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Root causes and improvement proposals for cost overrun in projects

A contractor's perspective

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ABSTRACT:
Project costs tend to overrun, regardless of the size and type of the project. Research has shown that little progress has been made in this field. The problem also applies to contractors, which repeatedly struggle to stay on budget and therefore face cost overruns in their projects.

This study aims to locate the root causes of cost overrun in the projects of the case company, which is a global technology company. Moreover, areas for improvement are proposed for the mitigation of future cost overruns. To do so, several theories and methodologies are applied: The RAL concept, the Analytical Hierarchy Process, the Critical Factor Indexes, the Sense and Respond methodology, the Manufacturing Strategy Index, the Sustainable Competitive Advantage method, and Knowledge and Technology. Two questionnaires were used for the data collection and were answered by a total of 18 respondents. Besides, interviews were carried out to get background information and to validate the results with the Weak Market Test. This study focuses on the engineering process and the site management process of the projects, which contribute the most to the cost overruns of the case company.

Challenges in resource management and the cooperation with the client were found to be the root causes of cost overrun in the examined projects. To mitigate future cost overruns, it was proposed to lay a special focus on Project Scheduling, Basic Design, Detailed Design, and Off-site Validation. Moreover, improvements in Resource Management, uniform working directives, and special attention to new clients and clients with consultants contribute to the mitigation of future cost overruns. The Knowledge and Technology results indicate that the products and services of the case company are in the maturity phase of the technology life cycle. Thus, a reduction in production costs is suggested. The highest uncertainty is related to core technology, hence investments in core technology will further contribute to the success of future projects.

KEYWORDS: Cost Overrun, Project Management, Knowledge Management, Technology Management, Sense and Respond Method

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Abbreviations

AHP	Analytical Hierarchy Process
BCFI	Balanced Critical Factor Index
CFI	Critical Factor Index
CV	Coefficient of variance
ICR	Inconsistency ratio
K/T	Knowledge and Technology
MSI	Manufacturing Strategy Index
no.	Number
NSCFI	Normalized Scaled Critical Factor Index
RAL	Responsiveness, Agility, and Leanness
RCF	Reference Class Forecasting
S&R	Sense and Respond
SCA	Sustainable Competitive Advantage
SCFI	Scaled Critical Factor Index
VarC	Variability coefficient
WMT	Weak Market Test

1 Introduction

Olympic Games generated an average cost overrun of more than 300 percent between 1968 and 2012, with a median of 150 percent. The Channel Tunnel caused a cost overrun of 80 percent, and the Sydney Opera House was 14 times more costly than initially estimated (Segelod, 2018, p. 2). There are numerous famous projects with cost overrun, and worryingly, cost overruns don't seem to be smaller than 100 years ago (Flyvbjerg et al., 2002). This indicates that no progress has been achieved in mitigating the problem. Project costs overrun, independent of the size of the project, or whether it's a private- or public project (Klakegg & Lichtenberg, 2016, p. 177).

Not just project owners but also contractors struggle with cost overruns, even though the public rarely hears of this perspective. When a contractor detects cost overrun in a project, there are different strategies to cope with it. One possibility is the strategy of hope. In this approach, one hopes that the cost overrun is just a random deviation that will not repeat itself in the future. This strategy should not be relied on, as even moderate cost overruns could be symptoms of underlying problems. There is the thread that these problems will grow more prominent when they are let unnoted. Therefore, significant cost overruns must always be investigated. It is essential to know why they occurred, how likely they are to repeat themselves, and what corrective measures should be undertaken. The people closest to the problem must be consulted to find a solution (Luecke, 2004, pp. 131-132). Common causes given by management for poor outcomes of projects are bad luck or the unfortunate resolution of one of the major project uncertainties (Flyvbjerg et al., 2009, p. 172). However, the root cause for cost overrun usually lies somewhere else. The root cause must be located, and corrective measures must be launched to get a grip on the problem.

Cost overrun is a versatile topic. The problem must be examined from many angles. It can be studied by engineers, accountants, economists, sociologists, psychologists, and political scientists (Segelod, 2018, p. 5). This thesis considers research from a variety of disciplines to get a comprehensive picture of the topic.

1.1 Background

The case company is a global technology company. According to its website, it plans and delivers electricity-, automation-, instrumentation, and supervision systems as turnkey projects. Furthermore, the company also offers corresponding supporting services to its customers. The projects provide individual solutions for the clients and usually include engineering, manufacturing, and installation at the customer's site. The construction sites are around the world (Personal communication, June 25, 2020).

The case company is a contractor. It participates in competitive tenders to get new projects awarded. Respondent 15 of this study states that the market mostly defines the bid price in the tenders. There is not much room for adjustments. However, there are two kinds of customers. Some customers tend to choose the contractor who can deliver the required specifications within the lowest price. Other customers attach more importance to, e.g., quality and good relationships with the contractor. They are usually willing to accept a price premium for these features. However, the bid price must still be within reach of the competitors. When contracts are awarded to the case company, the vast majority are lump-sum contracts. Most of the customers are private companies, but they can also be public authorities.

1.2 Research problem and research questions

Cost overruns keep occurring in projects of the case company. Internal reports show the amount of cost overrun per year, month, project, and process within a project (Personal communication, 2019). The root causes of the cost overruns are recognized in the current process. However, the case company needs to investigate this further to find appropriate actions to address them and mitigate cost overrun in future projects. Therefore, completed projects in which cost overrun occurred are analyzed. Shortcomings from past projects shall not be repeated, and critical processes shall be improved. These objectives lead to the following research question:

"What are the root causes of cost overrun in projects, and how can this be improved?"

Thus, the objectives of this thesis are:

1. To identify the root causes for cost overrun in the selected projects
2. To identify areas for improvement to help mitigate cost overrun in the future

1.3 Limitations and Definitions

This chapter specifies the limitations of the research. Moreover, the most important terms relating to this topic are defined.

1.3.1 Limitations

Some factors limit the research. Cost overruns are examined from the perspective of the case company as a contractor, contrasting with the view of the project owner. The case company is organized in business units, and there are different segments within a business unit. Only projects from one particular segment are considered. When writing about the case company, this specific segment is addressed. Three recent projects with cost overrun were chosen for this research. They are called Project 1, Project 2, and Project 3. Only the engineering process and the site management process of the selected projects are examined, as these processes are usually the primary source for cost overrun in the case company's projects.

1.3.2 Definitions

Project owner – The project owner, who can also be called principal or client, is a buyer who hires a contractor to operate a project (Bose et al., 2011, p. 94).

Sales process – According to internal quality documentation, the sales process contains all activities conducted by the case company to win a tender. The sales process of a project ends when a project can be handed over from sales to project management (Personal communication, 2020).

Engineering process – According to internal quality documentation, the engineering process of a project, in which the case company is involved, includes planning the design, the manufacturing, and the off-site validation of the end-product (Personal communication, 2018).

Site management process – Internal quality documentation states that during the site management process, all deliverables are integrated at the customer's site into a system that fulfills the customer requirements (Personal communication, 2018). Respondent 15 furthermore states that the site manager leads and supervises the work at the site. Often there is a sub-contractor for electrification- and automation installations. The site manager is responsible for safety at the site and that the schedule is kept.

Cost estimation – Cost estimation is defined as the case company's process of forecasting the cost to complete a project within a defined scope. Cost calculation, which is the expression used by the case company to estimate the project cost during the sales process, is determined to be the same as cost estimation.

Estimated costs – In this thesis, the estimated cost of a project equals the planned cost and, therefore, the project budget of the case company. It is used as a baseline to measure cost overrun. The estimated costs are the same as the budgeted or forecasted cost (Flyvbjerg et al., 2018, pp. 175-176).

Cost overrun - The cost overrun, or budget overrun, is the amount by which any actual cost exceeded a budget or contract. It is, therefore, the difference between the approved budget and the final cost (Segelod, 2018, p. 5). It can also be called variance (Lock, 2013, pp. 57-85). The difference can be measured in either absolute or relative terms. When measured in absolute terms, the cost overrun equals the measured cost minus the estimated cost. In relative terms, the cost overrun is calculated either as actual cost in percent of estimated cost or the ratio of actual cost divided by the estimated cost. The cost overrun is usually measured as a percentage of estimated cost. A positive value is indicating a cost overrun, and a negative value a cost underrun. Furthermore, the cost should be measured in the local currency, with constant prices, and against a congruent baseline (Flyvbjerg et al., 2018, pp. 175-176, 187).

Cost Increase - Cost increases or cost growth means the increase in cost between two estimates. The first estimate doesn't necessarily need to be an approved budget or a figure stated in a contract (Segelod, 2018, p. 5).

1.4 Structure of the study

Chapter 1 provides an understanding of the research topic. The case company, the research problem, and the limitations of the study are presented, and the most important terms are defined.

Chapter 2 covers cost overrun in projects by presenting a literature review of the topic. The focus is on the contractor's perspective. This chapter gives a comprehensive insight into project cost estimation, offers possible explanations for cost overrun both from a technical- and behavioral perspective, and shows ways to mitigate cost overrun.

Chapter 3 thoroughly explains the research methodology. Several theories and models are combined to answer the research question, such as operations strategy, the RAL concept, Sense and Respond methodology, the Sustainable Competitive Advantage method, the Knowledge and Technology method, and the Sand Cone model.

Chapter 4 presents the empirical research. First, the research process is illustrated. It gives insight into the questionnaire creation, describes the respondents, and some challenges encountered. In the following data analysis, the questionnaires of every project are separately analyzed and compared to each other. Some interviews give more background to the study.

Chapter 5 discusses the results of the empirical research and answers the research question. The findings and contributions are presented, the validity and reliability are reviewed, and some possibilities for future research are presented.

Chapter 6 comprises of the conclusion, which summarizes the study.

2 Cost overruns in projects

This chapter contains the essential theoretical background related to cost overruns in projects. The goal is to establish a deeper understanding of the central factors related to the topic, with a focus on the contractor's perspective. The chapter starts with an overview of project cost estimation, which determines the project budget and therefore forms the baseline for the measurement of cost overrun. In a second step, an overview of the essential explanations for cost overrun is given. Finally, it is presented how cost overrun in projects can be mitigated.

2.1 Project Cost estimation

As already mentioned, it is the estimated project cost, which builds the baseline for the measurement of cost overrun. Thus, cost overrun can't be mitigated without an accurate forecast of the project cost. A contractor estimates the project cost and derives the bid price while preparing a tender.

2.1.1 Tendering

According to internal quality documentation, the case company as a contractor prepares tenders during its sales process. The goal of every tender is to compile a solution, which addresses the customer's needs. The offer submitted to the customer should drive towards a positive and early decision in favor of the case company (Personal communication, 2020).

In competitive tenders, contractors are challenged to make a balanced offer in which the cost estimate must be low enough to offer an attractive bid price and, therefore, a good chance of winning the contract. At the same time, the offer should be high enough to cover possible risks and thereby obviate significant losses (Sonmez et al., 2007). A contingency amount covers potential risks. The contingency is the amount of money that must be added to the base estimate according to previous experiences. It is typically determined as a percentage of the bare project cost (Kim et al., 2008, p. 398). It is meant as a precaution for uncertainties related to project definition and technology. The contingency is money that is expected to be spent but is not intended to cover for scope changes or unforeseeable circumstances beyond management's control, such as extraordinary storms. To be able to set a reasonable contingency, the base estimate of the known scope at market conditions must be realistic and competitive. A competitive approach is to set the contingency in a way that there is a 50% probability of cost overrun. In this case, there is a 50% chance that all contingency of a project is spent (Burroughs & Juntima, 2004, p. 31).

A contractor must determine the appropriate range of risks for a project, which must be covered through the contingency. The determination of risks is not easy, as various risk factors must be assessed. International projects usually come with a broader range of risks than domestic projects, as contractors are not necessarily familiar with the conditions of the host country. The hazards include possible problems because of language, cultural customs, business practices, laws, and regulations. These problems must be sufficiently understood to be able to include a proper amount of contingency to the final bid price. The cost estimate must be calculated accurately, flexibly, and comprehensively. Moreover, adequate consideration of uncertain factors relating to project cost is required. Uncertainty can be a result of incomplete information, disagreement between information sources, linguistic imprecision, simplification, or approximations. Nevertheless, it is impossible to ensure that a project will always be as successful as initially planned. Even while implementing a project, there might be unexpected factors that affect cost. These factors can result in either cost overruns or cost savings (Kim et al., 2008, pp. 398-399).

If the contractor wins the tender, the contract is awarded. According to Respondent 15, the case company usually enters a lump sum contract with the customer, where a single "lump sum" price for all work is agreed before the work begins. This kind of agreement bears the risk that the contractor underestimates the project cost and is therefore not able to cover the contract expense. The risk is principally transferred from the customer to the contractor. The contractor agrees to implement the work for the amount stated in the contract, regardless of its actual cost. This agreement is effective as long as there is no change or breach of contract from the customer (Smith et al., 2013, pp. 135-136).

2.1.2 Cost estimation techniques

There are different techniques to determine the appropriate amount of contingency included in the bid price. Most of the methods take an inside view by focusing on the project, considering its objective, resources needed, and obstacles to its completion (Flyvbjerg, 2008, p. 9). A popular technique is to use an **expert's judgment** to assist in setting an adequate contingency level. Skilled estimators and project team members determine the level of contingency by using their experience and expertise. However, the subjectivity of this approach can be the main disadvantage, as the skill, knowledge, and motivation of the experts may vary extensively (Burroughs & Juntima, 2004, p. 32). There are different variations of the technique. Klakegg and Lichtenberg (2016) promote the Successive Principle, which is based on expert's judgments in a strictly predefined setting. Sources for uncertainty are located, categorized by type, and evaluated successively and systematically. A brainstorming with 7-15 experts is organized, which mitigates disadvantages as the variabilities in skill, knowledge, and motivation between experts.

Another technique is to add a **predetermined percentage.** In this case, a contingency of either 5 or 10 percent is included in all the projects. The advantage of this approach is that it is consistent and straightforward. The disadvantage is the removal of specificity and subjectivity (Burroughs & Juntima, 2004, p. 31).

Risk analysis can also be used to find the right contingency level. This technique examines risk factors in a more structured way than expert judgment and applies specific quantitative methods to translate the assessed risks into contingency. Commonly, the Monte Carlo simulation is used as a quantitative method in risk analysis. This technique is probabilistic and allows confidence levels to be explicitly considered. A disadvantage is that the chosen estimate items are usually not risk drivers in themselves, as there are underlying causes for risk. Moreover, more time and resources are required to implement a risk analysis (Burroughs & Juntima, 2004, p. 32).

Historical performance data shows that using expert judgment outperforms the use of predetermined percentages regardless of project size, definition level, or complexity. Risk analysis techniques can perform slightly better than the other methods when a project tender is well defined. However, when a project is not well defined, risk analysis produces worse results than the other techniques (Burroughs & Juntima, 2004, p. 36).

There are also cost estimation techniques, which take an outside view. Flyvbjerg (2008) suggests **Reference Class Forecasting** (RCF), as he locates the problem in behavioral bias and not inaccuracy of estimates as of such. He underlines this with the fact that substantial resources have been spent over several decades to improve data and forecasting models. Nevertheless, the accuracy of forecasts has not improved. Bias will be further explained in Chapter 2.2.2. RCF is a method for debiasing forecasts by systematically taking an outside view on planned actions, which is possible by identifying a relevant reference class of past, similar projects. To find appropriate reference class projects is difficult when new and unfamiliar technologies are used in a project. However, most projects use well-known technologies. As a next step, a probability distribution for the selected reference class must be established. Finally, the specific project must be compared with the reference class distribution. The distribution shows the most likely outcome for the particular project, whose cost must be evaluated. This technique doesn’t forecast specific uncertain events that will affect the project. The idea is to place the project in a statistical distribution of outcomes from the class of reference projects. Research suggests that an outside view produces significantly more accurate results than an inside view. However, most companies use the inside view in planning new projects, as it is the conventional and intuitive approach to focus on the project itself and its details. Moreover, it is challenging to assemble a valid dataset that will allow reliable forecasts (pp. 6-10).

Control systems need to review the cost estimates before and after they are approved. Low cost estimates indicate that the control systems haven't worked as intended (Segelod, 2018, p. 9). The budget, which is determined by the cost estimate, can be crucial for the success or failure of the project, as it determines the resources given to people to complete their tasks. When monitoring budgets, there are some factors which should be considered: Inflation during long-term projects, unfavorable changes in currency exchange rates, failing to get form prices from suppliers and contractors, unplanned personnel costs including overtime which incurred in keeping the project on schedule, and unanticipated training costs and consulting fees (Luecke, 2004, pp. 64-66, 132). After spending a quarter, or at the most a third of the project budget, the project manager should have a good understanding of the final cost. The final cost is reported when the project is finished (Segelod, 2018, pp. 11-13).

2.2 Explanations for cost overrun

Possible explanations for cost overrun can either be of a technical- or behavioral nature. In the technical category, the actors are assumed to evaluate information and make decisions based on rational reasoning. The behavioral category suggests that emotions drive decision making and have at least a decisive influence (Segelod, 2018, p. 59). In this chapter, these two categories are explained and illustrated by examples.

2.2.1 Technical explanations for cost overrun

Cost overrun belonging into the technical category of explanations mainly results because of problems predicting the future and is therefore considered an "honest" error (Cantarelli et al., 2010, p. 11). In this case, estimating the project cost causes problems because of numerous **uncertainties** (Flyvbjerg et al., 2009, p. 172). The leading causes for cost overrun and, therefore, sources for uncertainties in the technical category are**:**

- **Inappropriate forecasting techniques**, which doesn't provide realistic cost estimates (Siemiatycki, 2015, p. 4).

- **Price rises** in the future, which are difficult to predict (Cantarelli et al., 2010, p. 11). The cost of equipment, critical construction materials, and skilled workers can increase throughout a project. Price rises are likely when projects are implemented during periods of strong economic growth and tight employment markets, which lead to scarcity and rising prices (Siemiatycki, 2015, pp. 3-4).

- **Poor project -planning, -design,** and -**implementation**, which can be the consequence of a **lack of experience** of the actors involved (Cantarelli et al., 2010, p. 11).

- **Disputes between the client and the contractor**, or the contractor and multiple subcontractors. The arguments include disagreement about work quality and responsibility for errors made in a project, which lead to schedule delays and rising project costs (Siemiatycki, 2015, p. 3).

- **Incomplete estimations**, which are often the result of **inadequate data** (Cantarelli et al., 2010, p. 11). Scarce data can, furthermore, lead to inaccurate underlying assumptions (Siemiatycki, 2015, p. 4). Tenders must possibly be made before all technical feasibility- and engineering studies are completed. This circumstance leads to higher costs during project implementation when more details about the project are confirmed. The explanation can be that governments want urgent projects to get started quickly or try to meet funding deadlines or election timelines (Siemiatycki, 2015, p. 3).

- **Scope changes** that occurred in the project and were not predicted. These changes can lead to additional costs (Cantarelli et al., 2010, p. 11). The cost overrun can be the result of **poor risk management**, when change is not effectively managed (Smith et al., 2013, pp. 1-2). Responsible for change can be external factors, such as market demand, price changes, and new regulations. Internal characteristics, such as changes in the original design, can also be responsible (Segelod, 2018, p. 73). Change orders to the project must be negotiated and approved between the client and the contractor. This process can be time-consuming, costly, and lead to conflicts (Siemiatycki, 2015, p. 3).

- An **inappropriate organizational structure of the company**, or a **lousy decision-making and planning processes**. They lead to inefficiency, which results in costs higher than expected. In these cases, the organization is not able to adapt well enough to changing- circumstances, accountability and control, and planning (Cantarelli et al., 2010, pp. 11-12).

- **Project delays**, caused by strikes, challenges in sourcing materials, or skilled workers, or disputes among different contractors and sub-contractors (Siemiatycki, 2015, p. 4).

- **Unforeseen events**, as extreme weather conditions, pandemics, or accidents, can delay projects and increase the cost (Siemiatycki, 2015, p. 4).

- **Poor supplier management**, when supplier- and sub-contractor performance is not monitored and reported. Consequently, it is not possible to select partners with a proven track record of similar projects (Siemiatycki, 2015, p. 4).

The planning and implementation of a project is a process of reducing uncertainty. The uncertainty will be diminished, the more information the actors get and the greater the knowledge of how to realize the project. The technology involved, and the way how the actors learn more about the project, influence this process. The sources for uncertainty presented above can be divided into **static-** and **dynamic uncertainty**. The difference is that dynamic uncertainty can be dealt with during the planning period, but static uncertainty is a source of unexpected events throughout the whole planning and implementation process. Static uncertainty can't be reduced because it derives from external factors, which cannot be entirely avoided by careful planning. Static uncertainty might cause changes in project plans. Examples of static uncertainty are inflation, war, strikes, flooding, accidents, political uncertainty, or instability (Segelod, 2018, pp. 59, 74-76).

There are categories of projects which are more likely to cause cost overruns because of uncertainty (Segelod, 2018, pp. 74-76):

1. **Projects which need to develop knowledge new to the world**. The cost overrun is usually higher, the greater the advance in technical knowledge, which is necessary to implement the project. This likely not only applies to technical knowledge but also new knowledge and technology in general. Such projects contain the risk that surprises cannot be wholly avoided during project implementation, no matter how good the planning is. It can be distinguished between implementation and development projects. Implementation projects can be based on existing knowledge to reduce dynamic uncertainty, whereas development projects require progress in new knowledge. If new knowledge can be acquired and developed during the planning period, dynamic uncertainty in development projects can be reduced (Segelod, 2018, pp. 71, 74).

2. **Complex projects**. The cost overrun is usually higher, the higher the complexity of the project. The existence of dependencies characterizes this category. These dependencies are sub-projects and activities, which must be completed in time so that other activities are not delayed. The complexity can be measured with the number of dependencies in a project, how interrelated these dependencies are, and with their negotiability. The dependencies can occur due to both internal

and external actors, processes, and events. Complex projects have a lot of dependencies and allow little slack in time and trade-off between goals. The size of a project is not a primary factor for complexity, even though large and high-tech projects tend to be more complicated. Complex projects have dynamic uncertainty, which can be resolved during the planning period (Segelod, 2018, pp. 71-72, 74).

3. **Projects where actors have no experience in similar projects**. When the actors planning, estimating, and implementing the projects don't have experience of similar projects, the cost overrun tends to be larger. These are usually projects which are one-of-a-kind or projects that are implemented infrequently. It is easier to cost standardized items and work processes when data from earlier, similar projects are available. This category is categorized by the need of the actors to acquire and develop new knowledge to reduce dynamic uncertainty. The projects in this category are not necessarily unique to the world or exceptionally complex, but the actors involved don't have the required knowledge (Segelod, 2018, pp. 72, 74-75).

4. **Projects which are affected by exogenous static uncertainty**. These are projects where cost overrun occurred because of unforeseen events, such as unanticipated price increases or inflation, war, strikes, flooding, etc. (Segelod, 2018, p. 74).

5. **Systems innovations projects**. These are projects which are affected by static uncertainty. The development of electric vehicles could be taken as an example. The new vehicle system faces exogenous- and endogenous uncertainties. Exogenous uncertainties are, for example, the buyers' willingness to pay more for a more environmentally friendly vehicle, or whether subsidies and advantages are offered to owners and manufacturers of electric cars. Examples for endogenous uncertainties are related to actors developing the required infrastructure, such

as charging stations, service and repair, and a cluster of firms developing components for electric vehicles. (Segelod, 2018, p. 75)

2.2.2 Behavioral explanations for cost overrun

Inaccuracy in cost estimation is not merely caused by incomplete information and honest errors regarding cost and complexity, as the technical explanations suggest. Behavioral science explains cost overrun in human bias, psychological and political (Flyvbjerg et al., 2018, pp. 183-184). A lot of research on heuristics and biases was, for example, done by Amos Tversky and Daniel Kahneman (Gilovich et al., 2002; Tversky & Kahneman, 1974; Kahneman, 2011). Behavioral science sees the root cause for cost overrun in the fact that planners and managers repetitively keep underestimating the cost of scope changes, complicated interfaces, archaeology, geology, bad weather, business cycles, etc. The cost is underestimated, even though the planner and managers know that these factors can influence the cost. The problem is that planners often underestimate these factors and possible mitigation measures due to **optimism bias**, **planning fallacy**, and **strategic misrepresentation** (Flyvbjerg et al., 2018, p. 183). Especially in more complex projects and in projects based on new technologies, cost-, benefit-, and time- forecasts are systematically over-optimistic in comparison to less-complex projects (Flyvbjerg et al., 2009, p. 172).

Behavioral explanations can further be divided into the following categories:

- **Psychological explanations**

  Optimism bias and planning fallacy belong in the category of psychological explanations (Cantarelli et al., 2010, p. 12). The optimism bias is a cognitive predisposition found with most people to judge future events in a more positive light than is appropriate by experience. Planning fallacy means that people underestimate the costs, completion times, and risks of planned actions while overestimating the benefits (Flyvbjerg, 2008, pp. 6-7). This condition can also be called delusion

(Flyvbjerg et al., 2009, p. 172). When previous data and experience are missing, and the uncertainty is therefore high, cost estimates are based more on hope and vision than on information. The less is known about the actual cost, the more a cost estimation is based on belief (Segelod, 2018, p. 87). The lack of information makes the estimates susceptible to bias, which leads to cost underestimation, which leads to cost overrun.

- **Political-economic explanations**

  In this category, the cause for cost overrun is explained in terms of strategic misrepresentation. It means that forecasters and planners deliberately and strategically overestimate the benefits and underestimate the cost of a project (Flyvbjerg, 2008, p. 6). Such projects are unlikely to stay on budget or time and hardly deliver the promised benefits (Flyvbjerg et al., 2009, p. 173). The difference between economic and political explanations is relatively small, only their starting point diverge. Economic explanations are based on the lack of incentives and resources, whereas political explanations are based on interests and power for utility maximation (Cantarelli et al., 2010, pp. 12-13).

  From the contractor's perspective, a political-economic explanation of deliberately underestimating cost is **strategic behavior.** Underestimating the costs increases the chance of getting the project awarded (Cantarelli et al., 2010, pp. 11-12). This behavior can be alluring when the primary interest is to win the tender, which is usually achieved by offering the lowest possible price (Flyvbjerg et al., 2009, p. 179). An explanation could be the prestige, which follows from the delivery of a particular project. The too-low bid price leads to high cost overruns, which must not be a problem if the losses are supposed to be made up in future projects. But this should not be a common practice for most of the projects, as it is not sustainable. Furthermore, once contractors got the contract awarded, they know that they might be able to drive up the price later through change orders (Siemiatycki, 2015, p. 5).

There are several political-economic reasons for cost overrun, which are not feasible from the contractor's perspective, but instead of the customer's perspective. The customer as project owner might need approval and funding for the overall project. Therefore, project promoters like forecasters, planners, or politicians might systematically distort or misstate facts, which can also be called lying in response to incentives in the budget process (Jones & Euske, 1991, p. 437). Lying increases the likelihood that their project, and not the one of a competitor, gains approval and funding (Flyvbjerg, 2008, p. 6). From the project owner's perspective, there is often a lack of incentives to provide accurate estimates, as exact figures decrease the chance of receiving funding for the project. Decision-makers must, furthermore, often choose between projects because of a lack of resources, which leads to competition. Project promoters, therefore, deliberately underestimate costs to make their projects look more interesting and enhance the chance of being selected. It is also possible that forecasts are manipulated to advocate a project (Cantarelli et al., 2010, pp. 11-14). For example, a politician wants to compete successfully for a federal grant and therefore lets adjusting the cost figures downward (Flyvbjerg et al., 2018, p. 184). All this is encouraged by the fact that once a project is started, few are ever halted (Siemiatycki, 2015, p. 5).

Strategic misrepresentation is enabled because of the lack of consequences that is related to this kind of behavior. There are no consequences due to the lack of coordination, the lack of long-term commitment, and the lack of discipline of the people involved. Organizational and political pressures are additional reasons. Forecasts are adjusted to achieve the most politically or organizationally attractive outcomes. Asymmetric information is another cause. Decision-makers have little information and therefore rely on the data obtained from forecasts, which allows forecasters to misrepresent information (Cantarelli et al., 2010, p. 12).

Optimism bias and strategic misrepresentation are both deceptions. The difference is that strategic misrepresentation is intentional; optimism bias is not. Optimism bias is a form of self-deception. Nevertheless, the result of the deception is the same, namely inaccurate forecasts, which lead to cost overrun (Flyvbjerg, 2008, p. 6).

2.3 How to mitigate cost overrun

2.3.1 Technical explanations

As explained in Chapter 2.2.1, technical explanations are mainly based on problems predicting the future. The problems occur because of numerous uncertainties. Thus, cost overrun can be mitigated by **reducing dynamic uncertainty**. Depending on the case, this could be done as follows:

- **Reduction of forecasting- and calculation errors**. Forecasting errors can be reduced by having adequate data at disposal (Cantarelli et al., 2010, pp. 11, 13). Furthermore, proper risk management should already be in place in the tendering process, as an early inclusion increases the probability of a successful outcome of the project (Elkington & Smallman, 2002, p. 56). Moreover, the right forecasting method should be chosen, which allows adequate cost estimation.

- **Improvements in the planning process, project design, and implementation** of the project. As shortcomings in this area are usually the result of a lack of experience, experienced staff is one way to achieve this. Furthermore, planning concepts can help (Cantarelli et al., 2010, pp. 11, 13).

- **Improvements in the structure of the company**. This point refers mainly to the way how decision-making works in the company. The decision-making must be primarily based on market needs and requirements (Takala, Shylina, et al., 2013, p. 66).

- **Enhancement of performance monitoring, reporting, and information sharing.** Big data and analytics are getting increasingly important. Performance is being improved by methods that rely on collecting and statistically analyzing vast amounts of data. Therefore, there must be a systematic tracking implemented which compares cost and schedule estimates with the outcome. Systematic tracking enables institutional learning from experience and real-time information gathering, which improves decision-making. Sufficient data quality and information management are required for reliable results. The data to be collected includes the type, size, and location of the project, companies and project managers involved, significant scope changes, causes for cost overrun and schedule delays, quality and safety measures at the site, and long-term defects. Over time, large datasets are available, which can be statistically analyzed. As a result, trends relating to cost and quality can be seen, and the right conclusions can be drawn (Siemiatycki, 2015, pp. 5-6).

- **The hiring of a competent team for the implementation of the project**. The team must have a proven track record of similar projects to be able to deliver the project within cost and time (Flyvbjerg et al., 2018, p. 185). The track record has to be possessed by internal resources as well as external resources, such as suppliers and sub-contractors. Furthermore, suitable suppliers must be chosen which can deliver materials on schedule, in the right quality, and for a low price. Therefore, supplier and sub-contractor performance must be tracked to select the right partners for future projects. They must have a strong record of delivering with the right quality, on budget, and schedule (Siemiatycki, 2015, p. 4).

The ways mentioned above to reduce uncertainty concerning technical explanations for cost overrun are reliable on appropriate technology and experienced employees. Thus, the reduction of uncertainty is backed by technology- and knowledge management. Porter (1985) recognized that “everything a firm does involves technology of some sort” (p. 62). Hence, it is essential to have **effective technology management** implemented, which is the ability of a company to shape and accomplish its strategic and operational objectives through planning, directing control, and coordination of the development and implementation of technological capabilities. Technology can be a major source of competitive advantage and growth for a company (Cetindamar et al., 2010, pp. 1-2). Especially for a technology-based company, a sustainable competitive advantage is not only reached through cost reduction and operational efficiency. The company must be able to manage its technology assets (Skilbeck & Cruickshank, 1997, p. 138). In combination with a highly motivated and adequately trained workforce, technology enables the company to adapt rapidly according to customer demands. Furthermore, new market opportunities can be accessed and developed. However, it is complex to integrate technological considerations into business processes. There are various challenges associated with the management of technology. Possible risks include increased cost, complexity, and pace of technology advancement, increased diversity of technology sources, globalization of competition and alliances, and the impact of information technology. On the other hand, these risks can also be an excellent opportunity for companies, which can fully exploit their technological potential (Cetindamar et al., 2010, pp. 1-2).

Effective technology management requires experienced employees, which in turn requires **effective knowledge management.** According to Zou and Lim (2002), knowledge management is defined as

> the management processes (including planning, organizing, implementing, controlling, and evaluating) of creating, capturing, transferring, sharing, retrieving, and storing of data, information, knowledge experiences, and skills by using appropriate information and network technology, with the endorsement of total involvement in organizational learning to enable knowledge acquisition throughout the processes. (p. 1746)

Knowledge is the ability to use information effectively. Only to possess the information required is not enough. Knowledge resides in the workforce of an organization and aggregated it is called “organizational capability”, which is a critical attribute. Without adequate knowledge, the individuals can’t perform an activity within a practical context

(Miller & Morris, 1999, pp. 94-95). A companies' knowledge base includes its technological competencies, its knowledge of customer needs, and supplier capabilities. These competencies include individual skills and experiences and the ways how things are done within the company. The competencies consist of various processes, procedures, routines, and structures existing in practice (Cetindamar et al., 2010, p. 9). The individuals are applying explicit and tacit knowledge to handle tools and technology in processes. Explicit knowledge is the knowledge written in books or discussed in classrooms and conference rooms. Tacit knowledge exists in an inexpressible form and is critical to success in professional careers. It consists of experiences and the understanding of how something must "feel". For example, one can't know how it feels like to hold and use a hammer unless one has done it. Especially, one can't say when it feels right (Miller & Morris, 1999, pp. 75, 94-95).

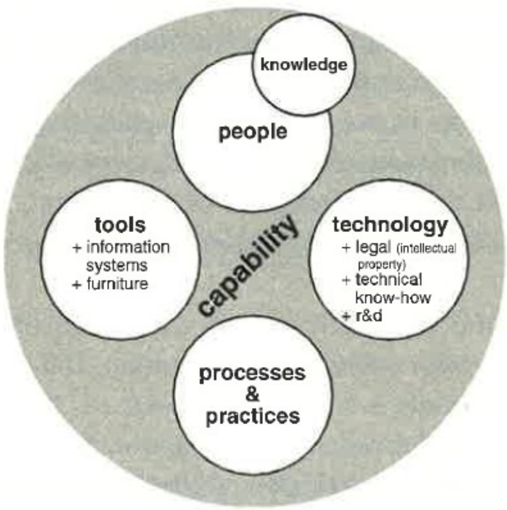


Figure 1. Components of capability (Miller & Morris, 1999, p. 76).

The different components of capability are illustrated in Figure 1. Capability is a combination of the right tools, the right technologies, efficient processes and practices, and the people with the knowledge required. Differences in capability can distinguish market leaders from followers, as it is the basis of good performance. Capability development has an impact and can improve speed, quality, and costs within existing product platforms. Furthermore, it can generate discontinuous innovation and new dominant designs (Miller & Morris, 1999, p. 76). Because knowledge and technology have such a significant impact on capability, and as a result on cost overruns, these aspects will be further examined in this thesis.

2.3.2 Behavioral explanations

As explained in Chapter 2.2.2, the leading causes for cost overrun according to behavioral science are cost underestimation because of optimism bias, planning fallacy, and strategic misrepresentation.

When it comes to optimism bias and planning fallacy, cost overrun can be mitigated by using forecasting methods that allow **reliable, de-biased estimates of cost**. This advice suggests that forecasters are irrational in a predictable way (Flyvbjerg et al., 2018, pp. 185, 188). Contractors are influenced by systemic biases in both project cost and return (Kim et al., 2008, p. 398). These biases must be considered to get more accurate cost estimates. Conventional cost estimation methods produce an error as well as bias, which is why they have a century-long track record of inaccuracy (Flyvbjerg et al., 2018, pp. 185, 188). Forecasts adopt an inside view, which means decision-makers have a strong tendency to consider problems as unique and therefore focus on details of the current project when creating solutions. An outside perspective, which ignores the specific details of the project and uses a broad reference class of similar projects for the forecast, mitigates bias (Flyvbjerg et al., 2009, p. 173). Flyvbjerg (2008), therefore, suggests the Reference Class Forecasting method, as explained in Chapter 2.1.2.

Cost overrun based on strategic misrepresentation can be mitigated by **establishing an incentive structure, which encourages to stay on budget** (Flyvbjerg et al., 2018, p. 185). The incentive structure can be established by appropriate contracts and procurement models (Siemiatycki, 2015, p. 8). Furthermore, **accountability** must be provided. When multiple people are responsible for the outcome of a project, it might be difficult to hold someone accountable for a bad result (Flyvbjerg et al., 2009, pp. 173, 180). The incentive structure should, therefore, be established in a way that accurate forecasts are rewarded, and inaccurate ones are punished (Flyvbjerg, 2008, p. 19). Also, **transparency** must be enhanced, which means information regarding the specifics of the projects must be disclosed. The disclosure can be achieved through financial and non-financial rewards. Moreover, forecasts tend to be unbiased when there is a **good learning environment**. A good learning environment means that similar decisions are taken regularly, to be able to learn from them (Flyvbjerg et al., 2009, pp. 173, 181-185).

As explained in Chapter 1.1, the case company is participating in tenders. The competition for the award of contract usually leaves little flexibility to increase the bid price to mitigate cost overrun. Therefore, there is little room to reduce optimism bias, planning fallacy, and strategic misrepresentation in cost estimations. Furthermore, there are fewer incentives for strategic misrepresentation from the contractor's perspective than from the customer's perspective. Consequently, behavioral explanations play a less prominent role for contractors compared to the client, who must estimate the cost of the whole project to make an investment decision. The case company must focus on staying on the budget, mostly determined by the market. Keeping the budget can be done through a good operative performance during the planning and implementation of the project. Therefore, the methods used in this thesis mainly focus on locating causes, which ultimately reduce uncertainty, as explained in the technical explanations for cost overrun. Nevertheless, adequate cost estimation shouldn't be neglected. Respondent 16 confirms that if a higher price would have been offered, it is not sure that the case company would have gotten the projects awarded. In principle, it is the market price which is offered. The profit margins are smaller than in other businesses. In this competitive market, it is not a solution to simply raise the price.

3 Methodology

Several methods are used and combined to locate the root causes of cost overrun in the examined projects. The methodology is thoroughly explained in this chapter. It mainly concentrates on technical explanations for cost overrun by locating the critical operative processes within the projects. Besides, there is also a method introduced to examine the impact of the used technologies on cost overrun. The methodology used provides a way to turn qualitative data into quantitative data, which allows the empirical research.

3.1 Operations Strategy

Operations are the resources that create and deliver products and services based on customer requests. A company sets the role, objectives, and activities of the processes in the operations strategy (Slack et al., 2013, p. 70). The resources are allocated based on how the company competes in the market and how it estimates its business environment. In a successful operations strategy, opportunities are identified and prioritized while being aware of possible trade-offs (Takala, Shylina, et al., 2013, pp. 65-66). To follow a successful operations strategy, which fits the organization, is crucial. It contributes to the success of the projects and can, therefore, mitigate cost overrun.

According to Miles et al. (1978), there are four strategic types of organizations: Defenders, Analyzers, Prospectors, and Reactors. They all have their configuration of technologies, structures, and processes that are consistent with their market strategy. Even if organizations operate in the same industry, they can fit in different categories of strategic types and therefore differentiate themselves from each other. The pure forms of strategic types are as follows:

- **Defenders**

  The focus of the Defenders is on cost (Takala et al., 2012). They like to operate in an environment where a stable form of organization is suitable. Therefore, they produce only a limited set of products directed at a narrow segment of the total potential market. They react aggressively to prevent competitors from entering their niche market. The reaction comprises economic actions like competitive pricing or high-quality products. They also tend to ignore developments and trends outside of their niche, as they prefer to grow through market penetration and limited product development. As a result, they can carve out and maintain a small niche within the industry, which is difficult for competitors to penetrate. Most of the available resources of the Defender go into the efficient production and distribution of goods and services, which is usually achieved by technological efficiency. It is ensured by developing a single core technology, which is highly cost-efficient. The top-management is dominated by production and cost-control specialists to ensure efficiency. This strategic type is more common in industries where technological change is not an issue. The Defender gets in trouble if its market shifts dramatically, as there is little capacity for locating and exploiting new opportunities (Miles et al., pp. 550-551).

- **Prospectors**

  Prospectors focus on quality (Takala et al., 2012). Compared to the Defenders, the Prospectors have an oppositional approach of reacting to the chosen environment. Their prime capability is to find and exploit new product and market opportunities and therefore maintain a reputation as an innovator in product and market development. This capability might be as important or even more important than high profitability. As failures associated with a sustained product and market innovation can’t be avoided, it might be challenging to attain the profit levels of the more efficient Defenders. The area of expertise is broad and in a continuous state of development. To be able to survey a wide range of environmental conditions, trends, and events, the Prospector invests heavily in individuals and groups who scan the environment for potential opportunities. Change is the way for this type of organization to distinguish itself from competitors. It requires flexibility in both its technology and administrative system. The

Prospector, therefore, creates multiple prototypical technologies. They all have a low degree of routinization and mechanization. They must be able to deploy and coordinate resources among numerous projects. It is not possible to plan and control the operations of the entire organization centrally. Therefore, the top management is dominated by marketing and research & development experts. The planning is characterized as broad and oriented towards results rather than methods. The project structures have, amongst others, a low degree of formalization, decentralized control, and horizontal as well as vertical communication. The risks of this approach are low profitability and overextension of resources. The efficiency of a Prospector is compromised, as multiple technologies are present (Miles et al., 1978, pp. 551-553).

- **Analyzers**

  The focus of this type is on balancing quality, cost, and time (Takala et al., 2012). The Analyzer is a combination of the Defender and Prospector types and can be a reasonable alternative to these other strategies. An Analyzer tries to minimize risk while maximizing the opportunity for profit. The Analyzer, therefore, combines the strengths of both the Defender and the Prospector. It is a strategy that is difficult to implement, especially in industries with rapid market- and technological change. An Analyzer tries to "balance" between the two extremes, Defender and Prospector. Such a company attempts to locate and exploit new product and market opportunities while simultaneously maintaining a base of traditional products and customers. The Analyzer is open towards new products and markets but waits until it is assured that they are relevant, which is achieved by imitation. This kind of company adopts only the most successful product or market innovations, which are developed by prominent Prospectors. The main share of the revenue is generated by a relatively stable set of products and customers, which is a Defender characteristic. The right mix of technological flexibility and technological stability must be found. The stable part achieves cost-efficiency through a functional organization, high levels of standardization, routinization, and mechanization. The flexible part has a low degree of routinization and automation. The Analyzer often uses a matrix organization structure to accommodate both stable and dynamic areas of operation in its design and processes. As a dual technological core must be established, the management must operate fundamentally different planning, control, and reward systems simultaneously. This balance of stability and flexibility makes it difficult to move fully in either direction if required. The risks are, therefore, both inefficiency and ineffectiveness if the necessary balance can't be kept (Miles et al., 1978, pp. 553-557).

- **Reactors**

  The strategy types described above are all proactive to the environment in their way. The reactor, however, adjusts to its environment in both an inconsistent and unstable way. There are no response mechanisms available to a changing environment. As a result, there is continual instability. Reactors keep reacting inappropriately to environmental change and uncertainty, which leads to poor outcomes. The reactor strategy is a result of improperly pursuing one of the other three strategies. There are some reasons to become a reactor. The top management may not have clearly articulated the organization's strategy. Or the management doesn't entirely shape the organization's structure and processes to fit a chosen strategy. The market, technological-, and administrative decisions must be aligned correctly in an operations strategy. Otherwise, the strategy is only a statement, not a useful guide on how to approach it. The third reason for instability is that the management keeps its current strategy type, even though there are fundamental changes in the environmental conditions (Miles et al., 1978, pp. 557-558).

Which operations strategy to pursuit must be primarily based on market needs and requirements. Different companies focus on different capabilities and competitive priorities (Takala, Shylina, et al., 2013, p. 66). According to Slack et al. (2004), there are four main competitive priorities, namely Quality, Cost, Time, and Flexibility, which will be further described in Chapter 3.2.

The available resources of a company must be aligned to the chosen strategy type, which enables to exploit its advantages as good as possible. These resources allow the company to prosper and mitigate cost overrun in its projects. The following subchapters explain the determination of the strategy type and the alignment of the resources to the strategy type.

3.2 RAL concept

The key which strategy type to choose in the decision-making process of operations managers is the competitive priorities. They indicate the strategic emphasis on developing individual capabilities, which improve the market position of a company. The trend towards global competition, focus on customer satisfaction and quality excellence, amongst others, creates an image of the future company as “lean” or “agile”. Everything a company does must add value for the customer. The main fields of interest for the customer are price, quality, service, and delivery (Takala et al., 2012).

The Responsiveness, Agility, and Leanness (RAL) model is a holistic and multi-focused operations strategy tool based on business goals. It was created to understand the success factors of logistics but can be applied to operations strategies and operations management (Takala et al., 2012). The RAL model can be seen in Figure 2. It is considered to consist of all the main factors that affect the operations of a company.

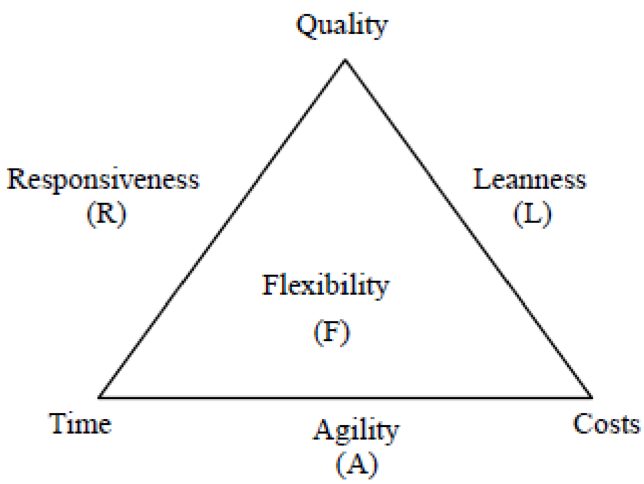


Figure 2. The RAL model (Takala et al., 2012).

The dimensions of the RAL model are:

- **Responsiveness**

  The responsiveness is the speed by which the system satisfies unanticipated requirements (Takala et al., 2012).

- **Agility**

  The agility is the speed by which the system adapts to the optimal cost structure (Takala et al., 2012).

- **Leanness**

  Leanness is the minimization of waste in all resources and activities. (Takala et al., 2012)

- **Quality**

  Quality means that things are done right. There is design quality and process quality. The design quality is the set of features that a product or service has and the part of quality which the customer experiences and judges. The process quality is related to the quality inside the operations and can lead to cost reduction and dependability increase (Takala, Shylina, et al., 2013, p. 66). Dependability means that things are done in time, and customers, therefore, receive their goods and services when they are promised (Slack et al., 2013, p. 49). Dependability is a direct consequence when fewer mistakes are made during the operation process, and hence less time must be spent on fixing these mistakes. There will also be less dissatisfaction and confusion inside the company (Takala, Shylina, et al., 2013, p. 66).

- **Cost**

  Even if a company is not competing for cost leadership, the cost is always an essential objective for operations management. Savings in the operation's cost can directly be added to profits. Operation costs can occur on staff, facilities, technology, equipment, and materials (Slack et al., 2013, p. 55).

- **Time**

  Time means the duration between the point when customers are requesting products or services until they receive them. Advantages of short lead-time are that customers are more likely to order, that they will pay more, or that they receive a greater benefit for their order. Moreover, the time aspect is also essential inside the operation of a company, which means there should be fast decision making and quick movement of materials and information. Speed reduces inventories and reduces risks, as accurate forecasting is easier, the quicker the throughput time of a process (Slack et al., pp. 47-48).

- **Flexibility**

  Flexibility is the ability to change the operation in some way. The change can be related to what the operation does, how it is doing it, or when it is doing it. A company must possess different kinds of flexibility. Product/service flexibility means that the operation must be able to introduce new or modified products or services. Mix flexibility is the operation's ability to produce a wide range of mix of products and services. Volume flexibility means the ability to change its level of output or activity to produce different quantities or volumes of products and services. The operation must be capable of changing the timing of delivery of its services and products, which is called delivery flexibility. Flexibility inside the operation saves time, maintains dependability, and can save costs (Slack et al., 2013, pp. 53-54).

Quality, time, cost, and flexibility are proportional (%) values. They are used to compare all types of companies with each other (Takala et al., 2012). Sub-criteria, which belong to the competitive priorities, Quality, Cost, Time, and Flexibility, can be seen in Figure 3.

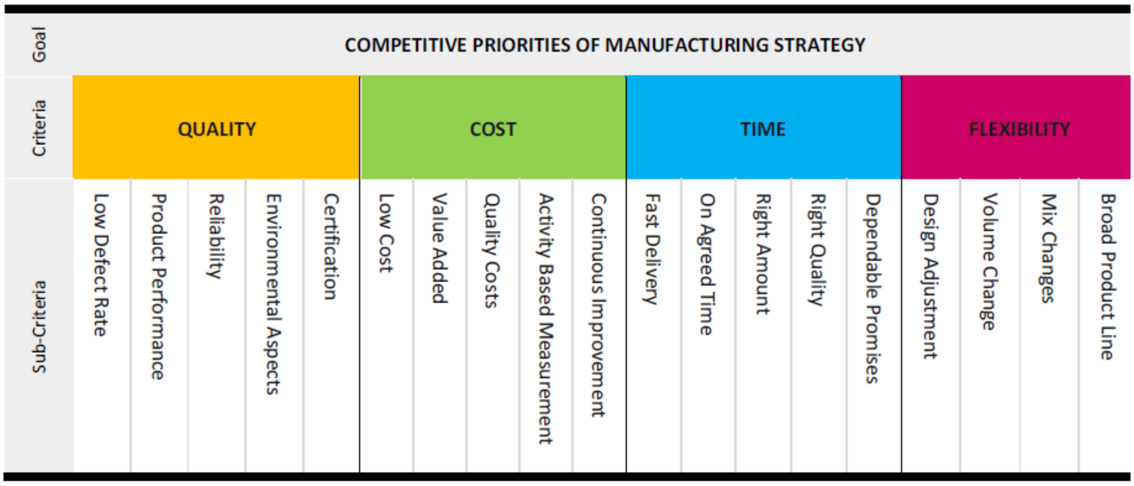


Figure 3. The Competitive Priorities of the RAL model (Takala & Uusitalo, 2012, p. 57).

3.3 Analytical Hierarchy Process (AHP)

To get a ranking of the RAL components Quality, Cost, Time, and Flexibility, and therefore an overview of the competitive priorities of the company, the Analytical Hierarchy Process (AHP) is used. By ranking the components, it can be seen which preference has been given to which component (Saaty, 2008, p. 84). The priorities of the components allow us to analyze if the resources of the project have been appropriately allocated.

The AHP model consists of five steps of decision-making in an organized way and thus generates priorities (Saaty, 2008, p. 85):

1. Problem definition and determination of what kind of knowledge is sought (Saaty, 2008, p. 85).

2. Development of a decision hierarchy with different levels. At the top of the hierarchy is the goal of the decision (Saaty, 2008, p. 85).

3. Construction of a pairwise comparison matrix. Each element of an upper level is used to compare the elements of the next lower level concerning it (Saaty, 2008, p. 85).

4. Priorities obtained from the comparisons are used to weight the priorities in the next lower level. This approach must be made for every element. The weighted values for each element in the level below are added to obtain its global priority. The process of weighing and adding is continued until the final priorities of the alternatives at the lowest level are received (Saaty, 2008, p. 85).

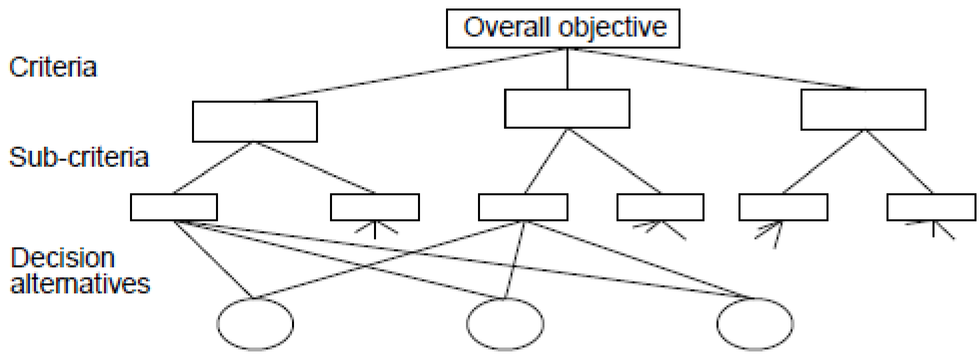


Figure 4. The hierarchical structure of a decision problem (Rangone, 1996, p. 106).

The relative weights are determined by making pairwise comparisons using a preference scale. The scale goes from 1 to 9, as illustrated in Table 1. One factor can be up to nine times as important as another factor (Rangone, 1996, pp. 108-109).

Table 1. The measurement scale for the AHP method.

Verbal judgement	Degree of preference
Equally preferred	1
Moderately preferred	3
Strongly preferred	5
Very strongly preferred	7
Extremely preferred	9
Intermediate values to reflect compromise	2, 4, 6, 8

As all the relevant decision criteria are included in the AHP method, their pairwise comparison allows determining trade-offs between objectives. It consists of the knowledge and expertise of the respondents in the priority setting process by utilizing their subjective judgments. An overall priority of each alternative is achieved by summing up the results (Takala et al., 2007, pp. 331-332).

The results of the ranking are used for the Sustainable Competitive Advantage Model (Chapter 3.5) and the Sand Cone model (Chapter 3.6.2).

3.4 Sense and Respond Methodology

It can be useful to analyze a company from the resource side rather than from the product side (Wernerfelt, 1984, p. 171). Operations strategy provides a broad framework for how a company can prioritize and utilize its resources. The ability of a company to quickly adjust its processes and allocate its resources is crucial.

The Sense and Respond (S&R) Methodology was introduced to develop the operative management system (Liu & Takala, 2012). It helps companies to understand their business situation better. As a result, it enables a fast and more precise reaction to shortcomings (Takala, Muhos, et al., 2013, p. 62). The S&R method "senses" the critical processes of the operations management, which allows developing them effectively. This approach leads to a competitive advantage (Takala, Shylina, et al., 2013, p. 65). The term "Sense and Respond" was first introduced by Haeckel (1992), who argued that companies would get increasingly service-centered and therefore need to change the way how their businesses are structured, measured, and managed. The S&R thinking was later developed by Bradley and Nolan (1998) and Markides (2000) to be able to analyze the dynamics of business performances and strategies.

The S&R method can be applied as a questionnaire (Takala, Shylina, et al., 2013, p. 66). The S&R questionnaire was developed by Rautiainen and Takala (2003). It was evolved by Ranta and Takala (2007), paying attention to controlling and evaluating the company's internal and external attributes from experience and expectation perspective. The questionnaire defines attributes that represent market needs. It enables them to react to the present important attributes in a way that they develop and change in the right direction (Takala, Shylina, et al., 2013, p. 67). The format of the questionnaire can be seen in Table 2. The respondent must evaluate the expectation and experience of every performance attribute. The evaluation is on a scale of 1 to 10 in the defined duration. Furthermore, the direction of development must be determined on a scale of "worse", "same", or "better". For the analysis, the counts of "better" and "worse" are derived into percentage weights (Liu & Liang, 2015, p. 1027).

Table 2. Format of the Sense and Respond questionnaire.

Performance attribute	Scale: 1 = low, 10 = high		Direction of development		
	Expectation (1-10)	Experience (1-10)	worse	same	better
Performance 1					
Performance 2					
…					

Several indexes were introduced to evaluate the questionnaire. Ranta and Takala (2007) developed the Critical Factor Index (CFI) as an enhancement of the Emphasized Implementation Index created by Rautiainen and Takala (2003). Nadler and Takala (2010) developed the Balanced Critical Factor Index (BCFI) based on the CFI. Liu et al. (2011) added trend research into the study and therefore created the Scaled Critical Factor Index (SCFI). Finally, Liu and Liang (2015) further developed the SCFI, which led to the creation of the Normalized Scaled Critical Factor Index (NSCFI). These indexes can be used to optimize strategic adjustments and therefore support the fast-strategic decision-making process. The CFIs are composed of several indexes, which must be calculated (Takala, Shylina, et al., 2013, pp. 66-67). The following equations are part of calculating the CFIs:

- **Gap index**

  This index helps to understand the gap between the experience and the expectation of a specific attribute (Takala, Koskinen, et al., 2013, p. 49). A value of one means that there is no gap. A value above one indicates that experiences are lower than expectations and a value below one means that experiences are higher than expectations (Liu & Liang, 2015, p. 1027).

$$\left|\frac{Avg\ (experience) - Avg\ (expectation)}{10} - 1\right| \tag{1}$$

- **Development index**

  This index shows the direction of the company's development, which means if an attribute's development has a positive or negative trend compared to the old situation (Takala, Koskinen, et al., 2013, p. 49). When the value is one, the performance remains at the same level. A value above one means that the performance is worse, and a value below one means that the performance is better (Liu & Liang, 2015, p. 1027).

$$|(better - worse) * 0.9 - 1| \tag{2}$$

- **Importance index**

  The importance index illustrates the importance of an attribute for a company by showing how high the expectation towards an attribute is (Takala, Koskinen, et al., 2013, p. 49). The scale goes from 0 to 1, with large values indicating high expectations (Liu & Liang, 2015, p. 1027).

$$\frac{Avg\ (expectation)}{10} \tag{3}$$

- **Performance index**

  This index shows how well the performance of an attribute was according to the experiences of the respondents (Takala, Koskinen, et al., 2013, p. 49). The scale goes from 0 to 1, in which a larger value stands for better performance (Liu & Liang, 2015, p. 1027).

$$\frac{Avg\ (experience)}{10} \tag{4}$$

- **The standard deviation of expectation index (for CFI and BCFI)**

  This index discloses if the expectations of the respondents towards an attribute are similar, or if the expectations differ from each other (Takala, Koskinen, et al., 2013, p. 49).

$$\frac{std\{expectation\}}{10} + 1 \tag{5}$$

- **The standard deviation of experience index (for CFI and BCFI)**

  This index shows if the experiences of the respondents towards an attribute are similar, or if the experiences differ from each other (Takala, Koskinen, et al., 2013, p. 49).

$$\frac{std\{experience\}}{10} + 1 \tag{6}$$

- **Gap index' (for NSCFI)**

  This is an improved Gap index for the calculation of the NSCFI (Liu & Liang, 2015, p. 1026).

$$2^{\frac{Avg\{expectation\}-Avg\{experience\}}{10}} \quad (7)$$

- **Development index' (for NSCFI)**

  This is the improved Development index for the calculation of the NSCFI (Liu & Liang, 2015, p. 1026).

$$2^{(worse\%-better\%)} \quad (8)$$

The presented indexes enable to calculate, CFI, BCFI, SCFI, and NSCFI, which have been validated in empirical studies involving more than 100 case studies (Liu & Liang, 2015, p. 1026):

- **Critical Factor Index (CFI)**

  This index was developed to find the critical attributes and areas of an organization (Takala, Shylina, et al., 2013, p. 68).

$$\frac{std\{experience\}*std\{expectation\}}{Gap\ index*Direction\ of\ development*Importance\ index} \quad (9)$$

- **Balanced Critical Factor Index (BCFI)**

  The BCFI is an enhancement to the CFI (Takala, Shylina, et al., 2013, pp. 67-68). Compared to the CFI, it lowers the strong influence of the standard deviation and increases the weight of the experience section (Nadler & Takala, 2010, p. 1334).

$$\frac{std(experience)*std(expectation)*Performance\ index}{Importance\ index*Gap\ index*Direction\ of\ development\ index} \quad (10)$$

- **Scaled Critical Factor Index (SCFI)**

  The SCFI was developed to solve the problems which occur in the BCFI when the number of respondents is narrow and limited (Takala, Shylina, et al., 2013, p. 68). The SCFI has been validated to have better sensitivity, accuracy, and wider tolerance of sample size (Liu & Liang, 2015, p. 1025).

$$\frac{a^{*} * b^{*} * Performance\ index}{Importance\ index * Gap\ index * Development\ index} \tag{11}$$

  where

$$a^{*} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(experience(i) - 1)^{2}}$$

$$b^{*} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(expectation(i) - 10)^{2}}$$

$$n = number\ of\ informants$$

- **Normalized Scaled Critical Factor Index (NSCFI)**

  The SCFI was further improved and led to the development of the NSCFI (Liu & Liang, 2015, pp. 1026-1027).

$$\frac{\sqrt{\frac{1}{n} * \sum_{i=1}^{n}[experience(i)]^{2}} * \sqrt{\frac{1}{n}\sum_{i=1}^{n}[expectation(i) - 11]^{2}} * Performance\ index}{Gap\ index' * Development\ index' * Importance\ index} \tag{12}$$

  where

$$n = number\ of\ informants$$

The results of the questionnaire calculated by one of the CFIs can be illustrated in a bar chart. The bars are in the colors of a traffic light, as shown in Figure 5. Red attributes are critical, must be thoroughly examined, and additional resources should be attributed to them (Takala, Shylina, et al., 2013, p. 87). Green attributes are balanced. Yellow attributes are over-resourced, and it must be considered if these attributes can be allocated more effectively. An equally distributed resource allocation is considered to be ideal (Takala, Koskinen, et al., 2013, p. 48). The average resource level is defined by dividing the whole resource, which is 100%, to the total number of attributes. The upper bound of a balanced attribute, which takes the green color, is calculated by adding 1/3 of the average resource level to the average resource level. The lower bound is found when 1/3 of the average resource level is subtracted from the average resource level. CFI values below the lower bound are defined as under-resourced and take the red color. CFIs that are higher than the upper bound are determined to be over-resourced and take the yellow color (Liu & Takala, 2012, pp. 29-30).

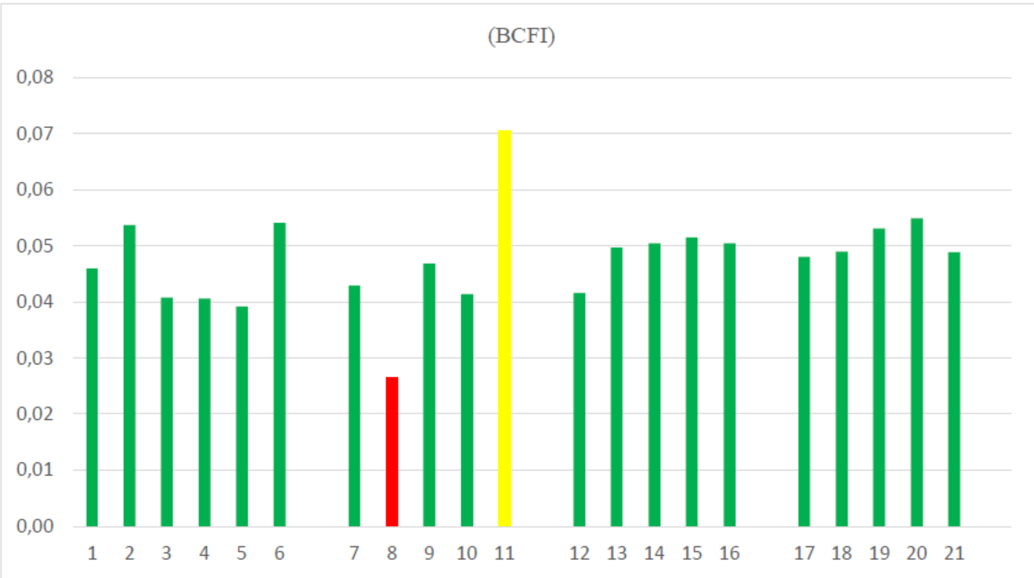


Figure 5. Example of the resource allocation of a company based on BCFI (Tilabi et al., 2019, p. 136).

The strategic types defined by Miles et al. (1978) are integrated into the Sense and Respond methodology by assigning one of the dimensions (Quality, Cost, Time, or Flexibility) of the RAL model to the performance attributes. The RAL dimension is chosen for the performance attribute, which represents its focus best. This approach is used to determine the operations strategy of the company examined, using the Manufacturing Strategy Index described in the next chapter (Takala, Koskinen, et al., 2013, p. 46).

In this thesis, the S&R methodology is used to locate the critical attributes within the projects. The method is an excellent indicator to understand which attributes require special attention. The assumption is that by allocating more resources to the root causes for the critical attributes and therefore improving them, the cost overrun can be reduced. Cost overruns occur directly or indirectly because of the critical performance attributes, indicated in red.

3.5 Sustainable Competitive Advantage (SCA) Method

To construct and pursue a sustainable competitive advantage, organizations must use their available resources and capabilities. In the resource-based view, a company achieves a competitive edge when optimally using its heterogenic strategical resources. As these resources are not entirely mobile across companies, this heterogeneity can be long-lasting. The resources of a company include all assets, capabilities, organizational processes, company attributes, information, knowledge, etc., which are in its control. A company has a sustainable competitive advantage when it can implement a value-creating strategy. Furthermore, no current or potential competitor should be able to implement it simultaneously and duplicate the benefits of the strategy (Barney, 1991, pp. 99-102).

The Sustainable Competitive Advantage (SCA) method assures that the resources of the company are operating according to the company's strategy (Takala, Muhos, et al., 2013, p. 62). Besides, the method offers a possibility to see which strategy type may bring a better business performance to the company. It is also a way to check whether all units follow the general strategy if the method is used to analyze several branches of a company (Takala, Liu, et al., 2013, p. 1243). The same applies when different projects of a company are examined.

Success in the market over a long-term period requires a company to make decisions about how to allocate its resources. The resource allocation allows the company to define its position in the market by determining an operational strategy. Skinner (1969) introduced the so-called Manufacturing strategy, which is an integrated part of calculating the SCA value and systematically links up manufacturing with corporate strategy. The model enables to evaluate the competitive priorities of the company, to reach competitive advantages in the market. The evaluation allows a classification of the company or examined unit into one of the strategy types, Analyzer, Defender, Prospector, or Reactor (Takala, Shylina, et al., 2013, p. 68). The strategy types were already described in Chapter 3.1. Manufacturing strategy can also be applied to the project-based business of the case company.

The Manufacturing Strategy Index (MSI) is modeled based on the multi-criteria priority weights of the four main competitive priorities Quality (Q), Cost (C), Time (T), and Flexibility (F). These are determined by using the AHP method described in Chapter 3.3 and presented in a function as $MSI = f_{MSI}(Q, C, T, F)$ (Takala et al., 2012). After the priority weights are determined, the normalized weights of the main competitive priorities are calculated with the following equations (Takala, Koskinen, et al., 2013, p. 49):

$$Q\% = \frac{Q}{Q+C+T} \quad (13)$$

$$C\% = \frac{C}{Q+C+T} \quad (14)$$

$$T\% = \frac{T}{Q+C+T} \quad (15)$$

$$F\% = \frac{F}{Q+C+T+F} \quad (16)$$

In the next step, the equations for the MSI of operational competitiveness in each group are calculated as follows (Takala, Koskinen, et al., 2013, p. 49):

- **MSI model for Prospector group:**

  When Q% is more than 43%, the company focuses on quality and belongs to the Prospector group. Thus, the factor is weighted by taking 1/3 of power to Q%. The principle of this group is that the smaller F%, the better and bigger are Q%, T%, and C% (Takala et al., 2012).

$$\mathrm{MSI_P} = 1 - \left(1 - Q\%^{\frac{1}{3}}\right)(1 - 0.9 * T\%)(1 - 0.9 * C\%) * F\%^{1/3} \tag{17}$$

- **MSI model for Analyzer group:**

  The Analyzers focus on F% and therefore balance Q%, T%, and C%, which are between 23-43% (Takala et al., 2012).

$$\mathrm{MSI}_A = 1 - (1 - F\%)\begin{bmatrix}[ABS[0.95 * Q\% - 0.285) \\ * (0.95 * T\% - 0.285) \\ * (0.95 * C\% - 0.285)]]\end{bmatrix}^{1/3} \tag{18}$$

- **MSI model for Defender group:**

  When C% is more than 43%, the company focuses on cost and belongs to the Defender group. Defenders try to be cost leaders. Thus, the factor is weighted by taking 1/3 of power to C%. The principle of this group is that the smaller F%, the better and more significant C%, T%, and Q% (Takala et al., 2012).

$$\mathrm{MSI}_D = 1 - \left(1 - C\%^{\frac{1}{3}}\right)(1 - 0.9 * T\%)(1 - 0.9 * C\%) * F\% \tag{19}$$

The results of the MSI can be shown in a triangle, as illustrated in Figure 6. It presents the operations strategy of an organization belonging to the Prospector group, where quality is in focus. The closer the value is to 1, the more significant are the characteristics of the strategy type (Heimonen, 2017, p. 62).

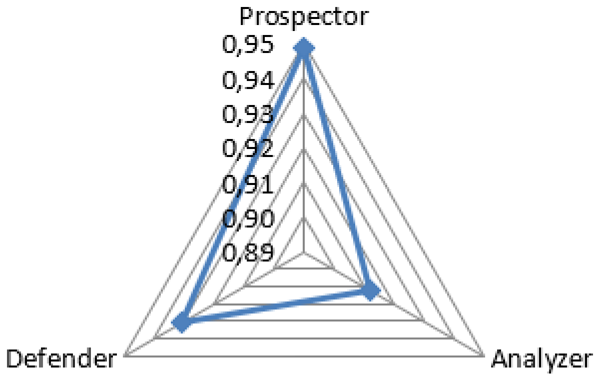


Figure 6. Manufacturing Strategy Index

These models have been tested in the context of studying global manufacturing strategies (GMSS) in approximately 100 deep case company studies in around ten countries all over the world (Takala et al., 2012).

Finally, the MSI is used to calculate the SCA. The SCA value indicates how well the resource allocation supports the company's operations strategy and is, therefore, a risk measurement tool, which estimates its functionality. The closer the SCA value is to 1, the more consistent are the resource allocation and the operations strategy of the company. There are three methods to calculate the SCA: MAPE, RMSE, and MAD (Takala, Koskinen, et al., 2013, pp. 49-50).

- **MAPE (absolute percentage error)**

  This is a statistical measure to predict the accuracy of a forecasting method (Heimonen, 2017, p. 42).

$$\text{MAPE} = SCA = 1 - \sum_{\alpha\beta\gamma} \left| \frac{BS - BR}{BS} \right| \tag{20}$$

where B refers to the angle (Prospector (β) -, Analyzer (γ)- or Defender (α) angle) in radians, S to the MSI (Operations Strategy), and R to S&R resource allocation (Takala, Shylina, et al., 2013, p. 69). The strategy, how much of which resource in which ratio is put into operation, depends on the angle (Takala, Liu, et al., 2013, p. 1242).

- **RMSE (root means squared error)**

  RMSE is frequently used to measure the differences between values (sample and population values) predicted by a model or an estimator compared to the values observed (Heimonen, 2017, p. 42).

$$RMSE = SCA = 1 - \sqrt{\sum_{\alpha\beta\gamma} \left(\frac{BS-BR}{BS}\right)^2} \tag{21}$$

- **MAD (maximum deviation)**

  MAD is the average distance of each data value from the mean (Heimonen, 2017, p. 42).

$$MAD = SCA = 1 - \max_{\alpha\beta\gamma} \left|\frac{BS-BR}{BS}\right| \tag{22}$$

The SCA is a value between 0 and 1. If the SCA is 0.97 or greater, the value is high, and therefore the resource allocation supports the company’s operations strategy well. Values between 0.90 and 0.97 are medium-high, and values below 0.90 are low (Takala et al., 2014, p. 72).

3.6 Knowledge and Technology (K/T)

The Knowledge and Technology (K/T) model allows us to examine the problem of cost overrun from the perspective of the technologies used in the operations of projects. How this is done is explained in this chapter.

3.6.1 Knowledge and Technology Model (K/T)

The technologies applied in a company can be situated in a technology pyramid. The technologies can be divided into basic-, core-, and spearhead technology. Thereby, it is possible to get a snapshot of the current technological situation of a company. Basic technology illustrates the crucial know-how on which the products and the business are based. They are essential to the business. Core technologies represent the differentiative and sophisticated know-how, which aim to give the company a competitive advantage. The spearhead technologies illustrate the future areas of know-how and are, therefore, the key factors to future markets and businesses. They are essential for success in the future (Tuominen et al., 2004, p. 10). For example, in the automotive industry, a car's engine would be basic technology. It is an essential part of a vehicle. Environmental responsibility is the core technology, as it can achieve a competitive advantage in the present. The self-driving car is spearhead technology, as it could be an exciting business opportunity in the future (Heimonen, 2017, pp. 25-26). The objective is to locate the type of technology (basic, core, or spearhead), which causes the highest amount of uncertainty for the case company. This procedure allows them to take measures by investing in it to reduce the risk and therefore sustain competitive advantage and success in the market (Tilabi et al., 2019, p. 133).

The sectors of the technology pyramid can be linked to the technology life cycle, as can be seen in Figure 7 (Tuominen et al., 2004, p. 10).

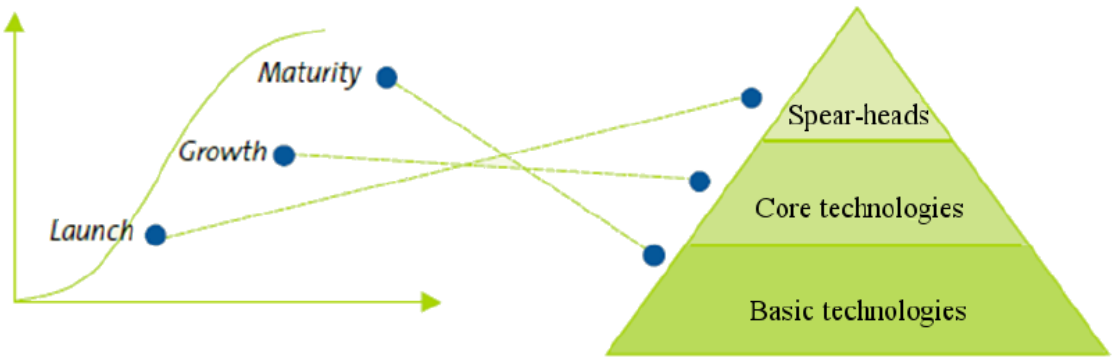


Figure 7. The linkage between the technology life cycle and technology pyramid (Tuominen et al., 2004, p. 10).

When a new product or service is launched, this is closely connected to spearhead technology. In the launching phase, the manufacturing costs are high. In the growth phase, the new product or service has proven itself to be able to make a difference. The production processes are optimized in a way that the product can be produced economically. In this phase, both product and process development are at an optimal level, and core technology is dominating. The maturity phase supersedes the growth phase. In the maturity phase, neither the product nor the processes can be developed much further. This phase is related to basic technology (Tilabi et al., 2019, pp. 138-139). In the technology life cycle, the y-axis stands for the growing technology performance or the cumulative adoption of technology. The willingness of customers to pay for better technology performance sinks once the performance has reached an acceptable level. When the technology performance still increases, customers might not be ready to pay the same price premium for it as earlier in the curve. The closer a product or service gets to the maturity phase, the more important it gets to present a balanced offer between price and technology performance. Once the maturity phase is reached, a new disruptive technology might eventually emerge and replace the old one. This evolution marks the beginning of a new technology life cycle (Adner, 2004, as cited in Taylor & Taylor, 2012, p. 545). To sustain its position in the market in the maturity phase, a company should lay the focus on reducing the production costs, on newly invented products, and on innovative technology (Tilabi et al., 2019, pp. 138-139).

To determine the technology share for each performance attribute, a K/T section is added to the S&R questionnaire. The respondent must divide the technologies used for every performance attribute on a percentage basis in basic-, core-, and spearhead technology. The total share of technology used must equal 100% (Takala & Tilabi, 2010, p. 3). The K/T part of the questionnaire is presented in Table 3.

Table 3. Format of the Knowledge and Technology part of the Sense and Respond questionnaire.

Performance attribute	Technology share of performance attribute		
	Basic %	Core %	Spearhead %
Performance 1			
Performance 2			
…			

As a first step, the K/T-Data can be analyzed by comparing the (B)CFI values to the (B)CFI K/T values. It shows the resource allocation from the K/T perspective. The calculation of the (B)CFI K/T values can be seen in Table 4. First, the color of the performance attribute must be taken into consideration and, after that, its dominating technology. A technology is dominating when its average value is more than 43%. If all technology levels are less than 43%, the one with the highest value is dominating (Takala, Koskinen, et al., 2013, p. 48).

Table 4. Technology Rankings: General formulas (Takala, Koskinen, et al., 2013, p. 48).

	RED attributes	YELLOW attributes	GREEN attributes
Basic	(B)CFI / (B% / 100)	(B)CFI * (B% / 100)	(B)CFI / (B% / 100)
Core	(B)CFI * $(C\% / 100)^2$	(B)CFI / (C% / 100)	(B)CFI * $(C\% / 100)^2$
Spearhead	(B)CFI * $(SH\% / 100)^3$	(B)CFI / $(SH\% / 100)^2$	(B)CFI * $(SH\% / 100)^3$

The uncertainty regarding each type of technology is calculated by the coefficient of variance (CV) (Takala & Tilabi, 2010, p. 4). The calculation is based on the assumption that the difference in the opinions of the respondents on the technology shares is the primary source of uncertainty and risk (Tilabi et al., 2019, p. 133).

$$CV_{Basic} = \frac{Standard\ Deviation_{Basic}}{Average_{Basic}} \tag{23}$$

$$CV_{Core} = \frac{Standard\ Deviation_{Core}}{Average_{Core}} \tag{24}$$

$$CV_{Spearhead} = \frac{Standard\ Deviation_{Spearhead}}{Average_{Spearhead}} \tag{25}$$

More precisely, Formulas 23-25 show the level of deviation among the respondents' answers (Takala & Tilabi, 2010, p. 4). If there is a deviation, there are different understandings of how technology must be used to succeed. The deviation can be interpreted as the uncertainty of how to use technology. The uncertainty must be reduced as much as possible.

As a next step, the variability coefficient (VarC) is calculated, which takes the four components of the RAL model into account (Takala et al., 2016, p. 847):

$$VarC_{C1,C2,C3,C4} = \sqrt{\sum_{i=B,C,SH} C1, (C2, C3, C4) \left(\frac{std_i}{mean_i}\right)^2} \tag{26}$$

where C1 represents the RAL component Quality, C2 Cost, C3 Time, and C4 Flexibility.

The total amount of risk of technology is calculated with the following formula (Takala et al., 2016, p. 847):

$$K/T\ risk = \sqrt{\sum_{i=c1,c2,c3,c4} VarC_i^2} \tag{27}$$

It shows how much the competitiveness of the company falls if the K/T risk materializes (Takala et al., 2016, p. 847).

The idea of K/T is that high technology risk levels can compromise the success of a project and therefore lead to cost overrun. Therefore, ways must be found to lower the technology risk as much as possible.

3.6.2 Sand Cone Model

The Sand Cone model of cumulative performance has been developed by Ferdows and De Meyer (1990) and has been a lasting and popular feature of operations strategy for many years (Bortolotti et al., 2015, p. 228). It is a model to describe phenomena or concepts that have some multi-focused, multidimensional, or hierarchical aspects. The performance elements of the studied objects form a "sand cone" (Takala et al., 2006, p. 338). According to the model, the best firms seek to improve performance elements in a sequence. Previous performance elements must be improved before developing the next ones. In the sand cone of Bortolotti et al. (2015) illustrated in Figure 8, the performance elements are Quality, Delivery, Flexibility, and Cost.

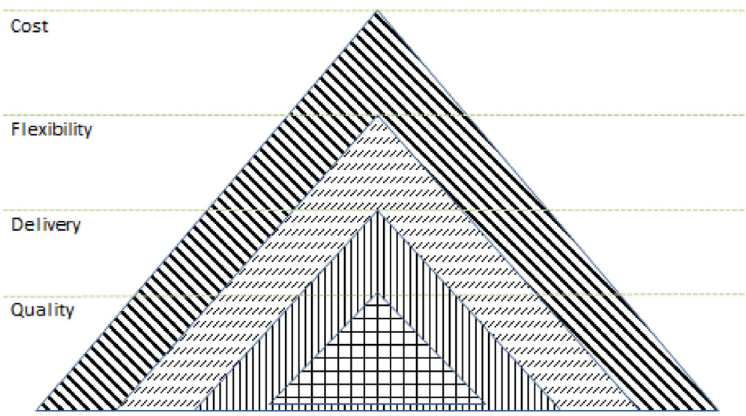


Figure 8. Sand Cone model of cumulative performance (Bortolotti et al., 2015, p. 229).

The quality performance is the foundation of the sand cone. The delivery performance, which equals time in the RAL concept, is built upon this foundation. As the delivery performance is developed, the quality foundation expands, and the second layer of the sand cone is made. Flexibility performance is built on the foundation of quality- and delivery performance. Cost performance creates the peak of the sand cone and, in turn, expands the foundation of quality-, delivery, and flexibility performance (Bortolotti et al., 2015, p. 228). Cost efficiency, which is on the top of the sand cone, is the goal. It is the most visible layer when examining a company. But according to the model, cost efficiency can only be reached when a stable structure consisting of quality, delivery, and flexibility is built first. Cost efficiency itself has only a small influence on the structural stability of the sand cone, which means that cost-saving measures are not the primary way by which cost efficiency is accomplished. In general, one can say that the elements on the bottom of the hierarchical structure are internally crucial for the organization. The elements on the top of the sand cone are usually not so internally critical. They are instead the results of the performance of the internal elements (Takala et al., 2006, pp. 338-339).

A strength of the sand cone is that it can be used for many purposes and with many different performance elements (Takala et al., 2016, p. 847). In this thesis, the four components, Quality, Cost, Time, and Flexibility of the RAL model, are used as performance elements and inserted into the sand cone. The components are inserted into the sand cone based on the ranking, which was achieved by the AHP method. The first level is the foundation of the sand cone. It is composed of the components to which the most significant importance was given. The first level should have 2/3 of the total weight of the components. The higher levels are composed of the components, which are ranked to have a lower level of relative importance. They have 1/3 of the total weight (Takala et al., 2006, p. 340). In Figure 9, C1-C4 stand for the criteria, which were weighted by the AHP method. The criteria were inserted in three different sand cones, one for each department of the example company. As a next step, all VarC calculated with Formula 26 are inserted into the sand cone. They represent the uncertainty connected to K/T, that can cause collapses in the layers of the sand cone. A risk of over 100% questions the whole evaluation based on the criteria. The uncertainty is presented as the dark grey area in the layers of the sand cone in Figure 9. Finally, the K/T risk, which is calculated with Formula 27, is presented right to the sand cone. It represents how much the competitiveness of each department falls if the K/T risk materializes (Takala et al., 2016, p. 847). This additional triangle also enables us to compare different departments or projects to each other, as it shows the overall picture (Zucchetti, 2016, p. 44).

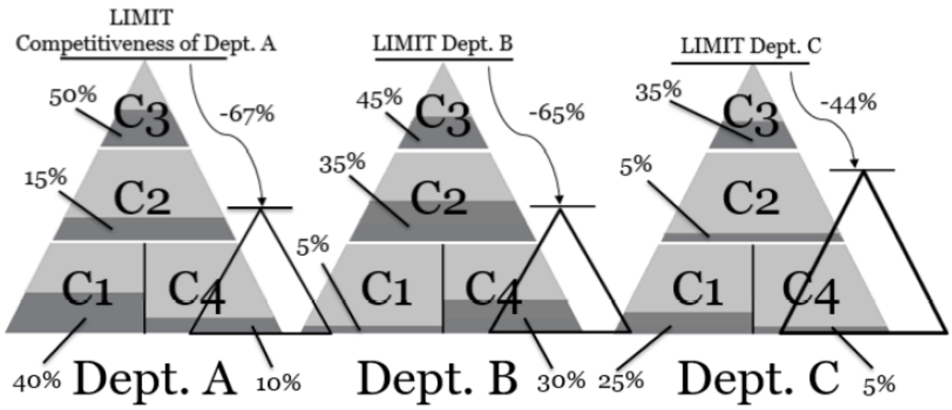


Figure 9. K/T risk and the Sand Cone model (Takala et al., 2016, p. 847).

4 Empirical Research

This chapter presents the empirical data collection with subsequent data analysis. It starts by describing the research process, followed by the data analysis. The data are analyzed separately for each project before comparing the projects to each other. For the study, the methods presented in Chapter 3 are adapted.

4.1 Research process

The research process describes how the empirical data was collected. It is presented how the questionnaire was created, who responded to it, how the received answers were verified, and how additional data was collected.

4.1.1 Questionnaire

Two questionnaires were created for data collection: The S&R Questionnaire and the AHP Questionnaire. Both were sent to the respondents as Microsoft Excel files.

The S&R method has the advantage that it is highly customizable and therefore allows the design of a questionnaire perfectly shaped to the research question. For this questionnaire, 46 performance attributes were created, which reflect the main operations within the engineering process and the site management process of the case company. The possible technical explanations for cost overrun introduced in Chapter 2.2.1 were considered while creating the performance attributes. Furthermore, the internal guidelines and advice of experts of the case company supported the creation. The analysis indicates the critical attributes, which contribute to cost overrun in the projects. It is essential to take note that the influence of the sales process on the engineering process and site management process is not included and can, therefore, not be analyzed, as most respondents can’t assess it.

The performance attributes and the respective allocation to the RAL-dimensions are presented in Table 5. The attributes are divided into the categories “Supporting Processes”, “Engineering and Validation Process”, “Site Management Process”, and “Soft factors”. The Supporting Processes are furthermore divided into the Startup-, Execution-, and Closeout phase of the project. The Engineering and Validation Process and the Site Management Process are divided into Automation- and Electrical work, as these two categories might produce very different results. The RAL dimensions are allocated to the performance attributes, which are most affected by it. For instance, Time is the essential RAL component for Project scheduling. This procedure allows us to determine the strategic type of the respective project, which can be compared to the strategic type of the case company. Eighteen performance attributes were allocated to Quality, 12 attributes to Cost, 11 attributes to Time, and five attributes to Flexibility.

Table 5. Performance attributes of the Sense and Respond questionnaire

		PERFORMANCE ATTRIBUTES	
Supporting Processes			
Startup	1	Project scheduling	← Time
	2	Establishing of project team	← Quality
Execution	3	Resource Management	← Flexibility
	4	Financial & Cost Management	← Cost
	5	Communications Management	← Quality
	6	Procurement & Contractor Management	← Cost
	7	Change Management	← Cost
	8	Risk & Opportunity Management	← Cost
	9	Schedule Management	← Time
	10	HSE Management	← Cost
	11	Quality Management	← Quality
	12	Requirement Management	← Quality
	13	Decision-making	← Time
	14	Information Management	← Time
	15	Knowledge Management	← Quality
	16	Technology Management	← Quality
Closeout	17	Project acceptance, take-over and closeout	← Cost
Engineering and Validation Process			
Automation	18	Resource Management	← Flexibility
	19	Conceptual Design	← Cost
	20	Basic Design	← Quality
	21	Detailed Design	← Quality
	22	Manufacturing	← Time
	23	Off-site Validation	← Quality
Electrical	24	Resource Management	← Flexibility
	25	Conceptual Design	← Cost
	26	Basic Design	← Quality
	27	Detailed Design	← Quality
	28	Manufacturing	← Time
	29	Off-site Validation	← Quality
Site Management Process			
	30	Resource Management	← Flexibility
	31	Site Establishment and Mobilization	← Time
General	32	Construction and Installation	← Time
	33	Commissioning	← Quality
Automation	34	Construction and Installation	← Time
	35	Commissioning	← Quality
Electrical	36	Construction and Installation	← Time
	37	Commissioning	← Quality
	38	Demobilization	← Cost
Soft factors			
	39	Professional relationship	← Flexibility
	40	Know-How / Experience	← Cost
	41	Knowledge	← Quality
	42	Competence	← Cost
	43	Engagement	← Quality
	44	Innovation	← Cost
	45	Teamwork	← Time
	46	Organizational culture	← Quality

The questionnaire is identical for all projects, which ensures comparability between the projects. However, some performance attributes are not necessarily feasible in every project, and some respondents are not able to answer all performance attributes, as they were not involved in the whole process. In such cases, the respective performance attributes can be left empty. Instructions and comments were added into the Excel questionnaire file to ensure that all respondents knew what to do, and all performance attributes are understood in the right way.

There are different sections to assess, as presented in Table 2. First, the respondents must determine the expectations for each performance attribute. They must therefore evaluate how well the attribute at least must perform in future projects (next three years) that the project stays on budget, and thus no cost overrun occurs. The scale goes from 1, which means low expectation, to 10, which means high expectation. Five is defined to be "normal expectation", which means that the attribute must not perform exceptionally well but is not allowed to perform poorly for a good overall performance of the company.

Next, the experiences for each performance attribute must be assessed, which means how the performance (success) of each attribute was in the project on the same scale with 1 meaning worst possible outcome and 10 meaning best possible outcome. Five means that the outcome (success) of the attribute was neither exceptionally good nor bad.

In the "Direction of Development" section, the respondents must assess the performance of the attribute compared to previous projects, which were two to five years before. This section shows a trend, how the performance has developed from past projects to the assessed project. Together with the "Expectation" and "Experience" section, the CFIs can be calculated. This approach provides a snapshot of the situation when the examined project was implemented. As most respondents are engineers, which are usually not involved in the strategic development of the case company, they can't assess the future development of a performance attribute. Therefore, there is no such section. But thanks to their experience, they can evaluate the trend from past projects to the assessed project.

The “Compared with competitors” section, which is often a part of the questionnaire (e.g., in Tilabi et al. (2019)), was left away because the respondents are not necessarily able to compare the case company to its competitors. Moreover, the specific solutions designed for the clients make comparison difficult.

The K/T part is integrated into the same questionnaire. The same performance attributes must be divided into the shares of basic-, core-, and spearhead technology required for their completion. Explanations and company-specific examples are placed in the questionnaire file to simplify the allocation of technology shares for the respondents. The technology examples were verified with experts from the case company.

The AHP questionnaire was created based on the Excel template created by Goepel (2013). It allows a simple pairwise comparison of the RAL dimensions Quality, Cost, Time, and Flexibility and ensures consistency of the answers. The questionnaire was set in a way that the answer is considered valid and reliable if the inconsistency ratio (ICR) is less than 0.30 (Takala, Shylina, et al., 2013, p. 68). This questionnaire is to determine the relative importance of the RAL dimensions and therefore choose the operations strategy of the case company.

4.1.2 Acid-Test

Before the questionnaire was sent to the respondents, an acid-test was conducted. One expert in the case company filled out the S&R and AHP questionnaires. The results were reviewed together. This proceeding led to some adaptions, as ambiguities were removed. Overall, the performance attributes in the questionnaire covered all the essential operations, and the results were behaving correctly, which allows to proceed to the next step.

4.1.3 Respondents

The respondents of the S&R questionnaire were all experts actively involved in the Engineering Process, or Site Management Process of the examined projects, or both. The questionnaire was sent to all employees who worked in the concerned projects long enough to be able to assess some or all the performance attributes. The respondents are engineers, site managers, and project managers of the case company. By coincidence, no respondents have been working in more than one of the examined projects.

The AHP questionnaire was sent to four respondents who are qualified to rank the competitive priorities of the case company.

The questionnaires were sent by e-mail. Additional instructions were given online if requested. It was not possible to meet the respondents in person due to the prevailing Covid-19 situation, which led to further challenges in the data collection process. Getting enough answers was challenging and time-consuming. The potential respondents were occupied with many ongoing projects.

4.1.4 Market-based validation and additional data collection

Once the data is analyzed, the findings require validation from the respondents. Moreover, further feedback is needed to uncover the root causes of critical performance attributes and technological uncertainty. Therefore, the so-called Weak Market Test (WMT) was used to get the respondent's opinions on the results. The WMT is passed if the respondents accept the results and thus would be willing to apply them in their actual decision making (Kasanen et al., 1993, p. 253). Therefore, some respondents were selected for an additional interview. The results were compared to their opinions, and further background to the results was gathered. The interviews took place online, as the Covid-19 situation prevented meetings in person.

4.2 Data analysis

This chapter analyses the data from the questionnaires. In the first step, the data from the AHP questionnaire is analyzed. Second, Project 1, Project 2, and Project 3 are analyzed separately. Lastly, the analyses of the three projects are compared to each other. All analyses are directly followed by the marked-based validation and additional data collection from interviews.

For the S&R questionnaires of Project 1, Project 2, and Project 3, answers were received from a total of 15 respondents. The detailed division of responses received can be seen in Table 6, separated into answers to the S&R and the K/T part of the questionnaire:

Table 6. Number of answers received

			Project 1		Project 2		Project 3	
		ATTRIBUTES	No. of answers		No. of answers		No. of answers	
Project Management Process			S&R	K/T	S&R	K/T	S&R	K/T
Startup	1	Project scheduling	4	4	2	2	3	3
	2	Establishing of project team	4	4	2	2	3	3
Execution	3	Resource Management	5	5	3	3	3	3
	4	Financial & Cost Management	3	4	3	3	3	3
	5	Communications Management	3	4	3	3	3	3
	6	Procurement & Contractor Management	3	4	3	3	3	2
	7	Change Management	4	4	3	3	3	3
	8	Risk & Opportunity Management	3	4	3	3	3	3
	9	Schedule Management	4	5	3	3	3	3
	10	HSE Management	3	4	3	3	3	3
	11	Quality Management	4	4	3	3	3	3
	12	Requirement Management	4	4	3	3	3	3
	13	Decision-making	4	4	3	3	3	3
	14	Information Management	4	4	3	3	3	3
	15	Knowledge Management	4	4	3	3	3	3
	16	Technology Management	4	4	3	3	3	3
Closeout	17	Project acceptance, take-over and closeout	3	4	3	3	3	2
Engineering and Validation Process								
Automation	18	Resource Management	3	4	3	3	3	3
	19	Conceptual Design	2	3	3	3	3	3
	20	Basic Design	3	4	3	3	3	3
	21	Detailed Design	3	4	3	3	3	3
	22	Manufacturing	3	4	3	3	3	3
	23	Off-site Validation	3	4	3	3	3	3
Electrical	24	Resource Management	5	5	3	3	3	3
	25	Conceptual Design	2	3	3	3	3	3
	26	Basic Design	3	4	3	3	3	3
	27	Detailed Design	5	5	3	3	3	3
	28	Manufacturing	3	4	3	3	3	3
	29	Off-site Validation	3	4	3	3	3	3
Site Management Process								
	30	Resource Management	4	4	5	4	3	3
	31	Site Establishment and Mobilization	3	4	5	4	3	3
General	32	Construction and Installation	3	4	4	4	3	3
	33	Commissioning	4	4	4	4	3	3
Automation	34	Construction and Installation	3	4	4	3	3	3
	35	Commissioning	4	4	4	3	3	3
Electrical	36	Construction and Installation	3	4	5	4	3	3
	37	Commissioning	4	4	5	4	3	3
	38	Demobilization	3	4	4	3	3	3
Soft factors								
	39	Professional relationship	5	4	4	3	3	3
	40	Know-How / Experience	5	4	4	3	3	3
	41	Knowledge	5	4	4	3	3	3
	42	Competence	5	4	4	3	3	3
	43	Engagement	5	4	4	3	3	3
	44	Innovation	5	4	4	3	3	3
	45	Teamwork	5	4	4	3	3	3
	46	Organizational culture	4	4	4	3	3	3

The number of answers per attribute varies from 2-5. There are multiple reasons for this. Not all the respondents could assess all the performance attributes, as they were working in the project for a short time or only for a limited task. Sometimes there were not more respondents working in the project, which would be able to assess the attribute. In some cases, a potential respondent couldn't be reached or was not working for the case company anymore.

Microsoft Excel was used to analyze the data, as the software was successfully used for other similar studies. When it comes to the S&R analysis, the NSCFI was used. It is the most advanced of the presented indexes and is suited for a relatively small number of respondents, as explained in Chapter 3.4.

4.2.1 AHP Analysis

The result of the AHP questionnaire looks as follows:

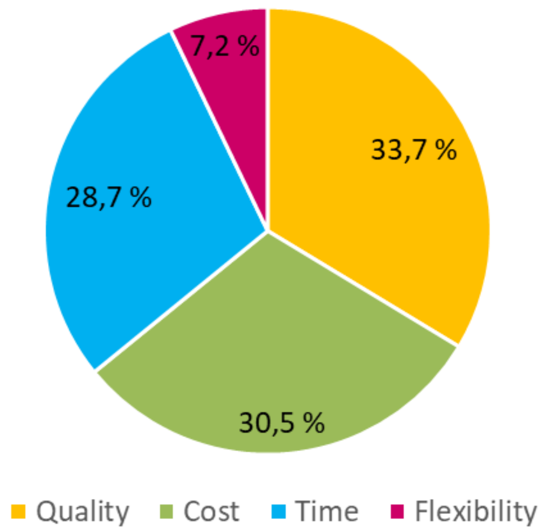
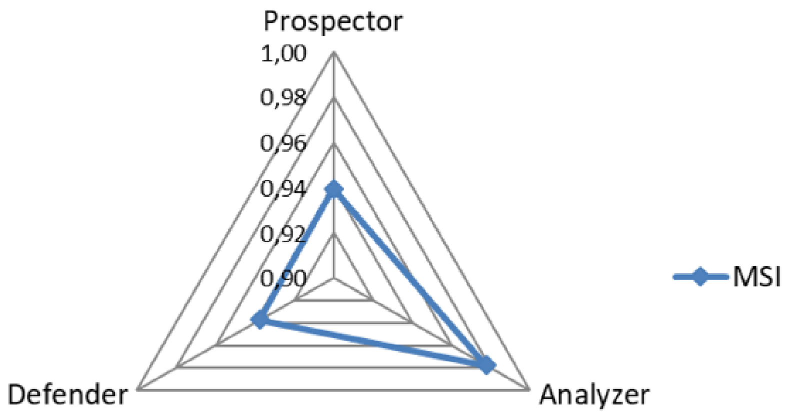


Figure 10. Competitive priorities of the case company.

Figure 10 presents the competitive priorities of the case company. The respondents, on average, give Quality he most weight in the projects of the case company with 33,7%. Cost is the second most crucial component with 30,5%. Next follows Time with 28,7%. Flexibility with 7,2% plays the smallest role, according to the respondents. The opinions of the respondents varied considerably regarding the weights of Quality, Cost, and Time. There only was unanimity regarding Flexibility, which all respondents considered as the least essential RAL component.



Strategy type	Prospector	Analyzer	Defender	Reactor
MSI	0,939	0,978	0,937	0,938

Figure 11. Operations strategy of the case company based on MSI.

The operations strategy based on MSI can be seen in Figure 11. It is calculated with Formula 18. The strategy type of the case company tends to be an Analyzer. It is a combination of the Defender and Prospector types where Quality, Cost, and Time are balanced. An Analyzer tries to minimize risk while maximizing the opportunity for profit. This strategy type, therefore, combines the strengths of both the Defender and the Prospector. The main share of the revenue is generated by a relatively stable set of products and customers, which is a Defender characteristic. The risks of the Analyzer are both inefficiency and ineffectiveness if the necessary balance between stability and flexibility can't be kept (Miles et al., 1978, pp. 553-557). The closer descriptions of the strategy types can be found in Chapter 3.1.

Market-based validation

Respondent 16 accepts the AHP results. The description for the Analyzer matches the business of the case company. It fits surprisingly well. This segment of the case company is not always about the newest technologies, and risks must be minimized.

4.2.2 Project 1

Next, the answers received from the questionnaire for Project 1 are analyzed.

Sense and Respond Analysis

The analysis starts with a comparison of the average of expectation to the average of experiences.

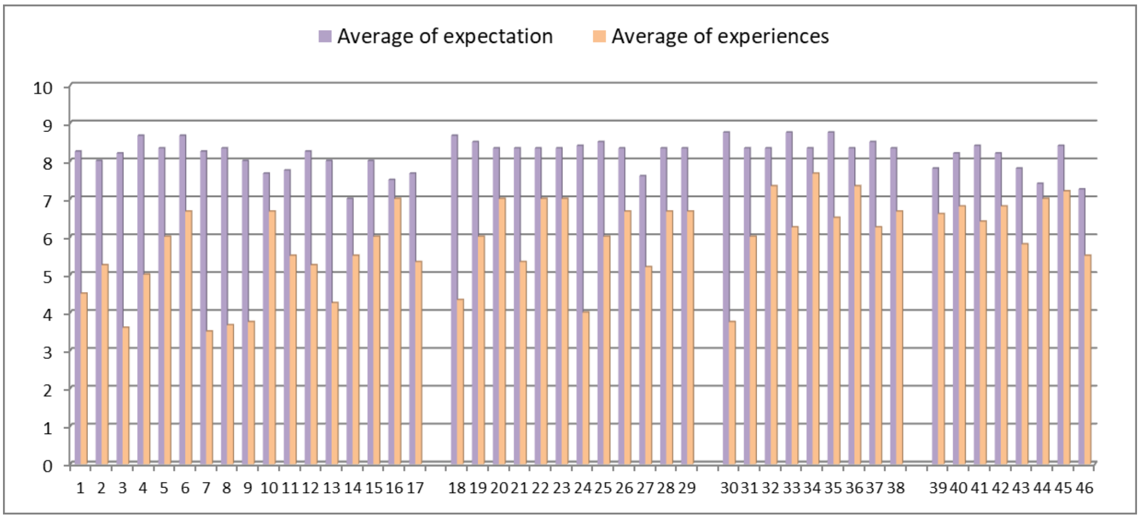


Figure 12. Comparison of the average of expectation vs. the average of experiences in Project 1.

Figure 12 shows that the expectation towards all attributes is high, from seven upwards. All attributes must therefore perform well, that cost overruns can be avoided. The average of experiences is below the average for the expectation for all performance attributes. Thus, all performance attributes have room for improvement. In some cases, the gap between expectations and experiences is vast, such as for attributes 3, 7, 8, 9, 25, and 30.

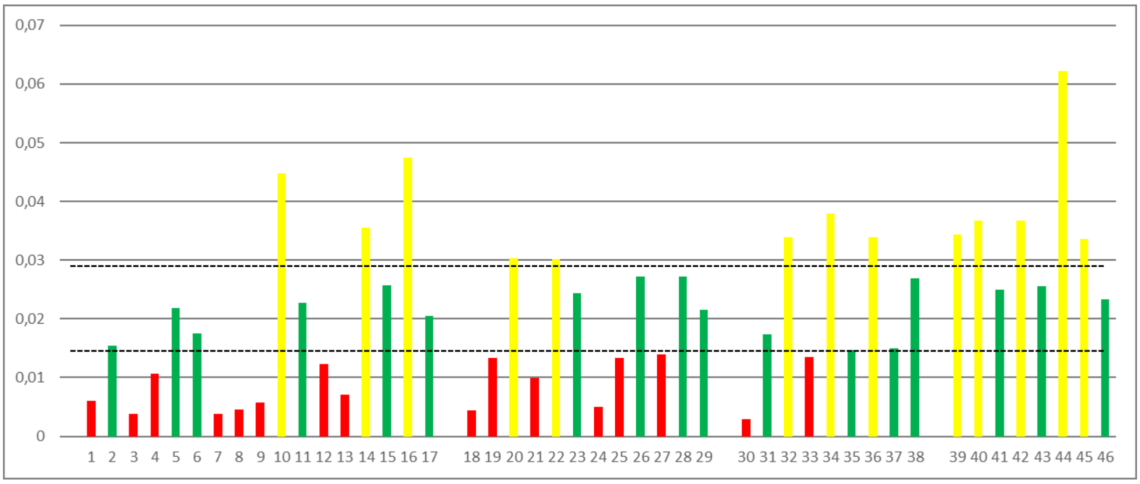


Figure 13. Resource allocation in Project 1 based on NSCFI.

A closer look is required to locate the performance attributes which contributed most to the cost overrun. Figure 13 illustrates the resource allocation in Project 1 based on NSCFI. The average resource level is at 0,021, with the upper bound at 0,029 and the lower bound at 0,015 for balanced resource allocations, marked by the black dashed lines. All NSCFI values added up would give 1 (or 100%). When a performance attribute is balanced (green) or over-resourced (yellow), this doesn't necessarily mean that it performed well. It performed just close to the average resource level (green) or clearly over average (yellow), and therefore accounted less to the cost overrun than a critical performance attribute (red).

Table 7. Critical performance attributes of Project 1

Process	Phase	Number	Description
Supporting Processes	Startup	1	Project scheduling
	Execution	3	Resource Management
		4	Financial & Cost Management
		7	Change Management
		8	Risk & Opportunity Management
		9	Schedule Management
		12	Requirement Management
		13	Decision-making
Engineering and Validation Process	Automation	18	Resource Management
		19	Conceptual Design
		21	Detailed Design
	Electrical	24	Resource Management
		25	Conceptual Design
		27	Detailed Design
Site Management Process		30	Resource Management
	General	33	Commissioning

There are many critical performance attributes in Project 1, as the red bars in Figure 13 show. Table 6 lists all these critical attributes, which were mainly responsible for the cost overrun. Almost half of the attributes in the Supporting Processes are critical. Moreover, half of the attributes in the Engineering Process are critical. Notable is that all attributes related to Resource Management are critical. Resource Management is critical as a Supporting Process (no. 7), in the Engineering Process both in the Automation- (no. 18) and Electrical category (no. 24) and the Site Management Process (no. 30) and therefore seemed to be a big problem. The fact that Change Management, Risk & Opportunity Management, Schedule Management, Requirement Management, and Decision-making are all critical indicates that it was tough to cope with the challenges encountered in the project. In the Site Management Process, Commissioning (no. 33) was critical.

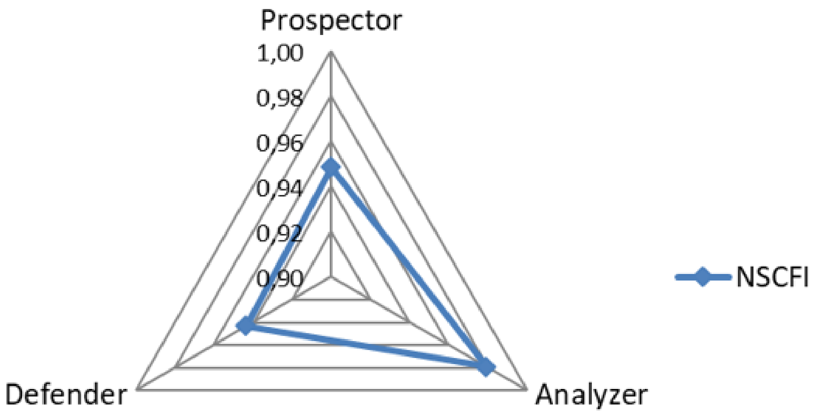
Sustainable Competitive Advantage Analysis

The results of the SCA analysis indicate how well the resource allocation based on the NSCFI values support the operations strategy of the case company.

Table 8. NSCFI values per RAL component of Project 1.

Dimension	Quality	Cost	Time	Flexibility
NSCFI	187,88	140,16	129,36	24,34

When summing up all NSCFI values of the allocated attributes, the results are as in Table 8. These are used to calculate the strategy type according to Project 1.



Strategy type	Prospector	Analyzer	Defender	Reactor
NSCFI	0,949	0,979	0,943	0,946

Figure 14. Operations strategy in Project 1 based on NSCFI values.

The strategy type of the case company, according to NSCFI in Project 1, tends to be Analyzer, as can be seen in Figure 14. This result corresponds with the strategy type of the case company, which tends to be Analyzer as well.

Table 9. SCA values of Project 1.

Technique	MAPE	RMSE	MAD
NSCFI	0,99	1,00	1,00
NSCFI T/K	0,99	0,99	0,99

The resource allocation in the project is compared to the operations strategy of the case company by calculating the SCA values. The results are as in Table 9. MAPE, RMSE, and

MAD are very close to 1, or even 1, which means the resource allocation, according to NSCFI, is almost entirely supporting the operations strategy of the case company. The values for NSCFI T/K are also very close to 1. The resource allocation in Project 1 is, therefore, very consistent with the operations strategy of the case company.

Knowledge and Technology Analysis

This section concentrates on the results from the K/T part of the questionnaire.

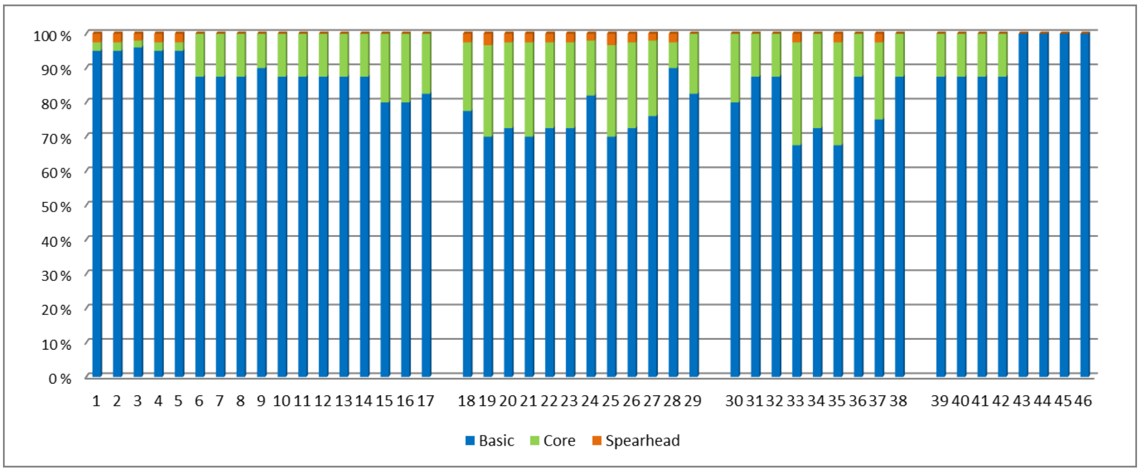


Figure 15. Technology shares in Project 1.

The average technology shares, according to the respondents in Project 1, can be seen in Figure 15. Striking is the dominance of basic technology for all performance attributes. The share of spearhead technology is almost negligible, which means that almost no innovative technologies, which illustrate future areas of know-how, were used. Basic technologies are commonly used and should, therefore, be familiar to the employees. Their usage should not lead to challenges and hence to cost overrun.

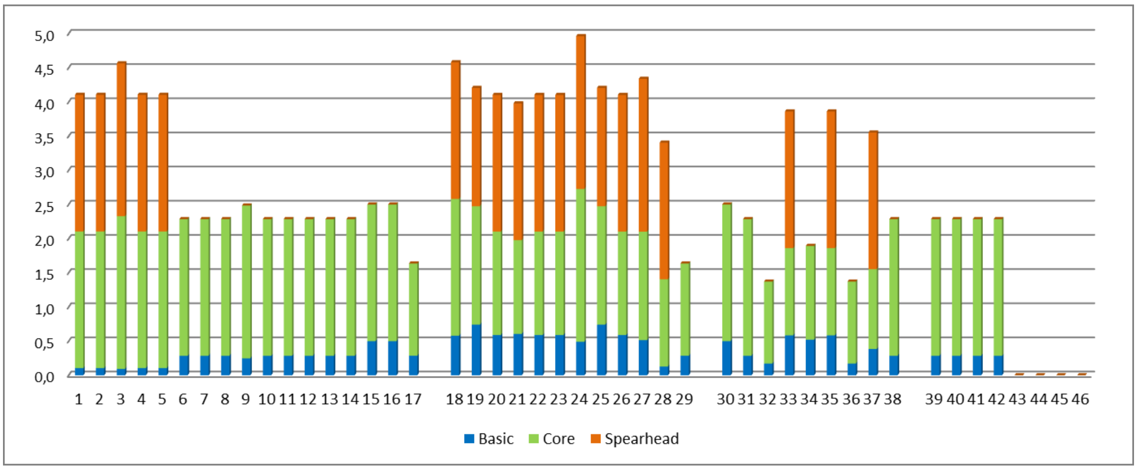


Figure 16. K/T uncertainty (CV) by performance attribute in Project 1.

Figure 16 shows that uncertainty (CV) is highest for attributes no. 1-4 in the Supporting Processes, no. 18-28 in the Engineering Process, and no. 33, 35, and 37 in the Site Management Process. For attributes no. 43-46, there is no uncertainty at all. In the Site Management Process, the critical attributes (30, 33, 35, 37) have higher uncertainty than the other attributes of the same process.

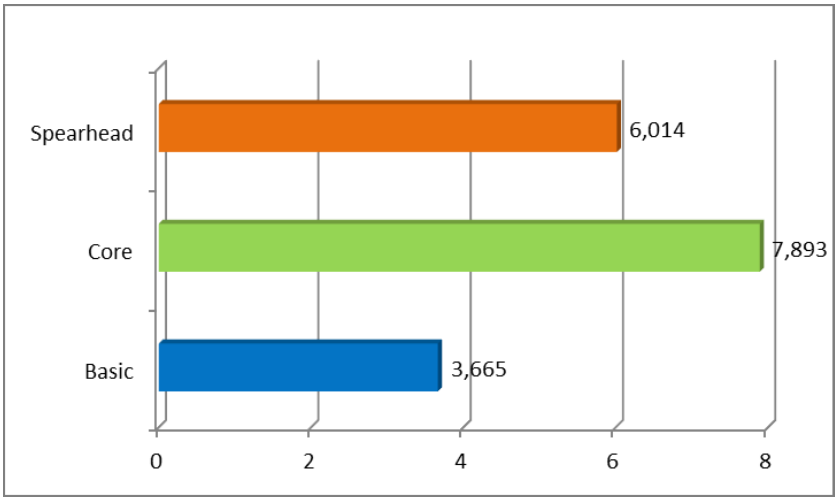


Figure 17. CV of K/T in Project 1.

Most uncertainty is related to core technology, as can be seen in Figure 17. The second most uncertainty is related to spearhead technology. This figure shows that the respondents disagree on the technology shares, which could indicate uncertainty in the use of the technologies. As a result, the best performance can't be achieved.

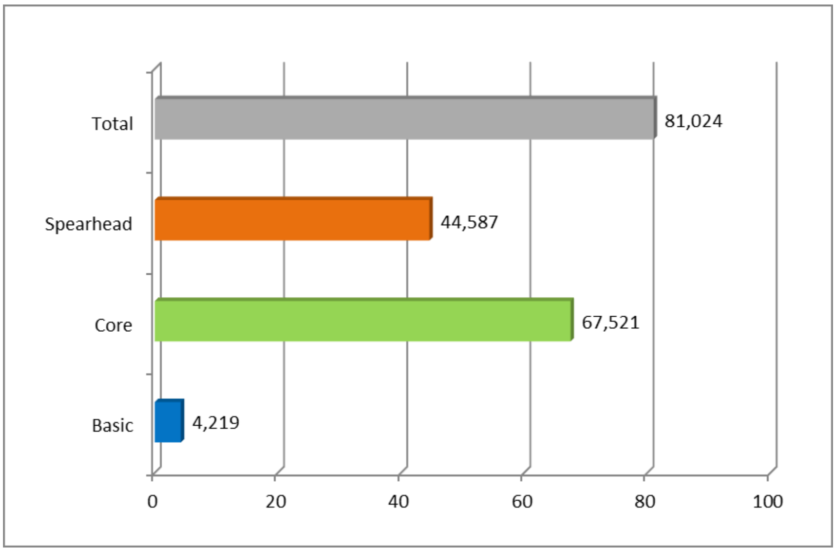


Figure 18. K/T risk by technology in Project 1.

Figure 18 shows the K/T risk. Most risk is related to core technology, followed by spearhead technology. There is only a little risk related to basic technology, which is good, as the most significant share of technology is basic technology.

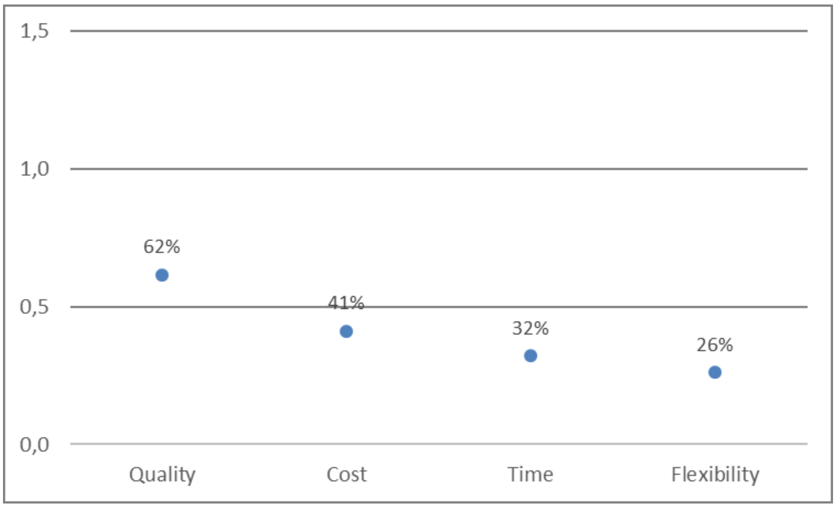


Figure 19. Variability coefficients (VarC) of Project 1.

Figure 19 presents the K/T risk related to the RAL components, calculated with Formulas 26 and 27. The most significant risk is related to Quality, with 62%. Thus, the competitiveness of the project might have fallen by up to 62% because of performance attributes linked to Quality. At this moment, one must consider that many attributes were connected to Quality. All values are clearly under one (<1), which means that the risk levels are passable.

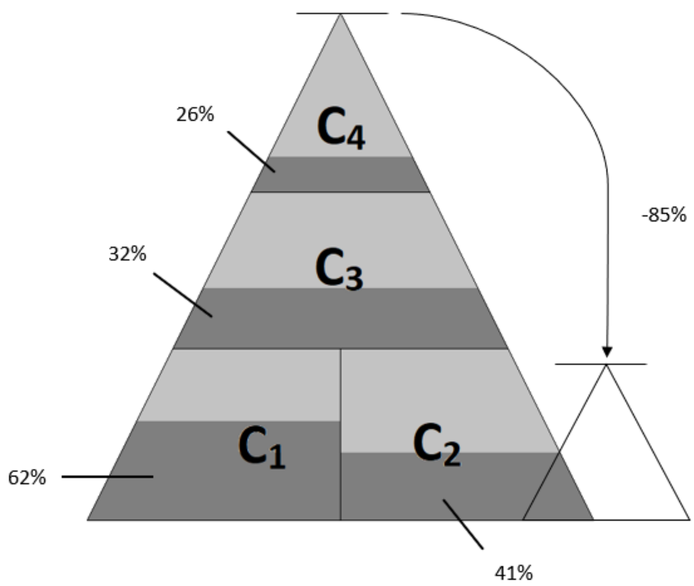


Figure 20. K/T uncertainty of Project 1.

Figure 20 presents the sand cone of Project 1. C_1 stands Quality, C_2 stands Cost, C_3 stands for Time, and C_4 stands for Flexibility. The absolute risk is 85%, which means the total competitiveness of Project 1 has fallen up to 85% if the K/T risk materialized. This risk undoubtedly contributed to the cost overrun.

Market-based validation and additional data collection

The results were presented to Respondent 1. The respondent confirms that the critical attributes are correct and sees Resource Management (no. 3, 18, 24, 30) as the root cause for the cost overrun. The team members changed a lot, and therefore the same learning curve had to be gone through many times. Respondent 6 was part of the project team for the commissioning. Relating to Resource Management (no. 3, 18, 24, 30), the respondent sees the main problem in the fact that the whole project team except for the project manager changed during the project. The employees from the beginning of the Engineering Process were not involved in the final stage of the project. As a result, the team during commissioning didn't know what was agreed on earlier in the project. This circumstance caused a loss of knowledge and information. Consequently, many things were done multiple times. The key persons changed, too. For instance, there were three different leaders appointed for the site in different stages of the project. Furthermore, the project team in the original composition at the beginning of the project had experience from similar projects in other countries, but not from the country where this project was implemented. The respondent has understood that in this particular country, where the project was implemented, the project team has to work more autonomous to stay on schedule and doesn't get that much support from the customer's consultant in setting strict deadlines and leading the planning. Respondent 1 suggests nominating lead engineers who accompany the whole project and overlook the technical part. There should be an automation lead and an electrical lead. A project manager has several ongoing projects at the same time and, therefore, usually doesn't have the time to manage all technical aspects of the project. It moreover requires a lot of time to immerse oneself in all the technical aspects. Respondent 16 states that there were competent employees in this project. However, because of time-scheduling and other reasons, there were finally many employees working in the project, which made it messy. In the beginning, there was a team that has worked successfully together before. Therefore the starting position was good. However, this changed at some point, and it was not the initial team anymore. Moreover, there was one new employee who started working in this project in an important role. This employee left the case company again in the middle of the project. The employee had to be replaced by somebody else, which was challenging. This circumstance can be seen in the performance of the commissioning (no. 33, 35, 37). The respondent depicts that the main challenge is to have the right employees available for the suited projects. Employees sometimes must be changed in the middle of projects even though it is not a good solution. It is not possible to get entirely rid of that. Maybe it would be good to concentrate on minimizing the impact of changing personnel resources, for example, by defined routines. The employee, who came newly to Project 1, didn't have the case company's ways of working. There should be somebody, be it a lead engineer or the project manager, who pulls strings and directs the project technologically and according to the client's requirements. The quality suffers when the employees are changing a lot. It should be an objective that Resource Management goes well in all projects. Respondent 16 sees an additional reason for the criticality of Requirement Management. The team realized in the final stage of the project that one component was completely missing. A new person started planning it in a rush. The startup phase with performance attributes no. 1 (Project Scheduling) and no. 2 (Establishing of project team) were critical according to Respondent 1 because the contract was received late, and the planned team members were occupied in other projects. There were many projects ongoing at that time, and the schedule was tight.

Respondent 1 explains the criticality of Change Management (no. 7), Risk & Opportunity Management (no. 8), Requirement Management (no. 12), and Decision-making (no. 13) with a very demanding client (no. 39, Professional relationship, was a balanced attribute though, but experiences were on average 1,5 points lower than expectations). The negotiations were time-consuming, as there were some strong personalities on the customer's side. Changes were challenging to realize. Respondent 6 saw problems in cooperation with the client, too. The client had a consultant who could be difficult and demanding. The consultant had written a project description, from which no deviation was tolerated. The project description was furthermore written in a way that the case company had a lot of responsibilities and liabilities. The case company might not have been sufficiently aware of this in the early stage of the project. Respondent 1 explains the criticality of the Conceptual design (no. 19, no. 25) also by this project description. For Respondent 4, Conceptual Design was a completely new term when filling out the questionnaire. Furthermore, the respondent has never seen the quality documentation, where the Engineering Process is described and guesses that many others have neither.

According to Respondent 6, it would have been good to visit the site more often during planning in the Engineering Process. At the site, a lot of changes had to be made to delivered components. A lot of additional parts were needed. Moreover, the sub-contractor in charge of the installations encountered some challenges as the case companies' new systems had to be connected to the existing old systems, whose documentations were incomplete in many sections. Respondent 1 confirms that there was additional work at the site, as new components had to be connected to the old system. This circumstance might have compromised Commissioning (no. 33, 35, 37). Furthermore, Respondent 3, who joined the project for the commissioning, reported communication problems between the project team and the sub-contractor in the time before the respondent was at the site. Moreover, Respondent 6 would have wished for more support from the management in the commissioning phase, as the project team had to decide on matters themselves at the site. A lack of support in this stage certainly compromised the attribute Decision-making (no. 13). Furthermore, Respondent 6 states that inept requirements from the client shouldn't have been accepted that easily.

When it comes to the scope of the project and the technologies used, the project was ordinary, according to Respondent 6. There shouldn't have been anything new or unique, which the technology shares in Figure 15 confirm. Respondent 1 explains that the scope of this project was broad compared to other projects and that the site was old.

4.2.3 Project 2

This section concentrates on the results of the questionnaire for Project 2.

Sense and Respond Analysis

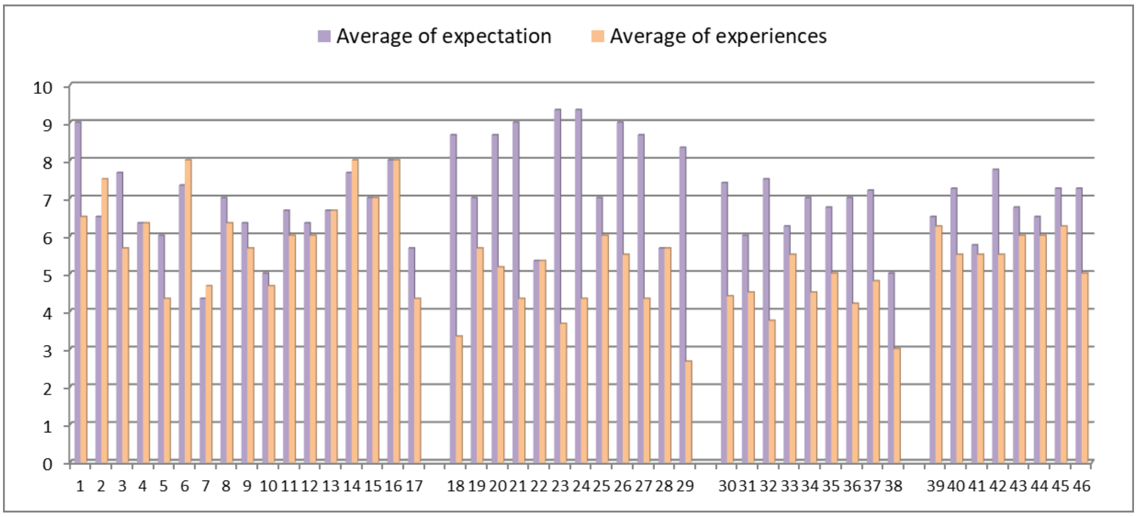


Figure 21. Comparison of the average of expectation vs. the average of experiences in Project 2.

Figure 21 compares the average of expectation to the average of experiences. The expectations in Project 2 are between 4,3 and 9,3. The respondents have the lowest expectation towards Change Management (no. 7), HSE Management (no. 10), and Demobilization (no. 38). The respondents, in turn, have very high expectations (9 and more) towards Project scheduling (no. 1), Detailed Design Automation (no. 21), Off-site Validation (no. 23), Resource Management Electrical (no. 24), and Basic Design Electrical (no. 26). In the Supporting Processes, there were some performance attributes, which performed even slightly over expectations.

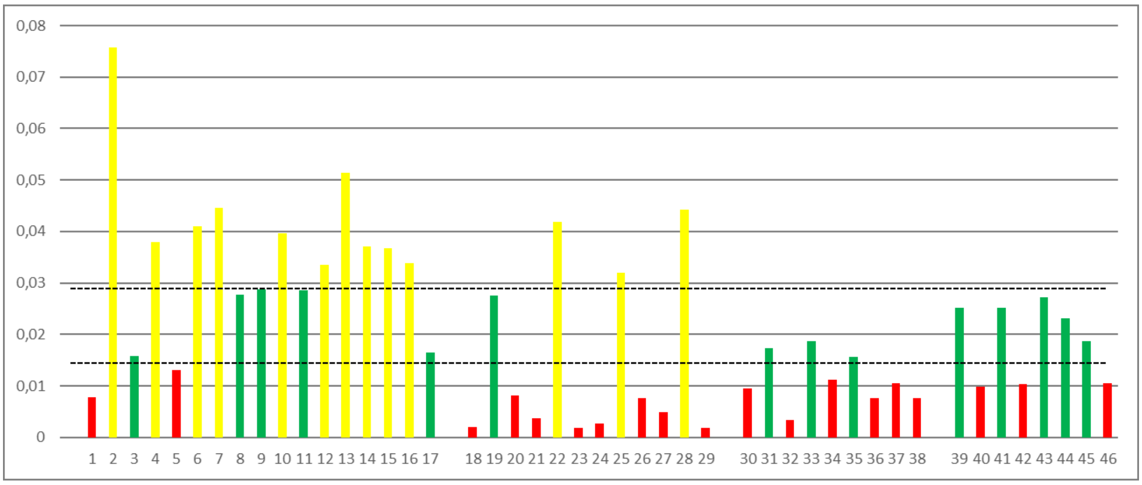


Figure 22. Resource allocation in Project 2 based on NSCFI.

Figure 22 illustrates the resource allocation in Project 2 based on NSCFI. The average resource level is at 0,021, with the upper bound at 0,029 and the lower bound at 0,015 for balanced resource allocations. The many critical performance attributes in the Engineering Process and Site Management Process are standing out. Supporting Processes mainly went well.

Table 10. Critical performance attributes of Project 2.

Process	Phase	Number	Description
Supporting Processes	Startup	1	Project scheduling
	Execution	5	Communications Management
Engineering and Validation Process	Automation	18	Resource Management
		20	Basic Design
		21	Detailed Design
		23	Off-site Validation
	Electrical	24	Resource Management
		26	Basic Design
		27	Detailed Design
		29	Off-site Validation
Site Management Process		30	Resource Management
	General	32	Construction and Installation
	Automation	34	Construction and Installation
	Electrical	36	Construction and Installation
		37	Commissioning
		38	Demobilization
Soft factors		40	Know-How / Experience
		42	Competence
		46	Organizational culture

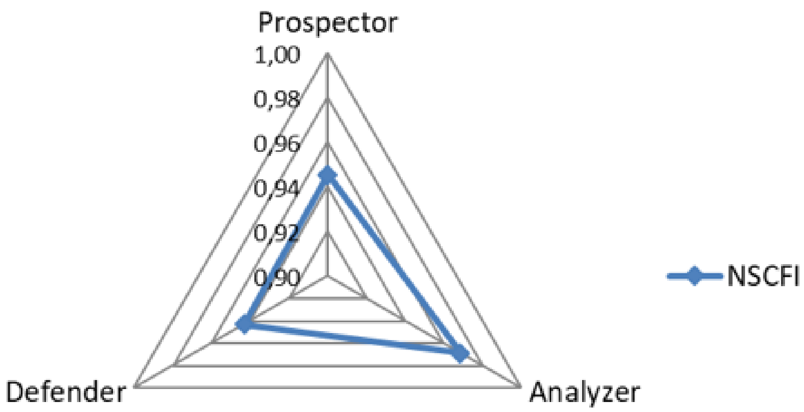
The critical performance attributes are presented in Table 10. Resource Management (no. 3, 18, 24, 30) is very critical in Project 2. Only no. 3 is narrowly a balanced attribute. In the Engineering Process, both in the Automation and Electrical category, the same attributes are critical. The critical attributes in the Engineering Process are besides Resource Management (no. 18, 24), Basic Design (no. 20, 26), Detailed Design (no. 21, 27), and Off-site Validation (no. 23, 29). In the Soft factors, Know-How / Experience (no. 40), Competence (no. 42), and Organizational culture (no. 46) are critical.

Sustainable Competitive Advantage Analysis

Table 11. NSCFI values per RAL component of Project 2.

Dimension	Quality	Cost	Time	Flexibility
NSCFI	294,23	261,56	221,65	45,47

The overall NSCFI values per RAL component are presented in Table 11 and are used to calculate the strategy type in Project 2.



Strategy type	Prospector	Analyzer	Defender	Reactor
NSCFI	0,945	0,969	0,943	0,944

Figure 23. Operations strategy in Project 2 based on NSCFI values.

As presented in Figure 23, the strategy type, according to Project 2, tends to be Analyzer. The strategy type corresponds with the one of the case company. The operations strategy of the case company was followed well.

Table 12. SCA values of Project 2.

Technique	MAPE	RMSE	MAD
NSCFI	0,98	0,99	0,99
NSCFI T/K	0,95	0,97	0,97

The SCA values in Table 12 support this impression. The case company's operations strategy is almost entirely supported by the resource allocation, as the NSCFI values are all close to 1. When looking at the NSCFI K/T, the values are only medium-high, as they are between 0,90 and 0,97.

Knowledge and Technology Analysis

The results of the K/T part of the questionnaire are presented below.

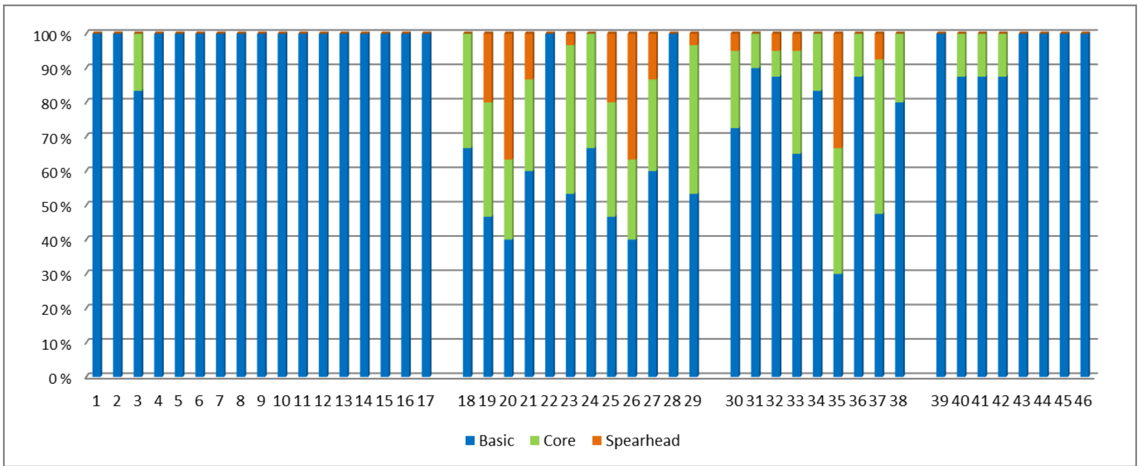


Figure 24. Technology shares in Project 2.

Especially in the Supporting Processes and in the soft factors, basic technology is dominating, as illustrated in Figure 24. In the Engineering Process and the Site Management

Process, there are higher shares of core- and spearhead technology. However, basic technology still accounts for the most significant share, except for attribute no. 35.

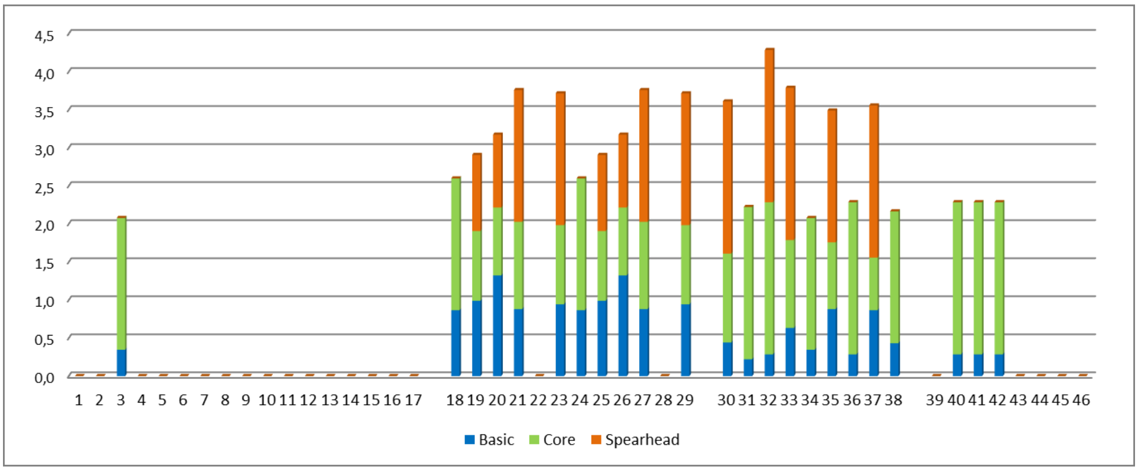


Figure 25. K/T uncertainty (CV) by performance attribute in Project 2.

Figure 25 shows a broad consensus about the technologies used in the Supporting Processes and soft factors. The variance grows in the Engineering Process and Site Management Process, where there seems to be much more uncertainty.

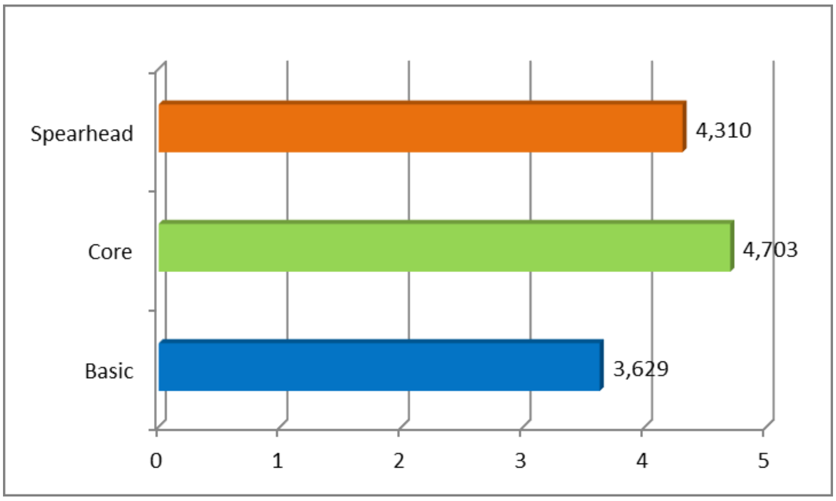


Figure 26. CV of K/T in Project 2.

The uncertainty (CV), which is presented in Figure 26, is the most prominent related to core technology, followed by spearhead technology.

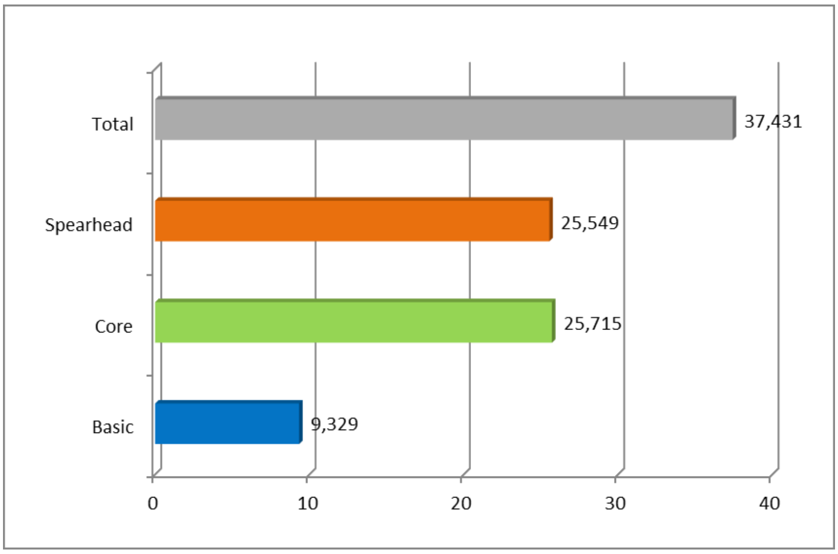


Figure 27. K/T risk by technology in Project 2.

According to Figure 27, core technology also bears the biggest risk, closely followed by spearhead technology. The risk connected to basic technology is smaller.

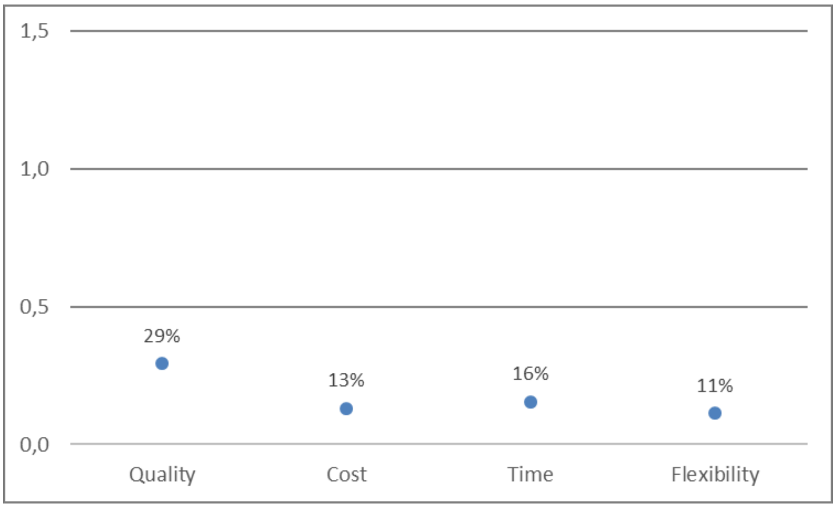


Figure 28. Variability coefficients (VarC) of Project 2.

When the variability coefficients are calculated relating to the RAL components, the highest risk is related to Quality, as can be seen in Figure 28. All values are clearly under one (<1), which means that the risk is relatively low.

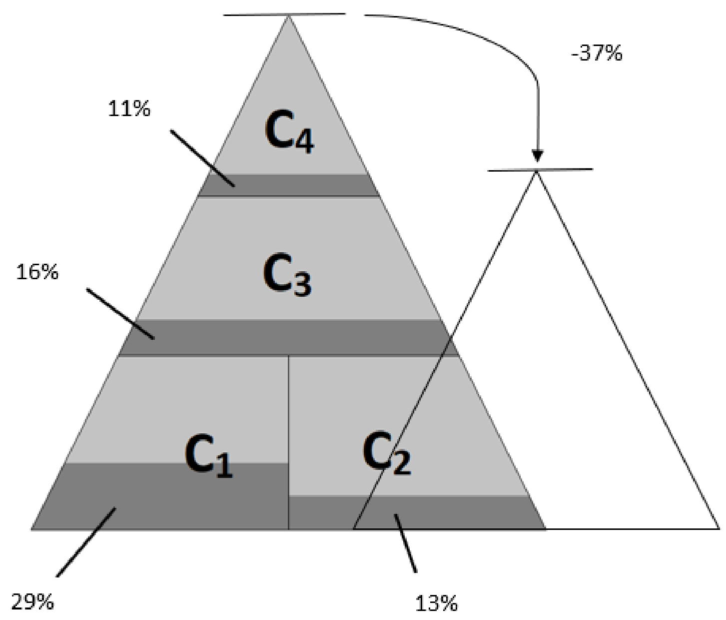


Figure 29. K/T uncertainty of Project 2.

Figure 29 presents the sand cone of Project 1. C_1 stands Quality, C_2 stands Cost, C_3 stands for Time, and C_4 stands for Flexibility. According to the K/T model, the competitiveness of Project 3 might have fallen up to 37% if the K/T risk materialized.

Market-based validation and additional data collection

Respondent 9 confirms that the results look correct. The first critical attribute (no. 1, Project Scheduling) sticks out. When looking at the whole project from the beginning, there would have been a lot of time, and the attribute should not be critical. But as the engineers answered the question from their perspective, it looks different. They came into the project when it was more urgent. There was almost no contingency included in the offer, as it was crucial to get the project awarded. Therefore, the cost overrun could easily occur.

Respondent 9 sees the root cause for the cost overrun in Project 2 in the missing personnel resources and therefore confirms the criticality of Resource Management in performance attributes no. 18 (Engineering Process, Automation), no. 24 (Engineering Process, Electrical), and no. 30 (Site Management Process). The project started relatively well, but problems started in the Basic Design. Own resources were short because of many other ongoing projects. Therefore, resources from other units of the case company were used both for the Engineering Process and for the Site Management Process. However, these employees had no experience of this type of project and didn't speak the language of the country where the project site was located. This deficiency led to problems. Mistakes in the design processes could have been corrected during the Off-site Validation or latest during Commissioning. Nonetheless, there were still no additional resources made available. Respondent 9 would consider it helpful if there were core teams, which are assigned to projects. These would already know each other, know how to act and what can be expected of each other. Respondent 7, who was actively involved in the project in the Site Management Process, confirms the criticality of Resource Management by stating that the main problem in this project was that almost the whole project team changed when the Site Management Process began.

Respondent 9 confirms the criticality of Communications Management (no. 5) if it was related to the project documentation. The problem was that everything went into manufacturing without approval, which was a significant risk. Problems had to be fixed at the site. The Engineering Process must go well; otherwise, there is three times more work during the Site Management Process. Because of a shortage of time and changing personnel resources, it was difficult to move the documentation to the employees who newly came to the project. Communication, in general, was critical, as there was a language barrier. On the client's side, they were reluctant to speak English, and most employees of the case company didn't speak the local language.

Respondent 9 confirms that within the critical attributes, Basic Design (no. 20, no. 26) went better than Detailed Design (no. 21, no. 27), which in turn went better than Off-site Validation (no. 23, no. 29), as the results show. It was in Basic Design when the project started to fail. The first two to three months of the project went well. In Construction and Installation (no. 32, no. 34, no. 36), risks were taken, as the sub-contractor was chosen for the first time.

Respondent 16 says that it is precise as the results show that Know-How/Experience (no.40) is critical. There were personnel resources used from other units who didn't have the required experience. They were experts but didn't have the expertise in this segment. Respondent 9 thought about the personnel resources, who came from another unit, when answering to Organizational Culture (no. 46). They were experienced commissioners. But they worked a lot in places where there is a vast cultural difference. There, when something doesn't function, one doesn't react to it. One is not allowed to make changes without permission. Here, the problems are fixed. They didn't know that hence they didn't intervene. The respondent emphasizes that the cooperation with the client in this project went well.

4.2.4 Project 3

The questionnaire analysis for Project 3 can be found below.

Sense and Respond Analysis

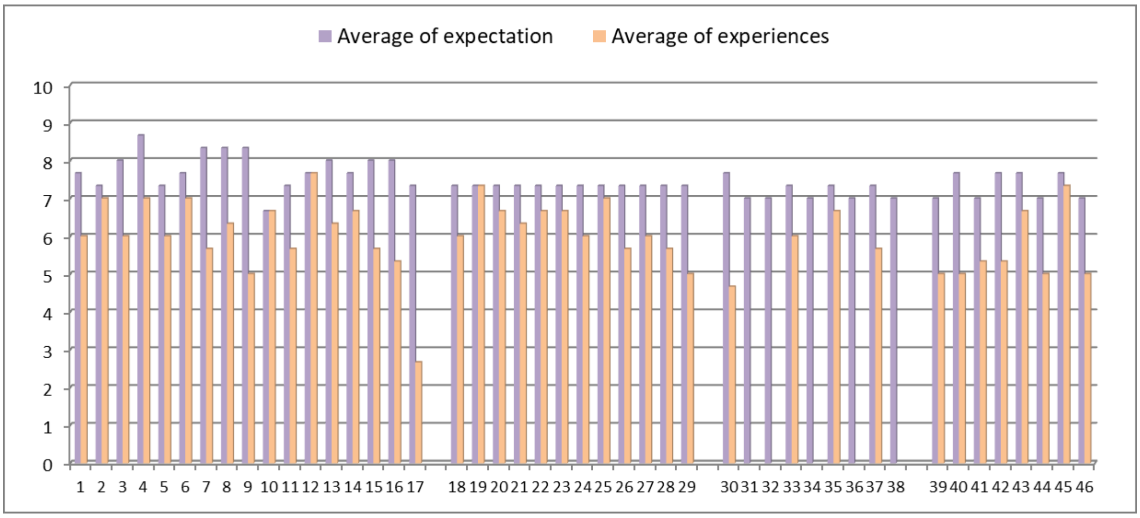


Figure 30. Comparison of the average of expectation vs. the average of experiences in Project 3.

Figure 30 compares the average of expectations to the average of experiences. All expectations are over seven, except for HSE Management (no. 10), which is slightly less. This circumstance shows that the respondents have high expectations towards the performance attributes, that the project can stay on budget. The experiences are always lower than the expectations, which means there is room for improvement for all attributes. There are no experiences for attributes no. 31, 32, 36, and 38, as they were not in the scope of the case company in this project.

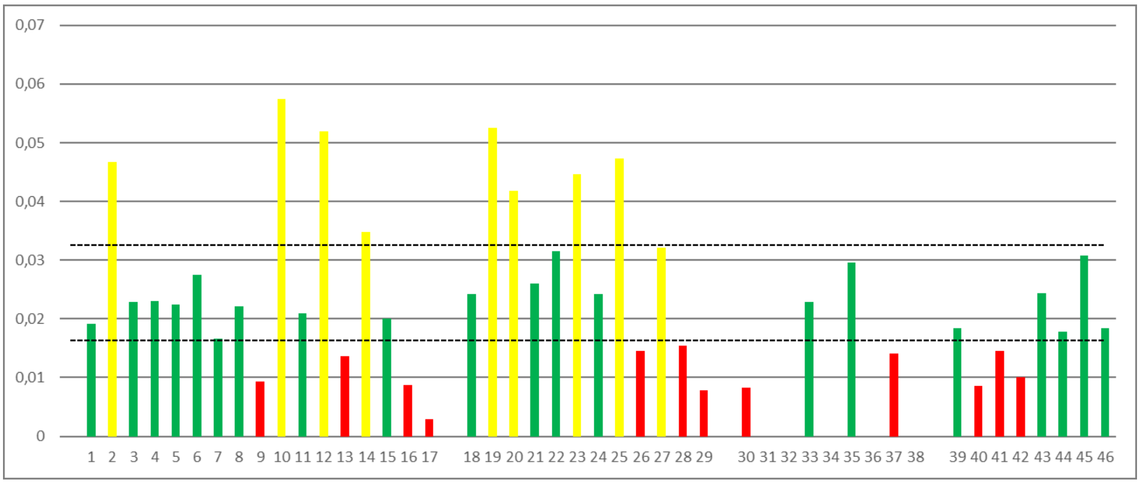


Figure 31. Resource allocation in Project 3 based on NSCFI.

Figure 31 illustrates the resource allocation in Project 3 based on NSCFI. The average resource level is at 0,024, with the upper bound at 0,034 and the lower bound at 0,016 for balanced resource allocations, marked by the black dashed lines. The resource allocation for attributes no. 31, 32, 34, 36, and 38 cannot be calculated, as they were not part of the case company's scope and are therefore not feasible for the cost overrun of the case company in this project. The critical resources are presented in Table 13:

Table 13. Critical performance attributes of Project 3.

Process	Phase	Number	Description
Supporting Processes	Execution	9	Schedule Management
		13	Decision-making
		16	Technology Management
	Closeout	17	Project acceptance, take-over and closeout
Engineering and Validation Process	Electrical	26	Basic Design
		28	Manufacturing
		29	Off-site Validation
Site Management Process		30	Resource Management
	Electrical	37	Commissioning
Soft factors		40	Know-How/Experience
		41	Knowledge
		42	Competence

Especially noticeable when examining the critical performance attributes in Table 13 is that electrical work seems to be significantly more critical than automation work. In this project, four critical attributes are directly linked to electrical work, but none to automation work. In the category of soft factors, Know-How/Experience (no. 40), Knowledge (no.

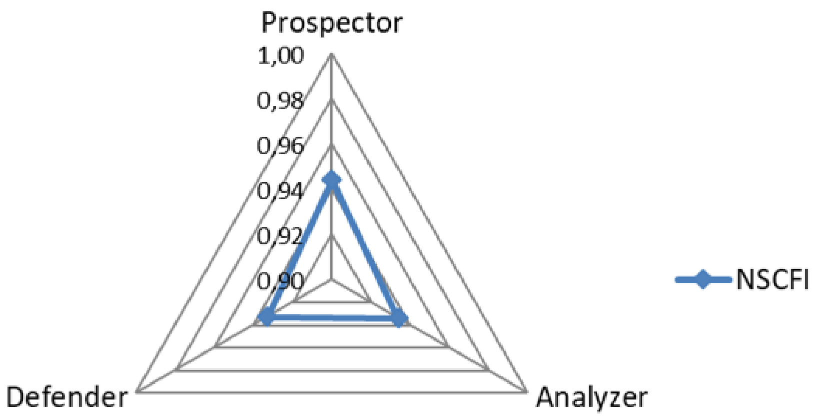
41), and Competence (no. 42) are all critical. In this project, Resource Management (no. 30) is only critical in the Site Management Process.

Sustainable Competitive Advantage Analysis

Table 14. NSCFI values per RAL component of Project 3.

Dimension	Quality	Cost	Time	Flexibility
NSCFI	347,52	215,25	116,49	73,79

The NSCFI values per RAL component are calculated in Table 14. They are used to define the strategy type of Project 3.



Strategy type	Prospector	Analyzer	Defender	Reactor
NSCFI	0,944	0,934	0,933	0,939

Figure 32. Operations strategy in Project 3 based on NSCFI values.

The strategy type of Project 3 has a slight tendency to be Prospector, as can be seen in Figure 32. All calculated values are relatively close to each other.

Table 15. SCA values of Project 3.

Technique	MAPE	RMSE	MAD
NSCFI	0,95	0,97	0,97
NSCFI T/K	0,93	0,96	0,96

The SCA values of Project 3 in Table 15 confirm that the resource allocations don't support the operations strategy as well as in Project 1 and Project 2. The values are slightly lower, but still medium-high, which means the resource allocation in Project 3 supports the operation's strategy well, too. NSCFI T/K values are slightly lower than the NSCFI values.

Knowledge and Technology Analysis

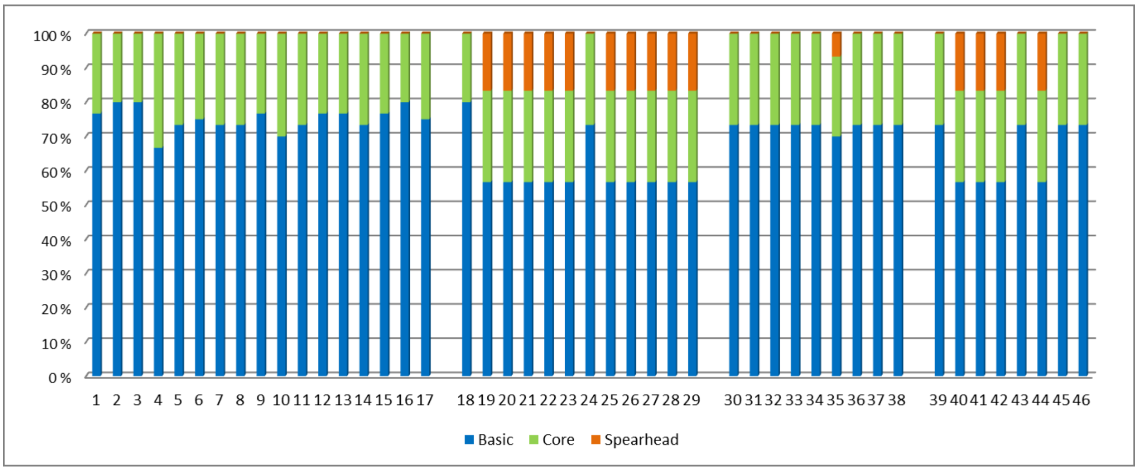


Figure 33. Technology shares in Project 3.

The technology shares per attribute in Project 3 can be seen in Figure 33. Basic technology is dominant for all attributes. There is some spearhead technology, mainly in the Engineering Process.

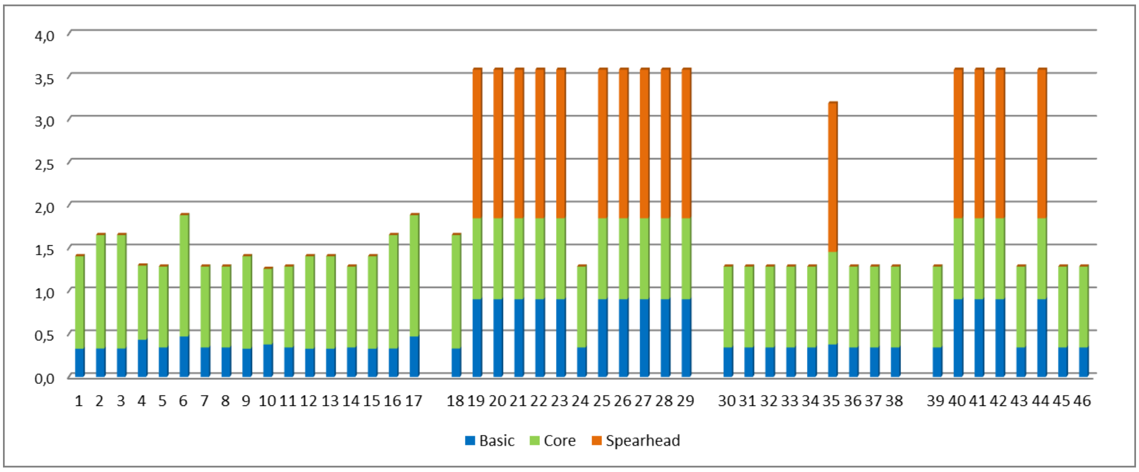


Figure 34. K/T uncertainty (CV) by performance attribute in Project 3.

When the K/T uncertainty is examined separately for every performance attribute, as in Figure 34, there is some uncertainty in the division into basic- and core technology for all performance attributes. Most uncertainty is in the Engineering Process, as there additionally is some uncertainty relating to spearhead technology.

There seems to be a limited correlation between the critical attributes and the T/K uncertainty by performance attributes. Attributes no. 26, 28, 29 40, 41, and 42 are critical and have relatively high levels of K/T uncertainty. Around half of it related to spearhead technology.

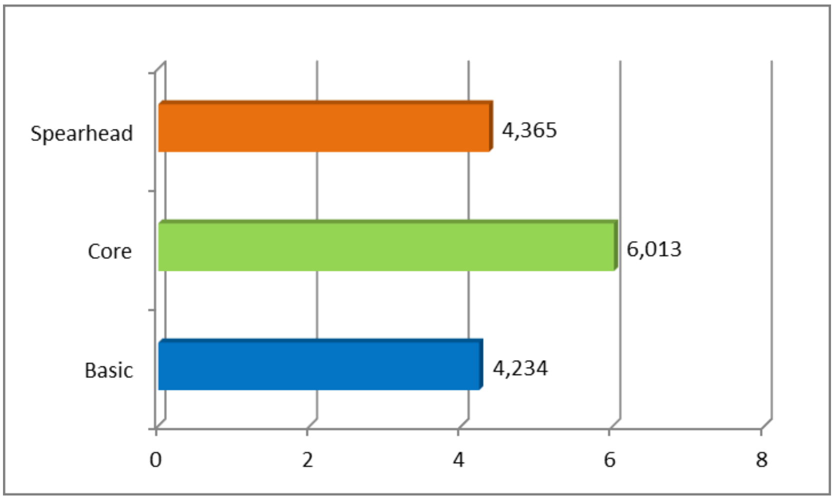


Figure 35. CV of K/T in Project 3.

Figure 35 shows the coefficient of variation of K/T. The most significant variation occurs relating to core technology, while spearhead- and basic technology have around the same average variation. This condition means that most uncertainty concerns core technology.

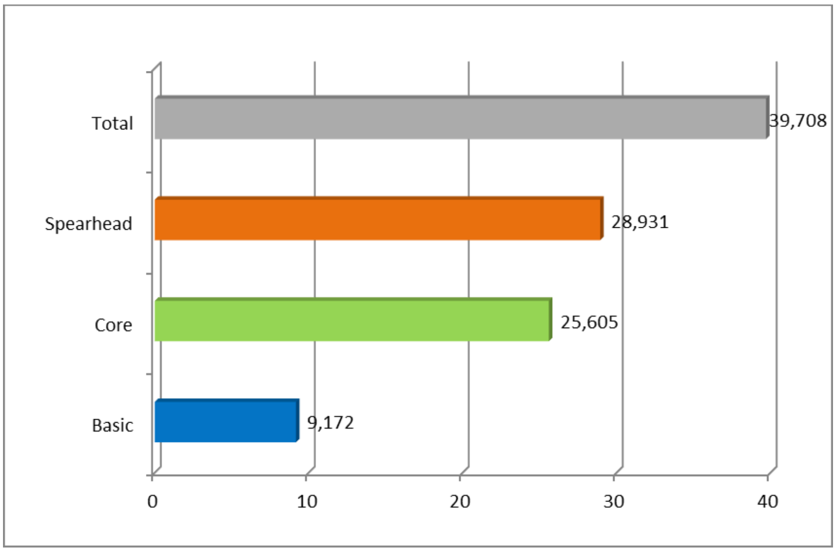


Figure 36. K/T risk (VarC) by technology.

Figure 36 shows the K/T risk when the RAL components are considered. Most risk is related to spearhead technology, followed by core technology. Basic technology is the least risky technology.

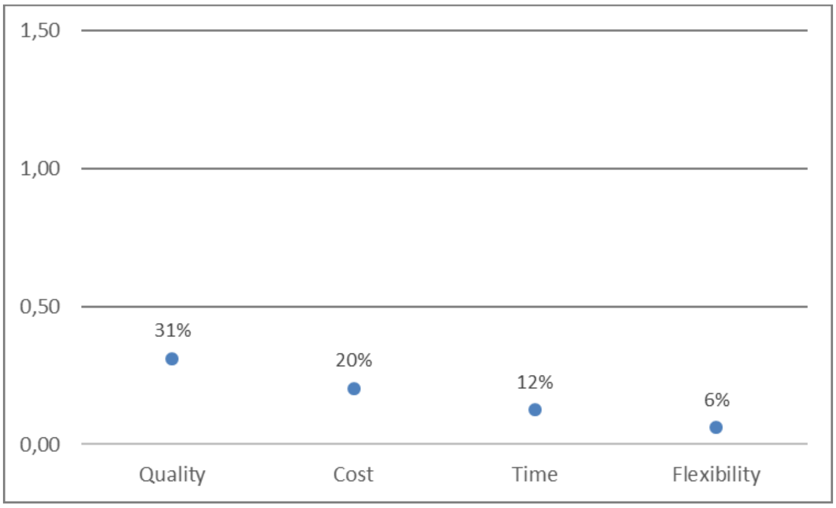


Figure 37. Variability coefficients (VarC) of Project 3.

When examining the variability coefficients in Figure 37, all values are clearly under one (<1), which means that the uncertainty levels are relatively low. The most uncertainty is related to performance attributes linked to Quality.

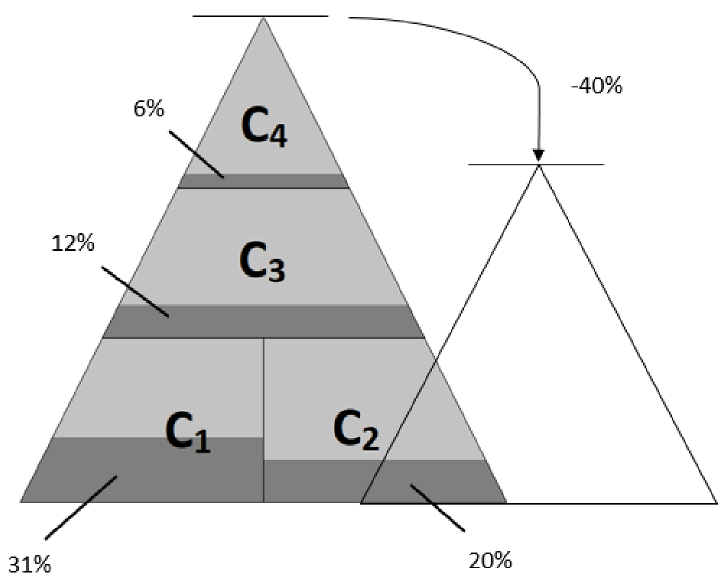


Figure 38. K/T uncertainty of Project 3.

Figure 38 shows the situation when the VarC are inserted into the sand cone, where C_1 is Quality, C_2 is Cost, C_3 is Time, and C_4 is Flexibility. According to the K/T model, the competitiveness of Project 3 might have fallen up to 40% if the K/T risk materialized.

Market-based validation and additional data collection

Respondent 12 explains that, in general, it is difficult to compare the cost reporting to the cost calculation. Only the project manager knows what the reported costs include and to which part of the cost calculation it must be compared. In this project, the site management was subcontracted and was therefore not relevant for the cost overrun of the case company. However, Commissioning was in the responsibility of the case company.

The project was affected by exogenous static uncertainty. As Respondent 12 reports, the whole scope could not be delivered because of sudden political restrictions. As some equipment was already explicitly manufactured for this project but could not be sold, this led to a cost increase. Nevertheless, there might be a chance that the equipment can be sold at a later point in time, which would reduce the cost overrun. The restrictions were unfortunate and could not be prevented through better planning. However, Respondent 12 states that the restrictions weren't responsible for a substantial share of the cost overrun. This circumstance primarily kept the project manager busy. The cost overrun mainly occurred because of materials, which were not calculated correctly in the sales process and because of more working hours than planned. There was a massive workload in the planning process; it was bureaucratic. The Commissioning exceeded the original schedule. Much more time was needed than scheduled. There was a lot of traveling, which included flying. The respondent confirms that Schedule Management (attribute no. 9) was critical. However, this was because of reasons independent from the case company but still contributed to the cost overrun. The reporting continued, and the project still had to be maintained, although there was no progress. The schedule exceeded already before the restrictions because of a sub-contractor of the client. The whole process was bureaucratic, and the acceptance process took a lot of time. Decision-making (no. 13) was also critical because of bureaucratic procedures and time-consuming communication. What Respondent 12 had in mind when answering to the performance attribute Technology Management (no. 16) was the condition monitoring tool, with which values were monitored. There was not enough know-how for the instrument. Consequently, this posed challenges in planning and commissioning. Respondent 12 can't confirm the criticality of Manufacturing (no. 28). From the respondent's perspective, nothing was below expectations there. Basic Design (both no. 20 and 26) was time-consuming. The results show that it is critical in the electrical category. It was partly unclear what the client expected. The client had a consultant who interfered with the plans. It was a long process and a little frustrating, which also applies to Detailed Design. Respondent 9 confirms that cooperation is more complicated when consultants represent the client, as was the case in Project 1 and 3.

Respondent 12 confirms that the challenges concerning Resource Management were in the Site Management Process, as the results show (no. 30). No commissioning manager was overseeing the process. There is no room in the budget for that. It was not always the same person commissioning, as the same person can't stay at the site for weeks. This circumstance led to information gaps. The client would have expected longer working weeks, but traveling took a lot of time, and the weeks were therefore shorter. In the Engineering Process, the team stayed together, and there were no problems relating to Resource Management. According to the results, Know-How/Experience, Knowledge, and Competence were all critical. Respondent 12 states that the team was not inexperienced; all had several years of experience. It was a young team, which got support from the rest of the organization. However, there was no experience concerning the condition monitoring tool, which could have led to the criticality of these attributes. Respondent 16 explains the criticality of these attributes as a possible consequence of the new market and new client. The team was experienced during the whole project, but the market and the end-customer were new. The respondent confirms that some tools haven't been used before. According to the respondent, there only has to be one or two of these that the attribute gets critical. It can be that there were problems with a single tool, which affected the assessment of Know-How, although the attribute was not so critical.

Respondent 12 sees the root cause for the cost overrun in the challenging planning process, the unclear requirements of the customer and the consultant, and the different consequential understandings. Moreover, the budget calculated for materials and working hours in the sales process was not enough.

4.2.5 Comparison between the projects

Sense and Respond Analysis

In all three projects, most experiences were well below the expectations, which shows that there is room for improvement in all performance attributes. It also shows that most performance attributes contributed at least somewhat to the cost overruns.

There was only one performance attribute, which was critical in all three projects. It was Resource Management (no. 30) in the Site Management Process. However, many performance attributes were critical in two of the projects or were only narrowly in the balanced zone and therefore took the green color. Still, every project had different challenges, and there were only a few common problems. However, having the right personnel resources at the right time caused difficulties in all three projects. Also, a significant problem in Project 1 and Project 3 was the cooperation with the consultant of the client, which was difficult. In both projects, Schedule Management (no. 9) and Decision-making (no. 13) were therefore critical.

Table 16. Average of expectations of all respondents in all three projects.

Rank	No.	Attribute name	Process	Category	Avg. expectation
1	24	Resource Management	Engineering and Validation Process	Electrical	**8,364**
2	23	Off-site Validation	Engineering and Validation Process	Automation	**8,333**
3	1	Project scheduling	Supporting Processes	Startup	**8,222**
3	18	Resource Management	Engineering and Validation Process	Automation	**8,222**
3	21	Detailed Design	Engineering and Validation Process	Automation	**8,222**
3	26	Basic Design	Engineering and Validation Process	Electrical	**8,222**
7	20	Basic Design	Engineering and Validation Process	Automation	**8,111**
8	3	Resource Management	Supporting Processes	Execution	**8,000**
8	29	Off-site Validation	Engineering and Validation Process	Electrical	**8,000**
10	30	Resource Management	Site Management Process	-	**7,917**
10	42	Competence	Soft factors	-	**7,917**
12	4	Financial & Cost Management	Supporting Processes	Execution	**7,889**
12	6	Procurement & Contractor Management	Supporting Processes	Execution	**7,889**
12	8	Risk & Opportunity Management	Supporting Processes	Execution	**7,889**
15	45	Teamwork	Soft factors	-	**7,833**
16	27	Detailed Design	Engineering and Validation Process	Electrical	**7,818**
17	16	Technology Management	Supporting Processes	Execution	**7,800**
18	40	Know-How / Experience	Soft factors	-	**7,750**
19	15	Knowledge Management	Supporting Processes	Execution	**7,700**
20	37	Commissioning	Site Management Process	Electrical	**7,667**
21	35	Commissioning	Site Management Process	Automation	**7,636**
22	9	Schedule Management	Supporting Processes	Execution	**7,600**
22	13	Decision-making	Supporting Processes	Execution	**7,600**
22	32	Construction and Installation	Site Management Process	General	**7,600**
25	12	Requirement Management	Supporting Processes	Execution	**7,500**
25	19	Conceptual Design	Engineering and Validation Process	Automation	**7,500**
25	25	Conceptual Design	Engineering and Validation Process	Electrical	**7,500**
28	33	Commissioning	Site Management Process	General	**7,455**
29	2	Establishing of project team	Supporting Processes	Startup	**7,444**
30	43	Engagement	Soft factors	-	**7,417**
31	14	Information Management	Supporting Processes	Execution	**7,400**
31	34	Construction and Installation	Site Management Process	Automation	**7,400**
33	36	Construction and Installation	Site Management Process	Electrical	**7,364**
34	11	Quality Management	Supporting Processes	Execution	**7,300**
35	5	Communications Management	Supporting Processes	Execution	**7,222**
36	46	Organizational culture	Soft factors	-	**7,182**
37	39	Professional relationship	Soft factors	-	**7,167**
37	41	Knowledge	Soft factors	-	**7,167**
39	28	Manufacturing	Engineering and Validation Process	Electrical	**7,111**
40	7	Change Management	Supporting Processes	Execution	**7,100**
41	22	Manufacturing	Engineering and Validation Process	Automation	**7,000**
41	44	Innovation	Soft factors	-	**7,000**
43	31	Site Establishment and Mobilization	Site Management Process	-	**6,909**
44	17	Project acceptance, take-over and closeout	Supporting Processes	Closeout	**6,889**
45	38	Demobilization	Site Management Process	-	**6,600**
46	10	HSE Management	Supporting Processes	Execution	**6,444**

Table 16 shows the combined average of expectations of all respondents in all three projects. It represents their opinion on how well the performance attributes must perform in future projects so that the projects stay on budget and no cost overrun occurs. The results show that the respondents expect all performance attributes to perform well, as all average expectations are over 5. Resource Management (rank no. 1, 3, 8, 10) is expected to perform very well, with an average expectation of at least 7,917. The respondents also have very high expectations (over 8) towards Off-site Validation (attribute no. 12, no. 29), Project scheduling (no. 1), Detailed Design (no. 21), and Basic Design (no. 26, no. 20).

Sustainable Competitive Advantage analyses

The resource allocation in all projects supports the operations strategy of the company well, which can be seen in the medium-high to high SCA values. Project 1 and Project 2 tend to be Analyzer strategy types, whereas the strategy type of Project 3 is less exact with a slight tendency towards Prospector.

Knowledge and Technology Analysis

Basic technology is the dominant technology in all projects and for all performance attributes, except for attribute 35 (Commissioning Automation) in Project 2.

The highest uncertainty is related to core technology in all three projects, followed by spearhead technology.

The highest risk is related to core technology in Project 1 and 2, followed by spearhead technology, whereas it was the other way around in Project 3. The lowest risk was related to basic technology in all projects, which is positive, as the shares of basic technology dominate.

Market-based validation and additional data collection

Respondent 9 agrees with the ranking in Table 16, as the respondent sees the same attributes as the most important to mitigate cost overrun.

Respondent 16 would put the technologies of the case company in the maturity phase of the technology life cycle, as the results show. The respondent states that clients want known technologies. The case company uses these technologies for a long time. Therefore they are well-known solutions. The clients are interested in new technologies, but they are not necessarily ready to pay for them. The cost for which the projects can be implemented is in a significant role in competitiveness. If a client is prepared to pay the case company more than a competitor, that is because they know what the case company delivers and not because of new or unique technologies. The case company should do its job as well as possible and as cost-efficiently as possible. From a technological view, it is challenging to differentiate from competitors. For the respondent, the underlying theories in this thesis show the reality surprisingly well.

Respondent 16 thinks it sounds reasonable to concentrate on core technologies or at least make more apparent what the core of the case company is. Maybe a concentration on core technologies could contribute to minimizing the impact of changing personnel resources. However, the respondent finds it hard to comment this further, as the underlying theory is not familiar. It must be checked what this result tells the case company.

5 Discussion

This chapter presents and discusses the findings. They are derived from the analysis in Chapter 4 and connected to the literature review in Chapter 2. Moreover, the contributions of this study are presented, and the validity and reliability are addressed. Finally, future areas of research are proposed.

5.1 Findings

The projects were analyzed in detail in Chapter 4. In Chapter 1.2, the following research question was formulated:

"What are the root causes of cost overrun in projects, and how can this be improved?"

The research question will be answered with the help of the two objectives, which were defined in Chapter 1.2 as well.

Objective 1: To identify the root causes for cost overrun in the selected projects

In Project 1, according to the respondents, the cost overrun mainly occurred because of too few or wrong personnel resources (Resource Management). Another leading cause was the challenging consultant of the client, who was very demanding. The critical performance attributes could mainly be traced back to these two influencing factors.

In Project 2, it was insufficient Resource Management, which was the root cause of cost overrun. The inadequate resources led to the criticality of most critical performance attributes, which all contributed to the ultimate cost overrun.

In Project 3, the situation looks somewhat different. The core team remained unchanged during the whole project; some challenges concerning Resource Management occurred only in the Site Management Process. The root cause was less exact but was connected to the fact that the whole project was bureaucratic, and therefore, much more working hours than expected had to be invested. There were unclear requirements from the client and his consultant, which led to different understandings. Static uncertainty contributed to the cost overrun as well, as there were some sudden political restrictions. This finding corresponds with Segelod (2018), who states that static uncertainty makes projects prone to cost overrun (p. 74), as described in Chapter 2.2.1.

These causes all belong to the category of technical explanations for cost overrun and were thematized in Chapter 2.2.1.

Objective 2: To identify areas for improvement to help mitigate cost overrun in the future

After having located the root causes of cost overrun in the selected projects, some possible areas for improvement are located. These are all derived from the results of the empirical research and the additional interviews conducted. The results are connected to the theory.

The areas for improvement are:

- **Special focus on the performance attributes with the highest impact on cost overrun**. Table 15 presented the average expectations of the respondents on how well the attributes must perform in future projects so that the project stays on budget. The table shows which performance attributes special focus should be laid on. Performance attributes with high average expectation should be improved by allocating more resources, as these are the ones that have the highest impact on cost overrun, according to the respondents. All attributes with an average expectation of at least 8 were critical in at least one of the projects. This fact underlines that there is a need to develop the attributes with the highest expectations. In the top ten are Resource Management (attribute no. 18, 24, 3, 30), Off-site Validation (no. 12, no. 29), Project scheduling (no. 1), Detailed Design (no. 21), and Basic Design (no. 20, no. 26). These are the essential attributes that should be promoted in future projects, as they have the highest impact on cost overrun.

- **Improvement of Resource Management**. Noticeable is that all performance attributes related to Resource Management were critical in Project 1, and all but attribute no. 3 in Project 2. In Project 3, Resource Management was critical in the Site Management Process. In the interviews, Resource Management was identified as a root cause for cost overrun in Project 1 and Project 2. This result allows the conclusion that cost overrun could be mitigated the best in the future by improving Resource Management, which corresponds with Flyvbjerg et al. (2018), who suggests hiring a competent team for the implementation of the project (p. 185) (Chapter 2.3.1). This conclusion is underlined by the fact that all performance attributes connected to Resource Management appear on top in Table 15. The most experienced employees should be allocated to the performance attributes with the highest impact on cost overrun. In this way, cost overrun can be mitigated when personnel resources are short. The attributes with the highest impact on cost overrun are Basic Design, Detailed Design, and Off-site Validation. Three other possible ways to improve Resource Management came up during the interviews. One way would be to establish core teams, which stay together during the whole project. The project manager would know the team better and have clear ideas about what to expect from the team members. Core teams would therefore simplify the allocation of work and reduce the risk that the project gets out of hand. However, this might not be possible when there are many ongoing projects, and personnel resources are short. Another way to improve Resource Management could be the nomination of lead engineers, one for automation and one for electrical work, who accompany the whole project and don't change during the project. They would be responsible for pulling strings from a technical perspective, while the project manager can focus on operational tasks. Compared to core teams, this has the advantage that fewer people are fixated to one project, which leaves more wiggle room to allocate personnel resources where needed most. A third way could be to concentrate on the mitigation of the consequences when Resource Management is critical, and the optimal personnel resources are not available. This conclusion leads to the next area for improvement.

- **Uniform working directives**. Often, there are personnel resources from other units deployed. According to Segelod (2018), this makes the project prone to cost overrun, as these actors have no experience of similar projects (pp. 72, 74-75) (see Chapter 2.2.1). Some of the problems occurred because they were used to a different organizational culture or other ways of working. Own personnel resources might have different ways of working, too. A dossier with working directives would ensure that everybody involved in the projects is on the same page and knows how to act. This approach would also reduce the impact of changing personnel resources. It must then be ensured that all employees involved in the projects have read and understood the directives. Information gathered from personal communication suggests that the existing quality documentation and guidelines are not necessarily read and followed by all employees.

- **Special attention to new clients and clients with consultants**. Another factor with a high impact on cost overrun in Project 1 and Project 3 was the consultant of the client. Also, the client was new in Project 3. The cooperation was bureaucratic and time-consuming in both projects. There were different understandings of the requirements. Consequently, there should be a consensus about the requirements already in an early stage of the project, which would prevent endless discussions and delays because of disagreements. In the best case, there is a consensus already at the end of the sales process. Special attention should therefore be given to projects implemented for new clients, or where consultants are involved. Furthermore, there might be possibilities for new innovative ways of cooperation.

- **Reduction of costs**. In the technology life cycle, a clear dominance of basic technology and low amounts of core- and spearhead technology is a sign that the products and services offered have reached the maturity phase. The theory presented in the literature review suggests that to sustain its position in the market, the case company should focus on reducing production costs, on newly invented products, and innovative technology, as explained in Chapter 3.6.1. Cost reductions are essential for competitive advantage, as customers are not necessarily ready to pay a premium for better technical performance. That was confirmed by Respondent 16, who stated that customers demand known solutions from the case company. High shares of basic technology furthermore mean that the case company can't differentiate from competitors from a technological perspective. Newly invented products might eventually get of concern, as technologies in the maturity phase are one day replaced by new technologies.

- **Investing in core technology**. The highest uncertainty in all three projects is related to core technology. It is the technology that should most be invested in to gain and sustain competitive advantage and to succeed in projects. However, spearhead technology should not be neglected. These investments will ultimately contribute to the mitigation of cost overruns. Investing in core technologies starts with the awareness of all parties involved, which technologies of the case company bring competitive advantage and allow to differentiate from competitors. As customers require known solutions, the investment in core technology should concentrate on the Supporting Processes. That would mean that the competitive advantage compared to competitors is not achieved by more innovative solutions for the customer, but by raising the efficiency and competitiveness of the Supporting Processes, which will contribute to the reduction of costs. This procedure ensures that competitive prices can be offered. The new core of the case company could comprise solutions to improve Resource Management, solutions for uniform working directives, and improved ways of cooperation with the clients, which are all areas for improvement presented before. Core technology can also refer to a very well-designed process that brings competitive advantage, not only to software or components.

The most critical areas for improvement were presented above. However, the results show that there is room for improvement in all performance attributes, which is typical for an ambitious company. It is hard to tell which attribute was responsible for which amount of cost overrun, as it is difficult to directly compare the cost calculation to the cost reporting and the performance attributes. Moreover, this thesis concentrates on the objective opinions of the respondents. Siemiatycki (2015) suggests the enhancement of performance monitoring, reporting, and information sharing to mitigate cost overrun (pp. 5-6), as explained in Chapter 2.3.1. For the case company, an alignment of the cost reporting to the cost calculation would simplify their analysis and concluding, as comparable data would be readily available.

Every project encounters individual problems, as, amongst others, the country, language, culture, requirements, and scope can vary a lot. Therefore, the reasons for cost overrun are diverse. This circumstance is verified by the results, which show different critical performance attributes for different projects. Resource Management, however, is an attribute that affects every project, as the resources for every project principally come from the same pool of staff. Improvements in Resource Management thus positively affect the mitigation of cost overrun in all projects. However, it doesn't guarantee that cost overruns won't occur in the future, as causes are manifold. Some reasons for cost overrun are related to static uncertainty, which can't be entirely prevented by better planning and better operations.

One must take note that performance attributes influence each other. Some might only be critical because of the criticality of another. As an example, poor Resource

Management in the Site Management Process certainly reduces the performance of all other attributes of the Site Management Process. Therefore, additional information through interviews was needed to locate the root cause for cost overrun.

Surprisingly, the performance attribute “Professional relationship” (no. 39) was not critical in Project 1 and Project 3. However, respondents reported difficulties in the cooperation with the client and even saw it as a root cause for cost overrun. The experiences were clearly under the expectations for this attribute in both projects, but the attributes were not critical. A possible explanation could be that all respondents did not read the additional description for the performance attribute. It clearly states that by this attribute, the relationship with the customer is meant. It would have been better to name the attribute, for instance, “Cooperation with the customer”, to avoid misunderstandings. However, the difficulties in cooperation with the customers could be seen in both projects in the criticality of Schedule Management (no. 9) and Decision-making (no. 13).

The influence of the sales process on cost overrun in the Engineering Process and Site Management Process could not be examined in this study because most engineers were not involved in the sales process. Consequently, the sales process couldn’t be included in the questionnaire. Therefore, it remains open how significant the influence of optimism bias and planning fallacy is. Still, it could be considered to organize schoolings on the topic for employees involved in the sales process to raise awareness for optimism bias and planning fallacy, as this probably is an influencing factor. Furthermore, the influence of the cost estimation technique used to estimate the costs of the Engineering Process and Site Management Process remains to be examined as well.

In the AHP analysis, the answers varied a lot, except for the RAL component Flexibility. This result raises the question if the operations strategy of the case company is defined clearly enough. All employees involved in the projects should know what the operations strategy of the case company is and, therefore, how the priorities in the project should be laid. According to the results, the strategy type of the case company is Analyzer. It is positive that the resource allocation in all projects corresponds well with the operations strategy, as can be seen in the SCA analysis and, therefore, didn’t contribute to the cost overruns in the projects.

5.2 Contributions

This thesis contributed to the theory by presenting a study that includes a comprehensive literature review on the contractor’s perspective on cost overrun in projects. This view contrasts with the project owner’s perspective. Although there are many similarities, there are also some significant differences between these perspectives.

This thesis furthermore located critical performance attributes and, therefore, important operations, which contribute to cost overrun in projects. Finally, some root causes were identified.

The thesis not only considered the operational perspective but also the importance of Technology- and Knowledge Management was described. The technology type which causes the most uncertainty was located and possible risks caused by technology were presented.

Improvement proposals were made, which contribute to the mitigation of cost overrun. The WMT provided evidence that the methods used were suited for the detection of root causes for cost overrun.

5.3 Validity and Reliability

Validity was increased by incorporating the advice of several experts in the creation of the questionnaire, which led to a comprehensive list of performance attributes for the Engineering Process and the Site Management Process. The experts confirmed that the questionnaire covered all important operations relating to the Engineering Process and the Site Management Process. The acid test increased validity, as the respondent agreed with the results, and further suggestions led to improvements in the questionnaire. When it comes to the AHP questionnaire, validity was guaranteed by ensuring that the ICR was always less than 0.3.

Reliability was ensured by adding clear instructions and examples to the questionnaires. Assistance in filling out the questionnaires was offered, if needed. Furthermore, the performance attributes in the S&R questionnaire cover the problem from many angles, which improves reliability. Objectivity was guaranteed by independent answers from the respondents in both the AHP- and the S&R questionnaire. Although the number of responses was limited, the experience of the respondents should sufficiently reflect the actual incidents in the projects. Furthermore, employees with different tasks and perspectives on the projects were included to get a comprehensive picture of the projects.

In the K/T analysis, all variability coefficients were clearly under 1, which shows a relatively broad consensus between the respondents.

Both validity and reliability were improved by carrying out a WMT. It was accepted for most of the results by the interviewed respondents.

However, there were also some challenges encountered during the studies, which might have compromised the results. The respondents' opinions on the projects partly varied a lot, depending on their perception, viewpoints, and role in the project. Therefore, the validation through the WMT could have brought different results, depending on with whom the WMT was carried out. The different perspectives on the project could also generally be seen in the assessment of the performance attributes. As an example, there were cases where some respondents only worked in the Engineering Process, and other respondents only worked in the Site Management Process. Therefore, they had different opinions about the performance of some attributes of the Supporting Processes and soft factors, as many influencing factors might have changed between the processes. Many respondents carried out isolated tasks in the project, which means they might miss the overall picture. Also, a project manager might have a different view on certain performance attributes than an engineer. Nevertheless, all opinions combined should give a representative result.

The number of projects in which cost overrun occurred was limited to three. Although these three projects can be considered representative, a bigger sample of projects would increase the reliability of the results. It would have furthermore been interesting to add a project where no cost overrun occurred, to see how the results distinguish.

In the K/T part of the questionnaire, the division into basic-, core-, and spearhead technology was considered to be rather difficult by the respondents. Even more examples and background information on the method might have helped the respondents answering the questionnaire. Also, some performance attributes directly influence the success of the Engineering- and Site Management Process, but the respondents themselves are not responsible for these particular performance attributes. This condition means they can assess the performance of the attribute, but they don't necessarily know all underlying technologies. An example is performance attribute no. 6, Procurement & Contractor Management. It influences the work of the respondents and the success of the project. But as there is a separate purchasing team, the respondents don't necessarily know all technologies involved. Therefore, the share of technology must be interpreted from the perspective of the respondents and doesn't necessarily reflect the actual reality.

Not every respondent could assess all performance attributes because some respondents carried out isolated tasks in the project. Thus, there are some performance attributes with only two answers in the S&R part or K/T part of the questionnaire. The reliability of the results for performance attributes with less than three answers is somewhat compromised. Especially in the K/T analysis, the reliability of the CV of K/T, the VarC, and the K/T risk might be slightly compromised because of attributes with few answers.

For some respondents, the examined project was the first in this particular segment of the case company. Therefore, they couldn't assess past projects in the "Direction of Development" section. Consequently, they left this section empty, and the Development Index was only calculated with the help of the answers from the other respondents, which could assess this section. In Project 2 and Project 3, the Development Index is therefore built from fewer answers, which slightly compromises the reliability.

Furthermore, the influence of the sales process could not holistically be studied by the methods used in this thesis. Which share of the cost overrun in the Engineering Process and Site Management Process was due to actions in the Sales Process, remains, therefore, open. However, the price is primarily determined by the market, which significantly reduces the impact of the sales process on cost overruns of the case company.

5.4 Future research

There are various possibilities for future research in this field.

The research could be extended to more projects, in which cost overrun occurred. An extension would provide further insight into the topic, and more root causes might be found. This thesis focused on the Engineering- and Site Management Process, in which usually the most significant share of cost overrun occurs. Future research could concentrate on other processes of the projects. Especially interesting would be a more in-depth look into the impact of the sales process on cost overrun. It would be interesting because the cost estimation, which forms the baseline for the measurement of cost overrun, is created in the sales process. Consequently, the process plays a crucial role in cost overrun. Future research could examine the possibility of including RCF and, therefore, an outside view of cost estimation as a possible new way to determine the project contingency in the sales process.

The research could also be extended to other segments of the case company, which might require some adaptions in the S&R questionnaire. Moreover, a similar study could also be conducted on the organizational level to improve the operations in general.

A further possibility for research would be to examine and improve Resource Management, which was located to be the primary root cause of cost overrun. The objective could be to redesign the process, how personnel resources are allocated to projects.

6 Conclusions

This research aimed to locate the root causes for cost overrun from a contractor's perspective and to present improvement proposals for its mitigation. A wide range of methods was used for this purpose to gain a comprehensive picture of the situation in the case company. The methods comprised the Analytical Hierarchy Process (AHP), the Critical Factor Indexes (CFI), the Sense and Respond method (S&R), the RAL-concept, the Manufacturing Strategy Index (MSI), the Knowledge and Technology method (K/T), and the Sustainable Competitive Advantage model (SCA).

Based on the analysis, it can be concluded that there were mainly two root causes of cost overrun in the examined projects. The first and most serious root cause is Resource Management. There were challenges to have the right personnel resources in the projects at the right time, which led to manifold problems during the Engineering Process and Site Management Process. The second root cause found was the cooperation with the client and the client's consultant, which was difficult and time-consuming in Project 1 and Project 3. The research furthermore presented improvement proposals for the mitigation of cost overrun in future projects. The recommendations are all connected to the root causes for cost overrun, some of them strongly, others more loosely. Particular focus on performance attributes with a high impact on cost overrun, improvement of Resource Management, uniform working directives, and special attention to new clients and clients with consultants are suggested for the mitigation of cost overrun based on the S&R analysis. The K/T results suggest cost reductions and investments in core technologies.

A comprehensive literature review on cost overruns in projects from the perspective of a contractor was presented. There are technical- and behavioral explanations for cost overrun. However, the technical explanations are considered more important for a contractor in a competitive market. The results are based on the subjective opinions of the employees involved in the projects of the case company. The data was collected with the help of questionnaires. Receiving the answers from the respondents took some time, not least because of the prevailing COVID-19 situation. The respondents all had different perspectives and tasks in the project, and their opinions differed. Nevertheless, the methods used could point out which operations were critical in the projects and therefore contributed most to the cost overruns. The methods examined the projects from an operative and a technological perspective. The results and the proposed areas for improvement allow addressing the problem of recurring cost overruns specifically.

Generally, project costs tend to overrun, and progress in the field has been slow, as numerous examples show. It is a topic that will continue to be of concern in the future, as cost overruns in projects can’t entirely be ruled out. However, the problem can be mitigated when the root causes are known. The presented improvement proposals allow the case company to maintain a sustainable competitive advantage and to reduce the risk of cost overruns. The recommendations will eventually contribute to the realization of successful projects in the future.

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Appendices

Appendix 1. AHP questionnaire

Master Thesis, Root causes and improvement proposals for cost overrun in projects
Tobias Lutz, University of Vaasa

Instructions and Explanations

Dear project team member,

Thank you for filling out the AHP questionnaire.

In the AHP questionnaire, you have to weight the components "Quality", "Cost", "Time" and "Flexibility" according to their importance in the projects. More detailed instructions can be found in the questionnaire.

The collected information is confidential. It will be used as statistical data in my thesis, but individual responses are not separately identifiable.

Please feel free to ask if there are questions or uncertainties.

Thank you for your help.

Best regards,

Tobias Lutz

Please weight the components "Quality", "Cost", "Time" and "Flexibility" according to their importance in the projects. Consistency of the answers is important. For example, it is not possible that "Cost" is more important than "Time", when at the same time "Quality" is more important than "Cost" but less important than "Time".

Due to consistency: If comparisons are highlighted after giving your answers (different shades of red, 1, 2 and 3 in column M), please adjust the importance and scale until no comparisons are highlighted anymore.

Hint: It's easiest to alter the answer highlighted in dark red

AHP Analytic Hierarchy Process

n= 4 Input 1

Objective: Weighting of the components Quality, Cost, Time and Flexibility

Only input data in the light green fields!

Please compare the importance of the elements in relation to the objective and fill in the table: Which element of each pair is more important, **A or B**, and **how much** more on a scale 1-9 as given below.

Once completed, you might adjust highlighted comparisons 1 to 3 to improve consistency.

n	Criteria	Comment	RGMM	+/-
1	Quality	Quality means that things are done right. It includes design quality (set of features which a product/service has) as well as process quality (quality inside the operations).	25,0%	
2	Cost	These are the operational cost, which should be optimized, such as for staff, facilities, technology and equipment and materials.	25,0%	
3	Time	The duration between customers requesting products/services until they receive them.	25,0%	
4	Flexibility	This is the ability to change the operation during the project in some way. The change can be related to what the operation does, how it is doing it, or when it is doing it.	25,0%	

1

Name Weight Date

α: 0,3 CR: 0 % 1

Consistency Ratio

i	j	Criteria A	Criteria B	more important ? A or B	Scale (1-9)
1	2	Quality	Cost		
1	3		Time		
1	4		Flexibility		
1	5		Flexibility		
1	6		Flexibility		
1	7		Flexibility		
1	8		Flexibility		
2	3	Cost	Time		
2	4		Flexibility		
2	5		Flexibility		
2	6		Flexibility		
2	7		Flexibility		
2	8		Flexibility		
3	4	Time	Flexibility		
3	5		Flexibility		
3	6		Flexibility		
3	7		Flexibility		
3	8		Flexibility		
4	5		Flexibility		
4	6		Flexibility		
4	7		Flexibility		
4	8		Flexibility		
5	6		Flexibility		
5	7		Flexibility		
5	8		Flexibility		
6	7		Flexibility		
6	8		Flexibility		
7	8		Flexibility		

A
B

Intensity of importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong Importance	Experience and judgment strongly favor one element over another
7	Very strong importance	One element is favored very strongly over another, it dominance is demonstrated in practice
9	Extreme importance	The evidence favoring one element over another is of the highest possible order of affirmation

2,4,6,8 can be used to express intermediate values

Appendix 2. Sense & Respond questionnaire

Master Thesis, Root causes and improvement proposals for cost overrun in projects
Tobias Lutz, University of Vaasa

Instructions and Explanations

Dear project team member,

Thank you for filling out the questionnaire.

You can find the questionnaire on the next Excel sheet (Sense and Respond Questionnaire). There is a list of 46 Performance Attributes, which cover the operations within the project. Please fill out all performance attributes, which you can assess. The focus is on the engineering- and the site management process of the project.

Each Performance Attribute must be evaluated from following perspectives:

Expectation: How well does the attribute has to perform in coming projects (next 3 years) to deliver a successful project? Scale: From 1 (low expectations) to 10 (high expectations)

Experience: Assess the outcome (success) of the attribute in this project on a scale from 1 (worst) to 10 (best)

Direction of Development: How was the performance of the attribute compared to previous projects (trend, compared to projects 2-5 years ago)? - worse, same or better

Technology share of performance attribute: State the share of basic-, core- and spearhead technology in %, which is used for the completion of every performance attribute in this project. Please check the examples in the questionnaire sheet before filling out.

More detailed explanations are added as comments into the questionnaire and can be viewed by holding the cursor over the respective cell.

Example:

		Expectation (1-10)	Experience (1-10)	Direction of Development			Technology share of performance attribute			
PERFORMANCE ATTRIBUTES				worse	same	better	Basic	Core	Spearhead	Sum **(has to be 100 %!)**
1	Project scheduling	8	5		x		60 %	30 %	10 %	100 %

The collected information is confidential. It will be used as statistical data in my thesis, but individual responses are not separately identifiable.

Please feel free to ask if there are questions or uncertainties. We also can fill out the questionnaire together.

Thank you for your help.

Best regards,

Tobias Lutz

Project: Name of Respondent:

SENSE AND RESPOND Questionnaire

This questionnaire assesses the performance of the project's operations from the point of view of the project team.

Please fill out the whole row (Expectation, Experience, Direction of Development and Technology share of performance attribute) for every performance attribute you can assess, as accurately as possible, for the project in question, from your point of view.

Please check the more detailed explanations, which can be found by holding the cursor over the respective cell

		Please answer all attributes and sections you can assess, as accurately as possible (green cells)	Expectation (1-10)	Experience (1-10)	Direction of Development			Technology share of performance attribute			
		PERFORMANCE ATTRIBUTES			worse	same	better	Basic %	Core %	Spearhead %	Sum **(has to be 100 %!)**
Supporting Processes											
Startup	1	Project scheduling									0 %
	2	Establishing of project team									0 %
Execution	3	Resource Management									0 %
	4	Financial & Cost Management									0 %
	5	Communications Management									0 %
	6	Procurement & Contractor Management									0 %
	7	Change Management									0 %
	8	Risk & Opportunity Management									0 %
	9	Schedule Management									0 %
	10	HSE Management									0 %
	11	Quality Management									0 %
	12	Requirement Management									0 %
	13	Decision-making									0 %
	14	Information Management									0 %
	15	Knowledge Management									0 %
	16	Technology Management									0 %
Closeout	17	Project acceptance, take-over and closeout									0 %
Engineering and Validation Process											
Automation	18	Resource Management									0 %
	19	Conceptual Design									0 %
	20	Basic Design									0 %
	21	Detailed Design									0 %
	22	Manufacturing									0 %
	23	Off-site Validation									0 %
Electrical	24	Resource Management									0 %
	25	Conceptual Design									0 %
	26	Basic Design									0 %
	27	Detailed Design									0 %
	28	Manufacturing									0 %
	29	Off-site Validation									0 %
Site Management Process											
	30	Resource Management									0 %
	31	Site Establishment and Mobilization									0 %
General	32	Construction and Installation									0 %
	33	Commissioning									0 %
Automation	34	Construction and Installation									0 %
	35	Commissioning									0 %
Electrical	36	Construction and Installation									0 %
	37	Commissioning									0 %
	38	Demobilization									0 %
Soft factors											
	39	Professional relationship									0 %
	40	Know-How / Experience									0 %
	41	Knowledge									0 %
	42	Competence									0 %
	43	Engagement									0 %
	44	Innovation									0 %
	45	Teamwork									0 %
	46	Organizational culture									0 %