initiate their work and transfer of information for the flexibility analysis process. Problems were raised by stakeholders when gathering Data 1 of this thesis related to the lack of cooperation between the Piping Design and Process teams. This weakness was not included in the results of the CSA because it was not in line with the objective of this thesis. However, for improvement purposes stakeholders have argued that the gathering of inputs will be more effective should the Process team be more involved and aware of its importance.

The cooperation between the Process and other teams within the Piping and Mechanical Engineering department has always been perceived as “inexistent”. Recent efforts to promote team spirit by focusing on a common goal where all the teams adopt a “us” approach within the department has led the Process team to acknowledge that much is needed from their side to improve cooperation. The initiative has begun with the support of the head of department and line managers of all three teams. Meetings have been scheduled and improvements will be added to the “path to flexibility analysis” document which will be published later internally and therefore will not be included in this thesis.

Involving the Process team is aimed at raising awareness of the importance of inputs to the flexibility analysis process, the necessity to provide certain information at the early stage and more importantly, facilitating the process of tracking changes in the inputs throughout plant design projects. In addition, this will not only be beneficial to the flexibility analysis process but also the whole Piping and Mechanical Engineering department as the case company moves forward to adopt a more sustainable and innovative strategy.

6.3.2 Path to Flexibility Analysis Document

The initial draft proposal of the concept was strongly endorsed by key stakeholders. Although the visual representation of the draft proposal gave a clear picture of the key focus areas of the concept, the stakeholders argued that there was a need for an internal document that is going to help its implementation and use. The Line manager of the SCSA team pointed out the following:

> *Engineers are practical and therefore require the concept explained in Engineering language that is easy to follow and ready to be used even by a newly recruited. A document that could be produced later and named “path to flexibility analysis”. (Respondent 15)*

The Lead Engineers agreed that the availability of such a document will add value to the process and could continue to undergo improvements in the future. The *path to flexibility* *analysis document* will include tools such as the flexibility analysis checklist, inputs traceability matrix and the RACI matrix. It will also include a short description of the role and responsibilities involved in a flexibility analysis process, inputs-techniques and tools-outputs table of the flexibility analysis process, emphasis on flexibility analysis follow-up list and how it should be created. Moreover, effective communication practices with emphasis on the choice of a technical database and preferred media for effective communication will also be included as well as the flexibility analysis flow chart. It is however important to emphasize that this document is under construction and has been reserved for internal publication and will not be presented in this thesis.

6.4 Final Proposal of Concept

Based on feedback from piloting aspects of the initial proposal of the concept enabling capture of mutual expectations of input between the SCSA and Piping design teams, and feedback from key stakeholders, it was agreed to involve the Process department or team in the gathering of inputs for the flexibility analysis process. In addition to this improvement to the concept, it was also agreed to produce a *path to flexibility analysis internal document* at a later stage that will expand the concept from a graphic version to a simple but more detailed version. The final version of the concept with its additional elements is presented in Figure 18.

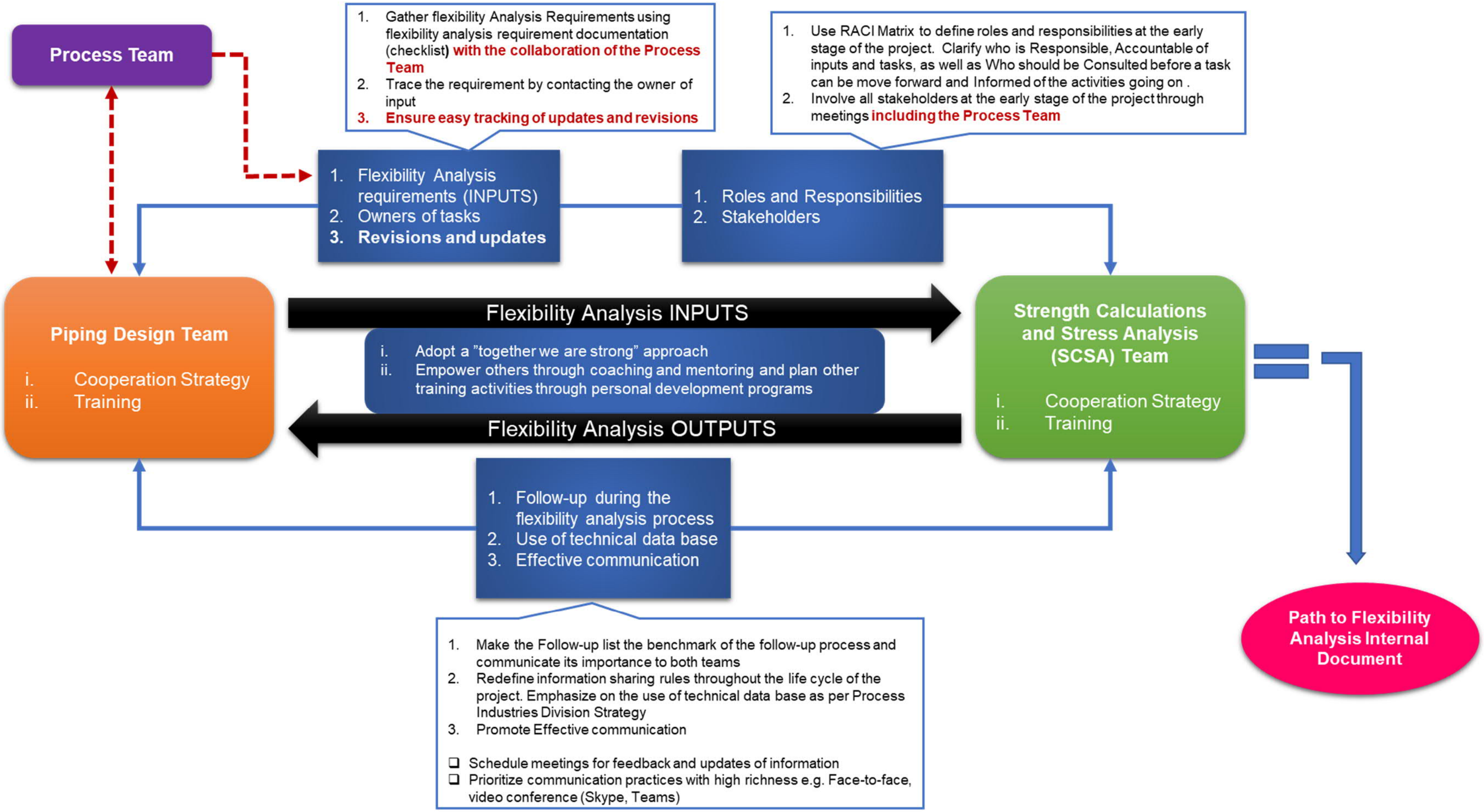

Figure 18. Final version of concept enabling capture of mutual expectations of inputs and outputs between SCSA and Piping Design teams.

As seen in Figure 18, the structure of the final version of the concept is similar to that of the initial proposal in Section 5 of this thesis, with additional elements written in red. As shown, the Process team as a key stakeholder has been included, especially during the gathering of inputs for the flexibility analysis process. Although the involvement of the Process team seems minor in the chart, its importance is very significant as has been demonstrated in previous sections. This additional element enhances the engagement of the Process team and further improves the inputs gathering process. Thus, the Process team will be involved at the early stages of the process when defining roles and responsibilities, help facilitate the inputs gathering process, trace inputs and facilitate tracking revisions of inputs data.

The second important element that was added to the final version of the concept is for illustration purposes. It indicates that the whole final version of the concept will result in an internal document called the *path to a flexibility analysis*. The purpose of this document will be to facilitate its implementation and enable further improvements beyond its implementation.

This concludes Section 6 of this thesis that produced the outcome of its objective which was to develop a concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams. The next section focuses on drawing conclusions from this applied research study and presenting an executive summary of this thesis.

7 Conclusions

In this final section of the thesis, an executive summary of the main findings is first presented followed by the next steps towards implementation of the concept within the Piping and Mechanical Engineering department of the case company in Finland. Next, the thesis is evaluated based on four main criteria and then the section is concluded with closing words.

7.1 Executive Summary

The objective of this thesis was to develop a concept enabling capture of mutual expectations of inputs and outputs between the Strength Calculation and Stress Analysis (SCSA) and Piping Design teams during the flexibility analysis process involving critical piping. The SCSA team cooperate intensively with internal Piping Design team in Finland and abroad during plant design projects. For this interface to be efficient, mutual expectations, that is, each other's inputs and outputs must be agreed at the project planning stage and as the project evolves. Flaws and delays in the flexibility analysis process have an impact on the success of a project. The absence of a conceptual approach of capturing these mutual expectations of inputs and outputs within the Piping and Mechanical Engineering department of the case company resulted in the objective of this study.

In order to achieve the objective of this thesis, an applied action research approach was selected, for which information was collected by a qualitative method to explore the business challenge. The chosen methods of generating data were in-depth one-to-one interviews of relevant stakeholders, internal documents and workshops.

Once the research approach was selected, the research started with the analysis of the current inputs and outputs exchange practices between the SCSA and Piping Design teams, followed by a literature review. The choice was made due to existing practices, which the case company has relied on but that follow no particular concept. The current state analysis (CSA) revealed that the flexibility analysis constituted of four main phases: Initiation, Modelling, Analysis and Reporting phases. During the CSA, strengths of the exchange practices emerged such as availability of state-of-the-art tools, competent and experienced Engineers capable of finding quick solutions to complex tasks, availability of a flexibility analysis report template, ability to effortlessly generate reports from the stress analysis software and a well-organized follow-up approach when well implemented. The CSA also revealed weaknesses in the exchange practices and four major weaknesses were selected for development through exploration of existing knowledge.

In relation to challenges in gathering inputs in the initiation phase and provision of information often too late to the SCSA team, perceived lack of cooperation between the teams, Stress Analysis Engineers not using 3D model to provide solutions, follow-up approach and technical database not effectively utilized, different topic in existing literature were explored. Accordingly, a literature review was conducted on collecting stakeholder needs and requirements in projects, effective communication in cross-functional teams, knowledge and skills emphasis, as well as leadership and performance attributes. The outcome of the literature review was the conceptual framework (CF) of this thesis.

The key focus areas of the CSA and CF set the basis for the data collection of the proposal building stage of the concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams. A wider range of viewpoints was considered for this proposal building stage due to its importance to achieving the objective of this thesis. Therefore, the proposal building was a systematic co-created effort between stakeholders. A number of suggestions emerged from stakeholders during interviews and were prioritized based on the frequency of agreement among stakeholders. First, it was suggested to develop a flexibility analysis inputs checklist, an inputs traceability matrix and emphasized on role clarity in order to improve gathering of inputs by the Piping design team at the initiation phase of the flexibility analysis process. Second, it was suggested to involve stakeholders early on in projects, initiate the flexibility analysis process early through the collaboration of Lead Engineers from both teams to minimize delays of inputs to the SCSA team. Third, it was agreed to make the flexibility analysis follow-up list the benchmark of the follow-up process and assign its responsibility to the Lead Stress Analysis Engineer, in order to strengthen its application. Fourth, it was suggested to redefine the rules related to exchange of data and communicate them to all stakeholders, in order to prioritize the use of technical database which is in line with the Process Industries Division internal strategy. Fifth, it was suggested to promote cooperation, schedule meetings early on, adopt effective communication practices, provide feedback including negative, to tackle the perceived lack of cooperation between both teams. Finally, it was agreed to empower colleagues and new recruits through coaching, monitoring to help close skills gap as well as training through formal approaches within the case company. Based on this co-created effort, an initial draft proposal of the concept was developed, and the results presented one more time to relevant stakeholders.

The validation of the concept relied on a limited number of stakeholders on leadership positions. Some aspects of the concept were also piloted in a medium scale project that started in the fall of 2020. Although, the draft proposal received a strong validation by stakeholders, improvements were requested especially related to the gathering of inputs by the Piping Design team. Improvements included involving the Process team as the owner of most of the inputs of the flexibility analysis process. It was also agreed to produce a document outside the scope of this thesis for internal use. Consequently, the final version of the concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams was established.

The implementation of this concept will not only help improve cooperation between teams but also teamwork and the flexibility analysis process. In addition, it could help minimize delays related to gathering of inputs to initiate the flexibility analysis process as well as get rid of ambiguities related to ownership of tasks and decision making. It will also create a platform for every newly recruited to embrace a working culture as soon as they join the company.

7.2 Next Steps Toward Implementation

The validation stage of this thesis resulted in defining the next steps toward implementation of the concept by the Line Manager of the SCSA team. This will consist of first creating the *path to flexibility analysis document*. Then, the document shall be approved for implementation for future use in projects involving flexibility analysis of critical piping. Finally, the document shall be distributed or made available for downloads. In addition, aspects of the new concept, such as effective communication practices and cooperation, will be promoted with the support of the Line Mangers of the teams as well as the Department Manager.

The *path to flexibility analysis* document is under development and the time schedule has been set until the next performance review meeting scheduled for March 2021. The path to flexibility analysis is the transformation of the concept for enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams from a flow diagram to a document version.

7.3 Thesis Evaluation

The objective of this thesis was to develop a concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams within the Piping and Mechanical Engineering department in Finland. Although both teams are involved in more than one activity requiring exchange of inputs and outputs, this thesis was limited to the flexibility analysis process of critical piping. In recent years, these two teams have relied on different approaches to capture mutual expectations of inputs and outputs, none of which followed an established or agreed procedure.

The existence of different approaches and tools, some more effective than others, allowed the concept to be created based on existing practices. Accordingly, the objective was first addressed by conducting an in-depth study of the current inputs and outputs exchange practices with the contribution of key stakeholders. In order to understand issues in the inputs and outputs exchange practices, the thesis relied on sources from business and project management researches or studies. This enabled finding best practices, tools and strategy to develop the concept. However, the lack of sources in the engineering consulting industry or plant designing projects led to the use of sources in alternative industries, such as the construction industry. Despite sources not focusing particularly on the business context of the case company, best practices were chosen in relation to the key focus areas. To align external knowledge from sources to the inputs and outputs exchange practices and case company's ways, key stakeholders were again involved and based on their inputs a concept was developed, validated and given the greenlight for its implementation.

7.3.1 Validity and Reliability Evaluation

Validity and *reliability* are concepts used to evaluate the quality of a research (Patton 2001). Validity in qualitative research means the extent to which data is plausible, credible and trustworthy, and thus can be defended when challenged. Two kinds of validity should be taken into account when conducting a research. While *Internal validity* refers to how well the study is run and determines how confidently results can be concluded, *External validity* refers to whether the findings are generalizable, i.e. if they can be used in another context as well. (Bryman and Bell 2007).

The first step in ensuring *internal validity* was using a variety of ways to collect data (interviews, workshops and internal documents), a method known as data source triangulation. Multiple references were also used as data source, thereby acknowledging the contribution of other writers and researchers as well as providing evidence to support the assertions and claims in the thesis. Data triangulation was less successful in the CSA due to the absence of documents within the case company related to the flexibility analysis process. Most of the CSA analysis was based on the contribution of key stakeholders. Despite the poor content of internal documentation, in-depth interviews and involvement of key players of the inputs and output exchange practices enabled the collection of important data for the thesis. In the proposal and validation stages of the concept, triangulation was successful as several and wider range of data sources were used, including piloting some of aspects of the concept in a medium scale project.

The second step in ensuring *internal validity* was using key stakeholders from the SCSA and Piping design teams. This approach relied on different viewpoints, ensured that the effort was a co-creation and eliminated any personal bias and expectations from the researcher. In the proposal and validation stages of this thesis, citations of key stakeholders are used as expressed in their own words. This further illustrate another approach to overcome intrinsic bias and simultaneously strengthening *internal validity*.

On the other hand, *external validity* can be considered fulfilled to some extent. A group of experienced Engineers from two teams were chosen as participants of this research. If the participants were to be substituted by a group of younger or less experienced Engineers, the outcome would have been different. Moreover, despite trying to eliminate bias, the fact that the researcher had an interpersonal relationship with most of the participants may have impacted their contribution and results would have differed in another context. This put some reservation to what extent the findings of this thesis can be generalized but provide “thick” descriptions of the situation studied in this thesis. However, piloting the most important aspects of the concept in a project involving the Piping Design team based in China allows to conclude that the results of the study can be transferred across different teams and projects requiring a flexibility analysis process within the case company. External validity has also been ensured to some extent by incorporating best practices from literature related to cross-functional teams on how to enable capturing of mutual expectations of inputs and outputs in projects.

Reliability is referred to as the extent to which results are consistent over time and an accurate representation of the total population under study and if the results of the study can be reproduced under a similar methodology, then the research instrument is considered reliable (Bryman and Bell 2007; Wilson 2010). In depth one-to-one interviews were conducted, some by emails and others recorded via skype. While interviews conducted via emails allowed the participants to review their written answers before forwarding them, copies of transcribed notes from audio recordings were not sent back for reviews. By allowing the participants to review interview responses would have given them the opportunity to verify the interpretive accuracy, thereby increasing reliability.

However, the participants were presented results of previous data collection prior to collecting new data. In addition, results of the previous data collection stage together with the next set of questions were sent prior to the interviews, allowing the participants to familiarize themselves with the progress of the study as well as prepare for the next set of questions. Initially, it was planned to take the data and interpretations back to the participants through workshops, so that they can confirm the credibility of the information and narrative account as well as agree on a consensus of the outcome of each data collection stage. This approach would have further increased the *internal validity* of this thesis. Instead, a smaller focus group was relied upon to approve the outcome of each data collection stage, hence confirm its credibility.

When collecting data from key stakeholders, similarities in viewpoints were prioritized in order to corroborate information collected during interviews. The percentage of agreement was also accounted for when reporting suggestions, thereby further ensuring reliability.

7.3.2 Ensuring Relevance and Logic

The other two research evaluation criteria used in this thesis include relevance and logic. Relevance of this thesis refers to the extent its outcome is relevant to the case company. It is also related to finding an interesting and up-to-date business-related topic or a practical business problem (Eriksson and Kovalainen 2008). Relevance of this thesis has been ensured by first aligning the objective of this thesis to the internal strategy of the Process Industries Division of the case company. Then followed by the involvement of key stakeholders throughout the research and keeping them informed on the progress. Finally, the outcome of the thesis was adjusted and validated by key stakeholders and will further undergo a strategical final stage for its internal implementation.

Qualitative research uses inductive logic, where the researcher first designs a study, collects data and then attempts to derive explanations from those data. Logic and logical construct on the other hand was ensured through the validity evaluation presented earlier. Logic was also insured by a systematic approach to the research illustrated in the research design flow diagram of this thesis.

7.4 Closing Words

The objective of this thesis was to develop a concept enabling capture of mutual expectations of inputs and outputs between the SCSA and Piping Design teams: two internal teams within the Piping and Mechanical Engineering department of the case company. Through a well-designed research approach and with the contribution of passionate colleagues the outcome of the thesis was achieved. To ensure a high quality of the research, internal validity, external validity, reliability, relevance and logic were ensured at different stages of the study. The experience would not have been complete and interesting without some ambiguities and imperfections in the research process. However, the main goal was achieved, and the same commitment will be shifted toward a strategical implementation of the concept which is the next step outside the scope of this thesis.

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Flexibility Analysis Inputs Checklist – Preliminary Version.

Input Owner	Input		Type	Due Date	✓
Project management/Client	Project code statement		Doc		
	Design code		Doc		
	Project Standard		Doc		
Process Engineer	Pipeline list	Design pressure	Doc & Isos		
		Design temperature			
		Piping diameters			
		Piping wall thicknesses			
		Piping materials			
		PED class			
	Pipeline list/Other	Hydrostatic pressure	Doc/Isos		
		Piping insulation thicknesses	Doc/Isos		
		Flow substance density	Doc		
	Piping and Instrumentation (PI) diagrams		Doc		
	Process Flow Diagram		Doc		
Design Engineer	Piping geometric layout - 3D model		File		
	Piping isometrics		Drawings		
Equipment Manufacturer/Provider	Valves and instruments weights		Doc		
	Equipment and pumps drawings		Drawings		
	Equipment and pumps allowable nozzle loads		Drawings or reference		
	Safety valves reaction forces		Doc		
Occasional cases					
Project management/Client	Additional loads on the piping		Doc		
	Snow load on piping		Doc		
	Wind load on piping		Doc		
	Horizontal and vertical ground acceleration due to earthquake		Doc		
	Boiler's house horizontal movement due to earthquake		Doc		

Flexibility Analysis Inputs - Tools, Techniques, Activities – Outputs Matrix.

<table>
<tr><th>INPUTS</th><th colspan="2">FLEXIBILITY ANALYSIS PHASES</th><th>TOOLS, TECHNIQUES AND ACTIVITIES</th><th>OUTPUTS</th></tr>
<tr><td rowspan="6">➢ Project code statement
➢ Design code
➢ Project standard
➢ Pipeline list
• Design temperature
• Design pressure
• Piping diameters
• Piping wall thicknesses
• Piping materials
• PED class
• Hydrostatic pressure
• Insulation thicknesses
• Flow substance density or specific gravity
➢ PI diagrams
➢ Piping Flow Diagrams
➢ Piping Geometric layout – 3D model
➢ Piping isometrics
➢ Valves and instruments weights
➢ Equipment and pumps drawings
➢ Equipment and pumps allowable nozzle loads
➢ Safety valves reaction forces</td><td colspan="2">Initiating</td><td>➢ Data gathering
• Use technical data bases for saving and sharing documents throughout the project (avoid own computer data bases)
➢ Data organizing
• Flexibility analysis follow-up list
• Packages and Sub-packages
➢ Activity sequencing – schedule activities into a logical order
➢ Activity duration estimating</td><td>➢ Technical data base
➢ Flexibility Analysis follow-up list
➢ Packages and sub-packages</td></tr>
<tr><td colspan="2">Modelling</td><td>➢ From boundary to boundary: From Anchor to Anchor, Anchor to equipment connection or equipment to equipment connections
➢ 1 package or sub-package per model/report
➢ Caepipe software or others</td><td>➢ Caepipe .mod files</td></tr>
<tr><td colspan="2">Analysing</td><td>➢ Model flexibility analysis
➢ Frequent interactions/meetings
➢ Use effective communication tools to speed up the process – chose conference calls and presentations over emails
➢ Keep track of suggestions, comments, changes and updates
➢ Pdf formats
➢ Caepipe software or others</td><td>➢ Review of models and flexibility analysis
➢ High stress levels & high nozzle and support forces solutions – Piping support type and location changes, piping new routing
➢ Support loads summary for larger and critical piping
➢ Spring hangers and spring support preliminary report summary
➢ Nozzle loads for approval</td></tr>
<tr><td rowspan="3">Reporting</td><td>Phase 1</td><td>➢ Pdf format, report templates</td><td>➢ Preliminary flexibility analysis report for checking & approval</td></tr>
<tr><td>Phase 2</td><td>➢ Pdf format, report templates, technical database</td><td>➢ Final model file
➢ Final Spring hangers and supports summary
➢ Final flexibility analysis report</td></tr>
<tr><td>Phase 3</td><td>➢ Pdf format, technical database</td><td>➢ Revisions</td></tr>
</table>