THE ROLE OF AN ENGINEERING CONTRACTOR IN QUALITY ASSURANCE AND QUALITY CONTROL IN E, EPC AND EPCM PROJECTS

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Energy Technology, Master's thesis

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ABSTRACT

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As the subject of the study, the business unit of the case company providing process industry engineering office services has recently been running a development project to promote unified operating models. Concerning the theme of the development project, the study's objective in this thesis was to analyse the role of the engineering office in quality assurance (QA) and quality control (QC) when providing services as a contractor in different project contract models. The contract models examined in the work were the contract models for Engineering service (E), implementation service; engineering, procurement and construction management (EPCM) and contracting service; engineering, procurement and construction (EPC). In the study, the responsibilities of the design office were evaluated in terms of QA/QC measures and their variations in these different contract models.

In the background theory section of the thesis, the literature review introduced quality as a concept in the project environment in the context of implementation projects in the process industry, as well as the practices of QA/QC measures in project work. In the work's applied research, the participant observation method was used by acting as an active member of the project organisations. Based on the observations, the work discussed four different example cases, which were selected to represent the quality management of the implementation project in the different phases, i.e. engineering, procurement and construction. Also, regarding the quality deviations of the example cases, categorising the root causes was an important criterion when selecting the cases to be discussed. To complete the observations, individual interviews were conducted with the project personnel by applying open interview methods. Development proposals for corrective measures were derived from the example cases.

When acting as the contractor of the implementation project, the design office is responsible for preparing and implementing its own QA/QC process to meet the quality criteria for its scope of delivery. E, EPCM and EPC contract models, in that order specifically mentioned, are from the narrowest to the broadest in QA/QC measures in terms of the project's overall responsibility. In the EPCM model, contract technicality is emphasised, and in the EPC model, the responsibility lies primarily with the contractor, i.e. the engineering office.

TIIVISTELMÄ

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Suunnittelutoimiston rooli laadunvarmistuksessa ja -valvonnassa E, EPC ja EPCM projektisopimusmalleissa

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71 sivua, 17 kuvaa, ja 1 taulukko

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Tutkimuksen kohteena ollessa prosessiteollisuuden suunnittelutoimistopalveluja tarjoavassa esimerkkiyrityksen toimialan liiketoimintayksikössä on viimeaikoina ollut käynnissä kehitysprojekti yhtenäisten toimintamallien edistämiseksi. Kehitysprojektin teemaan liittyen tässä työssä tehdyn selvitystyön päämääränä oli selvittää suunnittelutoimiston roolia laadunvarmistuksessa (Quality Assurance – QA) ja laadunvalvonnassa (Quality Control – QC) urakoitsijana toimittaessa eri projektisopimusmalleissa. Työssä tarkastellut sopimusmallit olivat suunnittelupalvelun (E, Engineering), toteutuspalvelun suunnittelu, hankinta ja rakennustyön johtamisen (Enginreering, Procurement and Construction Management - EPCM) ja urakointipalvelun suunnittelu, hankinta ja rakennus (Engineering,

Procurement and Construction – EPC) sopimusmallit. Työssä arivoitiin suunnittelutoimiston vastuita QA/QC toimenpiteiden osalta näissä eri sopimusmalleissa.

Työn taustateoriaosuudessa perehdyttiin kirjallisuuskatsauksessa laatuun käsitteenä projektiympäristössä prosessiteollisuuden toteutusprojektien kontekstissa, sekä projektityöskentelyn QA/QC toimenpide käytäntöihin. Työn soveltavassa tutkimuksessa sovellettiin osallistuvan havainnoinnin menetelemää toimimalla projektiryhmien aktiivisena jäsenenä. Havaintojen pohjalta työssä käsiteltiin neljä eri esimerkkitapausta, mitkä valikoitiin siten, että ne edustaisivat toteutusprojektin laadunhallinta toimenpiteitä projektien eri vaiheissa, eli suunnittelussa, hankinnassa ja rakentamisessa. Myös esimerkkitapausten laatupoikkeamien osalta juurisyiden kategorisointi oli merkittävä kriteeri käsiteltäviä tapauksia valittaessa. Havainnoinnin täydentämiseksi suoritettiin yksilöhaastatteluja projektin henkilöstölle avoimen haastattelun menetelmin. Esimerkkitapauksista johdettiin kehitysehdotuksia korjaaville toimenpiteille.

Suunnittelutoimisto on vastuussa toteutusprojektin urakoitsijana toimiessa omasta QA/QC prosessin laatimisesta ja toteuttamisesta laatukriteerien täyttämiseksi toimituslaajuutensa osalta. E, EPCM ja EPC sopimusmallit edellä mainitussa järjestyksessä ovat projektien kokonaisvastuun osalta QA/QC toimenpiteissä suppeimmasta laajimpaan. EPCM mallissa sopimusteknisyys korostuu ja EPC mallissa vastuu on ensisijaisesti urakoitsijalla eli suunnittelutoimistolla.

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Touko, my 9-month-old son at the time of writing, served as a significant motivator in completing this thesis. He would also have been very willing to write. Here is his contribution to the academic community: “aaaaaaaa3s Y.”

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ABBREVIATIONS

CoC	Cost of Change
CoQ	Cost of Quality
DE	Detailed Engineering
DMAIC	Define, Measure, Analyse, Improve and Control
E	Engineering
EPC	Engineering, Procurement and Construction
EPCM	Engineering, Procurement and Construction Management
KPI	Key Performance Indicator
NDT	Non-Destructive Testing
NoBo	Notified Body
PDCA	Plan, Do, Check, Act
PED	Pressure Equipment Directive
QA	Quality Assurance
QC	Quality Control
QM	Quality Management
RT	Radiographic Testing
SEP	Sound Engineering Practice
UT	Ultrasonic Testing
VT	Visual Testing
WBS	Work Breakdown Structure

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1 Introduction

In the case company, a development project has been underway to promote unified operation procedures within the business unit, where the purpose is to standardise common methods of operation tailored to serve the needs of the business unit and its projects. In the case company, there is guidance from the top level of the industry division on operating procedures for the implementation of projects. The purpose of the case company's recent development project is to create more detailed guidelines for the business unit’s needs, where the level of detail at its extreme is already step-by-step guidelines for certain design tasks of process industry production facilities.

Quality management and quality assurance measures are an integral part of the core business of the case company in the projects it implements. The case company implements implementation projects of process industry production facilities applying different contract models. These contract models set additional requirements for quality assurance (QA) and quality control (QC) measures. This work aims to clarify the role of the engineering office in quality assurance and control measures in implementation projects and the requirements set for them by different contract models. The work results are usable in the following stages of the development project. The contract models examined in this work are the E, EPC and EPCM contract models, which are the most common contract types of the case company.

QA includes determining measures to ensure that the set quality criteria will be achieved. This covers the defined measures for the implementation of deliverables and the ways to react based on the findings of quality control. Quality control (QC), on the other hand, consists of measuring and monitoring the realisation of quality criteria and the implementation of primarily proactive but also responsive measures defined in the QA process. The measures defined in the QA process are essential in achieving the quality criteria set for the optimal allocation of project resources. Presumably, all parties involved in the projects strive to produce quality at a level they see fit the purpose. QA and QC processes as part of quality management (QM). The aim is to promote the formation of a common understanding of the quality criteria sought and harness tools, methods and guidelines to pursue quality criteria that benefit all parties. To promote this, the purpose of the ongoing development project in the case company is to guarantee easily accessible instructions for the personnel stored in the case company's own systems and to harness tools that support the quality management that is actively present in the projects, e.g. by means of monitoring and continuous follow-up.

Several different disciplines are represented in the design work of implementation projects in the process industry: process, mechanical, automation, electricity and civil, to name a few. Each discipline has its own quality criteria, and QA/QC measures should naturally be tailored to serve the purpose of the disciplines. The case company has recurring projects with common features. For example, the case company has supplied several sub-production units of forest industry production facilities based on the same technology. The variable factor is mostly the targeted production capacity. The general operating model has been to rely on the know-how of reference projects. Still, if this know-how is not systematically and collectively available, it can be challenging for new members of the project organisation to access this information. Systematic and standardised operational models built into the systems used in the design, including QA/QC measures, would primarily serve these repetitive projects because even if similar projects are repeated, the organisations implementing them may vary.

In this work, a literature review is carried out in the background theory part, where quality is discussed as a concept in the project environment. The QA/QC measures of project work are introduced, connecting them to the context of implementation projects in the process industry. The work also discusses the differences between different contract models, as well as the content of QA/QC measures in them. The applied research section discusses a few challenging cases encountered in the projects that have occurred in the projects of the contract models in question. The selected example cases to be discussed have been chosen to represent the stages of implementation projects and the categorisation of different root causes. However, the example cases mainly concern the mechanical design discipline, except one case generally related to the project operating model. Based on these, preliminary development proposals have been prepared for the next stages of the development project in the case company.

2 Quality as a Concept in Projects in the Context of the Process Industry

Quality is a multifaceted concept that extends and is widely related to the project's various aspects and phases when examined in the project environment. This chapter discusses quality as a concept, its dimensions, what is essential in forming a unified understanding between all the stakeholders within the project and which measures are included in promoting the achievement of the optimal quality goals.

2.1 Quality – Definition

According to ISO 9000 standard, the Quality of the products and services is defined by their ability to meet the satisfactory level from the customer's perspective and also by their intended and unintended impact on relevant interested parties. The quality of products and services naturally includes their intended function and performance, but additionally, an as important part of their quality is what value and benefit they bring to a customer. Quality can be defined as the degree to which a set of inherent characteristics of an object fulfils requirements (The International Organization for Standardization, 2015).

In the context of an engineering contractor delivering a process plant for the customer, all the activities needed for the end result, in this case, the process plant, fall under the concept of service. Similarly, the end result of the services provided by the engineering contractor in the form of a process plant goes under the concept of a product. For the definition of quality for a product or service, it is convenient to use the concept of quality dimensions. For both concepts, product and service, there has been developed a variety of sets of quality dimensions by professors from different universities in the field of business administration and marketing.

2.1.1 Product Quality Dimensions

One of the most widely used and respected collections of quality dimensions for a product was developed by David Garvin from the Harvard Business School. In Garvin's collection of quality dimensions, the quality of a product is defined specifically by eight dimensions (Foster, 2017, p. 27).

Figure 1 Product Quality Dimensions by David Garvin (Foster, 2017, p. 28)

In Garvin's collection of quality dimensions, as seen in figure 1 above, the dimension of **performance** points out at which level the product is able to achieve its intended purpose. Again, in the context of a process plant engineering and construction project, this would refer, for example, to the intended production capacity of the delivered process plant.

Features can be described as a single or combination of properties in addition to the primary function of a product. Features of the process plant could be, for example, its adaptivity to altering production capacities, different feedstocks of the process or diverse maintenance programs for the plant provided by the plant's licensor to be mentioned.

In terms of **Reliability**, process plants are designed to function in a stable way to achieve their expected degree of consistent production and availability during their lifetime. Availability represents the rate at which the process plant is "available" for production. Vice versa, the process plant is not "available" during the expected and unexpected shutdowns during failure and shutdown cases. One sub-field of quality management is reliability management which is based on the accurately estimated probability of the failure cases of a product. If a failure state would occur, e.g. with a 2 per cent probability on an evaluated item, then it would be described as 98 per cent reliable.

One of the most traditional definitions of quality is the quality dimension of **conformance** in Garvin’s collection. Typically at least the most essential and typical characteristics of a product shall be specified in advance before the design work and manufacturing can begin. For the process plant design and manufacturing projects, the technical specifications, where these certain numeric dimensions typically with an allowed tolerance are specified, are prepared for the equipment from divergent fields of technology that the plant consists of, such as mechanical process equipment, rotating equipment (pumps, compressors etc.), automation and so on. When determining the quality metrics with conformance requirements, they have a clarifying effect on quality control since the quality requirements are easily quantified and, therefore, measurable. In process industry projects, examples of conformance requirements are, e.g. specified Non-Destructive Testing scope for certain equipment or surface treatment requirements where the thickness of the paint coating is defined in a definite value.

Durability expresses the product’s ability to withstand the wearing and damaging effects caused by the conditions present during the use of a product. In a process plant, process piping, process equipment, pumps, pressure vessels etc., need to be able to cope with the conditions such as chemicals used in the process, pressure and temperature conditions, stresses in the structures and external and internal corrosion, along with others. Therefore the proper analysis of the conditions affecting the durability is obligatory and decent solutions to confront them, e.g. by adequate material selection, shall be used. The solutions for encountering durability issues need to be as optimised as possible to meet the expected lifetime of a product when it comes to the financial aspect.

Process plants typically comprise a great amount of equipment with deviating demand for service and maintenance. To ensure stable operation for the process plant for its designed lifetime, the required maintenance/service operations need to be taken into account in the design. **Serviceability** is a dimension of quality that illustrates the ease of repair for a product, which could be measured, e.g. by costs resulting from maintenance operations and by their complexity and amplitude.

Aesthetics might not play that big role in the process industry when compared to interior design and the automotive industry since the focus group of the end users tend to prioritise the functionality of a product over its looks, sound and other sensory characteristics. Even though aesthetics might not be that highly prioritised in the process industry sector product design, it may still have the potential to provide additional value for the product, and it can have a positive effect when building the brand image for a particular supplier or engineering contractor. When the customer is in the process of making the buying decision, it might give value to an engineering company which is known for, e.g. aesthetically well-executed plant and piping layouts in addition to their satisfactory functioning.

Perceived Quality is strongly connected with the brand image of a product. Perceived quality is based on the customers' understanding of the product's decency and how they associate it, e.g. with some particular brand. This image of quality aspects and goodness related to a particular brand, trademark or supplier regularly rests on previous experiences, product/brand recognition and awareness, and commonly shared knowledge between the end users.

2.1.2 Service Quality Dimensions

Dimensions of service quality come into play when an engineering company offers design services in the form of a project with a considerable amount of customer involvement that generally causes wide variation. For this reason, service quality can be more challenging to define than product quality. According to Forster (2017, p. 29), despite services and production sharing many attributes, services tend to have a more complex set of attributes involved. For instance, the end user of a product, such as the operating personnel of process equipment, will predictably be satisfied with the equipment if it is functioning properly, even though the manufacturing organisation would have had any internal issues during the manufacturing process. However, the personnel of the end-user organisation who have been involved in the project where the engineering company had been providing the procurement services for that same process equipment, and during the project there has arisen difficulties in co-operation between the engineering company and the end user organisation, may result to dissatisfaction among the end user project personnel and therefore they may consider co-operating with another organisation in the future projects. Therefore it is necessary to understand the basic concepts of service quality dimensions when providing services in association with process plant implementation projects.

2.2 Quality Management

2.2.1 The Three spheres of Quality

Foster (2017, pp. 40-42) indicates one approach to conceptualising the field of quality management as the three spheres of quality. Figure 2 illustrates the three main functions and their overlapping as three spheres, which are Quality Management, Quality Control and Quality Assurance.

Figure 2 Three Spheres of Quality

According to Foster, **quality management** includes all the management processes that overarch and link together the activities of quality assurance and quality control (Foster, 2017, p. 41). Foster presents a viewpoint of quality management as an integrative function, where the responsibility for the overall quality does not lie only on quality managers, but instead, the responsibility is shared between the whole managerial body of the organisation. When quality management is organised and structured according to Forster's aspect, a number of managers, supervisors, and employees take part in quality management activities, such as:

- Design work to establish an organisational system to reinforce quality ideals,

- Assisting the progress of organisational communication,
- Creating an organisational quality culture, and
- Quality improvement planning (2017, p. 42)

In Rose's approach (2014, p. 49), the concept of quality management combines to include four elements based on the definitions of the PMBOK® Guide and the so-called The Juran Trilogy, known as Quality Trilogy by Dr Joseph M. Juran. Rose determines quality management to cover the functions of quality planning, quality assurance, quality control and quality improvement. Rose agrees with the definition of PMBOK® *Guide* 5th edition that project quality management "…includes the processes and activities of the performing organisation that determine quality policies, objectives and responsibilities so that the project will satisfy the needs for which it was undertaken." He finds the definition to be sufficiently general to comprise the needs of a project in terms of its triple constraint: time, cost and scope.

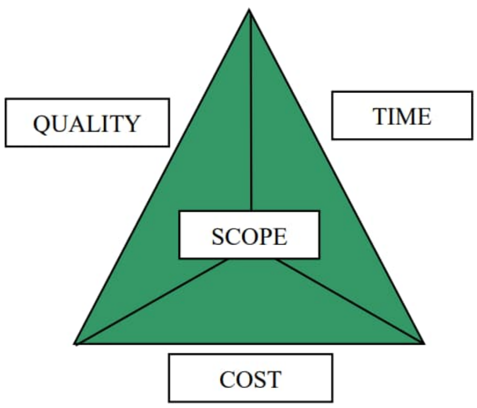

Figure 3. The traditional iron triangle (Caccamese & Damiano, 2012, p. 4)

Additionally, in terms of the defined requirements, he finds it to also essential to cover the needs of the product or customers of the project. On the basis of process costs, project quality management is connected with overall organisational quality management (Rose, 2014, p. 50). In figure 3, the "iron triangle" identifies the integrative role of project management, where these diverse constraints require identification, negotiation, mediation and integration in the light of the on-carried project (Caccamese & Damiano, 2012, p. 4).

2.2.2 Quality Planning

The quality Management planning process is defined in the 5th edition of *PMBOK® Guide* as ”The process of identifying quality requirements and/or standards for the project and its deliverables and documenting how the project will demonstrate compliance with quality requirements” (Project Management Institute, 2013; Rose, 2014, p. 50). To implement the ideology of quality being ”*planned* in, not *inspected* in”, the quality management planning process serves as a fundamental element for the project. The deliverable production process in the project shall preferably be set to use conformance and prevention to achieve an acceptable degree of quality, and this can be facilitated through planning so that the quality is designed and built into the processes. When the organisation is planning the quality management system, the risks and opportunities that need to be addressed shall be considered (European Committee for Standardization CEN, 2015). If the project quality relies on inspection and correction, it may result in unwanted outcomes, e.g. in terms of quality-related costs, and this can be justified with theories of Boehm’s Cost of Change curve and Lundvall-Juran’s Cost of Quality (COQ) model, which will be demonstrated later in this document.

Tom Kendrick (2010, pp. 179-180) proposes that the aim of quality planning is in the project planning phase to produce quantified project standards and objectives that the explicit plans support. Quality planning consists of defining the measurable standards for the project results that are identified to be valuable for the subject stakeholders and determining the steps and procedures for achieving them. In this context, Quality planning is closely related to project scope management, considering the primary goal of project quality management, which is to define and deliver realistic project deliverables.

The first step in quality planning is to determine the customer requirements to such a degree that all the relevant stakeholders have a clear understanding of them, with as little room left for interpretation as possible. For customer and stakeholder expectation management to be successful, quality planning plays an important role in achieving it. Kendrick (2010, p. 179) suggests exploiting techniques such as customer interviews, product benchmarking and market research to conclude a profound requirements collection.

The quantitative value of the needs from the customer's point of view must be determined thoroughly to enable the prioritisation of needs. It is typical for projects that limited resources need to be utilised as effectively as possible, so it is essential to prioritise the tasks and the receivers of one’s output. Rose (2014, pp. 54-65) presents a simple three-step method for prioritising the customers and their requirements by using an L-shaped matrix, where the customers are first compared between each other to discover a quantitative value for each customer that indicates their comparative importance. This method is also applicable for prioritisation purposes in general for other applications. The first step is to rank the customers. The evaluated customers may be external, internal or even hidden. External customers are the most obvious ones (suppliers, paying customers, i.e. the receiving organisation and end users). Internal customers can be found inside the project organisation, that is, for example, organisational elements such as project teams and, again, in the context of process plant design projects, the design teams representing different disciplines. The L-shaped matrix evaluation method can be utilised, e.g. when prioritising the inputs and outputs between the project teams from different disciplines (mechanical, process, automation etc.). Figure 3 presents how the evaluation can be proceeded by giving a value for the importance of one specific customer when compared to another. In the figure, customer A on the vertical column is compared to customer B on the horizontal column, and the evaluating party finds customer A to be more important, which is indicated by a value of 5.

	A	B	C	D	E	F	Row Total	Relative Dec. Value
A		5	1	10	1/5	1/5	16.4	0.21
B	1/5		1/5	1	1	5	7.4	0.09
C	1	5		1/5	1/10	5	11.3	0.14
D	1/10	1	5		1/5	1	7.3	0.09
E	5	1	10	5		1/10	21.1	0.26
F	5	1/5	1/5	1	10		16.4	0.21
						Grand Total	79.9	

Key:
10 Much more important
5 More important
1 Equally important
1/5 Less important
1/10 Much less important

Figure 4 L-shaped matrix for customer evaluation by Rose (2014, p. 55).

Similarly, the same L-shaped matrix evaluation can be conducted in the second step for the requirements set by the customers. Figure 4 presents the requirement evaluation of the customer “State of Dakota,” where five different requirements are set in order according to their importance to the evaluated customer. Again, in the context of a process plant design project, the evaluation can also be done for internal customers, e.g. design engineer teams representing different disciplines and their requirements.

Requirements Prioritization, State of Dakota View	Access	Speed	Reliability	Enviro-Friendly	Regulatory Compliant	Row Total	Relative Decimal Value
Access		5	1	0.2	0.2	6.4	0.14
Speed	0.2		0.2	0.2	0.2	0.8	0.02
Reliability	1	5		0.2	0.2	6.4	0.14
Environmentally Friendly	5	5	5		1	16.0	0.35
Regulatory Compliant	5	5	5	1		16.0	0.35
					Grand Total	45.6	

Figure 5 customer-specific prioritisation of requirements (Rose, 2014, p. 60)

In the last phase, when the evaluation has been done for all the evaluated customers in terms of the same requirements that were included in the evaluation, the results can be combined to form an integrated prioritisation matrix of requirements and customers that indicates the holistic requirement-specific valuing among the evaluated customers or stakeholders according to which the allocating of resources can be aligned, e.g. in terms of cost of quality expenditures in prevention and appraisal activities. After the prioritisation of the requirements, the cost of achieving the requirements shall be determined and based on that; the cost/benefit analysis is recommended to be conducted to evaluate if it is appropriate to fulfil the requirements.

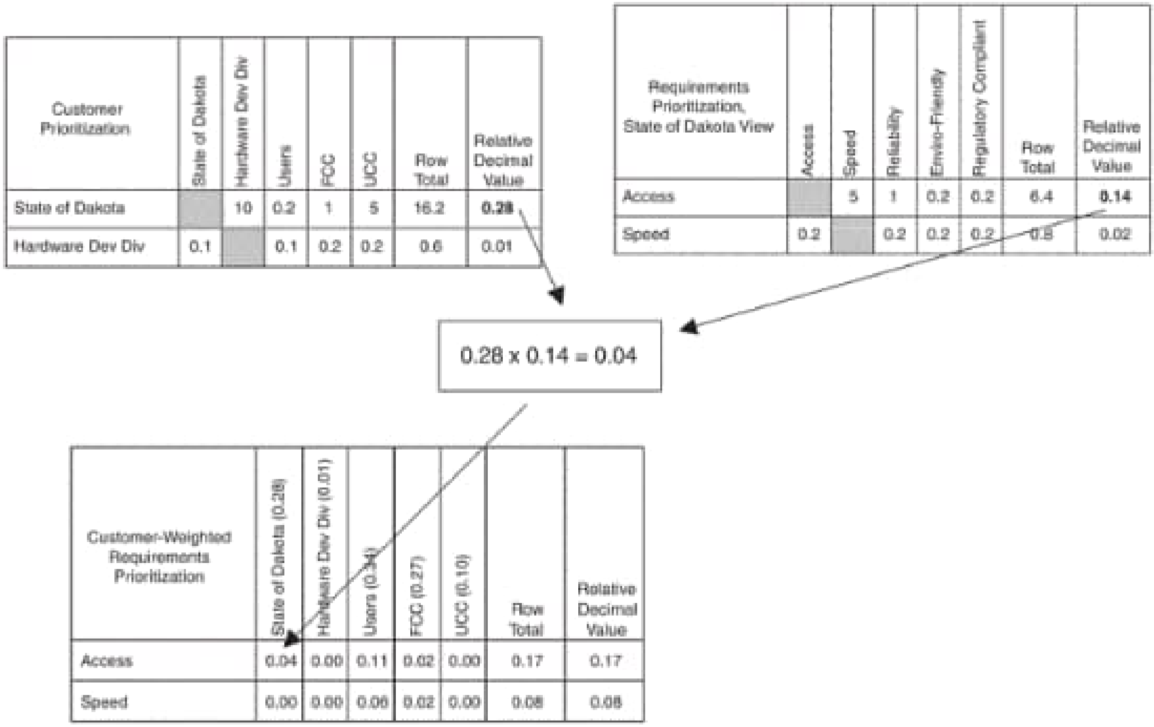

Figure 6 Forming of an integrated customer-weighted prioritisation matrix of requirements (Rose, 2014, p. 64).

After the requirements have been prioritised and verified that they are appropriate in terms of quality, the documentation of the specifications shall follow. It is part of the project's scope definition to take into account the defined specifications that are supplemented by the chosen applicable standards and organisational quality policies and requirements that are applicable for the deliverable to be specified. When the specifications are prepared, the quantitative definitions shall be preferred to avoid defects occurring due to misinterpretation and lack of detailed information. In terms of scope definition, it is also crucial to define detailed final approval criteria in the early phases of a project and to get approval from the relevant stakeholders and customers about the acceptance tests. In the process of plant execution projects, the majority of the acceptance criteria fulfilment evaluation activities are conducted in the commissioning phase, where, e.g. the plant's ability to attain the design limits is reviewed. Again it is essential not to leave room for interpretation in the acceptance criteria to enable the project closing to be fluent.

2.2.3 Quality Management Plan

A quality management plan serves as a fundamental document for project quality and is typically included as a subordinate management plan among several other plans within the main project plan. Rose (2014, p. 50) points out that when the quality management plans are drawn up in an appropriate form to function as a facilitating tool for project management, they end up being more described than they typically are presented in the project management literature. Rose also highlights that typically every project is a unique entity, and if project managers seek to utilise an existing template for a project quality management plan, it may disallow the application of the precise aspects that are inseparable elements due to their uniqueness in the project. Rose finds it more appropriate that for every project, an individual quality management plan is crafted to fit the needs of the project instead of making a format of a published template. However, in terms of maintaining a systematic approach in project planning and project instructions, an advantage can be taken of templates if they are structured in the way that they function as guiding and instructing, and they challenge the party preparing the document to think and take into account the necessary aspects that can be found in the typical projects that the organisation takes part in general, but also the unique valuable aspects for the specific project to be executed.

When the situation is brought back into the context of the process plant project execution-oriented organisation, plenty of similarities can be identified between the projects, but they always include variations also. The basic structure of the typical process plant implementation project is the same, that covers the phases of engineering, procurement, construction and commissioning and the distribution of the responsibilities in them is done according to the contracting and work breakdown structure (WBS) between the organisations participating in their execution. Comparable and even identical tasks can be found in every process plant project: engineering of the process and the equipment, procurement according to specifications, construction work of the plant and so forth. Nevertheless, variation might occur, e.g. from the unique new innovative technology utilised in the process that needs to be taken into account in process and equipment engineering, updated modern engineering tools and software, unfamiliar suppliers of equipment, local legislation, competence and size of the project teams and so on. The effect of these contributory factors is essential to be evaluated and taken into account in the quality management plan.

7th edition of PMBOK® *Guide* defines a Quality management plan as "…a component of the project or program management plan that describes how applicable policies, procedures. And guidelines will be implemented to achieve the quality objectives (Institute, P. M., 2021,

p. 186). Rose (2014, p. 50) introduces a general framework of a quality management plan that consists of four key elements, which include the quality policy of the organisation and answers to the three following questions: who is in charge, where are we going and how are we going to get there? According to ISO 10006 standard: “the quality plan should identify the activities and resources necessary for achieving the quality objectives of the project. The quality plan should be incorporated into, or referenced in, the project management plan (the International Organization for Standardization, 2018, p. 10).”

2.2.4 The Motivating Factor of Engagement in Quality Planning

It could also be beneficial for the project management in terms of project planning if the quality management plan would also evoke engagement of the project teams to come up with ideas or even innovative solutions that they can utilise to promote their performance on the basis of quality. This could be put into practice, for example, by engaging the project teams by involving them in the quality planning phase, where every team would define monitorable quality metrics relevant to their work process. It could be determined in the quality management plan that every team from different disciplines shall prepare a discipline-specific quality plan that would be a subdocument of the main quality plan, and at least the project management or even the whole project organisation would have access to it. To consider the uniqueness of every project, this discipline-specific document could be structured in a way that guides and challenges the personnel to think about the object and the work process from a quality perspective. This could be done, for example, with an open questions form that would be tailored to fit the discipline. Based on this questionnaire that is answered by the selected representatives of the team, or even better, all the members of the team, a holistic collective discipline-specific quality management plan could be formed that, in conclusion, sets the quality metrics, i.e. KPIs that will be monitored during the project. Of course, the project management shall approve the metrics that support the project performance.

Bergström & Martínez (2016, p. 67) came up in their study that when employees have the ability to make decisions related to their work, they most likely experience being more connected with the task they are performing, which will enhance their engagement. If they experience that they cannot contribute to the task they are performing, it may result in lacking motivation. Additionally, Bergström & Martínez pointed out in their findings with manager interviews that managers tend to agree with the expectancy theory that states that employees will be motivated to contribute with their inputs and participate in decision-making only if they experience that their efforts will be valuable in achieving a certain level of performance. The motivating factor of the engagement shall never be undervalued, and in this case, it could improve the performance in terms of quality. That would be another matter if the project team would be rewarded appropriately if the KPIs that they themselves have defined (and approved by the management) would achieve and sustain a satisfactory level during the project resulting in enhanced performance.

2.2.5 Quality Assurance

Quality assurance (QA) incorporates the planned and systematic activities aiming for the fulfilment of the quality requirements within a project (Hickson & Owen, 2022, p. 472). In other words, in the QA process, tools are harnessed for the use of the quality control process in monitoring quality criteria and implementing corrective measures. In the process industry project context, by the QA process, the methods for design-related management of the quality of services, assembly of materials and equipment on-site and off-site surveillance, delivered materials quality management, oversight of engineering, procurement and construction services are set up.

2.2.6 Quality Control

Foster defines the term "**quality control (QC)**" as "the process relating to gathering process data and analysing the data to determine whether the process exhibits non-random variation", where non-random variation is defined as variation that shall be controllable and again random variation uncontrollable variation (2017, pp. 455, 458). The sphere of quality control represents the control process that is based on the scientific method, where the phases of analysis, relation and generalisation take place. In the *analysis* phase, a closer look is taken into the deliverable production process, and the fundamental elements of the process are identified and separated to enable a comprehensive assessment. *The relation* phase covers the efforts to improve the understanding of these fundamental elements of the process, and eventually, the *generalisation* phase aims to perceive the effect of these interrelationships on the integrated phenomenon of quality that is being studied. Quality control covers activities such as:

- Monitoring the efficiency and stability of the process,
- Process performance measurement,
- Process variability monitoring and adjustment,
- Process optimisation to measures to be as nominal achievable,
- Development and maintenance of control charts and
- Execution of acceptance sampling (Foster, 2017, p. 40).

Kenneth Rose cites the definition of quality control from the 5th edition of the PMBOK Guide in his publication: ”The process of monitoring and recording results of executing the quality activities to assess performance and recommend necessary changes” (Rose, 2014, p. 83). Rose also points out the important purposes that quality control activities, such as monitoring specific project results serve.

If the conducted monitoring verifies that the results do not have variance present in them and the results are aligned with the specifications, it serves as feedback for the project team that the process is set correctly and the performance is proceeding as intended. Correspondingly monitoring the specific project results may indicate the need for corrective measures in the process, e.g. when the specified attributes in the design, product or generally in the deliverable are not fulfilled respectively. When the variance is identified in the process, to perform the corrective actions profitably and to prevent the variance from reoccurring, it is essential to identify the originating source causing the variance in the deliverable quality.

Again, in the process plant implementation project, an example of this kind of undesirable variance can be, e.g. that in piping design, the pipe routing is continuously designed so that the routing design can not pass the pipe stress calculations that, result in a continuous loop of proceeding to reroute the piping design to pass the stress calculations. To avoid this kind of ineffective utilisation of resources, with the aid of regular quality control measures, this sort of issue can be solved. With this example case given, the quality control activities and tools used in this specific case could be, e.g. regular design reviews, where defects in the design quality are identified, root causes that contribute to the defects occur are diagnosed and based on these findings, the corrective actions will be defined. Contributory factors such as insufficient instructions can be the root cause of making these types of events occur as a consequence, and as a corrective action, the instructions shall be revised as a response to inadmissible variance in the deliverable quality. The revised instructions shall be then updated with more specific information related to the issue, which can be, for example, that due to special material used in piping while extraordinary process conditions are present, the pipe routing, design and calculation shall follow specified methods that have been approved among the key personnel in the project teams, and then correspondingly these revised instructions shall be communicated effectively to all the related stakeholders, in this case at least the piping design and stress analysis teams, to implement them successfully to reduce the variance in the quality of the produced deliverables.

According to Rose’s (2014) findings, the monitoring of the specific project results as part of quality control also works as a feedback tool about the quality assurance process applied in the project. Quality audits are one of the tools used in projects to analyse the suitability of the quality assurance activities applied to the project. In quality audits, the data collected by quality control activities are analysed. If the analysis indicates that the performance does not conform to the specifications, it also indicates that the quality assurance activities that shall function to ensure that the performance would be conforming are not fulfilling their intended duty without gaps. If such a disadvantage is detected, the data that the quality control provides shall be investigated in detail to determine the shortcoming and further readjust the quality assurance activities to encounter the findings of the investigated data. Based on all this, the quality assurance plan of the project shall then be updated, and its capability would be then analysed in the next quality audit that is performed in accordance with the project’s quality management plan that preferably determines the interval of the audits.

When again bringing these previously mentioned activities to the context of the previously given example in piping design, would this then give a more concrete example of how these methods can be applied in the process plant design project. For example, if the project team has set a quality metric as a target that 70 % of the designed pipelines shall pass the stress analysis in the first attempt, continuous monitoring of this target value, i.e., KPI, is performed that operates as an indicator if the performance requires a reaction from the team. If such a case happens to occur that the performance level (KPI) fails to achieve its target continuously, it provides feedback about the appropriateness of the quality assurance activities related to the piping design by pointing out that they need to be improved. In this case, these improvements can be based on further investigation of the stress analysis of the piping by identifying the most problematic phases of the work and objects, e.g., if there happens to occur repetitively similar parts of piping in the piping and pipe routing design causes most of the failures in the stress analysis of the piping, and based on these findings, as a corrective action, the quality assurance activities related to the piping design and routing can be updated. A concrete example of this kind of improvement, in this case, could be that the piping design team has to use internally a quality checklist which now would have more detailed instructions on how the design review should be conducted the way that it takes into account the problematic work phases and parts in the piping properly that have caused trouble downstream, in this case, the stress analysis phase.

2.2.7 Quality Improvement

Rose (2014, p. 89) introduces the concept of quality journey, where quality improvement is the finalising element, as seen in figure 6. In the case company's general instructions, Plan-Do-Check-Act (PDCA) cycle is mentioned as the basis for continuous quality improvement (Case Company, 2020). PDCA process was pioneered by W.E. Deming (Foster, 2017, p. 456).

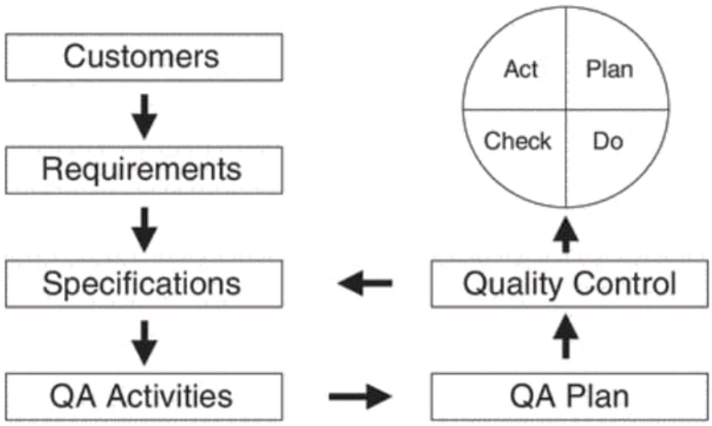

Figure 7 Quality journey. (Rose, 2014, p. 89)

2.3 Quality Management in Projects

A Guide to the Project Management Body of Knowledge (PMBOK® Guide) and the Standard for Project Management is a flagship publication by Project Management Institute (PMI), and it is a widely used resource of knowledge in the project management industry. The Standard for Project Management is an approved American national standard by American National Standard Institution (ANSI). During the development of the latest edition of this publication, PMI actively engaged with global stakeholders in the project management sector on their experiences with the previous editions of the publication. One key point that was pointed out by the feedback was to sense the information and the needs of the stakeholders and to provide revised complementary content supporting the practical application. Based on that feedback, the content of the latest edition was formed. It presents essential information on project management that is applicable to projects and organisations of varying sizes, industries, locations and so forth, and it outlines the framework for activities that typically exist in the project environment.

2.3.1 System for Value Delivery

Projects are part of a system for value delivery, which consists of a set of business activities by which the aim is to deliver value for all the stakeholders associated within the system. Projects are temporary in their nature, with a beginning and an end of the work in the projects, and they are performed to establish a unique product, service or result. Typically the aim is to grow, maintain or develop the target organisation with all the relevant managed activities included in the organization’s portfolio, which the projects besides programs, subsidiary portfolios and operations are part of. With the outcomes of the projects, the receiving organisations are expected to have an improved capability in performing in their business environment, and the outcomes of the projects are intended to function the way that the organizations would be capable of achieving their strategic objectives. E.g., if an industrial operator has identified that they could utilize new potential resources in the sector they are operating, it can set up a project for utilizing them. The outcome of the project can be, for example, a new process plant that produces products that the industrial operator identifies as valuable in their product portfolio, which it maintains in alignment with its strategic objectives. This project outcome is supposed to bring value for the organization that had invested in the project that would result in a product which's functions the organization would be able to use to gain benefit less the cost achieving the benefit when metered financially (Institute, P. M., 2021, pp. 4-5).

It is typical that projects of this scale require a great number of manpower to complete them, and therefore external resources in addition to the industrial operator's own organization are necessary. At this point, engineering companies step into the picture to provide services in engineering project execution. Engineering companies are the external resources for their customer organizations equipped with the knowledge, skills, tools, and techniques to be applied in the project to meet its goals, and naturally, they provide the required labour force as a project team for conducting the project activities where the labour force for the project management is also included to guide the project work towards the intended outcomes. Project managers are the persons leading the project teams by performing a variety of functions, such as facilitating the project's teamwork and managing the processes of the project in the way that the planned outcomes will be met, e.g. in terms of quality.

To ensure that the workflow is smooth, the encountered issues will be managed, and support for decision-making is provided, a governance system to operate alongside the value delivery system is essential to furnish with a framework with functions and processes for guiding purposes of activities performed within the value delivery system where projects are performed. The elements of the governance framework can consist of capabilities like oversight, control, value assessment and decision-making. When the projects are producing deliverables within the value delivery system, the changes, issues and risks in the environment that may occur can be evaluated with the aid of the integrated structure that the governance system provides. To establish a well-functioning project organization and well-controlled project workflow, in terms of project governance, it is vital to define the authority to approve changes and make other business decisions related to the project (Institute, P. M., 2021, p. 12). Again, in the context of an engineering company delivering design and construction for a process plant, there may be a case where an additional budget, e.g. for additional resources to cope with encountered challenges, is required to achieve the set requirements for quality. When there exists a predefined process in the project governance system for cases like this, the continuity of work and progress remains stable, and simultaneously the control of the work and its scope is kept up. The event described above falls under the concept of “Change Management”, which is also a vital part of project management when performing quality requirement-achieving projects.

The Standard for Project Management provides a couple of examples of functions commonly associated with projects. The project delivery is driven by people by implementing necessary functions for the project that enable effective and efficient work progress. For a successful project, it is highly essential that the collective work effort is coordinated accordingly (Institute, P. M., 2021, p. 12).

It is typical for the engineering companies that execute projects in the process industry sector that the coordination is centralized with the leadership and guidance of a designated project manager, and the project organization includes self-organized project teams that represent the different disciplines involved in the process plant design and construction. Regardless of how the coordination is organized in the project organization, to establish successful outcomes, it is part of good practice to implement supportive leadership models and to perform continuous engagement between project teams and other stakeholders (Institute, P. M., 2021, p. 12).

Project Management Institute (2021, p.13) mentions **providing oversight and coordination** as a first example of functions commonly found on projects that are performed by people in roles in which, generally by orchestrating the project work, the aim is to help the project team to achieve intended outcomes of the project. This function consists of activities such as leading the planning, monitoring, controlling, evaluation and analysis. For instance, when the progress of the work is monitored during the project with clearly illustratable measurables that are in relation to the objectives in the scope of a project (e.g. hours used for design vs the amount of equipment/piping etc., to be designed) and this information is then made easily accessible for all the relevant parties concerning that specific measurable, would this allow effective reaction for the project coordination, e.g. if some improvements in project performance might occur. Establishing effective quantifiable measures i.,e. Key Performance Indicators (KPIs), which would be monitored in real-time during the progress of the project, would allow the project team to use this information which would preferably be made easily accessible to make timely decisions and take effective actions (Institute, P. M., 2021, p. 95).

2.3.2 Build Quality into Processes and Deliverables

The Standard for Project Management lists a set of principles that are meant to provide guidance for the behaviour of practitioners participating in projects. One of the listed principles is to "Build Quality into Processes and Deliverables (Institute, P. M. (2021), p. 21) ". In terms of quality, it is essential to keep up the quality in the focal point that produces deliverables that meet the project objectives and line up with the needs, uses and acceptance requirements detailed by relevant stakeholders. For that reason, it is fundamental to ensure that the processes used in the project are convenient and as effective as possible for producing deliverables that meet the acceptance criteria, fulfil the project and product requirements and satisfy stakeholders' expectations. In this context, the expectations should not be mixed with assumptions since there should be left as little room as possible for interpretation when defining the acceptance criteria and requirements for the deliverables produced in the project. Instead, the acceptance criteria shall be measurable and quantifiable to the most obtainable degree possible (QA/QC in construction management, 2022).

Quality is measured within the project teams by using transparent metrics and acceptance criteria that are established in accordance with the agreed requirements set by the relevant stakeholders. When the metrics are defined so that they are easy to interpret and follow up, the aid that they provide for the project work is maximized.

A requirement is a state that is obligatory to take place in the deliverable, either product, service or other delivered solution, to satisfy an identified need. Stakeholders, organizational policies, a contract, regulatory bodies and standards together are the typical sources which set the requirements for the contextual deliverable within a specific industry. For instance, if an industrial operator as a customer orders the design and construction of a process plant from an engineering company, typically, the process plants include pressure equipment that needs to fulfil requirements set by the local legislation, which are fulfilled by using the correct standards that are harmonized with the regulation for the design and manufacturing of the equipment. Quality in this context is associated with the acceptance criteria that are set in these standards and specifications that are applied in the project for the pressure equipment, e.g. that the equipment shall be tested according to the design code. These criteria should be updated as the project progresses, as experimentation and prioritization take place and verified as part of the approval process (Institute, P. M., 2021, pp. 47-49).

Quality is firmly linked with the activities and approaches used in the project in producing the deliverables. Project teams evaluate the quality of the deliverables that they are creating through inspection and testing, and the methods and processes used in the creation of deliverables are evaluated through audits and reviews. In both occasions, with quality-related activities, the aim is to prevent and detect defects and errors that may cause the excess need for resources to fix them or cause reduced performance in the deliverable (Institute, P. M., 2021, p. 48).

When the tools and methods are set accordingly for the project to ensure quality, it will enhance the optimization of effort and resources used to produce the deliverables that meet the quality requirements. The tools for quality assurance can consist, e.g. of constant collection of measured data that is aligned with the accordingly set quality metrics and with the information produced by this and then after prioritizing shared for the well-targeted parties involved in the corresponding operations within the project. With the technology and tools that we have available nowadays, the collecting, processing and distribution of data can be very effective if it is done correctly, and it can give significant support for the project performance.

It can be stated that there is always room for improvement in how communication is organized in a project work environment and in work life in general. In the nowadays work environment, the production of data and information tends to be on a quite high volume, so the processing and distribution of the data shall be optimized by prioritising it and then distributing it to the well-targeted audience, e.g. the project team that represents one discipline in the design work. Nowadays, technology can be adjusted to serve project work in the way that communicated prioritized information is available for the corresponding parties in real-time, which would allow the project teams to adjust their work according to it. This would allow the project teams to perform effectively, and it would also have a positive impact on quality.

The Quality activities that are performed during the project aim to ensure that the deliverables reach the satisfactory degree of requirements set by the customer and other stakeholders in the most straightforward way. The intention of the performed quality activities is to optimize the use of resources and minimize their waste while simultaneously reinforcing the feasibility of attaining the desired outcome. When the quality activities are in line, it would result in that the deliverables are able to reach the phase of delivery as quickly and effectively as possible, but simultaneously the defects and errors are avoided or at least detected that they can be fixed in the early phases when they could occur to prevent the use of resources for resulting rework and scrap in the later phases. Whether there exists a clear statement of quality-related requirements before the efforts for producing deliverables initiate or the requirements are listed progressively and incrementally and updated during the progress of project work, the quality activities serve and support the project work the same way (Institute, P. M., 2021, p. 49).

Quality management processes and practices are a vital part of a successful project, and with the help that they provide, the project teams can produce deliverables that meet the goals set for the project and follow the expectations, uses and acceptance criteria introduced by the receiving organisation and related stakeholders. Continuing focus and observation on quality in project processes and deliverables constitutes positive outcomes, such as:

- Project deliverables that match the purpose as determined by acceptance criteria,
- project deliverables that conform with the stakeholder expectations and business objectives,
- project deliverables with a minimum amount of imperfections, if any,
- timely or expedited delivery,
- improved cost control,
- increase in the quality of the final delivered product,
- reduction in the amount of rework and scrap,
- declined amount in a customer complaint,
- valuable supply chain integration,
- advanced productivity,
- boost the collective project team morale and fulfilment,
- solid service delivery,
- enhanced decision-making, and
- constantly corrected processes (Institute, P. M., 2021, p. 49).

2.3.3 Delivery Performance Domain

The Delivery Performance Domain is a performance domain that demonstrates the activities and functions related to delivering the scope and quality that the project was set out to realize. With the effective execution of the delivery performance domain, the desired outcomes of the project will be facilitated with a more focused and timely work effort that results in a contribution to business objectives and promotion of the strategy of the receiving organization. It also contributes to the realization of the project benefits within the time frame they were planned, clarifying the understanding of the requirements among the project team and stakeholders' acceptance and satisfaction with the project deliverables that will drive the intended outcomes, such as penetrating the market with a high volume of the available supply of the product produced in a delivered well-performing process plant (Institute, P. M., 2021, p. 80).

2.3.4 Quality in the Delivery Performance Domain

Delivery does not only consist of the determination of the scope and requirements. Where the scope and requirements focus only on what needs to be delivered, the performance levels that are necessary to be achieved are the focal points of quality. The specifications concerning quality are typically indicated in the finalisation criteria, the definition of done, the statement of work or prerequisite documentation (Institute, P. M., 2021, p. 87).

The majority of the costs interconnected with quality emerge from the sponsoring organisation and are demonstrated in policies, procedures and work processes since the internal instructions of the sponsoring organization that present guidelines on how the work shall be performed and procedures that determine work processes are ordinarily contained in the sponsoring organization's quality policy. General continuing costs of operation, training and process audit arise by the sponsoring organization, and they are allocated to the performed project. It is essential in projects to find the appropriate level of the costs resulting from the activities, use of resources etc. and balance them in response to the actual demand in terms of the quality of the processes and products (Institute, P. M., 2021, p. 87).

2.3.5 Cost of Quality(COQ)

The cost of quality (COG) is a common methodology used in the wide sector of industries when examining the optimised investment amount in quality-related resources and activities. Professor S. Thomas Foster (2017, p. 113) theorises in his publication a PAF paradigm that explains the quality costs in three broad categories that are again divided into subcategories. The three main categories of the PAF paradigm quality costs are costs resulting from **Prevention, Appraisal** and **Failure**. Project Management Institute (A Guide to the Project Management Knowledge, 2021, p. 88) again subdivides the failure costs into costs arising from **internal failure** and **external failure**.

Prevention costs are obtained to avoid or at least reduce defects and failures in the final deliverable. Foster (2017, p. 113) states that prevention costs are the most subjective of all the cost categories. Prevention costs are connected with the design, implementation and maintenance of the quality management system, and chronologically in the project life cycle, they are planned and acquired before the actual operation. Costs resulting from quality problem prevention consist of activities such as training, quality planning, process engineering and so forth. Costs emerging from prevention and appraisal activities are the costs associated with compliance with the requirements, and naturally, failure costs are associated with noncompliance. Prevention costs include costs emerging from functions such as:

- Defect data measurement and analysis for purposes of corrective actions,
- Documented quality system: setting up, planning and maintaining,
- Quality planning: production conformance establishment to procedures of design specifications, test equipment and test procedure design, creation of plans for quality, reliability and operation,
- Product or service requirements, e.g. determining the specifications for material, process, finished product, and service received.

Appraisal costs are the costs that result from the functions which directly measure and monitor quality for the determination to which degree the quality requirements are met. Evaluation of purchased materials and processes, products and services for conformity ensuring purposes with specifications, are the functions that associate with appraisal costs. These functions are, e.g.:

- Inspection and tests by inspectors and noninspectors,
- On-site performance tests,
- Internal tests and design reviews,
- Quality assurance of suppliers and supplier assessment, and
- Quality system audits (Foster, 2017, p. 113, Institute, P. M., 2021, p. 88).

Internal Failure costs arise due to the defect finding and correcting activities during the project prior to deliverables received by the end user. Internal failure costs are consequently induced when the design quality standards are not met in the results of project work. These costs include, for example:

- Costs resulting from troubleshooting,
- Corrective action to deliverable (redesign, repair),
- Waste: e.g. when unnecessary work is performed due to poor organisation or communication
- Failure analysis, such as required activities for the internal product or service failure cause identification.

External failure costs are related to the imperfections that occur after the end-user has taken possession of a product, and restorative or corrective measures are identified to be necessary since the unfulfilled design quality standards are not detected in the earlier phases. To recognise these failures holistically, it is necessary to take into account the conditions that can occur with varying likelihoods while the delivered product is in operation for a practically considered period after the handover. Examples of when external failure costs take place can be events such as:

- Lost of production resulting from problems in the delivered system (i.e. cost of idle time due to missing instructions or material),
- Concessions (additional re-engineering and redesign time with reduced or excluded compensation),
- Warranty claims, e.g. when the products that fail are replaced or reperformed services under guarantee,
- Reputation, where subject to the type and severity of the defects, the public perception and reputation can be harmed.

It is vital for quality cost optimisation of the project deliverables to invest in resources for conducting inspection and review activities in the early phases of development in the project life cycle. If the inspection and review process is organised to follow such a procedure that the defects in the deliverables are likely to be found in the later phases of the project's development, would this result in a prohibitive effect in terms of time and cost due to increased amount of scrap and rework? Additionally, the ripple effect on downstream outputs and stakeholders will affect the quality costs to deviate from their optimal rate (Institute, P. M., 2021, p. 89).

PAF quality cost categorisation is a practical and simple approach to understanding how the costs related to quality are formed. To indicate the trade-offs of quality costs, they can be modelled by applying the law of diminishing marginal returns. This simple economic model states that when the amount of investment in resources targeted to prevention and appraisal activities is increased, this would also increase the conformance of quality. Lundvall-Juran Model can be seen in figure 2 below.

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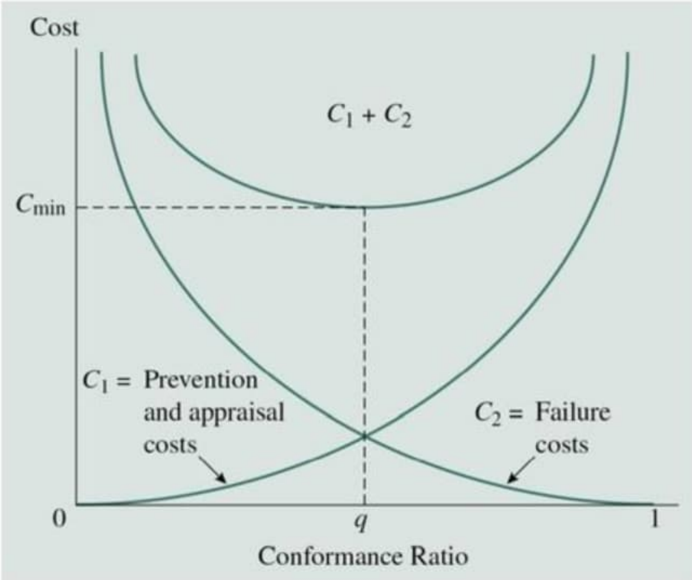

Figure 8 Lundvall-Juran Model (Foster, 2017, p. 116)

For instance, in the manner of the Lundvall-Juran model, the more expenditure is allocated to training and developing the employees, the more benefit is gained. Again in the case of a project where quality planning, e.g. deliverable production conformance establishment to procedures of design specifications and internal tests and design reviews being the activities of prevention and appraisal functions logically increase the prevention and appraisal costs when expenditures are allocated to resources in those functions. If the resources are well and timely organised in the prevention and appraisal functions of a project, they will provide appropriate guidance and constraints for the project work, which would then result, e.g. in a reduced amount of waste in resources by cause of poorly defined and unclear procedures that should be aligned with the quality requirements. When the prevention and appraisal functions of a project are in line, the conformity of the deliverables will most probably be improved, and due to improvement in conformity, the failure costs would also be relatively decreased.

Foster (2017, pp. 38, 116) states that if the theory of the Lundvall-Juran model is true so that there should exist an economic quality level that minimises the quality-related costs, would this be at odds with the ethic of continual improvement proposed by W. Edwards Deming among other. This statement might not holistically take into account the constantly changing environment where organisations from all possible industries operate and where constant improvement activities can be essential to sustain the optimal conformance ratio of quality-related costs. When thinking about the context of a project, there can definitely be an optimal rate of quality costs for every specific project. However, every project is a unique chain of events which are implemented by alternating organisations in the constantly changing environment where contributory factors such as the state-of-the-art solutions of technology and alternating market trends set the need for organisations to adapt to the prevailing situation at each moment, e.g. with the aid from lessons learned from previous projects. Therefore methods of continuous improvement take place to sustain the optimal performance of organisations in general, but also the projects executed by organisations so that they can be executed economically in the most optimal way from the quality cost perspective with the most recent knowledge, skills and technologies available.

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2.3.6 Cost of Change

Commonly the costs resulting from corrective functions to restore identified deficiencies become less cost-efficient the later the deficiencies that require corrective measures are detected in the project life cycle. This is because if the defect is detected in the later phases of a project, e.g. that the equipment is not suitable for operation with the design values the design work was initiated and the design work has already been ongoing with those values, the change in the design typically causes extra work in addition to the now become scrap progress with the initial faulty values. In addition to this, it may also contribute to the increase of costs due to change when the change has an impact on other stakeholders, such as design disciplines. A computer science researcher Dr Barry Boehm discovered in the 1970s that the relation between the average cost resulting from correcting an error and the time that has passed from the point of time when the error causing deliverable had been released from the process it had been produced is exponential where the costs increase exponentially as the time passes (Project Management Institute, Inc., 2022). Figure 3 illustrates this phenomenon as a cost of change curve where the cost of change is indicated as a function of time

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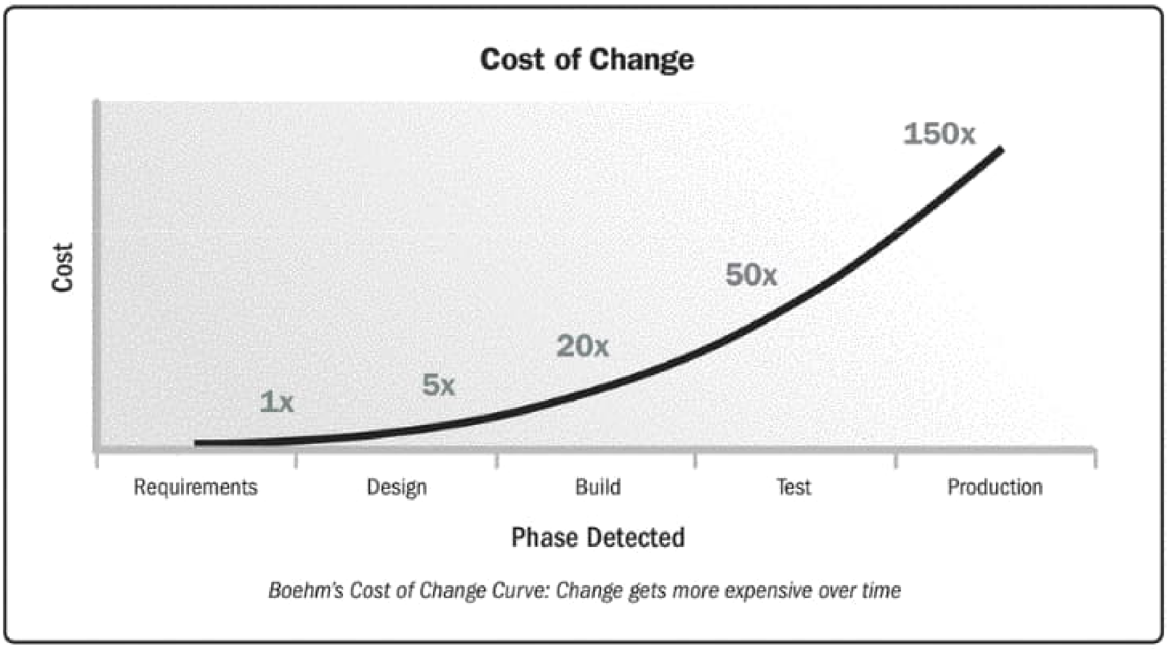

Figure 9 Boehm's Average Cost of Change Curve (Institute, P. M., 2021, p. 90)

In order to avoid incurring excessive costs according to the change cost curve, the project teams shall design the processes to follow the methodology of "built-in quality". PMBOK® Guide (Institute, P. M., 2021, p. 91) gives an example of this approach by quality analysts collaborating with designers and engineers to identify the methods by which the most favourable degree of quality can be achieved during every step in the project life cycle. This method could be, for example, executed in the early phases of the project and based on the identified fitting methods for every process step, the tools and workflow processes can be fixed for the project. These tools and predefined workflow processes can be, e.g. templates, checklists and design review and acceptance procedures, which are utilised during the design progresses and in predefined project milestones.

Proactivity can be stated to be the keyword in quality cost control, and it naturally is more cost-efficient to fix the quality issues between a small group of stakeholders (e.g. between two engineers within one design discipline) related to the specific issue than detecting the fault in design when the equipment has already been manufactured since depending on the equipment the manufacturing time can be relatively long (weeks or even months), and this can have a significant impact to the project schedule (Institute, P. M., 2021, p. 91). That said, it is good to remember that one characteristic of a high-quality project is that the project can be completed within the deadline

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3 Implementation Phase Project Types and Their Main Functions

Implementation projects in the field of process industry consist of engineering, procurement and construction phases. After the feasibility study and basic engineering, when the investment decision is made, the detailed engineering phase initiates. Figure 10 below illustrates one example of the process flow of engineering and procurement between the phases of finalised feasibility study and entering the construction phase.

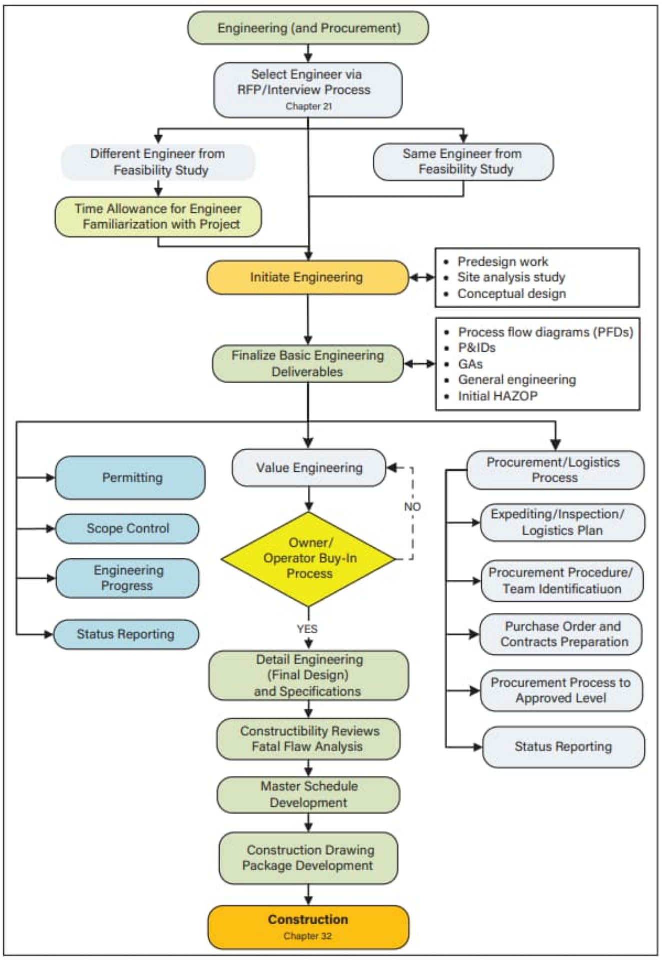

Figure 10 Simplified process flow sheet of main activities between the finalised feasibility study and construction phase (Hickson & Owen, 2022, p. 569).

Depending on the contract between the engineering company and the customer, the defined responsibility of the scope of project functions is determined according to the selected contract type, also known as the delivery model. The discussed delivery models in this chapter are E, EPC and EPCM.

After the feasibility study and basic engineering phases, engineering tasks are first in a row to initiate. Tasks are required to be prioritised according to the determined critical path.

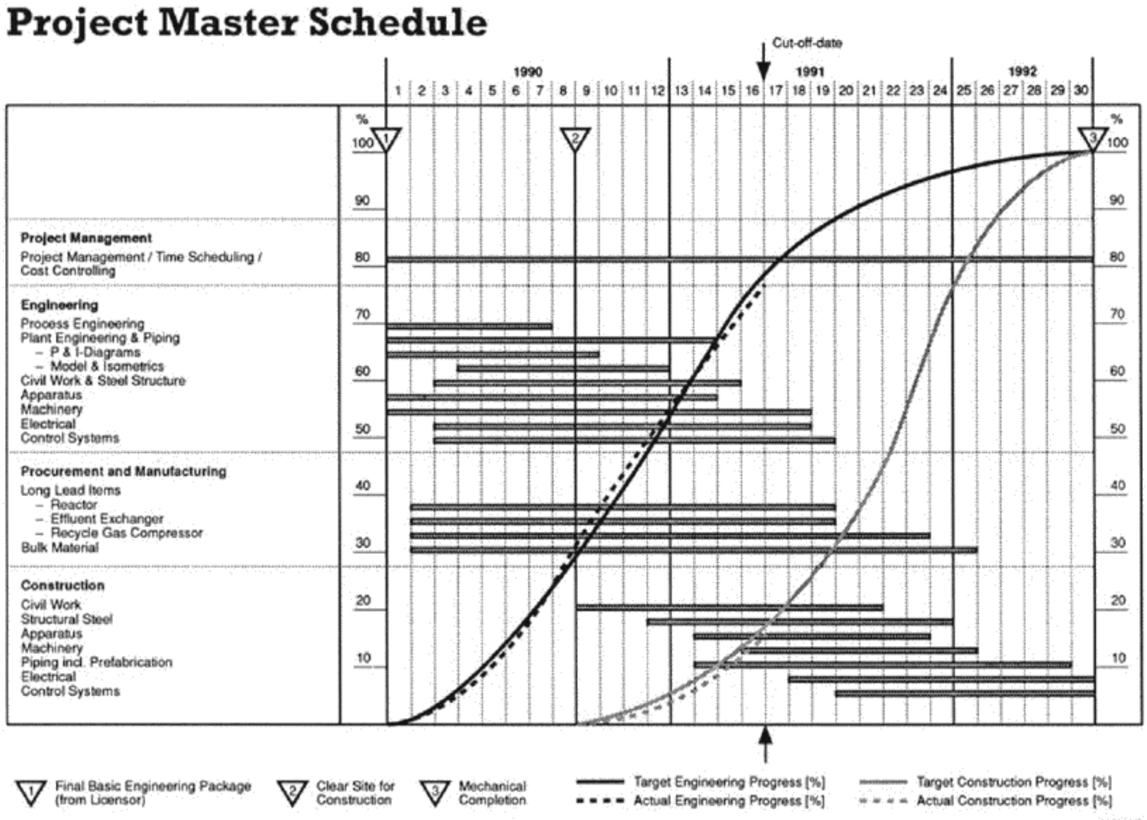

Figure 11 Example of project master schedule (Ullmann, 2005, p. 1057).

Figure 11 above illustrates a typical sketch of an implementation project master schedule. The engineering tasks regarding long lead items are typically prioritised as the first tasks in the early implementation phase due to the lengthy delivery time. The typical installation order of the construction phase is also indicated in figure 11, where civil work is the first to begin, and control systems are the last to be installed.

3.1 Implementation Phase Project Delivery Models

The selected delivery model sets requirements regarding responsibility, and it varies between the contracting parties. For example, when comparing EPC and EPCM delivery models, the EPC contractor experiences higher risk exposure due to contractual arrangements, where the customer only signs a single contract with the EPC contractor, which is responsible for the supervision of the sub-suppliers.

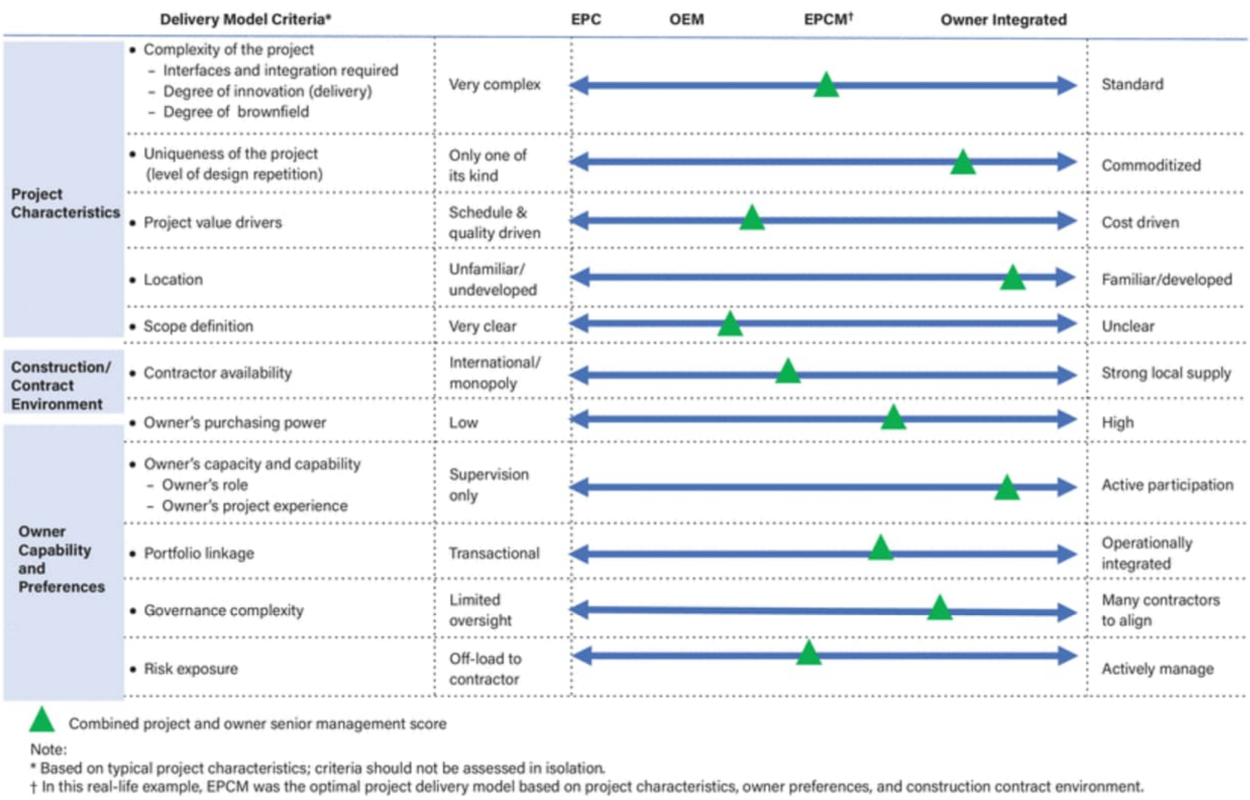

Figure 12 Project deliverer assessment (Hickson & Owen, 2022, p. 360)

Figure 12 above compares the different delivery models from the customer's perspective. The comparison is made by project characteristics, construction/contract environment and capabilities and preferences of the owner, known as the customer. If the EPCM delivery mode is selected, the risk exposure is more equal between the EPCM contractor and the customer if compared to EPC.

3.1.1 Engineering Services – Detailed Engineering ((D)E)

"Detailed engineering is the engineering developed based on the basic engineering/preliminary design after the customer's approval has been given for the project. It provides the specifications, implementation drawings, comments to vendor's documents and all other related documents which define all engineering aspects for the construction, erection, commissioning and start-up until the acceptance of a project. The services may include as-built drawings (Helin, 2020)."

3.1.2 Implementation Services – Engineering, Procurement and Construction Management services (EPCM)

Engineering, Procurement, and Construction Management services (EPCM) typically include engineering as well as procurement and project/construction management services on behalf of the customer.

The EPCM service provider will typically not provide schedule and price guarantees and will never provide warranties or performance guarantees.

The EPCM contract may include various incentives/penalties, e.g. on a project time schedule and investment budget (Helin, 2020)."

According to Hickson & Owen (2022, p. 355), when the project owner makes a choice to proceed with the EPCM delivery model, the contracting is not only made between the EPCM contractor but additionally the contracting is also made between the project suppliers and the owner. Hickson & Owen state that in this delivery model, all the aspects of engineering, procurement and construction management (EPCM) are under the responsibility of the EPCM contractor. However, it can be highlighted that, especially in this delivery model, contract technicality is emphasised. In terms of technical aspects of contracting, the EPCM delivery model cannot be understood as straightforward when compared to the EPC delivery model, where the EPC contractor owns and manages all the contracts and therefore takes responsibility for their flawless realisation. To put it simply, the EPC contractor delivers the project on a turn-key basis and is responsible for the majority of the project risks, whereas the EPCM delivery model involves more owner participation and therefore, the risks are more equally shared, or even concentrated more for the project owner.

The EPCM contractor takes responsibility for the management of the contractors, even though the project owner predominantly has made direct contracts with all the contractors and, in some cases, additionally with subcontractors participating in the project. Since in the EPCM delivery model, the risks of the project are more equally shared between the EPCM contractor and the owner (or the risks can be even more concentrated for the owner), it becomes more crucial to establish a clear understanding of the interfaces of responsibilities between the contracting parties. To enhance this understanding, a detailed and task-specific responsibility distribution in all the project phases needs to be considered in the contract between the EPCM firm and the owner. For example, there can be such a case that the owner has the capabilities and resources to take responsibility for some specific task in the project (e.g. equipment delivery supervision and inspection), and this can be naturally specified in the contract. However, this would naturally result in an increased amount of risk and required resources for the owner. Figure 10 illustrates the comparison between the delivery models on how they rank on the scale where the required size of the owner's project organisation team and required risk-carrying capacity are evaluated from the owner's perspective.

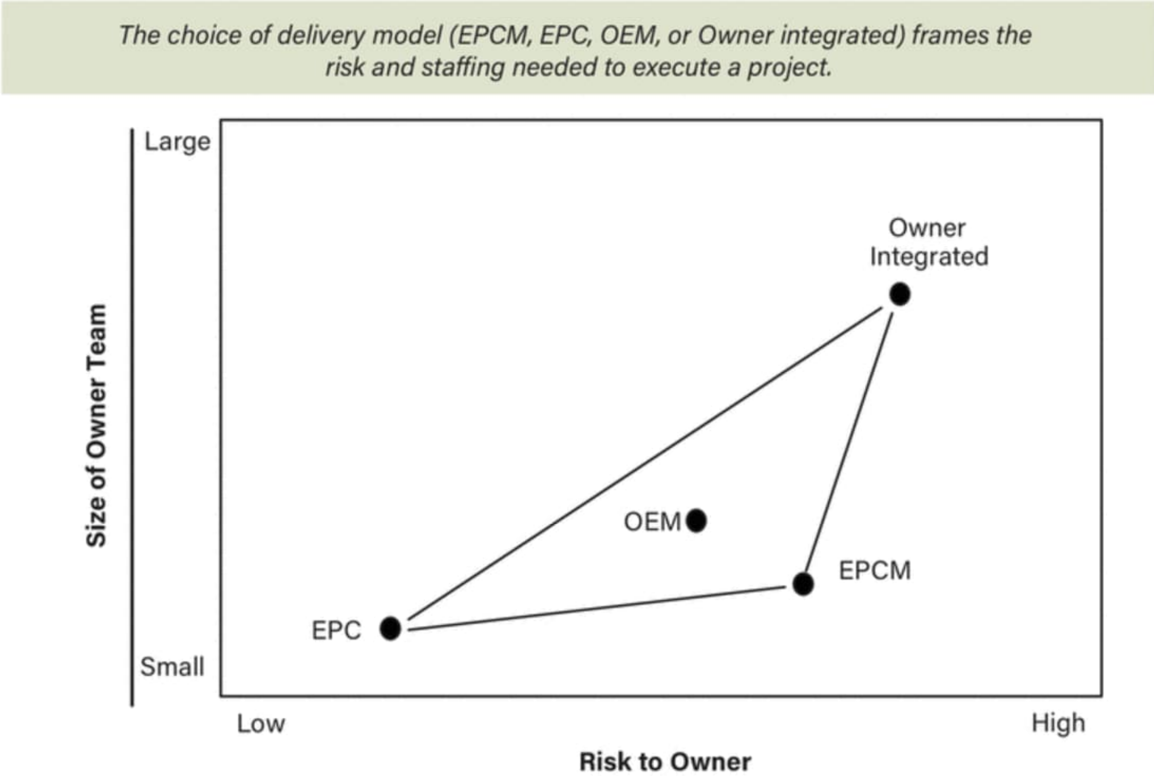

Figure 13 Project delivery model risk vs team size comparison (Hickson & Owen, 2022, p. 358).

Hickson and Owen (2022, p. 355) describe the role of an EPCM contractor as the Owner's agent that has created a relationship via contracting with the owner, project suppliers and construction contractors. As the owner's agent, the EPCM contractor is responsible for the overall project execution management to fulfil the owner's objectives.

Hickson & Owen (2022, p. 355) list the characteristics to be typical of the EPCM delivery model that is, e.g.:

- Multiple contracts are signed between the owner and suppliers, but most of them are aligned by the EPCM contractor.
- The construction site management is outsourced to the EPCM contractor.
- Amount of outsourcing for project execution is at a medium (or balanced) level in general.
- EPCM delivery model requires participation and input from the owner in some amount during all the project phases.

- It is the best delivery model for the owner willing to provide constant remarkable design input.
- It has minor dependence on the owner's capacity for the project's success.
- It is well When quality, cost and schedule are equal drivers for the project.

Among contractors using the EPCM delivery model, it is less common to agree on a fixed-price lump-sum in the project delivery contract. At the same time, it is more common in the EPC delivery model. It usually is a risk vs reward question where the contributory factors of still-fluid work scope and limited data availability have a notable impact on the decision about the compensation arrangement.

3.1.3 Contracting Services – Engineering, Procurement and Construction (EPC)

"Engineering, Procurement and Construction (EPC) contracts include the design, procurement of equipment, materials, services, construction and installation, erection and commissioning, testing and hand-over (typically on a turn-key basis). The EPC contractor carries the project risk for schedule, budget, performance, operational guarantees and warranty in return for a fixed price (Helin, 2020)."

Where in the EPCM delivery model, the owner makes multiple contracts with contractors and suppliers, and in the EPC delivery model, the owner contracts with a single contractor. According to Hickson & Owen (2022, p. 356), the EPC contractor is responsible for the execution of engineering, procurement and construction for the project as per the designated scope. EPC contractor holds the responsibility for the project delivery in all aspects that covers project planning, supply of the materials and equipment, construction execution, supervision of the subcontractor performance and commissioning. All the contracts are owned and managed by the EPC contractor, and site activity management is also, in all respects, under the EPC contractor's responsibility. Hickson & Owen presented the following characteristics to be exemplary for the EPC delivery model:

- A single contract is entered into and managed by the Owner.
- Restricted supervision is required by the Owner.
- Outsourcing of the project execution is maximised from the Owner's perspective.

- Required Owner project participation is minimised, resulting in the smallest Owner’s project team size.
- Capacity of the Owner’s team is not a determining factor for the project’s success.
- Least risk exposure is present in this model for the Owner if a qualified EPC contractor is used that shall be verified via appropriate evaluation for the contractor’s economic viability and specific contract wording to establish clear risk off-load.
- It suits well for projects with a schedule-driven focus.
- If the project includes multiple interfaces and interactions, this model may be inappropriate.
- It is typically used for a well-defined, stand-alone project work package with a lump-sum contract.
- It is usually more suitable for greenfield projects than brownfield projects.
- It is suitable for projects that have a very clear scope definition with no probability of scope change.

3.2 Activities and QA/QC Conducted in E, EPC and EPCM Delivery Models

Regardless of the delivery model selected for the project, all the implementation projects include the phases of engineering, procurement and construction, but the party responsible for the activities conducted within the phases varies according to the selected model. This chapter briefly discusses the main phases of process industry implementation projects in relation to QA/QC.

3.2.1 Disciplines Involved in Process Industry Implementation Projects

Table 1 lists the engineering disciplines involved in process industry implementation projects. Examples of every discipline’s core functions and deliverables are also included as an illustration in the table.

Table 1 Engineering disciplines and their illustrative core functions and deliverables (Case Company, 2022)

Engineering Discipline	Illustrative deliverables
Process engineering	• Process design o P&Ids o Equipment lists o Operating instructions etc.
Mechanical engineering	• Layouts o Mill site o Department • Equipment technical documentation o Enquiry specifications
Piping Engineering	• Route design • Piping isometrics • Flexibility analysis
Electrical Engineering	• Circuit & Wiring diagrams • Power distribution system modelling • Motor drive design
Process Control (Automation/Instrumentation) Engineering	• Sizing of control valves & flow meters • Instrument Application lists
ICT Engineering	• WLAN design and simulation • Operational Systems’ Data Network design
Civil and Structural Engineering	• Structural design 3D- models • Civil Guide Drawings
HSE Engineering	• Hazard and Operability Study • Emergency and Safety information layout
HVAC and Sanitary System Engineering	• Air and Heat Balance • HVAC P&IDs
Architectural Engineering	• Mill site architectural design
Infrastructural Engineering	• Mill site infrastructural design
Sustainability Engineering	• Equipment sustainability assessment • GHG emissions impact assessment
Engineering Applications	• PIM/BIM Execution Plan • Design discipline-specific EA tools setup

Different engineering disciplines are dependent on each other’s inputs and outputs. In terms of QA and QC, systemised inter-disciplinary communication methods together with a document control system that supports it enhances smooth workflow in producing quality criteria fulfilling deliverables.

3.2.2 Engineering Quality Plan

The engineering phase of a project is the most sensitive phase as measured by the cost of change (COC) or cost of poor quality (COPQ). According to Hickson & Owen (2022, p. 474) the most advantageous procedural approach is that the quality is addressed up front in the engineering phase, where quality is possible to be designed in, rather than downstream in the construction phase. If the preventive quality activities in the engineering phase are not at a sufficient level, it may result in corrective activities in the construction phase that appears to be significantly less cost-effective. Therefore, in order to achieve the optimal level of quality-related costs, the most quality effort is focused on engineering quality assurance (QA).

ISO 9001 Quality Management Systems and ISO 8000 Data Quality are commonly used standards that set the conformance criteria for the preparation of engineering quality plans. Conformance to these standards can be observed as a common element in nowadays EPCM contractor's engineering quality plans. Nevertheless, the engineering quality plans have been prepared to be close to perfect; it is typical that errors and omissions occur during a design project. The QA component in the quality management in the engineering phase consists of activities that aim to prevent errors from occurring initially, and the quality control (QC) component aims to correct the identified errors already in the engineering phase before the design deliverables are implemented in the field (Hickson & Owen, 2022, p. 474).

Hickson & Owen have identified the following comprehensive set of questions that an engineering QA/QC plan has to answer:

- Which specific documents (in wider context deliverables, e.g. 3D models etc.) are identified to require reviewing?
- Who is responsible for the reviewing process?
- What is the time slot (milestone) when the reviewing process takes place?
- In which possible forms may the errors appear in the reviewed deliverable that needs to be considered in the review process?
- What is the available allocated budget for the review process?

- What are the allotments for corrections the on the basis of schedule and budget?

The parties that are involved in the review process require definite instructions depending on the perspective from which the review is to be performed. Hickson & Owen (2022, pp. 474-475) listed different types of reviews that are categorised by their approach methods and are commonly performed within the project's engineering quality plan as follows:

- **Conceptual review**—An evaluation which is performed for the basic concepts that the implementation project is based on to verify that the outcome of a project, i.e. purpose-fitting functioning process plant is achievable with the given budget and schedule constraints.
- **Intradisciplinary review—**A person with a leading or senior position within a certain engineering discipline reviews the deliverables before issuing and releasing the deliverable downstream.
- **Interdisciplinary review—**A detailed inspection that is performed to establish compatibility and to detect possible interference and their effects on the design between different engineering disciplines.
- **Drawing-specification cross-check**—A detailed inspection where a specialist from a relevant discipline evaluates the drawing that it includes and confronts all the required information that is determined in the related specification.
- **Multifacility cross-check—**Regularly process plants built in EPC/EPCM projects consist of multiple facilities, and therefore this review is performed to detect possible inconsistencies between the observed facilities within the complex.
- **Vendor review—**A review that is proposed to be performed by the equipment and material suppliers as a result of which comments are expected on equipment incompatibilities, obsolete specifications and/or inappropriate material if such occur.
- **Constructability review**—The most optimal solution from one design discipline's perspective might not be the most optimal solution indicated by its constructability.

Therefore a constructability review shall be performed where the potential problems affecting constructability are sought after to be detected and removed.

- **Operability and maintainability review**—A representative of the Owner's/end user's organisation is recommended to participate in this review, where the potential problem-causing solutions in the design of the completed plant that might cause difficulties in the operation and maintenance of the plant, are sought after to be detected and removed.

The team that conducts the planning of the project execution shall specify the milestones of the project when these previously mentioned design reviews take place, considering that they are timely positioned in the project life cycle to ensure fluent progress. The size and complexity of the design in the project's scope are remarkable factors that determine the amplitude of the reviews since, in a long downstream design process, the cost of change (COC) can increase exponentially for the detected imperfection that may require redesign upstream (Hickson & Owen, 2022, p. 475).

3.2.3 Engineering Quality Assurance

According to Hickson & Owen (2022, p. 475), the managerial measuring and monitoring processes and resources in quality ensuring of the engineering deliverables (calculations, designs, drawings, specifications etc.) and, in addition, the services and inspection processes associated with the outputs of the engineering work combine the key functions of engineering QA. QA aims to guide engineering efforts to follow its two key principles, which are (1) *fit for purpose*, meaning that the produced deliverable is suitable for its intended use, and (2) *right first time*, where the purpose is to ensure the flawlessness of the deliverables by means if high-level instructions and quality assurance functions integrated into the delivering process. Common solution to ensure desired quality outcomes is to prepare the applied quality plan to be aligned with individual certification requirements of ISO 9001 *Quality management systems – Requirements.* Useful information for quality planning can be found in ISO 10006 *Quality management – Guidelines for quality management in projects* and ISO 10005 *Quality management – Guidelines for quality plans.* Measurement, monitoring, and comparison with standard processes and feedback loops are the key elements in Engineering QA to establish error prevention integration in the engineering process. One concrete example of QA in the engineering process is the QA forms, which that identify in what form the errors that are looked for may appear, what is looked for and what to measure for. The QA forms can be utilised as a benefitting tool in nonconformance identification.

3.2.4 Engineering Quality Control

Hickson & Owen (2022, p. 475) demonstrate their views on best practices in the engineering QC process that, according to them, shall include an independent review of all the project documents (deliverables). The party carrying out the review shall confirm that engineers and designers have implemented the verification activities and design reviews according to relevant procedures and plans. In an ideal situation, the party executing the QC review would be a peer or supervisor outside the project organisation directly involved in that relevant engineering deliverable. QC review panel executing the reviews in larger projects can be seen as appropriate. Hickson & Owen identify four main areas in engineering QC reviews:

1. **QA confirmation—**Prior to issuing any deliverable to project management, the party executing the QC review confirms that the quality checklists (specially prepared for the project) have been applied, and if any comments have emerged in the internal review by using these checklists they have been responded accordingly. Completed QC reviews shall be recorded (reviewer credentials, document log etc.)

2. **Consistency—**Consistency review includes cross-checking the project’s plan sheets and reports for their consistency, and again the documents (deliverables) are cross-checked for their consistency that they are aligned with the requirements. If there are deviations for a reason, they shall be mentioned in the consistency reports provided for the QC review. Appropriate WBS for consistency review shall be applied.

3. **Detail—**Typically, most of the imperfections will be already detected during the process by the engineers involved in that relevant task, but as the project proceeds, minor defects may be crept into the deliverables due to project staff becoming too familiar with the documents. Therefore the use of an external QC reviewer can be useful for errors in this area.

4. **Understandability—**The reviewed deliverables (documents, drawings, plans etc.) shall be formed in such a way that an external party with no previous experience from the project in question can, without challenges, interpret the information distributed by the deliverable. The engineering documents are fit for purpose in terms of understandability when the party receiving the information transmitted by the document receives correct information that is structured in sufficient detail that allows the receiving party to organise its measures accordingly with a minimum chance for error.

Suitable allocations shall be included in the project schedule and budget for the QC reviews and for the possible emerging corrective measures as a consequence of the reviews. Even though it is typical that the schedules and budgets are tight when operating in the project environment, appropriate financial and time reservations are necessary to enable a smooth proceeding for the project. A project control system shall be established for the authorisation and recording of the activities when the need for utilisation of financial and time reservations is discovered.

Hickson & Owen (2022, pp. 476-478) listed a comprehensive collection of factors that shall be verified and tasks to be conducted in the QC reviews focusing on engineering drawings, calculations and specifications. To give some examples about the details that they find important to be evaluated in the case of drawings, they shall be prepared in such a way that the scope of the drawing is satisfactory and covers all the intended work, necessary components are included, and facility structures and equipment have been evaluated from an overall operational perspective.

For the engineering calculations, Hickson & Owen (2022, pp. 476-477) highlight the importance of checking the design criteria for its completeness and accuracy prior to design initiation, for which an experienced lead person is recommended to be responsible. The utilisation of standardised design procedures as guides in calculations enables effective workflow since when all the parties involved in the calculation tasks use reproducible and unified methods, it enhances the transparency and certainty of the calculation work that predictably results in increased quality due to, e.g. improved error detection.

Engineering specifications are the documents where the constraints, limitations, framework, implemented standards etc., are defined that will be utilised in the design and manufacturing work of the equipment, systems, processes etc., within the project. Hickson & Owen state that to achieve an adequate degree of QC, the speciations need to be prepared as part of the first activities of the project. Their intended function as guiding and outlining documents for the design and manufacturing is fulfilled in the most beneficial way when the specifications are available for the project team in the early stages of the project.

3.2.5 Definition of Quality by Engineering Contractor

When an Engineering company is delivering an implementation project, e.g. in the role of EPCM contractor, the definition of quality from the EPCM contractors perspective arises on a professional performance basis. In the EPCM contractor's operations, quality consists of conformance with industry standards, which includes consistency with design standards and legislation. The delivered plant is aimed to fit the purpose, so the customer’s “problem” would be solved in the way that the product is suitable for its intended usage, which shall be taken into account in the design, which is aimed to be realised with minimal deviations. The realisation of Quality requirements is also measured by how well the EPCM contractor is able to fulfil the requirements attached to the contract concluded with the customer. Of course, the EPCM contractor aims to perform better than the competitive contractor to enhance the perceived quality among the customers (Hickson & Owen, 2022, p. 471).

3.2.6 PED, Machinery Directive and Their Harmonized Standards and Quality Requirements

The pressure equipment and machinery directives are legislative guidelines drawn up by the European Union for its member states regarding the equipment covered by them. There are also other legislative guidelines for equipment and systems in the process industry, such as the low-voltage directive, the electromagnetic compatibility directive, etc. Member states rely on legislation based on these, such as the Pressure Equipment Act (1144/2016) in Finland. The harmonisation of legislation in the EU area aims to promote equal safety requirements for equipment, which is also an essential quality factor.

For example, in the pressure equipment directive, pressure equipment is classified into different categories (I-IV), where the determining factors are the type of equipment (e.g.

pressure tank or piping), the content of the equipment under process conditions (liquid/gas, hazardous/non-hazardous), the maximum permitted pressure and volume or nominal size.

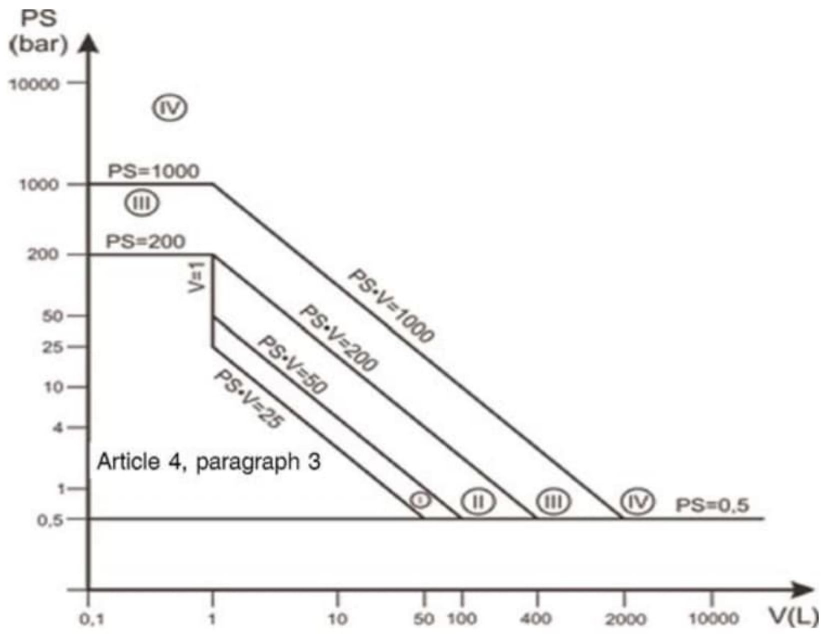

Figure 14 Pressure equipment classification (The European Parliament and the Council, 2014, p. 69).

As seen in figure 1 above, the equipment is classified according to its volume and maximum design pressure. The classification determines the conformity assessment module that indicates the assessment procedure for the assessed equipment, which, e.g. determines the necessity of notified body’s (NoBo) involvement in the assessment procedure. E.g., if the equipment is ranked in class I, the conformity assessment module A is the minimum requirement, where the assessment is conducted by internal production control where involvement of NoBo is not required. In class 4, module G can be used, where the notified body is involved in the assessment, e.g. in examining the technical documentation and carrying out the final inspection (The European Parliament and the Council, 2014, p. 101). As proof of completed conformity assessment in classes 1-4, the equipment will be CE-marked. If the equipment is ranked as Article 4, paragraph 3 equipment, the equipment shall be designed and manufactured according to the Sound Engineering Practice (SEP) of a Member state, and equipment will not be then CE-marked (Castrén, 2021, p. 9).

By applying the harmonised standards, where the detailed technical specifications are expressed for the design, manufacture and testing of the equipment, conformity with the relevant directive is verified. E.g. standards EN 13445 (Unfired pressure vessels) and EN

13480 (Metallic industrial piping) define specific details on materials, dimensioning, inspection methods, details and scope.

3.3 Procurement

The main tasks of the Procurement organisation are to execute scope control of the procurement, monitor and report progress and deliverables and manage the enquiry process of the equipment. When taking a closer look at the enquiry process, the next following measures as the project progresses are management of the tender and evaluation process and expediting and delivery process management (Case Company, 2022).

One of the key functions in the procurement phase of the project is to conduct the inspection and surveillance functions for the suppliers and vendors with the appropriate monitoring accuracy and intensity (Hickson & Owen, 2022, p. 479). Expediting is an essential function of the procurement process; the criticality assessment of procurement entities, i.e. procurement packages, is an important tool in order to determine the level of expediting that is suitable to be implemented for a specific package.

When evaluating the procurement packages, the complexity of the packages, the familiarity of the vendors, total cost impact and priority of the procurement package in relation to the project’s critical path are examples of the criteria that are considered in the evaluation process when defining the appropriate expediting and inspection measures for the packages. Based on this evaluation, such expediting-related measures are determined to be implemented for the procured packages as the amount of manufacturing shop inspection visits, in which detail the manufacturing documentation shall be reviewed and by whom it shall be approved, if final acceptance tests are required for the equipment etc.

In terms of QA/QC, reviewing the project specifications and purchase orders for quality conformance is one of the main tasks in the procurement phase of the project (Hickson & Owen, 2022, p. 479). When compiling the technical requirements that are included in the technical specifications according to which the goods or services are procured, it shall be verified that the requirements are expressed in appropriate detail, preferably by measurable definitions and that the requirement fits the purpose. The expediting process relies heavily on technical specifications, where the supervision of the delivery process of the procured equipment is based on verifying that the specified requirements are fulfilled.

3.4 Construction/Construction Management

The construction phase consists mostly of QC instead of QA when evaluating the implemented efforts for quality. QC, which is conducted during the construction phase, aims to ensure conformance with the original design through field inspections and testing for the most part (Hickson & Owen, 2022, p. 480). According to Boehm's cost of change theory, as the construction phase is one of the last phases of the implementation projects, the deficiencies observed during the construction phase are likely to be more expensive when compared to the earlier phases. Corrective measures may require redesign or reconstruction, or they may cause lower production performance.

On-site work-focused specifications play a significant role in facility design. Such specifications include references to commonly approved construction standards if operating in the market area of the EU; PED and its harmonised standards are the authorised documents that set the requirements to be fulfilled if pressure equipment is mentioned as an example.

The scope of delivery can be large, and the schedules and phasing of the construction phase are extremely tight. In QC, this should be sufficiently noted, and to promote this, there are different applicable practice models. One good practice is to carry out partial handovers, where when the deliverables completed from the previous phase are handed over to the next phase, the deliverables and their documentation are checked, regardless of whether it is a partial handover between internal or external operators. One example of this is piping manufacturing and installation, where the piping is partially premanufactured at the manufacturer’s workshop prior to installation at the site. During the partial handover, an intermittent check is done for the premanufactured equipment, where they are inspected and documented according to the specifications and applicable design codes to verify the conformance, and the documentation is required to be available for review prior to the installation phase.

4 Case Study

The research of the applied part of the thesis was carried out as a combination of observation and interviews. The observation was conducted as participatory observation by means of full participation, where the observer acts as a member of an operative group and during operation, the observations are formed in freely encountered situations (Hirsjärvi et al., 2007, p. 209). Observation included reviewing the project documentation about the discussed cases to allow sufficiently detailed evaluation. To complete the observation, individual interviews were conducted using open interview methods. The interviewed persons from the evaluated engineering company had been involved in the projects where the following discussed cases had been confronted, and the interviews were unstructured, free and non-directed in nature. It is characteristic of an open interview that the interviewer tries to find out the thoughts, opinions and perceptions of the interviewee as they come across during the conversation (Hirsjärvi et al., 2007, p. 204).

The following four cases to be discussed were selected for this study following the principle that the cases to be discussed would cover all phases of a typical implementation project; engineering, procurement and construction. The following cases are explained in sufficient detail, and the aim was to classify and categorise the information collected by the observation and interviews in the way that the defects that occurred as a result of a process can be categorised. Categorisation of the defects and their root causes then allows the targeted proposals for improvements in QA/QC measures that the evaluated engineering company implements in its projects.

4.1 Case 1: Quality Deviations in the Equipment Out of EPC Contractors’ Scope

In this case example, it was agreed in the contract between the customer and EPC contractor that part of the equipment will be delivered by another supplier than the EPC contractor, i.e. part of the equipment that is an essential part of the process that the EPC contractor delivers are defined to be out of EPC contractor’s scope. It was agreed with the customer that the customer procures the equipment from the equipment supplier whom the customer makes out a direct contract with.

This would mean that these specific items that were defined were not to be included in the EPC contractor’s scope, and it would not also be the EPC contractor’s responsibility to organise expediting and QA/QC measures for the items if it was not separately agreed between the customer and EPC contractor. As the project progressed to its construction phase and these specific items were delivered to the site for installation, imperfections were found in the equipment that needed to be fixed. In this case, the imperfections due to which the equipment did not fill the quality requirements were oxidation in the welds and contamination by unwanted material to the base material of the equipment (iron contamination on stainless steel). In this case, since the QC of the equipment was cut off from the EPC contractor’s scope and close to the scheduled installation, the detected imperfections in the equipment required corrective measures, which caused this readjustment of the project schedules.

When these kinds of shortcomings, as in this example case, occur during a project that requires to be restructured, it usually initiates a chain reaction that affects multiple stakeholders that can be, e.g. other contractors, equipment manufacturers, material suppliers, engineering companies responsible for the design and construction and at the end user. The costs that build up as a result of a combination of rearrangements required to fill the gap, that is, e.g. additional work with additional resources, contractor claims due to inability to execute the work according to the original schedule, extra costs in expediting the material supply and so forth.

4.1.1 Proposals for Corrections in Instructions

When aforesaid arrangements are made within a project, the detailed specification of task responsibilities of interconnected stakeholders in interfacing activities becomes highly valuable. To prevent such events from occurring, the party being responsible for the equipment delivery supervision shall have a clear understanding of the quality requirements of the equipment and the condition in which they are suitable to be handed over for installation. Since the QC of those couple of essential items of process equipment was now under the responsibility of another party than the EPC contractor that delivers the main process entity with its equipment and its construction, it shall have been clearly communicated and agreed between the parties on how the QC shall be organised. As the previously mentioned Boehm's Cost of Change Curve indicates, the later the need for change is detected, the more expensive it will become to execute the change (Institute, P. M., 2021, p. 90). Similarly, it becomes more costly to fix the imperfections in the later phases of the project in a reactive manner instead of preventing them from occurring with cost-effective measures to achieve satisfactory results.

In such "scope within a scope" contract cases where the delivery limits of separate responsible parties collide and form a technically functioning entity while being highly dependent on each other, the unified and solid understanding of the quality requirements that have a direct effect on the other party's work becomes essential. Therefore the QC shall be appropriately communicated to the concerned parties, e.g. in the form of QC reports where the parties in interest can monitor the QC results of interest, i.e. the other concerned party, in this case, the EPC contractor, can supervise the QC conducted by the supplier that the EPC contractor's work is highly dependent on.

The other option, in this case, could be that the QC scope is defined in the contract so that if there exists a minor scope delivered by another supplier within a major scope which together forms an entity, the party, e.g. the EPC contractor being responsible for the major scope would be responsible for the QC for the whole scope that the major and minor scopes collectively form. This would clarify the scope definition for QC between the parties, and simultaneously it would eliminate the communication barriers. Additionally, the QC conducted by the EPC contractor being responsible for the major scope could then focus the QC measures of the other party's scope to be aligned with the interests of the main contractor. Also, this kind of arrangement would not let that much room for claiming by the EPC contractor if the EPC contractor would not be able to detect the errors of the other party's work with the QC measures that the EPC contractor has conducted for the other party's scope.

4.2 Case 2: Inadequate Quality Control Measures by the Piping Contractor

The second case deals with confronted issues that occurred in the piping contract delivery and its supervision in one project where the engineering company acted as an EPC contractor to deliver a complete sub-production unit of a process plant and had ordered a piping contract to be supplied by a company that offers services in complete contracting of industrial pipelines and pressure equipment.

The piping contractor was responsible for supplying piping for the sub-production unit within the EPC contractor's scope according to PED harmonised standard EN 13480 ("Metallic industrial piping"). The majority of the piping in the contract consisted of piping where the examination of weld quality by NDT methods was done by sample inspection, where the volumetric inspection by RT/UT (Radiographic- /Ultrasonic testing) for the welds is required to cover at least 2 % of the welds but typically 5 %. Even if the volumetric testing is done by sample inspection, the EN 13480 standard requires visual inspection for all the welds. EN 13480 standard defines the quality levels for the welds and the requirements for the qualification of the personnel to perform inspections. For example, it is defined in EN 13480 that while standard level service conditions are present, the surface imperfections and imperfections in joint geometry shall fulfil visual testing (VT) quality level C requirements according to EN ISO 5817 ("Welding. Fusion-welded joints in steel, nickel, titanium and their alloys (beam welding excluded). Quality levels for imperfections") (European Committee for Standardization, 2019, p. 17). For instance, in the standard EN 5817 Table 1, the allowable limits for different quality levels (D/C/B) in relation to the base material thickness are defined for different types of imperfections that can occur in the welds (European Committee for Standardization, 2014, pp. 5-20).

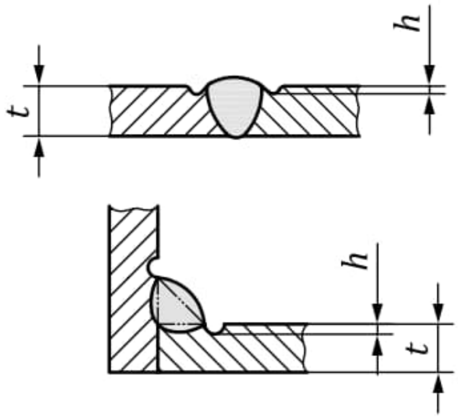

Figure 15. Continuous and intermittent undercut quality imperfection dimension limit definition in EN ISO 5817 (European Committee for Standardization, 2014, p. 6).

Figure 11 above demonstrates on how the limiting values are determined for the dimensions for imperfection that are, in this case, the continuous or intermittent undercut of the weld. Such imperfections shall be detected during the visual testing that is required to be conducted for all the welds of piping when manufactured according to EN 13480.

The piping contractor had already proceeded with the piping manufacturing, where the Pressure Equipment Directive (PED) and the harmonised standard EN 13480 –"Metallic industrial piping" set requirements for the manufacturing and its most significant process: welding and its QC, e.g. in the form of Non-Destructive Testing (NDT). The Piping contractor responsible for the manufacturing was certified according to ISO 9001 ("Quality Management System") and EN ISO 3834-2 ("Quality requirements for fusion welding of metallic materials — Part 2: Comprehensive quality requirements"). This means that the piping supplier used in the project shall have a quality management system in place and meets the requirements to execute this sort of work. EN ISO 3834-2 sets a requirement that "the manufacturer shall have at his disposal appropriate welding coordination personnel" (Technical Committees ISO/TC 44 & CEN/TC 121, 2005, p. 11). The piping manufacturer used in the project had a welding coordination personnel/welding engineer in place in their organisation being responsible for the quality activities with sufficient authority in enabling to take action, e.g. for corrective measures if necessary. However, the welding work had already progressed to a great extent, i.e. a great number of pressure-retaining seams had already been welded with deficiencies in the quality criteria without the welding coordination personnel intervening in the work. Also, the personnel committing the welding work shall be qualified for the specific work, and therefore they shall be able to detect the imperfections in their work quality. Nevertheless, this did not take place in this case either.

Figure 16 In the welds, a high root dome, bluing, and a sharp junction were noticed (Case Company, 2022).

According to the piping contractor, all the necessary visual inspections had been conducted for the manufactured piping, even though it was a bit unclear who was the responsible party for conducting the inspections. In this case, it meant that the contractor or notified body (NoBo) should conduct the inspections for the piping. The agreement on this issue between the EPC contractor and piping supplier had been uncertain. However, the EN 13480 standard announces it simply: “The fabricator and/or installer shall be responsible for carrying out the inspection and testing, including subcontracted NDT (if any) specified in this European Standard, for all piping (European Committee for Standardization, 2019).” It was also agreed in the contract between the EPC contractor and piping contractor that the piping contractor will act as a responsible manufacturer according to PED, where the following is stated: ”The manufacturer, having detailed knowledge of the design and production process, is best placed to carry out the conformity assessment procedure. Conformity assessment should therefore remain solely the obligation of the manufacturer. (The European Parliament and the Council, 2014).”

As the EPC contractor conducted an inspection at the manufacturer's workshop for the welded pipes, the quality of the welding was detected by visual inspection as not fulfilling the quality requirements. Additionally, a lack of conformance to quality requirements had also been found in the volumetric testing, where the imperfections mainly focused on welding work performed by specific welding personnel.

In this specific case, it had been agreed with the piping contractor that the kick-off meeting was arranged where the main topics related to the prefabrication of the piping at the piping contractor's workshop were gone through. It had also been agreed between the piping contractor and EPC contractor that the EPC contractor's representative would commit an inspection visit to the piping contractor's workshop to inspect produced goods after the prefabrication was progressed so that there would be samples of welded piping that represent the overall structure of the whole scope in terms of pipe diameters and piping parts. This would have been a sufficient arrangement if any or minor defects only had taken place. Since the number of defects was significant, it raised suspicion about the contractor's ability to perform the work within the scope of the contract to meet the minimum requirements. This also caused pressure on the EPC contractor's schedule to carry out critical phases of the project in their planned time slot and therefore also required the EPC contractor's resources and efforts to tackle the confronted issue. It was required to set up resources for supervision of the contractor's delivery in increased intensity to secure that the corrective measures by the piping contractor enable satisfactory results. Also, this evokes uncertainty in the customer's/end user's organisation, and again this required resources from the EPC contractor to report a turn of events in the process of correcting the unwanted course.

4.2.1 Proposals for Corrections in Instructions

The encountered problems revealed the need to refine the company instructions on how the engineering company as an EPC contractor shall take into account these kinds of possibly occurring problematic events in their contracting in its varying interconnected sectors: risk management, processes and measures in the different phases of the project (especially in the early phases), reactive measures and their scheduling and in the end the pricing of contracts, which appropriately leaves room for corrective measures, while still keeping the operation profitable.

Preventing this kind of issue from being confronted at all during large-scale industrial projects where the workload and operators are enormous in terms of man hours, variety and amount of equipment and their suppliers is a difficult task or even impossible. However, to improve the performance, it would have been advantageous if the scheduling of the project had taken the possibility of error into account in the project schedules with an appropriate buffer so that the corrective measures, i.e. plan B could have been put into operation in a cost-effective, well-organized and systematic manner. This could have also been able to reduce the consequential challenges with the scheduled tasks on the critical path of the project.

4.3 Case 3: Indistinctness in Stress Analysis for FRP Piping

In the strength calculations, i.e. flexibility analyses of the project's process plant's sub-unit's plastic piping, it was a problem to obtain the required strength values suitable for the calculation from the piping manufacturer. The manufacturer continuously offered the permissible stresses generated in the pressure test, and no party was willing to take responsibility for the mechanical stresses applied in the calculation. At that time, the design office relied on such information that no manufacturing standard suitable for plastic pipes was available, which would determine which tension values should be used to simulate the actual operating conditions or in design. In the operating situation, in addition to the internal pressure of the pipe, there are the effects of temperature and other mechanical loads, the own weight of the pipeline, the weight of the instruments, possible snow loads, the stresses caused by the movement of the piping caused by thermal expansion and its obstruction, etc. The behaviour of a plastic pipe naturally differs from the behaviour of a metal pipe under process conditions, and the load situation corresponding to reality is that of all external loads and in terms of the conditions, it does not correspond to the conditions of the pressure test alone, although the safety factor in the pressure test would be 6, that means that if the piping is designed to withstand 10 bars of internal pressure, it shall withstand an internal pressure of 60 bars in the pressure test with no malfunction. This design principle is mentioned in both DIN and SFS standards for FRP Piping (DIN, 1988; SFS, 1998).

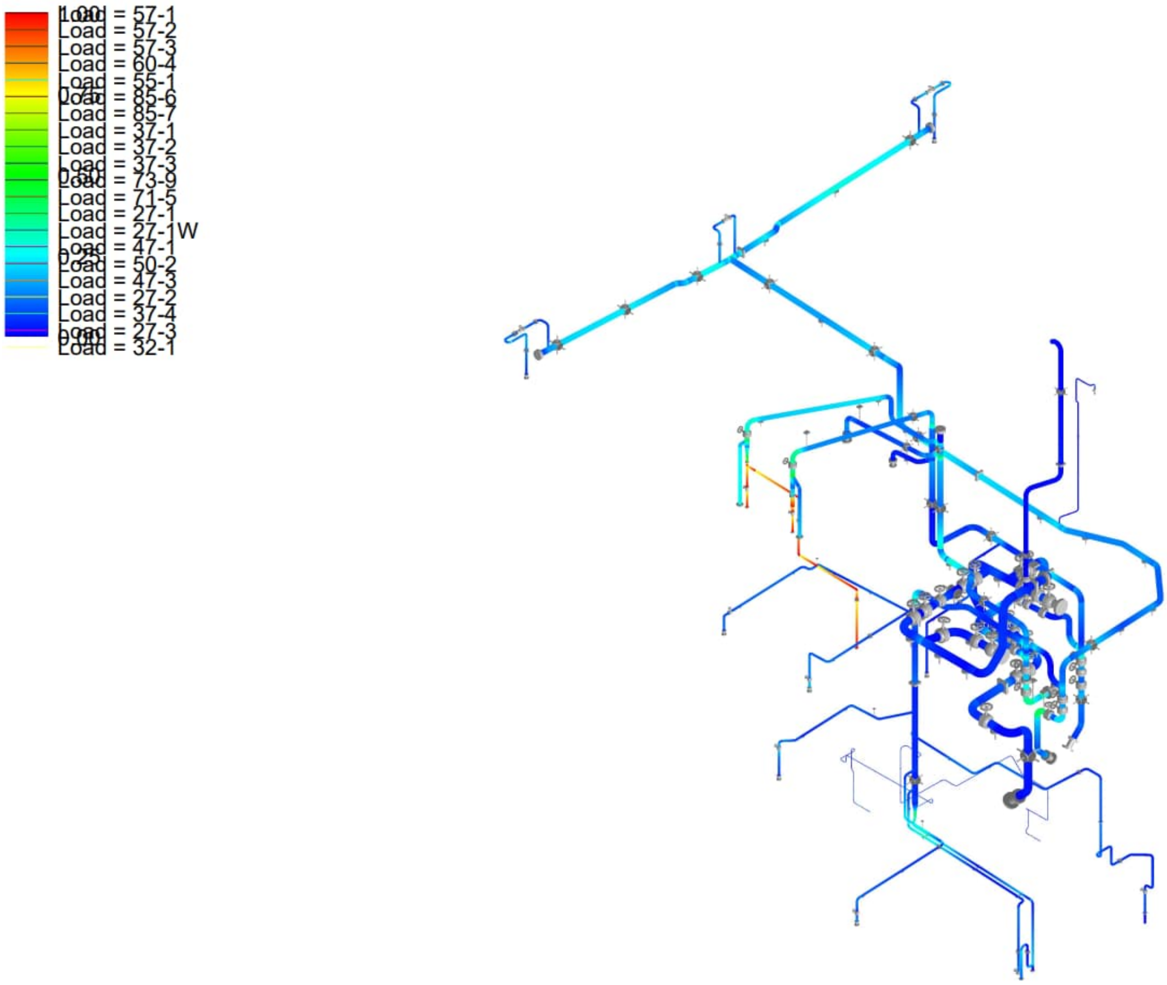

Figure 17 illustration of minimum longitudinal stress ratio in operating (wind-load + design pressure + design temperature) conditions where code EN 13480 is applied for flexibility analysis for FRP Piping (Case Company, 2022).

A conflict arose between the design office and the pipe supplier as to whether the calculations should use the stresses derived from the pressure test carried out at six times the nominal pressure and the safety factor in the design of the pipeline. The design office (in the role of EPCM contractor in this project) did not reach an agreement with the supplier on freezing the values used in the calculation. The values derived from the pressure test were later used, and based on them, it was found that the wall thicknesses of the pipeline were insufficient. The manufacturer did not want to increase the wall thickness of the pipes, as the work was already expected to be well-advanced. Likewise, the end customer did not see this as an option because, at that time, the already prefabricated pipes would have required modification and would probably have affected the costs.

Regarding the calculation of plastic pipes, the defined requirements were strict, and the experience-based knowledge of the flexibility analysis of plastic pipes was also not at a sufficient level. The flexibility analysis of the plastic pipes was a loss-making activity for the design office in terms of this project. The number of hours used in the calculation was exceeded, which, above all, ate up the engineering office's expected profit margin from the entire project as an EPC contract for one review period. Even this was not enough. As a result of the case in question, the whole business unit had a loss-making month, and on a quarterly level, this had considerable financial effects.

The root causes for this were the following. The design work was originally an assignment at a design office in a different country, and when the deadline approached, it became apparent that not a single pipe system had been completed from the design/calculation. As a result, the design was transferred to the office of the design office, which was located in the same country as the construction site. When continuing the design work, the design office was not aware at that specific moment of any standards applicable to the design of plastic pipes, which would give clear guidelines for the design of plastic pipes, above all in terms of flexibility analysis. In the standard available at that moment, the dimensioning instruction was to carry out a pressure test at room temperature at six times the nominal pressure, which the pipe could withstand under the test conditions without breaking. In other words, the total load situation was not addressed in the available standards, and they assume that dimensioning the piping to handle the stresses caused by internal pressure with a six-fold safety factor is sufficient to also cover the stresses caused by other forces, such as the weight of the pipe contents, bending stresses, thermal expansion, etc. The allowable stresses caused by these loads should be indicated by the manufacturer with a suitable safety factor, or there should be a harmonised applicable fit-for-purpose standard available.

In the example case, the pipeline manufacturer used calculation methods based on the selected pressure class, where the dimensioning was done by applying the strength values of the materials used to manufacture the pipes so that they could withstand the internal pressure prevailing in the pipe. When comparing metal materials according to the EN 13480 standard with plastic materials, the metal materials are standardised, and their properties are therefore more straightforward to apply, while the situation is very different with plastic materials. In terms of design and calculation, there is still room for development in the standardisation of plastic materials.

When the project in that situation was late in terms of calculation and already failed to some extent, insufficient methods were continuously applied in pursuing the finalisation of the calculation work. In retrospect, it would have been better practice to take a moment out of planning, evaluate the applied methods, and consider possible other alternatives to the methods used. It would have been good for the design office to finalise the plans thoroughly based on the available information and also transfer the responsibility to the manufacturer, for example, if the strength values required by safety factor 6 were simply not reached in combined load conditions.

It was decided to complete the flexibility analysis project with the properties of materials determined by the material manufacturer, and a mention was left in the calculation reports that the manufacturer must ensure the results shown in the calculation in terms of durability in the piping systems they manufacture, i.e. they had to accept the actual stress levels modelled in the pipeline found in the stress analyses and that the manufacturer's material solutions are sufficient. The pipeline manufacturer agreed to provide a manufacturer's declaration of conformity for the pipeline it produced, although, in the modelling, the ideal stress values were exceeded in some cases. The practice is that the manufacturer applies for approval by the notified body for the pipeline design drawn up by the design office they use for pipelines subject to the chemical and pressure equipment directive. The notified body, in turn, communicates with the manufacturer about the adequacy of the design.

4.3.1 Proposals for Corrections in Instructions for the Future Projects

It should be clearly agreed with the customer in the future how the flexibility analysis shall be conducted for plastic piping. In the example case, the limitation was made to a certain PED category (that are SEP(0), I, II or III) or to the chemical pipelines according to the definition of the local safety and chemicals authority and to the pipes connected to the equipment in accordance with the customer's factory instructions. Due to this, the number of pipes to be flexibility analysed was considerably high.

In the future, the operating model could be, for example, that the design agency draws up a pipeline design based on a reference plant from previous projects, where it is justified that the stresses caused in total load situations found in the stress analyses have been minimised in the design, and the pipeline manufacturer must therefore take responsibility for determining whether the structure of the pipeline they use is sufficient. If necessary, this will be approved by the notified body when applicable.

Another alternative is that the flexibility analysis software used by the design office for pipeline stress analysis has relatively comprehensive strength values for different plastic materials in the database, which would thus be used in flexibility analyses in the future, with the condition that the manufacturer accepts this method. For example, if in the plans drawn up by the design office, a need for a stronger-walled pipe due to the influence of the conditions is found in the load situation, for example, at a certain point of the pipeline, but the manufacturer wants to deviate from this, then the responsibility should still lie with the manufacturer, and the design office would work to support the customer in determining permissible deviations.

4.4 Case 4: Customer Requirements to Be Included in Early Phases of the Project

It has been observed that due to the extensive nature of the projects, there have been differences in the details of the quality requirements of the client and the EPC contractor, and these differences have not necessarily been dealt with comprehensively enough at the level of detail they require. An agreement on quality requirements should be reached with the customer already at an early stage of the project because, naturally, setting additional requirements after the procurement phase, for example, in the manufacturing phase, will probably cause additional costs.

An adequate mode of operation would be if the technical specifications and quality requirements could already be presented to the customer already alongside the E(-PC/-PCM) contract proposal, where it is precisely presented in terms of technical aspects of how the project's equipment will be designed, procured, quality controlled etc. when the engineering company acts as an EPC contractor for example. It would also be more favourable practice if the requirements regarding a certain part of the project were submitted in the early phase of the project to the engineering bureau for review made by the specialists in that specific area so that possible deviations could be handled, e.g. among the suppliers selected for the project, and have discussions with them if deviations are at all possible, and which deviations are acceptable to the customer, and whether there is a need to make deviations at all.

This has been the procedure to some extent so far in one evaluated currently ongoing project; for example, if the list of the client's permitted suppliers has differed from the corresponding one of the EPC contractor, and thus the client's requirements have been taken into account in this regard. However, the situation has been different in terms of technical manufacturing requirements, and for example, in a case where a price for delivery has already been agreed upon with the equipment supplier, the equipment supplier is probably not willing to make changes without additional costs if the requirements set by the customer cause modifications in the delivery, and they have not been taken into account in sufficient time, for example already in tender negotiations with the equipment supplier. A very simple thing but often challenging to implement due to scheduling challenges and the extensive amount of details to be handled within a limited time frame. Alternatively, if the customer had to be delivered in time for approval, a pre-prepared technical specification used by the engineering office, which is tailored to fit the delivery of the main equipment of the production unit that is part of the engineering office's own product range, for example, would most likely allow smoother procurement process.

From the point of view of the EPC contractor, a good practice would be to go through the technical requirements related to equipment deliveries in connection with the technical negotiations of the EPC contract with the customer sufficiently and comprehensively in terms of how the EPC contractor i.e. the engineering company, will acquire the equipment, instead of "blindly" using the customer's specifications. A better option would be to present “our way” of acquiring, buying, delivering etc., and thus customer is able to comment on possible modification needs or additional requirements. When delivering a familiar unit from an EPC contractor’s own product portfolio with equipment from well-known equipment suppliers, this would be a much more efficient practice.

4.4.1 Proposals for Corrections in Instructions for Future Projects

The main question is to discover the suitable methods for composing a consensus about the quality requirements between the customer and EPC contractor at a sufficiently early stage of the project, which can then be utilised, e.g. procurement process for the equipment conducted by the EPC contractor. The examination is also required to determine if the EPC contractor under research has its technical specifications aligned and tailored with its own product portfolio in such a way that the requirements included in the technical specifications are comprehensive enough. The ideal situation would be that the EPC contractor has its technical specifications tailored for its own product portfolio, and the customer either “takes it or leaves it”. Of course, there shall be left room for commenting for the customer, but preferably in a limited manner in order to prevent a cycle of continuous commenting and modification. It would be good to include the time required for the review in the project schedule, as anticipated and clear directions of progress to prevent expensive corrective measures. Of course, this is also a cost issue, but probably the time and resources reserved for timely reviewing of the requirements and the resulting costs from it would take the quality costs towards the zero point of the derivative of the total cost curve as indicated in Lundvall-Juran model (Foster, 2017, p. 116).

5 Conclusions

This study aimed to carry out a comprehensive outlook of the QA and QC measures of the implementation phase process industry construction project with a perspective of the engineering contractor's responsibilities. The research was concluded by taking a closer look at a few topical cases to cover the QA/QC measures implemented in the different phases of the project, to map the role of the engineering office in them and to identify possible development needs. The literature review in the theoretical background part of the thesis extensively dealt with quality assurance measures in project work, based on which the collected theoretical data was bound to practical examples selected through a sieve from recent projects in the reviewed engineering office. These evaluated cases selected to be examined in this study represented all the main phases of an implementation project. Participant observation was well suited to the study as a research method, where the undersigned worked normally in work tasks in the organisation of the project in question. To supplement the survey, individual interviews were conducted with the project staff using the methods of open interviews. A good example is the challenges encountered in the flexibility analyses of reinforced plastic pipelines. Based on this study, it can be concluded that the operating model for implementing flexibility analyses of reinforced plastic pipes would require further research, for example, in the form of a final thesis.

Engineering companies usually, like the company that was the subject of the study in this case, have repetitive projects in their product portfolio. The engineering office that was the subject of the study has such a repetitive project within the forest industry where they specialise in delivering sub-production units that are part of a larger entity of a forest industry process plant. In most cases, these subunits are delivered with the EPC contract model. As a general observation, the internal guidance used by the engineering company is well suited for a universal basis. Still, for projects with similar features typical for certain business units, it would be good to promote the preparation of standardised procedures with a sufficient amount of detail.

The role of the engineering contractor is to create systematic quality assurance tools tailored to fit their own product portfolio. Internal quality assurance is more straightforward since the accessibility is good within the project organisation, but unifying quality management with interfaces, e.g., with external parties and organisations, is more challenging. Except for the key personnel, such as project managers, the organisations performing in such a repetitive project may vary. Therefore, to enhance the optimal utilisation of resources, it is recommended to establish standardised procedures tailored for that specific repetitive project. At their simplest, these can be implemented as checklists, which act as a guiding document for the actions of the different phases of the project. As a result of further development, the quality requirements and related recordings could be transferred as data between the different systems used by the design office, where a 3D model, i.e. a so-called digital twin, could act as one review interface, where the data included in the design phase, e.g. for the purpose of quality control would be transferred to the customer's use, to be used later, e.g. for maintenance purposes.

These standardised procedures shall include detailed instructions on the QA/QC measures, which would e.g. cover the details of example cases discussed in this study, such as the quality control process with the pipeline contractors, quality monitoring measures in cases of the interface of delivery scopes, unequivocal operating methods for flexibility analyses of plastic pipelines, and comprehensive determination of quality criteria already in the sales/tender phase.

One of the research questions was how the QA/QC measures differ from each other between the different contract models where the E, EPC and EPCM contract models were evaluated. To put it simply, in the E contract type, the engineering company’s responsibility is to set up their QA/QC tool palette that covers the engineering scope to serve the purpose of the project in that form that the following phases after engineering can proceed with minimal readjustment or corrective measures.

In the EPCM model, the contractual relationship is only with the customer, and the customer has a contract with other purchasable delivery suppliers. The client orders "service" from the EPCM contractor to implement the project, whereas the suppliers who are in a contractual relationship with the client, the financial responsibility is more on the client. In the EPCM model, contract technicality is emphasised, and this also applies to the limitations of responsibility for QA/QC measures. In the EPCM model, therefore, scope delineation requires special attention.

In the EPC model, the contractual responsibility rests entirely with the design office. This also applies to financial responsibility because, in the EPC model, the customer is only in a contractual relationship with the contractor, which is in a contractual relationship with the subcontractors. Primary full responsibility for QA/QC measures is by the EPC contractor, where the customer's role is minor.

5.1 Further Research Proposals

Based on the observations made during the research, quality management is actively implemented in different project phases, but it is not necessarily done visibly. Although quality management is implemented, there are not necessarily clear standardised tools. Even in some work phases, quality management is unambiguous, an example of which is the NDT inspections of pipe welds. In some work phases of the implementation project, quality management is not necessarily so visible. For example, a designer who designs a PI diagram for a process plant, or routes a pipe in a 3D model, can know what the desired quality criteria are for the work the designer is performing, which can be inspected and approved according to the agreed practice. Still, the degree of fulfilment of the quality criteria and the evaluation methods are not necessarily as visible and unambiguous as the number of errors allowed in the weld (e.g. pores) as verified by an X-ray image.

It would be profitable to promote this quality assurance visibility and standardised procedures in the case company. To promote this, it would be advisable to conduct further research by analysing the needs of quality management and the tools applicable to them comprehensively, focusing on one project during the entire project life cycle. In the case of the case company, it would be advisable to carry out such research for a recurring project within the company's core product range.

The goal of such development work would be to make quality control a visibly present element in every work phase, which would be implemented with the most user-friendly, integrated and simple tools possible instead of it being invisible and relying mainly on silent information. An example of this could be the reporting of the equipment's material selection philosophy, which would unequivocally show on which criteria the material selection in question was based.

Implementing such a project would require that the sub-phases of the project be broken down into small enough parts, e.g. work tasks, and these should be evaluated in terms of at least two questions, which would be: what are the required quality criteria of this section? And what are the tools and methods to achieve the quality criteria? Based on this kind of study and development project, a tailored QA/QC tools palette for the specific project would be prepared, and in the next phase implementing them would be recorded. Their functionality and benefit achieved would be evaluated.

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