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PROJECT COST ESTIMATION

Promoting quality of cost estimation to reduce project cost variance

Master of Science Thesis
Faculty of Management and Business
Examiners: Prof. Teemu Laine and Dr(Tech) Jari Paranko

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ABSTRACT

Alexandra Valtanen: Project Cost Estimation: promoting quality of cost estimation to reduce project cost variance.
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One of the dimensions of evaluating project success is assessing whether the project has been completed within the assigned budget. However, it is unlikely that the actual costs will be exactly as planned, and historically, industrial projects are prone to cost overruns. Careful planning and a reasonable cost baseline are key to achieving project success. The cost baseline consists of the aggregated cost estimate and contingency reserve. Literature identifies various methods for increasing the reliability of the cost baseline via setting appropriate contingencies. However, there is a gap in the literature regarding the other of the two components of the project cost baseline – the cost estimate.

The objective of this thesis is to investigate and develop a method for reducing project cost variance by improving the quality of the cost estimation process in industrial project-based firms. The objective was achieved by observing the sales organization and the cost estimation procedure in the case company and identifying the underlying issue that results in the project cost variance. The method was developed by surveying the best available practices of cost estimation techniques and processes employed by industrial project organizations and synthesizing a holistic method for improving the quality of cost estimation and promoting knowledge management within an organization. From a practical perspective, the research offered the case company a new point of view on cost variances in terms of element-specific variances. This analysis revealed the need to update the cost estimation tools for specific elements in the company's product portfolio. From a managerial perspective, the work emphasizes the information and procedural requirements of the cost estimation process. Furthermore, the work provides advice on employing alternative cost estimation techniques to balance resource utilization as well as making the process more *lean*.

A new risk category that roots from within the organization was identified and the findings of the thesis suggest that this category should not be a part of the contingency reserve. The internal foreseen risks can be managed with procedural changes. The thesis proposes a stage-gate standardized model for cost estimation, that guides the organization to select an appropriate cost estimation technique corresponding to the stage of project preparation. The findings suggest that the cost estimation process should be followed systematically, and to proceed with the process, all milestone requirements should be met. In addition, the role of the historical information database was deemed central to the quality of the cost estimate, making it imperative to accentuate diligent high-quality reporting and knowledge management practices.

Keywords: Cost estimation, Project cost variance, Cost overruns, Cost deviation, Reducing cost variance, Method for cost estimation, Project management, Cost estimation accuracy, Lean

PREFACE

Writing the Master of Science thesis truly feels like a stepping stone to professional life. The work required every shred of knowledge I acquired as an environmental engineer and a student in industrial engineering and management. The process of writing the thesis, however, revealed how much there is still to learn. As Confucius said: *“I hear, and I forget. I see and I remember. I do and I understand”.* Hence, true learning is yet to begin.

I would like to express my deepest appreciation to Joni and Juhani, and the rest of the steering team and colleagues from the case company, for their guidance and mentoring, and the opportunity to gain invaluable first-hand experience. Special thanks to my colleague and my friend Milena, who brightened up my days. I am also grateful to my supervisors, Teemu Laine and Jari Paranko, for their guidance and feedback and for helping me to see the value in this work. Finally, I thank my husband for his love, patience, and continuous encouragement throughout my studies and the process of writing this thesis.

Tampere, 24 February 2020

Alexandra Valtanen

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LIST OF SYMBOLS AND ABBREVIATIONS

BAC	Budget at completion
BAP	Best available practice
BC	Budget cost
CBR	Case-based reasoning
CPV	Customer perceived value
CRM	Continuous risk management
CV	Cost variance
DoD	Department of Defense
DTC	Design-to-cost
EMV	Expected monetary value
ERP	Enterprise resource planning
EV	Earned value (note: not to be confused with expected value)
EVM	Earned value management
GAO	US Government Accountability Office
KM	Knowledge Management
NASA	National Aeronautics and Space Administration
PERT	Problem evaluation and review technique
RIDM	Risk-informed decision-making
SV	Schedule variance
TC	Triple constraint
TCM	Target cost management
VTC	Value triple constraint
WBS	Work breakdown structure

1. INTRODUCTION

1.1 Theoretical background

The modern industrial environment is characterized by increasing product complexity and a high degree of competitiveness (Hake, 1991). To differentiate from competitors, industrial supplier organizations choose to focus on the customers' needs and shift the focus of their operations towards the customers (Gebauer et al., 2011). The customer-oriented focus of operations entails providing innovative, tailored to the customer needs solutions, which increases the seller's potential to maximize delivered customer value (Abetti, 2002). Delivery of complex customized solutions requires a wide range of internal capabilities as well as management and inter-organizational mobility of these capabilities, which is achievable through adopting a project-based organizational form (Gann and Salter, 2000).

The project-based organizational form allows bringing together a wide variety of solutions by combining different skills within a temporary entity of a project (Whitley, 2006). The organizational capabilities and knowledge in project-based organizations are accumulated through executed projects (Whitley, 2006), and hence it becomes imperative to transform the gained knowledge into explicit form so that it can be transferred and accessed within the organization (Ulonska and Welo, 2014; Nonaka, 1991; Aliaga, 2000). Effective knowledge management practices is one of the sources of organizational competitive advantage (Meso and Smith, 2000). There are, however, challenges associated with project business and achieving project success.

One of the dimensions of assessing a project's success is completing the project within the assigned budget (Atkinson, 1999; Kerzner and Kerzner, 2013, p.43; PMI PMBOK, 2001, p.29; Baratta, 2006; Pinto and Rouhiainen, 2001). Unfortunately, cost overruns are a prevalent and often-times encountered issue that hinders project success (Kerzner and Kerzner, 2013, p.778; Goh and Hall, 2011; Hicks, 1992; Shehu et al., 2014; Kwan and Kang, 2018; Flyvbjerg et al., 2002; Bhargava et al., 2010). Kaplan (1975) states that the actual project costs will rarely be the same as the planned budget costs. Due to project complexity, implying numerous interactions between the elements within a project system, it is challenging to identify the root cause leading to impaired performance (Munier, 2014; Martinsuo, 2011). One of the oftentimes recognized major causes of cost overruns is inadequate planning (Havranek, 2017; Shane et al., 2009; Venkataraman and Pinto, 2008).

Constant cost overruns are a result of cost underestimation and are a threat to the seller's profitability, calling for advanced and enhanced practices of project planning (Chang, 2013; Asiedu and Gu, 1998). Deliberately increasing the cost estimate to compensate for uncertainties is no longer acceptable in the modern customer-centric environment with the purchasing power shifting towards the customer (Nicoletti, 2012, p.2). It is imperative to maximize the customer's perceived value for the customer to decide to invest in a solution as well as the supplier's profit for them to be incentivized to supply the offering (Kotler and Keller, 2012). It follows that overestimating the costs is every bit as dangerous as underestimating the costs, since overestimating may result in lost business opportunities (Akintoye, 1998; Asiedu and Gu, 1998).

Cost variance is a concept used to describe project cost deviations between the planned and the actual costs and describe whether the project spend exceeded the estimated costs. Cost variance is calculated by subtracting the actual costs from the budgeted costs, meaning that the positive cost variance implies cost savings, and negative – cost overruns. Broyles and Lay (1982) discuss that there are favorable and unfavorable cost variances, favorable being the cost savings and unfavorable – cost overruns. However, the cost deviations occur as a result of inadequate planning, and a project can be completed within the assigned budget only if the cost estimate is of a high quality (Shane et al., 2009). Coupled with the implications of the cost overestimation and underestimation, it can be concluded that in the context of project business there are no favorable cost variances, and to sustain the business operations, the seller must be able to produce a high-quality precise cost estimate.

1.2 Objectives and scope

This thesis is a case study research that focuses on the challenges related to cost variances in a project-based case company. The objectives of the thesis were set based on the goals that were set together with the senior sales & technology manager and the rest of the project steering team in the case company, consisting of the product sales manager, project manager, cost estimator, and project controller. The case company recognized that there is a lot of cost variance within projects. The main areas of interest, as well as desired outcomes of the research, consist of identifying why and where do the cost variances occur as well as developing suggestions for the case company that would reduce the project variance.

The literature on the reasons and causes for cost overruns in projects is abundant (Doloi, 2011; Torp and Klakegg, 2016; Flyvbjerg et al., 2002; Jørgensen et al., 2012; Skitmore and Lowe, 1995). The literature also provides methods for managing the uncertainties involved in cost estimation through risk analysis and contingency reserves (Shane et al., 2009; Kwon and Kang, 2018). However, the literature on the topic of reducing cost variance as a result of developing internal organizational processes is limited. The focus of the available literature is mostly on the cost overruns occurring due to external risk events and factors. The implications of the cost deviations in general, being cost overruns and underruns rooted from within the organization and a method for reducing the cost variances are not oftentimes discussed. Thus, the objective of this research is…

"…to develop a method for reducing project cost variance by improving the quality of the cost estimation process in industrial project-based firms".

Other areas of investigation that will support reaching the thesis objective include the investigation of existing accepted project variance limits. Part of the research is aimed at identifying what counts as an accurate enough estimate and what degree of cost variance is acceptable in the context of the project business. Additionally, a large part of the research is dedicated to surveying the best available practices of cost estimation in project-based firms. The objective of the casework consists of identifying the improvement areas in the cost estimation as well as the root causes for project variance.

The scope of the research is limited to the product portfolio and operations of one department within the case company. The scope of the investigation is narrowed down even further, as the case company's goal is to investigate and improve procedures during the sales phase of the project, implying that the research focuses on controllable cost variances. In other words, the cost variances caused by external risks and external factors are not considered, when developing a method for reducing project variance.

1.3 Structure of the thesis

The thesis consists of eight chapters. The current chapter, being the first chapter, serves as an introduction to the theme of the work as well as the definition of the scope and objectives of the research. Chapter 2 concentrates on the research methods and research processes employed throughout the thesis. The second chapter introduces how a practical problem can be interpreted from a theoretical point of view, creating a general theoretical framework solution to the type of problem through interventionist research strategy.

Chapter 3 presents an insight into project business and project management as one of the dimensions of managing project business. The chapter examines value management in the context of project business as well as the project's typical structure and lifecycle. Then, challenges and uncertainties characteristic to projects are outlined to create a common understanding of the uncertainty factors as well as define a separate new risk category of internal foreseen risks that is relevant to this work.

Chapter 4 deals with the concept of cost management in the context of project management. The process of cost incurrence is described alongside the basic principles and guidelines of cost management. Thereafter, the cost estimation process and techniques are reviewed. The chapter contains a survey of practices utilized by project-based organizations and the best available practice guidelines for cost estimation. At last, the chapter overviews budgeting, project control, and in particular cost variance as an integral aspect of project control, since cost variance is the central theme of the case study.

Chapter 5 presents a method for promoting the quality of cost estimation in the context of project business. The method is developed by identifying the challenges involved in cost estimation as well as examining typical causes for cost overruns. The best available practices and surveyed qualities of a good estimate serve as a benchmark to develop a method that incorporates corrective and preventive actions with regard to the identified challenges. In addition, the importance of historical information to the quality of the cost estimate as well as the concept of accuracy boundaries are introduced.

Chapter 6 describes the case company and the challenges that the case company is facing in the area of cost estimation and project variances. The chapter presents how the developed suggestions for improving the quality of cost estimation can be applied to the case company's processes as well as the implication of process changes on the state of the business.

Chapter 7 discusses the results of the intervention in the case company through feedback that was collected from the steering team of the case company. The chapter also discusses how the research objectives were met and brings up the limitations of the research. Additionally, further research needs are identified on a theoretical and practical level.

Chapter 8 is a concluding chapter of the thesis presenting the summary of the theoretical and practical problems and the essence of the improvement suggestion developed throughout the work. The summary also includes an overview of the limitations and further research opportunities.

2. RESEARCH PROCESS

2.1 Research process

The research process began in the autumn of 2019 when the case organization recognized the need for controlling and reducing their project variances through analyzing the root causes of these variances. The researcher became a part of the case company already earlier this summer and was transferred to another department to carry out the thesis work project. The prior company knowledge proved to be instrumental to the researcher, as it took less time to become familiar with the organizational culture and operations and allowed for a more in-depth analysis of the case department.

A senior sales and technology manager in the case organization was concerned with the current project cost variances and hypothesized that there exist areas for improvement in the current processes that will result in the reduction of the variances. The research began with the quantitative analysis of the budgeted and actual costs of two projects that were selected during the first steering group meeting in the case company. However, it was soon understood that the data from the two projects was not sufficient to draw definitive conclusions regarding the root causes of cost variances in the case department. The researcher decided to employ another method of variance analysis, which consists of analyzing variance on the element-specific basis across several projects, rather than on a project-specific basis. With that analysis, the researcher intended to identify patterns and systematic occurrences of cost deviation in specific elements.

Thereafter, it was noticed that the variance analysis cannot be fully relied on, as the cost traceability was challenging. Due to either purposeful or accidental cost misallocation, the variance could not be definitively attributed to specific elements or cost components. Nonetheless, the substantial amount of data obtained from the analysis of 110 projects was deemed reliable enough to identify the improvement areas. The researcher was directly participating in the meetings and observing the cost estimation process throughout their involvement in the case company. In addition to the direct observations, daily communication with the case department's internal stakeholders was a valuable source of information. The qualitative information and surveys regarding the findings helped the researcher to interpret the identified problem.

Through the variance analysis, observation and stakeholder interviews, as well as surveying the internal materials, the researcher identified that there are fundamental process aspects, which need attention. The research shifted towards process analysis, where the researcher investigated whether the cause of project cost variance is rooted within the company's daily operations and activities and whether there is potential to improve these operations. The particular area of interest to this research became the process of cost estimation and the interrelated activities impacting the process of cost estimation in the case company. The process analysis was based on the researcher's observations, communication with the stakeholders and qualitative interviews.

When the problem was identified and interpreted, the researcher began reviewing the literature to find the best available practices related to the main problem of the case company. The review included literature on the processes of cost estimation employed by other organizations, as well as the tools used to produce the estimates. The best available practices served as a basis for creating the theoretical framework for the cost estimation process that promotes quality and knowledge management. The general method was later benchmarked against the case company's processes and methods in order to identify the improvement areas and develop a set of recommendations for the case company.

Later on, the relevance of the results was assessed by presenting the recommendations regarding process improvements to the stakeholders in the case department. The intervention consists of the set of recommendations drawn from the reviewed best available practices compared to the outlined existing practices in the case company. The case company was also presented with supplementary material, such as the proposed structure for the cost estimate report, as well as the detailed quantitative variance analysis on the element specific-basis. The variance analysis reveals the elements and work packages, whose cost estimation methods have the potential to be improved to reduce the final project variance. The research timeline is presented in Table 1.

Table 1. *Research timeline.*

	2019				*2020*	
Action	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**Jan.**	**Feb.**
Gathering understanding of case department	■	■	■			
Analyzing cost data		■	■	■		
Analyzing internal material			■	■	■	
Literature review		■	■	■	■	■
Review of best available practices				■	■	
Building framework					■	■
Observation: participating in meetings		■	■	■	■	■
Observation: engaging in discussions with internal stakeholders			■	■	■	■
Documenting the case part of the thesis			■	■	■	■
Conducting interviews at the case company		■	■	■		■

The focus of the research was shifted two times throughout the research process in the light of other precedent prevalent issues. As the research went on, multiple processes were repeated, supporting the idea of the interventionist research being iterative in nature. Interestingly, while moving forward and more in-depth with the analysis and interpretation, the problem definition was moving towards a more general, rather than a specific level. The iterative process cycles are illustrated in Figure 1.

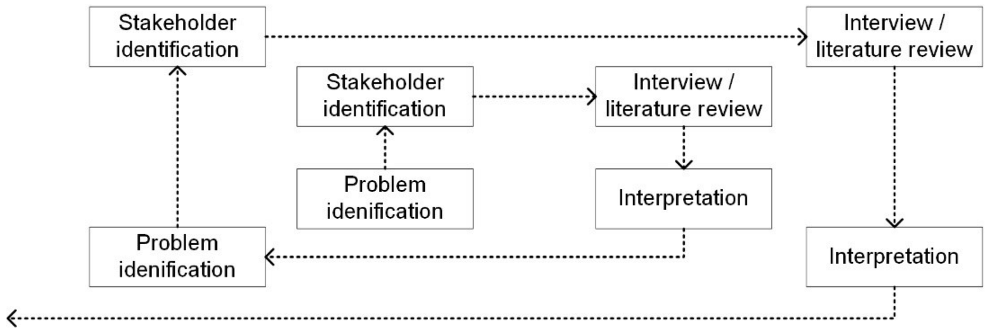

Figure 1. *Iterative research process.*

As the figure demonstrates, four main steps are repeated throughout the research – problem identification, stakeholder identification, interview and/or literature review and interpretation. Problem interpretation relates to identifying its underlying causes, and, in some cases, the identification of the underlying causes resulted in identifying a new problem, which consequently required interpretation. The quantitative variance analysis resulted in the need to investigate the element-specific variances across multiple projects, which in turn revealed the improvement areas in the cost estimation process. It was decided, that before developing an adjustment factor for the cost estimate to compensate for cost deviations, the process is to be improved to observe the effect of process development on the cost variances.

Pulse method was used to track the development of the thesis project. Pulse is a lean management methodology widely used in Sweden, which identifies the process deviations using a whiteboard and colored magnets (Kaya et al., 2014). Kaya et al. (2014) elaborate that the pulse method, besides monitoring the deviation, is a useful practice of deviation management and control throughout frequent meetings aimed at increasing efficiency and transparency of the process. To follow the pulse methodology, a roadmap and a target map were created for the thesis. The thesis target map is presented in Figure 2.

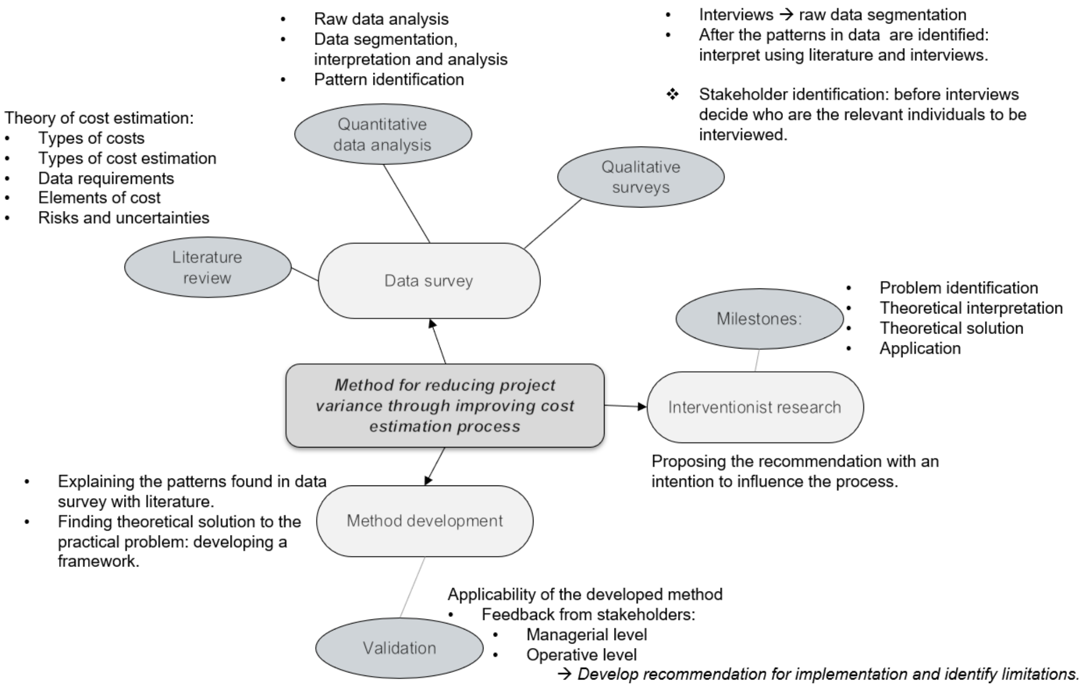

Figure 2. *Thesis target goals.*

Initially, the idea was that the pulse meetings are to be held weekly with the steering group, to facilitate the progress of the research and to generate new ideas. However, when the meetings started to be organized, a multitude of ideas and possible directions for the work started to be presented, which derailed and stalled the process. In the end, the meetings were held only a few times throughout the research process, and sometimes only the case company's cost estimator was present since the focus of the work is on the process of cost estimation. The pulse board was independently used by the researcher as an ideation tool and for individual progress tracking. The pulse board revealed the areas that needed to be concentrated on as well as helped in identifying the next steps and subjects for exploration.

2.2 Research methodology and philosophy

A research 'onion' (Saunders et al., 2009, p.108) is used to describe the construct of the research methods and philosophy employed in this study. The framework covers six layers describing the nature of research: (1) philosophies, (2) approaches, (3) strategies, (4) research choices, (5) time horizons and (6) techniques and procedures.

Research philosophy – the outer layer of the framework, lays the foundation for the assumptions utilized in the research. The oftentimes discussed research philosophies are positivism, realism, interpretivism and pragmatism (Saunders et al., 2009; Eriksson and Kovalainen, 2008; Lancaster, 2005). Pragmatic philosophy is employed in this research, as pragmatism is a combination of methods, where both phenomena and subjective meaning are relevant to knowledge generation and the focus is on integrative perspectives and data collection methods for data interpretation. In addition to the philosophical groundwork, a scientific paradigm of hermeneutics is applicable to describe the qualitative aspects of the research (Gummesson, 1993), as with the qualitative interviews, the researcher was interpreting the quantitative findings.

When it comes to the research approach, this research is inductive rather than deductive in nature. The hypothesis and theories in this research are developed in light of the empirical evidence (Lancaster, 2005). Interestingly, the hypothesis is formed based on the quantitative secondary data as well as past personal experiences of the researcher with the company. The researcher was employed in another business unit of the case company prior to undertaking the thesis worker position. Some elements of the deductive approach are present in the analysis, as the raw financial data needs to be validated and the causal relationships explained. The research can be described as ideographic, rather than nomothetic, as the focus of the study is to explain the empirical evidence and draw recommendations from that evidence (Burrell and Morgan, 1979; Deetz, 1996). Nomothetic research is controlled and structured, such as laboratory studies, in contrast, this research is less structured and it is explanatory in nature (Saunders, 2009).

This study is conducted in a form of a case study, which is defined as an empirical examination of issues that are related to industrial and economic spheres of life with the purpose of producing new knowledge concerning the case or the theoretical foundation of it (Eriksson and Kovalainen, 2010). The case study in the management field does not have to utilize only qualitative data gathering methods; on the contrary, it can benefit from a combination of both – qualitative and quantitative methods (Gummesson, 1993). To increase the credibility of the knowledge generated from the case study, triangulation is employed for data validation purposes. Triangulation possibilities are limited, as the data in the case company has not yet been analyzed from the same perspective, as was chosen by the researcher. One characteristic of this case study is employing a mixture of explanatory and theory generating case types (Gummesson, 1993), as the researcher aims to explore the previously unexplored area, as well as conceptualize the problem and the process. One of the objectives of this research is to generalize the findings to create a common methodology, a multiple case approach is utilized for the purposes of successful generalization. Additionally, the case study can be characterized as embedded rather than holistic, as the study is carried out more in-depth for one department of the case organization (Yin and Campbell, 2003).

The researcher, while conducting a case study, is in nature a consultant. Consultancy research is described by Lancaster (2005) as the provision of external and impartial knowledge, which serves as a piece of advice. Typically, the consultant possesses additional competencies and experience to that of the firm, providing fresh insight on the issue. Other reasons for addressing consultants, besides the need for additional expertise and impartiality, include lack of time and ethical reasons. When it comes to this research, lack of time and the need for a fresh perspective incurred the need for consultancy research. Some limitations of consultancy research include factors such as lack of familiarity with the organization and lack of accountability for results, which are alleviated due to the researcher's previous involvement with the case company as well as a desire for future co-operation. The role of the researcher as a consultant can be described as an intermediate between directive and non-directive, as the researcher raises questions, finds facts and proposes alternative courses of action (Lippitt and Lippitt, 1978). The research from the consultancy point of view is more task-oriented than process-oriented, aiming to provide an interpretation of the problem and further development suggestions (Margulies and Raia, 1972).

The desired outcome for the case organization is to identify the root causes of a practical issue and adopt the methodology developed in the research to tackle the problem of project variances. The researcher, in turn, aims to influence the case organization with the outcome of the study. The outcome of the study is a combination of practical numerical analysis as well as a theoretical method for solving the problem on a general level. The described is in line with a strategy of interventionist research. Suomala and Lyly-Yrjänäinen (2012) state that in interventionist research the researcher becomes actively involved in the case organization and tries to solve the organization's practical problems with the help of theoretical intervention. The results of the interventionist research are then comprised of the practical and theoretical parts, producing a concrete theoretical contribution. As a research method, interventionist research is a variation of action research and involves a combination of multiple methods, which include case study, consultancy, use of existing materials and qualitative interviews. Figure 3 shows a holistic visualization of the researcher's interpretation of the nature of the conducted research.

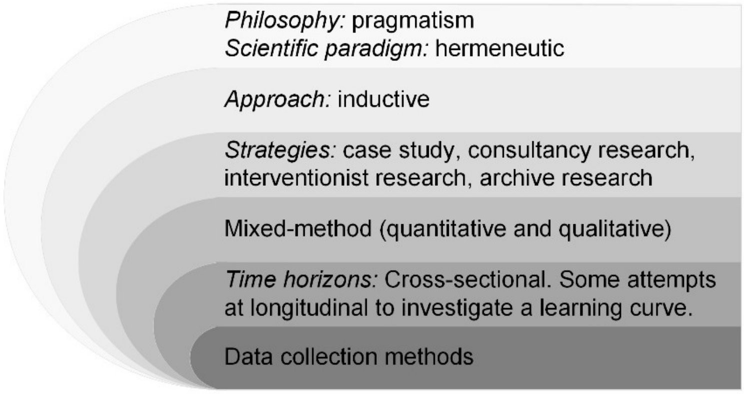

Figure 3. *Research philosophies and approaches in a form of research 'onion' (adapted from Saunders et al., 2009).*

A mixed-method study approach is employed throughout the research as both qualitative and quantitative data collection methods are utilized throughout the work. As was mentioned earlier, data triangulation is applied to validate the findings, however, the triangulation is carried out by confirming the results of the quantitative analysis with the information gathered through qualitative interviews. The data collection methods are further described in the next chapter.

2.3 Data-collection and generation methods

Multiple data-gathering methods were employed in this research. As was discussed, managerial research does not have to be limited only to qualitative data generation methods. On the contrary, Gummesson (1993) argues that both qualitative and quantitative data gathering techniques are applicable, especially when it comes to case study research. Interestingly, it was noticed that compared to the technical research, managerial research needs theoretical grounding throughout the research process since in qualitative research data collection and analysis occur simultaneously (Gummesson, 1993). Intermediate interpretation of the data guides the research process and assists in asking the right questions. The methods are listed in Table 2 and then elaborated on below the table.

Table 2. *Data-collection methods.*

Data-collection method	***Form***
Existing materials	Internal secondary data: internal reports, presentations, publications External secondary data: publications, research articles, similar projects
Qualitative interviews	Structured and semi-structured interviews of the stakeholders in the case company
Quantitative data	Archive research, financial data
Questionnaire surveys	Addressed to the company stakeholders with a purpose of data triangulation
Observation	Interpreting the processes and the organizational culture within the company; being actively involved.
Action science	Interventionist research

The existing materials can be subdivided into internal and external secondary data sources. Secondary data has been defined by Lancaster (2005) as second-hand data that is available usually in abundant quantities, as opposed to the newly collected data. The abundance of second-hand data is a blessing and a curse in the sense that it allows for large-scale comparative analysis, sometimes even longitudinal, at the same time making it difficult to choose the relevant data for the analysis. Internal secondary data is gathered within the organization and within the case department. For example, in the case company project, the researcher was presented with an extensive range of financial data collected over the course of decades and it was up to the researcher to select and organize the relevant data. External secondary data sources include scientific publications and literature related to the topic of research and are available in scientific databases and libraries. The main role of the internal secondary data in this research is problem identification and definition of the research approach. External secondary data, on the other hand, is used for theoretical grounding and interpretation, which is instrumental for generalizing the problem and creating the theoretical framework.

Qualitative interviews are used to obtain more information about the case company, processes within the department and feedback on the intermediate findings throughout the research process to assess the validity and reliability of the output and the data used to generate the output. Quantitative data is employed in the form of archival research and other numerical data obtained from the questionnaire surveys. The questionnaire surveys were typically built to clarify ambiguity through a set of concrete structured questions with limited options. Such questionnaires were valuable, as the perspective of different stakeholders within the case company could be tangibly compared with one another.

Observation, as a research method, is employed informally. Through observing the case company's culture and daily interactions, the researcher is able to identify some limitations caused by the human factor in the process of cost estimation during the sales phase. The results obtained from observation are challenging to translate into generalized objective findings. Although, without observation as a research method, action science in the form of interventionist research would not be possible. The essence of action science is for the researcher to be able to integrate into an organization, become actively involved in the processes and induce change throughout the research process (Gummesson, 1993). As a form of action science, interventionist research allows the researcher to produce practically and theoretically relevant results (Jönsson and Lukka, 2007).

3. PROJECT BUSINESS AND ORGANIZATION

3.1 Project business and value management

There exist various definitions of a project (PRINCE2, 2017; Artto et.al., 2011; Healy, 1998) and all of the variations emphasize that projects are temporary entities with a defined beginning and end, which aim at delivering value to customers within an agreed time frame and budget according to the quality requirements. In addition to that, projects are unique entities and their deliverables are unique in each situation. Project business can be described as a part of a firm's activities that rely on projects in order to achieve organizational objectives (Artto et al., 2011). When talking about project business and project management, there exist different contexts worth investigating. The management areas of the project business are presented in Figure 4.

	Single company	*Several companies*
Single project	Project management	Managing project network
Multiple projects	Managing a project-based firm	Managing a business network

Figure 4. *Contexts of managing projects (adapted from Artto and Kujala, 2008).*

As the figure illustrates, project management refers to managing a specific project within a firm. Managing a project-based firm implies managing several projects within a single company. Managing project network refers to managing a single project across multiple companies and managing a business network is concerned with managing multiple projects across several organizations. This thesis work investigates projects in the contexts of project management and managing a project-based firm.

Project management is defined as an application of skills, tools, and knowledge in order to achieve stakeholders' objectives and expectations throughout the project's lifecycle (Pinto and Rouhiainen, 2001). When it comes to project management, success is measured in terms of achieving project objectives. According to the guidelines developed by the Project Management Institute, a successful project is completed within schedule and cost baselines as well as with high technology and quality level (Kerzner and Kerzner, 2013). Additionally, a successful project, in the end, will be accepted by the customer. The essence of project management and project success is traditionally measured with the help of three project objectives: scope, time and cost, which are also known as the classical triple constraint (PMI PMBOK, 2001, p. 29). Project scope refers to the deliverables and the tasks associated with project execution, which are agreed upon between the supplier and the customer. Project time refers to a schedule established for the delivery of the goods, services or other offerings specified in scope. Finally, cost refers to the number of resources budgeted to create and deliver the value to customers.

However, the classical triple constraint has been criticized as a framework for evaluating projects' success (Baratta, 2006). Baratta (2006) proposes a concept of the value triple constraint (VTC), where the idea is to represent value as a function of capability and technology. The scope is a variable that remains unchanged, while time is translated into capability and cost – into value. Capability, instead of the time or schedule as a variable depicts a company's value-adding processes, which can also be interpreted in terms of efficiency and schedule management. Cost is a measure of expenditure required for project completion, such as raw materials and labor. Value measures the benefits created by the project for the customer and for the seller themselves. Interestingly, value and cost management are tightly linked in the project business.

Pinto and Rouhiainen (2001) discuss another variation of the triple constraint model – a quadruple constraint, where the success of the project is evaluated by four parameters: budget, schedule, performance and customer acceptance. This model emphasizes customer satisfaction as a determinant of the project's success, which responds to the customer-centric orientation of the modern B2B environment. The three models of project management constraints that are proposed to be used to evaluate a project's success are presented in Figure 5.

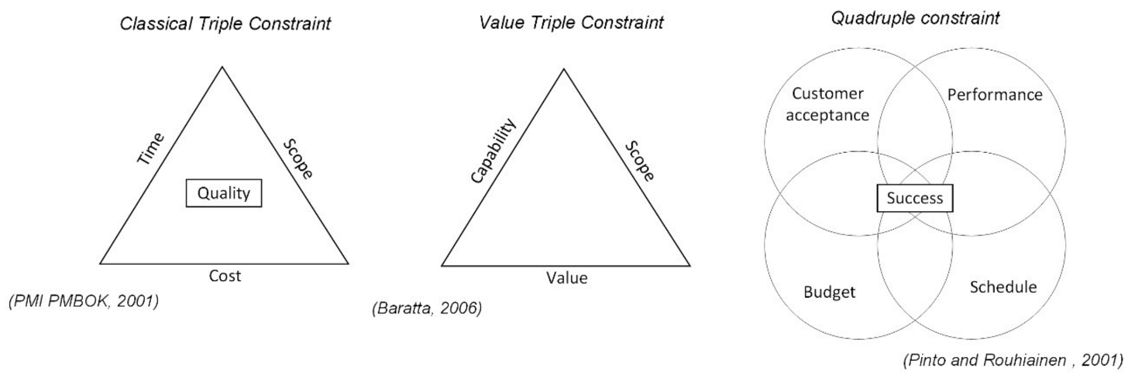

Figure 5. *Project management constraints.*

There exist other variations of the triple constraint framework that are used to assess the success of a project, such as the six constraints model (Siegelaub, 2007). Atkinson (1999) discusses a version of triple constraint called the Iron Triangle, where the vertices of the triangle correspond to cost, time and quality parameters. Despite the abundance of the models, all of them emphasize, that the cost and schedule boundaries are essential in measuring project success. Additionally, in order to retain customers and achieve customer satisfaction, organizations should emphasize cost and schedule efficiency throughout the value delivery process.

With the shift towards the customer-centric process orientation, comes a shift in the notion of value management. Nowadays, manufacturers strive to demonstrate the customer value that their products provide instead of a conventional emphasis on functionality and technological attributes (Jääskeläinen and Heikkilä, 2019). Only when the offering's benefits become apparent to the customer, they will contemplate about making the purchase. These perceived benefits are called customer perceived value (CPV) and it is described as a difference between the total customer benefit and the total customer cost (Kotler and Keller, 2012). The supplier's profit is the difference between the total customer cost and total supplier cost. The afore-discussed concepts are illustrated in Figure 6.

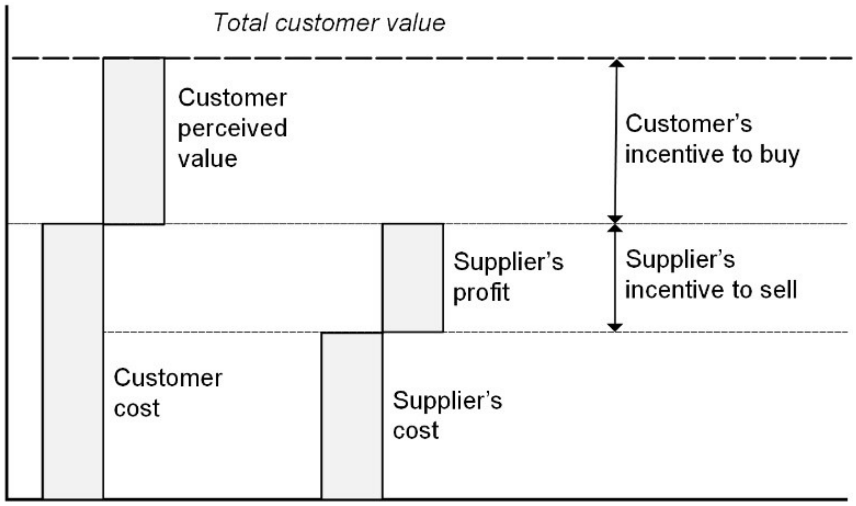

Figure 6. *Customer perceived value and supplier's profit (adapted from Kotler and Keller, 2012, and Töytäri et al., 2011).*

The figure demonstrates the CPV and supplier's profit as the determinants of the customer's incentive to buy and the supplier's incentive to sell. For a successful transaction, both incentives should be in balance. The figure also reflects the dynamics of the relationship between value and cost, in a sense that a shift in any of the variables shown in the figure will affect the balance between the customer's and supplier's incentives to participate in the deal. It follows, that for a successful sale deal to occur, the customer should be convinced that they are getting enough value for the price, and the supplier should be getting enough profit to cover the cost of their operations and make the target profit. In this scenario, it is not an option to increase the selling price to reach the target profit. The supplier should aim at cost savings through improved quality and efficient processes (Nicoletti, 2012, p.2). Managing value throughout the project, combined with managing costs establishes a fundament for successful project completion (Venkataraman and Pinto, 2008).

3.2 Project lifecycle and structure

A project is a temporary entity oriented at producing and delivering a unique product or service to the customer (PMI PMBOK, 2001). Other characteristics of project business are defined by the nature of projects – they are finite with a clearly established beginning and end date, must be completed within the agreed time frame and within the allocated budget (Kerzner and Kerzner, 2013; Artto et al., 2011). The project lifecycle can be viewed from the perspectives of the supplier and of the customer. From the customer's point of view, projects are termed as investment projects, and from the supplier's point of view – delivery project. In this work, the projects are perceived rather from the supplier's point of view, although, in customer-centric organizations, the investment and delivery projects tend to mirror each other (Venkataraman and Pinto, 2008). The project's lifecycle is schematically represented in Figure 7.

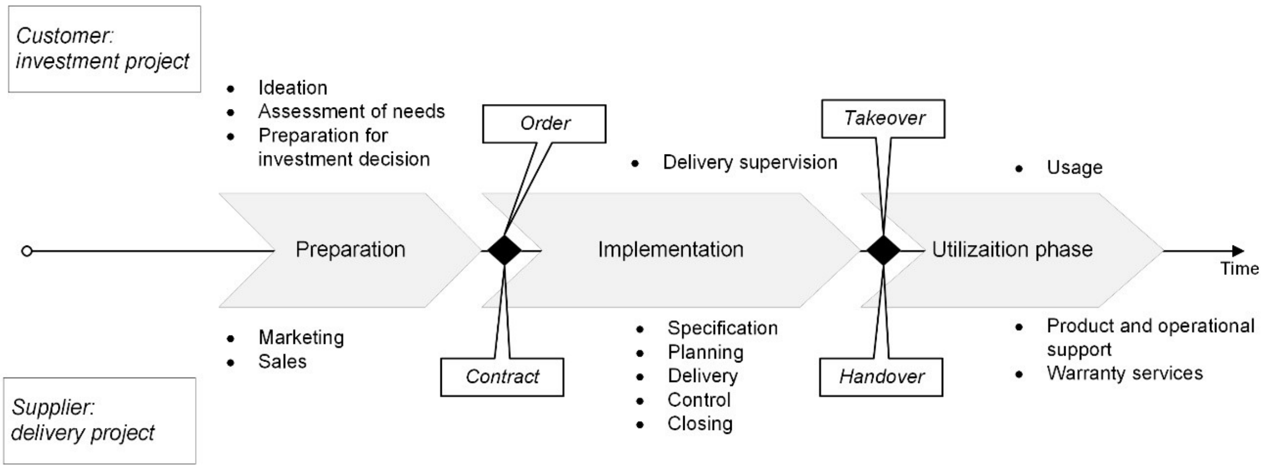

Figure 7. *Project lifecycle.*

The lifecycle can be subdivided into three general categories: preparation, implementation and utilization phase (Kerzner and Kerzner, 2013; Artto et al., 2011; Venkataraman and Pinto, 2008). The terms may differ source by source, but the category descriptions remain consistent. Kerzner and Kerzner (2013) discuss the sub-categories of the project preparation phase and identify four partitions: strategic, conceptual, planning and design phases. From the supplier's perspective, the sales and marketing efforts occur during the pre-contractual phase, placing the cost estimation and budgeting processes on the same timeline. While the supplier is carrying out the sales efforts, the customer is preparing for a decision to invest. Cost estimation and budgeting happen during the preparation phase of the project lifecycle; hence, the project preparation phase is the main focus of this thesis work. Nevertheless, a delivery project as a whole is to be considered, since the cost and schedule variances become apparent only as the project is being implemented, thus, the project implementation phase is of some relevance to this work.

Figure 7 shows one perspective to view a project – as a phased process. Taking into account the definition of a project, the entity may be viewed in terms of product or work breakdown structure. The concept of work breakdown structure (WBS) was introduced by the US Department of Defense (DoD) in the 1960s and NASA for the purpose of effective control of large projects (Norman et al., 2008). NASA (2018) states that WBS defines the work that needs to be completed throughout the project as well as enhances the understanding of the project's objectives, scope, and deliverables. Additionally, WBS is said to provide guidelines for the internal organization and communication needed for the successful achievement of project objectives. Work breakdown structure is available at different levels of detail, providing an opportunity to plan and evaluate the project's performance in terms of technical requirements, schedule and costs (NASA, 2018), which are coincidentally the three project objectives according to the classic triple constraint. Thus, WBS is a key element when it comes to project planning and execution (Norman et al., 2008).

Work breakdown structure is a hierarchy of work tasks, which are typically subdivided into up to four layers. PMI PMBOK (2017) describes WBS as a task-oriented tree of activities with a deliverable-oriented decomposition of work into work packages. According to PMI (2006), one of the core principles of a WBS is 100% rule, which states that the work breakdown structure should represent an entire scope of the deliverables, them being internal, external or of another type. In the context of project business, the first WBS level is typically a headline of the project. The second level represents major work elements, either physical or functional (Stewart and Wyskida, 1987), which are the major work packages. The third level of the WBS is comprised of minor subdivisions or activities followed by the fourth layer of specific tasks. It is rare that organizational WBS extends to more than 4 levels (Stewart and Wyskida, 1987), however, NASA's handbook of WBS (2006) illustrates a seven-level WBS. An example of a WBS is illustrated in Figure 8.

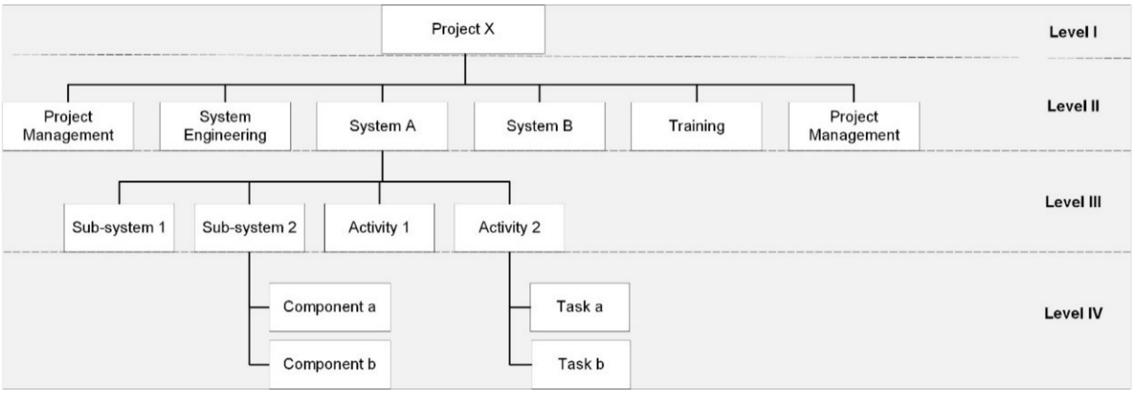

Figure 8. *An example four-level WBS.*

The figure demonstrates a visual scheme of the work packages and activities, although, often in a project, WBS takes a form of a table or a list with multiple levels since it may be difficult to encompass all the information into the visual scheme. Constructing a WBS is an iterative process, as more and more details are specified throughout the project planning stage. PMI (2006) emphasizes that for consistency within an organization, there should exist a WBS standard or a WBS template for the business units to be followed. The standards, however, must be adjustable to fit the scope of deliverables specific to each unit in order to eliminate unnecessary work and to include the entire scope of deliverables according to the 100% rule.

As was mentioned before, WBS can be used in project control. Cost account structure and cost itemization are the concepts used in accounting and project control. Cost accounts are represented at the second level of the WBS and represent the resources needed for executing a group of work packages. Cost items and work packages are illustrated in the lower levels of WBS and are more detailed and specified than the cost accounts according to the logic of hierarchy employed in WBS. Work breakdown structure's functionality is not bound strictly to cost estimation, resource forecasting and allocation, and responsibility division. If used effectively and extensively, WBS is instrumental in quality control as well as risk management and planning. A risk breakdown structure (RBS) can be created based on the WBS to identify and manage the risks involved in each of the work packages (Hillson, 2002). NASA (2018) confirms that WBS is instrumental in risk management as WBS provides a uniform consistent structure for documenting, managing, tracking and communicating the project risks.

3.3 Project risks and uncertainties

Project risk is defined as an event that, if occurs, will have consequences on the project's success in terms of achieving one or more project objectives (PMI PMBOK, 2001;

PRINCE2, 2017). The impact does not have to be negative – oftentimes, risks are undertaken to realize opportunities, even though it is acknowledged that in the worst-case scenario the impact on the project objectives will be of a negative nature.

The general process of risk management consists of four stages: (1) risk identification, (2) assessment, (3) response planning and (4) implementation (PMI PMBOK, 2001; Artto et al., 2011). However, NASA (2011) states that these steps are characteristic of risk-informed decision making (RIDM), which is merely one of the constituents of a risk management practice. NASA (2011) identifies that an effective risk management practice consists of RIDM as well as continuous risk management (CRM).

CRM is a cyclical process aimed at producing a comprehensive overview of the impact of individual risk events on the entirety of the project and the project's performance. The steps in CRM are (1) identify, (2) analyze, (3) plan, (4) track, (5) control, and (6) communicate and document. The first step to risk management, whether it is RIDM or CRM, is to identify the risks. The risks are subdivided into categories, which enables a more systematic identification and consecutively analysis of those risks. Some of the commonly discussed risk categories are listed in Table 3.

Table 3. *Example risk categories*

Risk category	*Example*	*Source*
Pure risks	Insurable damages, losses, etc.	*Munier, 2014* *Artto et al., 2011* *Martinsuo, 2011* *Roger and Petch,1999*
Financial risks	Risks associated with financial agreements, currency rates, and financial institutions.	
Business risks	Associated with project work – scope changes, delays, weather, lack of information, conflicts, performance issues.	
Political and country risk	Geographical risks, country-specific risks.	
Technical, performance or quality risks	The newness of the technology, unrealistic performance goals, industry or technology standard change throughout the project.	*Munier, 2014* *PMI PMBOK, 2001* *Roger and Petch, 1999*
Project management risks	Inadequate resource planning, scheduling, a poor project plan.	
Organizational risks	No project prioritization, conflicting project objectives, resource conflicts among projects within an organization.	
External risks	Statutory changes, labor issues, country risk, weather, disasters.	

As can be noticed from the table the two classifications cover the same aspects, even though the names of the risk categories and the bundles of specific risks within the categories differ. As the scope of this work concentrates on suggesting improvements to the foreseen risks that originate from within the organization itself, the unforeseen and external risks are not considered in this work. In other words, project management risks and organizational risks (PMI PMBOK, 2001) are further considered in this work. Additionally, the foreseen risks in the business risks category (Martinsuo, 2011; Artto et al., 2011). The business risks originating from the organization itself are lack of information and performance issues, and they are considered relevant to this work. The individual risks that originate from within the organization are considered in this work and are illustrated in Figure 9. These risks are bundled into their own category and classified in this research as internal foreseen risks.

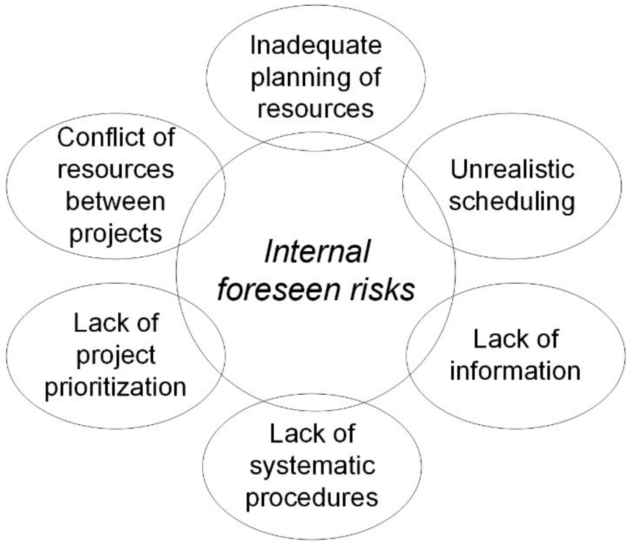

Figure 9. *Internal foreseen risks*

The figure shows the risks that the researcher identified as the key internal to the organization risks, which negatively affect the achievement of project objectives resulting in cost overruns. The internal foreseen risks are controllable since they originate from within the organization and it is within the firm's power to avoid the risks by adjusting own operations. It is noteworthy, that the risk management guidelines for the internal foreseen risks consist of procedural improvement.

The cost overruns are a manifestation of schedule delays, compromising quality and, naturally, exceeding the budget, hence it is safe to claim that in the context of project business cost overruns are a manifestation of risk embodiment. Assessing and evaluating project-specific risks is not straightforward even in the case of foreseen risks due to the lack of information, complete awareness of the project setting and project complexity. This uncertainty in the form of a lack of information and awareness may lead to unrealistic planning and unrealistic expectations from the execution team (Munier, 2014, p.2).

Project complexity is defined as the multitudes of interaction between the elements of the project, which spontaneously organize and reorganize over time, making it difficult to predict an outcome of a single impact on the system (Dao et al., 2016; Martinsuo, 2011). The complexity may indicate that the risks are interconnected and the realization of one risk may trigger some of the others. This may occur, for example, if the supplier is late to deliver a component, which results in schedule delay and idle equipment, consecutively resulting in cost overruns. Despite the complex interdependency of the elements within a project, the risk analysis is carried out in isolation with respect to each of the elements according to work breakdown structure or similar (PMI PMBOK, 2001).

The risk response strategies vary based on the probability and the severity of the risk. The four typically discussed risk response methods are risk acceptance, avoidance, mitigation and transfer (Munier, 2014). Risk acceptance implies recognizing the risk and electing to bear the consequences of it. Avoiding the risk entails the elimination of the root causes of the risk. Mitigating risks involves reducing the probability or the severity of the identified risk. Risk transfer means sharing the risk with some other party, for example, through contractual terms. After the risks have been identified and assessed, the planning of responses can be initiated and, as in case of the risks materializing, the execution of the risk response plans takes place.

Project uncertainties differ from the project risks, even though the terms might sometimes be used interchangeably. Roger and Petch (1999) define uncertainty as the “range or number of values existing for a particular quantity”. From that definition, it follows that risk, in turn, is “a possibility of a gain or a loss as a result of uncertainty” (Roger and Petch, 1999). According to Kähkönen and Artto (2008, in Martinsuo, 2011), project uncertainties can be subdivided into three categories: business, budget, and technology. Business uncertainties are related to the managerial decisions and strategy and formation of the business case. Budget uncertainties entail estimating and understanding project costs and committing costs, which is challenging during the planning phase of the project life-cycle since the complete information is not yet available at that stage. Technical uncertainties originate from the resources and activities that are needed to execute the planned scope. In this work, uncertainties will be treated as precursors of risk, according to the definition.

4. COST MANAGEMENT IN A PROJECT

4.1 Cost classification and cost incurrence

To understand the cost management process, types of costs, and cost incurrence and commitment processes within an organization are to be explored. The costs within a project can be classified into several categories, such as fixed and variable costs, direct and indirect costs, and recurring and nonrecurring costs. First, fixed costs are the costs that will incur over a period of time regardless of labor hours or product units manufactured. Variable costs, in turn, depend on the level of activity, such as the manufactured volume and labor intensity (Shuford in Stewart and Wyskida, 1987). The fixed cost component includes, for example, rent of the facilities and cleaning staff wages. Variable costs in manufacturing typically include raw materials and wages. As the production volume grows, variable costs, which are usually proportional to the increase in activity level, are distributed over the same amount of fixed costs, resulting in a cheaper cost of goods sold per unit – a phenomenon called economies of scale. Realistically, the variable costs will not exactly grow proportionally, as, in the B2B sector, manufacturers are often able to negotiate volume discounts.

While fixed and variable costs are used to analyze cost behavior, direct and indirect costs are instrumental when it comes to cost traceability and estimation (Bhimani et al., 2019). Direct costs are the costs that can be clearly attributed to the manufacturing cost of a product, such as raw materials, labor, and cost of equipment. Indirect costs, on the other hand, are the costs that cannot be directly traced and attributed as a manufacturing cost for a specific cost object, such as administrative and managerial wages, distribution costs and cost of indirect materials, such as lubricant for the machinery (Adithan, 2007). Recurring and nonrecurring costs are used to differentiate between repeatedly incurring costs throughout the project and one-time transactions (Venkataraman and Pinto, 2008). Recurring costs are, for example, salaries and wages and materials. Examples of nonrecurring costs include license fees and training.

The terminology of various cost types and classification is instrumental when it comes to pricing the offering and tracking costs throughout the project. To price an offering, the indirect costs should be allocated to the direct costs in order to cover the total cost of a product. Besides covering the expenses, an enterprise desires to make a profit for the goods they sell. It is important to clarify the difference between price and cost. Depending on the costing system that the company uses, the total of an offering may be represented as a sum of direct and indirect material costs, labor costs, direct and overhead expenses (Kesavan et al., 2009). The selling price of a product is then computed by adding a profit margin on top of the total cost of the product. This methodology is known as contribution costing, where all the indirect expenses are allocated equally among the produced goods. Some costing systems make use of a notion of overhead costs to allocate the indirect fixed expenses to a product in proportion to the direct costs associated with the specific product (Chang, 2013). Other costing systems allocate costs using cost drivers.

A cost driver is any part or factor that generates costs (Bhimani et al., 2019). Numerous cost drivers can be defined depending on the activity of a business unit or an organization. For example, in logistics, cost drivers may include a number of packages distributed, a number of trucks ordered, the weight of the product distributed and so on. It is vital to select an appropriate cost driver that reflects the business operation closely. For instance, if the company's portfolio includes products ranging by weight from 500 grams to 200 kilograms, such as house appliance manufacturers, it may be wise to select the weight of the product as a cost driver. On the other hand, for a clothes wholesaler, the number of packages distributed would be a more appropriate cost driver.

Understanding various cost types is a part of project cost management alongside the internal process of cost commitment and incurrence within an organization. Within an organization in a B2B context, the process of cost incurrence may differ from the common understanding of the equivalent in a B2C context. In industrial B2B firms purchasing decisions are never spontaneous and have to be approved by management. It follows, that the cost incurrence is in its nature a process rather than a singular event. An example of cost incurrence process described by Tanaka et al. (1993) is illustrated in Figure 10.

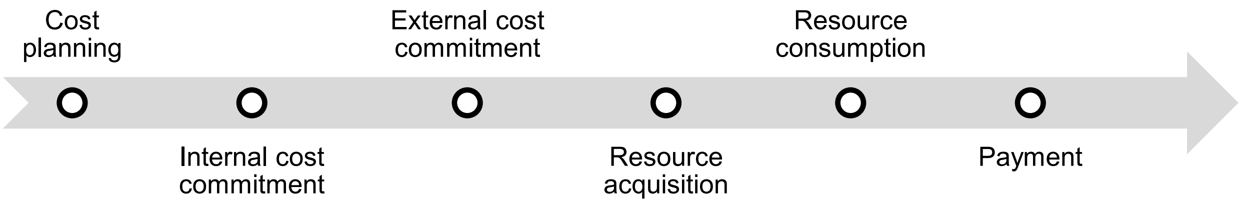

Figure 10. *Cost incurrence process (Tanaka et al., 1993).*

As the figure demonstrates, organizational cost incurrence is a process with several intermediate steps. First, cost planning is concerned with the general development of the cost structure of the company based on the available internal capabilities and resources. During the cost planning stage, it is decided how the company is going to deliver value to the customers and turn their payments into profits for the organization. Cost planning is crucial to a successful business model of the firm, as the relative importance of decisions influencing costs is the highest during the cost planning phase of the cost incurrence process (Tanaka et al., 1993). As the project progresses, it becomes more costly and difficult to modify the process design and the cost structure of established operations, hence proper cost planning is an essential part of the organizational activity (Venkataraman and Pinto, 2008; Kesavan et al., 2009; Rush and Roy, 2000). The relationship between the stage of the project's lifecycle and the importance of decisions influencing costs is shown in Figure 11.

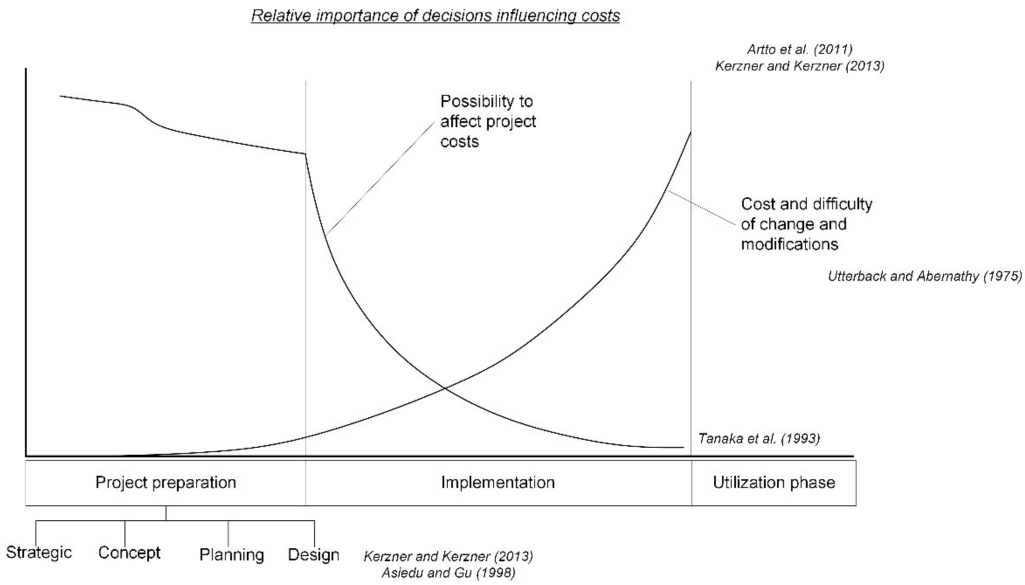

Figure 11. *Relative importance of decisions influencing costs.*

The figure demonstrates that overall there is a greater possibility to affect the total project cost before project execution begins. Additionally, the later into the project, the harder and more costly it is to implement changes into the project scope. Taking the cost of change into account, one of the most severe consequences in terms of cost overruns is caused by changes in the project's scope during the project execution. The cost overruns will be discussed more thoroughly in the next chapter of the thesis.

The next stages of cost incurrence process identified by Tanaka et al. (1993) are internal and external cost commitment. Internal cost commitment is a bureaucratic process of authorizing the budget and expenditures of a specific project. This is often done as a part of the project preparation phase, specifically during the audits occurring throughout the sales process. During the audits, it is determined whether the organization should proceed with the project at hand, typically referred to as a go/no-go decision (Bragg, 2007). External cost commitment takes place when the organization makes orders and contracts with the chosen suppliers and contractors. External cost commitment is the stage, after which the cost incurrence process cannot be reversed. In the early stages of the project, the largest share of the cost commitment occurs – about 70 to 80 % of the total project costs are committed during the conceptualization and planning stages (Stewart et al., 1986; Rush and Roy, 2000). The extensive cost commitment at the early stages of the project lifecycle is the reason for the difficulties and high costs of change later on in the project.

Resource acquisition is associated with the physical receipt of the resources ordered or contracted during the external cost commitment phase. Resource consumption, subsequently, involves the utilization of the resources received or contracted during the resource acquisition phase. The resource does not have to be physical, it may also be in a form of external expertise or capacity. The last stage of the cost incurring process is the one carrying a concrete economic impact on the organization – physical payment. The payment schedule and plan are specified in the contract between the supplier and the customer. In projects, the payment plan is usually distributed over several stages, including advance payment, milestone payments, and the final payment after the project is accepted by the customer. The payment plans may vary based on the company policy and the nature of the projects. Figure 12 schematically represents the relationship between the cost commitment and cost incurrence process.

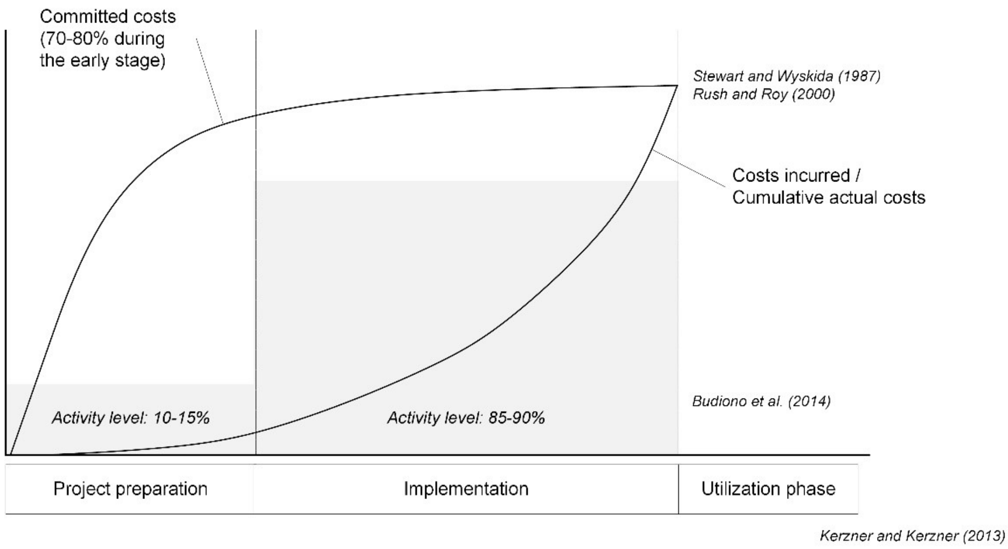

Figure 12. *Committed and actual costs throughout the project lifecycle.*

The figure shows that most costs are committed in the preparation phase of the project, while most of the costs are incurred over the project executing phase. The cost incurrence intensity can be partially explained by the activity level throughout the project lifecycle. In industrial and manufacturing projects, the activity level is the highest during the project execution phase, reaching 85 to 90% (Budiono et al., 2014). The figure additionally demonstrates that the cost incurrence within an organization is a process, rather than a singular event, and some stages of the process may take place simultaneously and recurrently throughout a project's lifecycle.

4.2 Basics of cost management

Cost management is an integral part of any project and it consists of the variables allowing the organization to ensure that the project is going to be completed within the desired financial targets (Parviz, 2002; Kerzner and Kerzner, 2013, p.7). Tanaka et al. (1993 p.13) describe cost management as a set of activities and decisions that improve the cost-efficiency of the organization. Some cost management operations are executed not only throughout a projects' lifecycle but additionally throughout the whole life span of the organization (Tanaka et al., 1993). Thus, cost management can be titled a continuous development process. The essential components of the cost management practice include resource planning, cost estimation, budgeting and cost control (PMI PMBOK, 2001), although, depending on the business peculiarities some additional functional elements can be observed. The components of the project cost management are shown in Figure 13.

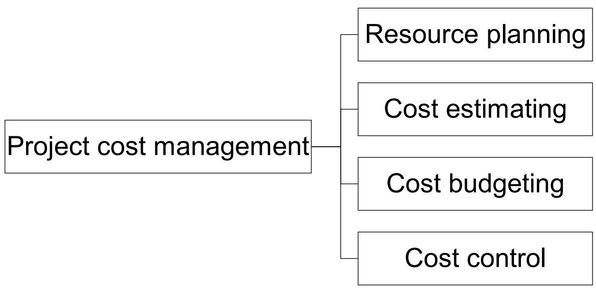

Figure 13. *Project cost management.*

Resource planning is a necessary component for cost management (PRINCE2, 2017, p.95-105). The aim of resource planning is to identify the resource requirements necessary for successful project delivery. To attain the resource requirements, several informational inputs are required – WBS, historical information, organizational policies, scope, resource pool and duration estimates (PMI PMBOK, 2001). Cost estimating produces a quantitative estimation of costs, which is used in pricing, bidding, and negotiations during the preparation phase of the project. The required inputs for a successful cost estimate, according to PMI PMBOK (2001) are WBS, resource requirement, resource rates (i.e. hourly wage), activity durations, historical data, risk identification, and clearly defined cost account structure.

Cost budgeting is the process of allocation of the cost estimates to specific activities or work packages, with the aim of establishing a cost baseline for a project (PMI PMBOK, 2001). In order to generate a successful cost baseline, individual cost estimates, WBS, schedule and risk management plan need to be available. Cost control is a practice of identifying and managing changes in the identified cost baseline (Taylor, 2007). Cost baseline, performance reports, and change reports and requests are necessary in order to carry out the control phase successfully. The results of cost control are manifested as revised cost estimates and budgets, lessons for future budgeting and cost estimation, corrective actions and successful project closing in terms of required documentation and reports. As can be noticed from the above-listed, all the elements of cost management are interconnected.

Remarkably, throughout the cost management literature, many authors and researchers emphasize the importance of readily-available relevant and reliable cost information for effective cost management (Tanaka et al., 1993; Stewart and Wyskida, 1987; Parviz, 2002, Venkataraman and Pinto, 2008; Artto et al., 2011). Additionally, it is emphasized that in order to be effective, cost management should be supported by all parts of the organization and be treated more like a policy to achieve standardization.

The goal of cost management is to reach the project objective together with the acceptable quality level within the established cost baseline. Parviz (2002) concludes that in order for the cost management process to be effective, it needs to be formalized and standardized as well as integrated with each function across the company. When effective, cost management enables tracing and tracking the performance of the project and analyzing the impacts of schedule and cost deviations on the success of the project completion. Additionally, Stewart and Wyskida (1987) emphasize the importance of cost analysis as a part of cost management practice, as the processed information and the lessons learned from the previous projects form a valuable fundament for future cost estimation and budgeting in a form of historical data.

Tanaka et al. (1993) define other requirements for effective cost management, such as timely product plans, aiming at generating profits, availability of cost to show the sources of profit and availability of relevant cost information and capabilities at the preparation stage. Artto et al. (2011) state that cost management practices follow the whole duration of a project's lifecycle to assess final profitability. Additionally, the researchers emphasize that cost management is an integral part of project management, meaning that it is affiliated with the other operations and processes that affect the revenue, such as resource and schedule management.

One example of a cost management strategy is target cost management, which is also considered a technology or product management strategy (Tanaka et al., 1993, p.35). Target costing originated in Japan as a measure to battle challenging market conditions and fierce competition (Angéniol et al., 2005). Target cost management (TCM) is used to attain an estimation and manage the costs over the entire product's lifecycle, keeping the offering competitive in the market. Target costing is a reverse costing method, which allows eliminating non-value adding activities to reduce the production costs and allows the product to enter the production phase only when the lifecycle cost of the product is lower than the estimated target cost (Gonçalves et al., 2018).

Another cost management strategy that is quite often brought up in conjunction with the target cost management is a design-to-cost (DTC) strategy. DTC is a product development strategy that emphasizes the design's convergence on costs, in other words, costs are considered as a parameter in design instead of being a target to reach (Angéniol et al., 2005). This strategy was invented by the American Department of Defense as an attempt to alleviate the constant cost overruns. With that technique, the cost is treated as an economic internal constraint, allowing for a more efficient cost control over the planning and design stages of production (Tanaka et al., 1993). The difference between the TCM and DTC is that the cost is considered from the external perspective in TCM while acting as an internal determinant in DTC.

4.3 Cost estimation

The International Cost Estimating & Analysis Association defines cost estimation as a process of collecting and analyzing historical data and using that data to estimate future costs of deliverables with the help of quantitative models. Cost estimation is a forecasting technique, in contrast to cost analysis, which is based on organizing and processing historical data (Stewart and Wyskida, 1987, p.1). A successful cost estimate can be effectively used in bidding, negotiations, cost tracking, and cost analysis.

The information requirement of the cost estimation process can be broken down into two categories: historical data and organizational operations. Historical data may include any archival data in a form of previous cost estimates or statistics, as well as published reports about similar work either from within the organization or external sources. Few companies, besides public organizations, disclose their cost structure and detailed financial figures, so obtaining the information from external sources may not always be possible. As an alternative, some scientific and research publications can be followed to trace the best available practices regarding cost estimation in a specific industry.

In a sense, without cost analysis, cost estimation would not be possible. Simply storing the data is insufficient for the purpose of effective cost estimation. Indeed, the literature confirms that as a best practice for cost estimation, the data should be analyzed, reported and systematically archived for the ease of retrieval and interpretation (PMI PMBOK, 2001; Stewart and Wyskida, 1987; Dagostino and Peterson, 2011). Interestingly, when it comes to archives in public and industrial organizations, usually the ones in public organizations are more traceable and more systematic in contrast to those kept by industrial organizations (Stenberg and Rajan, 2016).

There are a variety of identified requirements for cost estimation available in the existing literature. According to Stewart and Wyskida (1987, p.2), the required inputs for computation of a successful cost estimate are (1) information, (2) method, (3) plan for the estimate and (4) a set of necessary skills. The researchers identify twelve steps of cost estimation according to the previously mentioned requirements. The steps of cost estimating according to Stewart and Wyskida (1987) are shown in Figure 14.

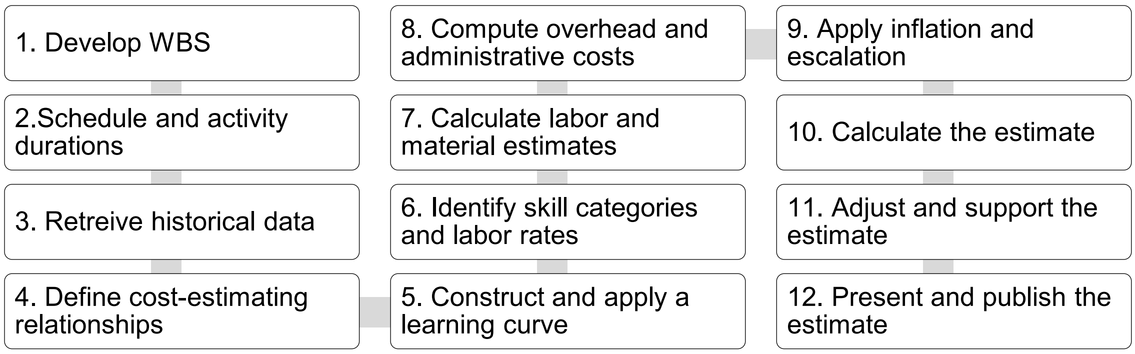

Figure 14. *Cost estimation process according to Stewart and Wyskida (1987).*

The process of cost estimation illustrated in the figure emphasizes the information requirements and supplementary actions in the form of adjusting and supporting the estimate as well as publishing the estimate for effective further utilization. Cost estimate adjustment is an iterative process and is based on recalculating the estimate due to the availability of new information or technical specifications. Additionally, the estimate adjustment is used in design-to-cost (DTC) cost management, meaning that the cost estimate, as well as the product design, are iterated to meet the target cost requirement. At the end of the cost estimating process, the estimate together with all the assumptions and relevant remarks should be recorded and presented for the purpose of organizational learning and process enhancement. Stewart and Wyskida (1987, p.40) propose a structure for a cost estimate report, which is shown in Table 4. A well-reported cost estimate information is invaluable as a part of future sales cases acting as reference material for analogous projects.

Table 4. *Contents of the published cost estimate (Stewart and Wyskida, 1987).*

	Title	***Content***
I	Introduction	Case with background information, date
II	Specifics	Ground rules and assumptions
III	Description of the work activity	Schedule, specification, quantities, location and other applicable factors
IV	Detailed cost breakdown	By work element, by cost element, by schedule element
V	Summary of the estimate	-
VI	Pricing factors	Labor rates including skill categories, inflation rates, material prices, overhead, SG&A costs, fee rates
VII	Estimating team details	Names and contact information
VIII	Rationale	Material backing up the cost estimate: an explanation of reasoning.

The table shows that the researchers identify eight sections as a guideline for a decent cost estimate report. The sections include an introduction, ground rules, and assumptions, description of work, cost breakdown, summary, pricing factors, estimating team details and rationale. The researchers emphasize, that the enlisted content is just a recommendation and a successful cost estimate should include as many case-specific details as possible. It is noteworthy, that the authors emphasize the need for clarity of the report, as it must be accessed and understood by the management and sales staff as well as those, who typically carry out the cost estimation tasks.

Other literature sources provide further variations of cost estimation procedures. For example, the Project Management Institute in their guidelines subdivides the process of cost estimation into three constituents – inputs, tools and techniques, and outputs. PMI PMBOK (2001) defines the information and procedures of cost estimating as shown in Figure 15.

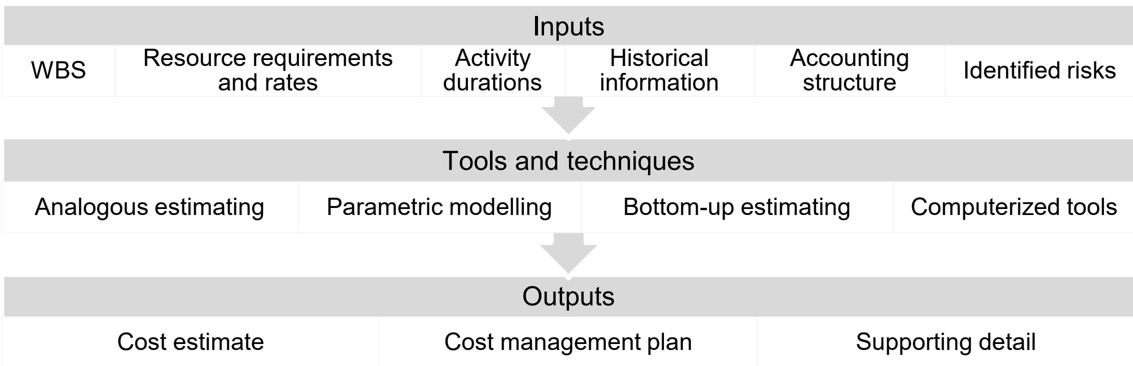

Figure 15. *Cost estimation process according to PMI PMBOK (2001).*

The cost estimation process shown in the figure defines the necessary inputs as the information requirements and separates the methods of cost estimation into categories. The tools and techniques of cost estimating include analogous estimating, parametric modeling, bottom-up estimating and computerized tools. Finally, an output of the cost estimate is not simply a number, which is the aggregated estimate, it also includes a cost management plan and a supporting detail. A cost management plan is an action plan originating from the risk evaluation that dictates how the unforeseen circumstances are to be managed in order to maintain the costs in check. Supporting detail includes the pricing factors, established rules, and assumptions, description of the scope of the work as well as the range of the expected costs. Both PMI PMBOK (2001), and Stewart and Wyskida (1987) provide different takes on systematic approaches for cost estimation.

In general, the process of cost estimation is commercially privileged information when it comes to private companies since a good cost estimating practice may be an important source of competitive advantage. Successful cost estimation and cost management plan ensure a target profit level for a company. Public and governmental companies, however, disclose their cost estimating procedures, as their finances and expenditures should be transparent and traceable (OECD/OAS, 2002). NASA (2015) provides a good example of a cost estimation procedure in their cost estimating handbook. NASA's cost estimation process is built according to the best available practice guidelines from the US Government Accountability Office (GAO, 2009). Interestingly, the most abundant cost estimation documentation comes from the construction and transportation industries. Another example of a cost estimate process is provided by the Queensland Government, the Ministry of Transport and Main Roads (2017). The cost estimation processes are illustrated side-by-side in Table 5.

Table 5. *Cost estimation process examples.*

	NASA (2015)	***GAO (2009)***	***Queensland Government (2017)***
1	Receive customer request	Define the estimate's purpose	Define project scope
2	Construct WBS	Develop estimating plan	Collect project information
3	Define technical specifications	Identify program characteristics	Become familiar with the project site
4	State ground rules and assumptions	Determine estimating structure	Gather estimating information
5	Select a cost estimating methodology	Ground rules and assumptions	Develop base estimate
6	Select cost model/tool	Obtain data (including historical data)	Conduct a reality check (reference and historical data)
7	Gather data (including historical data)	Develop point estimate and compare to the independent estimate	Assess risk
8	Develop the estimate	Carry out sensitivity analysis	Calculate contingency
9	Carry out a risk assessment and incorporate into the estimate	Carry out risk and uncertainty analysis	Determine escalation
10	Document the estimate	Document the estimate	Complete and document the estimate
11	Present the results	Present the estimate to be approved	Review the estimate
12	Update the estimate when required	Update the estimate according to the actual costs and changes	Present for approval

The table shows the three cost estimation processes side by side. Overall, due to the fact that NASA follows the best practice guidelines established by GAO, the cost estimation procedures from these sources are alike. The procedure established by the ministry of transport differs from the first glance, emphasizing transparency and bureaucratic process of a meticulous review of the cost estimate. Nevertheless, all the processes, including the ones discussed in Chapter 4.3 have functional similarities, namely developing scope and technical specification, gathering and reviewing pricing factors and cost data, surveying reference and historical material, risk review, rigorous documentation, specified information requirements, identifying ground rules and assumptions, and reviewing and updating cost estimates to be stored and easily retrieved and interpreted in the future. The commonality between the reviewed cost estimation processes is illustrated in Figure 16.

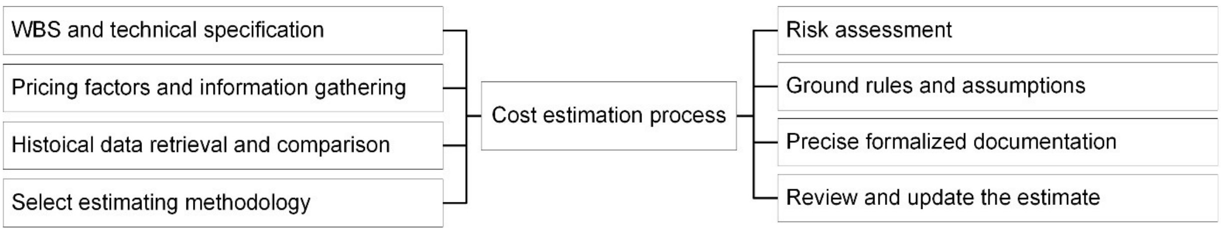

Figure 16. *Commonality in various cost estimation processes.*

The figure shows the most frequently mentioned elements of the compared procedures of cost estimation (Stewart and Wyskida, 1987, p.191; PMI PMBOK, 2001; NASA, 2015; GAO, 2009; Queensland Government, 2017). All the sources additionally emphasize the iterative nature of the cost estimation process. The cost estimate should be updated, revised and adjusted based on the incoming change requests and most recent information. The updated estimates are an effective and helpful tool for the companies during the initial estimation phases, as the estimate computation can be expedited with the data gathered from the previous equivalent projects (Taylor, 2007).

Cost estimation requires a set of skills for the estimate to be reliable. The skills and competencies required for a cost estimator are mathematical, statistical, engineering, production planning, communication, writing, and industrial engineering skills in addition to some specialty skills necessary to decimate and understand the company's operations (Stewart and Wyskida, 1987, p.3). Understanding of organizational operations is fundamental for cost estimating, and depending on the method of estimating, different levels of detail of technical expertise may be required. Dagostino and Peterson (2011, p.6) explain that a good estimator, in addition to possessing the aforementioned skills, should be experienced in the industry, organized to be able to meet deadlines and be able to deal with stress.

Such a set of skills is rarely present in one cost estimator, especially if the company's portfolio is complex and diverse. Additionally, when it comes to project business, in order to estimate the subcontractors' costs, the cost estimator should have an understanding of the subcontractors' processes as well as company-specific processes. Hence, cost estimation is often carried out in teams rather than individually. In some organizations, the whole cost estimating department is established in order to cover the necessary skill requirements (Kesavan et al., 2009, p.94). In some companies, a reporting relationship is established between a cost estimator and the departments responsible for the work packages and activities to provide the data and capabilities necessary for a comprehensive cost estimate.

Cost estimation requires information input regarding resources, schedule, materials, and facility requirements, as well as the company's cost account structure and historical data for reference (Artto et al., 2011, p.126; Taylor, 2007, p.126). Taylor (2007) defines reports from earlier projects and expertise of experienced employees as appropriate sources of information for cost estimation. Additionally, having a database of historical cost estimates is an invaluable source of information, if upkept and processed accordingly (Taylor, 2007, p.125). Sometimes, a database of standard data is available, most often in the manufacturing and construction industries (Kesavan, p.94). The databases may include manufacturing throughput times, machinery-related information and predetermined standards for time requirements, for instance in public construction projects. DoD (2010) utilizes the cost data from the Cost Book, which is a Tri-Service cost database for the construction industry, in addition to their own historical cost data archive.

4.3.1 Cost estimation techniques

Some of the techniques of cost estimation were already mentioned in a previous chapter as a part of the cost estimation process description. The oftentimes discussed cost estimation techniques are listed in Table 6.

Table 6. *Cost estimation techniques, literature review.*

Technique	***Source***
Analogous estimating / project comparison estimating / historical-bid estimating	PMI PMBOK, 2001; NASA, 2015; GAO, 2009; DoD, 2010; Rush and Roy, 2000; Queensland; Government, 2017; WSDOT, 2015; Kesavan et al., 2009; Dagostino and Peterson, 2011
Parametric modeling/functional estimate - R-squared - statistical significance - the F and t statistics - elemental parametric estimating	PMI PMBOK, 2001; NASA, 2015; GAO, 2009; Stewart and Wyskida, 1987; DoD, 2010; Rush and Roy, 2000; Chang, 2013; MOTI, 2013; WSDOT, 2015; Kesavan et al., 2009; Tanaka et al., 1993; Dagostino and Peterson, 2011

Detailed cost estimating / Bottom-up /engineering build-up	Stewart and Wyskida, 1987; Rush and Roy, 2000; Chang, 2013; MOTI, 2013; Queensland Government, 2017; PMI PMBOK, 2001; Tanaka et al., 1993; NASA, 2015; GAO, 2009; Dagostino and Peterson, 2011
Computerized tools	PMI PMBOK, 2001; Stewart and Wyskida, 1987; Queensland Government, 2017
Expert opinion/guesstimates	GAO, 2009; Queensland Government, 2017; Kesavan et al., 2009; PMI PMBOK, 2017
Learning curves and progress functions	GAO, 2009; Stewart and Wyskida, 1987; Tanaka et al., 1993
Top-down/ Design to cost (DTC) / target costing (TC)	Rush and Roy, 2000; Tanaka et al., 1993
Deterministic / factor-based /risk-based estimating - Monte Carlo simulation - Three-point estimating	Queensland Government, 2017; WSDOT, 2015; Mislick and Nussbaum, 2015; PMI PMBOK, 2017
Assembly estimating	Dagostino and Peterson, 2011

The most commonly mentioned techniques across the surveyed sources are analogous estimating, parametric modeling and detailed cost estimating. Analogous estimating is a technique that estimates the costs of a new project based on the previously carried out projects in situations of limited information availability. In order for the analogous cost estimating to be possible, the estimates from the previous projects have to be adjusted and completed based on the actual costs incurred as well as archived in an organized manner. Analogous estimating is a low-cost estimate, which tends to be less accurate producing merely a rough estimate.

Parametric modeling is a technique of predicting project costs with functions or mathematical models. The estimation is carried out based on parameter inputs, which are project-depended and reflect the scope of the project, for example, building heights in the construction industry (Dagostino and Peterson, 2011). The accuracy of the parametric estimate is dependent on the availability and relevance of the available historical cost data used for parametric input, scalability of the model and whether the parameters are quantifiable (PMI PMBOK, 2001). Detailed cost estimating is a technique of estimating the costs of individual work elements or work packages at the most detailed level of a work breakdown structure. This technique typically is the most demanding and costly and requires quite a complete level of scope and schedule specification for the estimate to be accurate.

Computerized tools include spreadsheets, project management software and statistical tools, which are invaluable in project cost estimation. The most effective computerized software in cost estimation was concluded to be a database type software, which is capable of storing and retrieving physical and functional properties of offerings and the associated costs (Galluzzo, 1991). Galluzzo (1991) concludes that a well-maintained cost database can effectively assist in analogous, parametric and detailed cost estimation, making the process less costly and yielding more accurate outputs.

Expert opinion is a subjective estimate of low accuracy, which is useful in the absence of data and for some preliminary estimate purposes. The learning curve concept originated from aircraft construction industry in the 1930s and is based on the assumption that organizations and individuals learn to carry out activities more efficiently as a result of repetition (GAO, 2009; Stewart and Wyskida, 1987; Wright, 1936). DTC, as was described in Chapter 4.2, is a product development technique, which is sometimes discussed in the cost estimation context, as in its essence, the idea of DTC is to guide the product design and planning towards the set target cost. The target cost may be determined through market and competitor analysis, which lets the firm set a competitive cost objective relative to the market. The target cost serves as a final estimate, from which the cost of activities and work packages is determined, which is a characteristic of a top-down estimating approach. Assembly estimation is used in construction projects and is a technique where the cost estimate is computed based on the bid for a work module or an assembly that consists of the material and labor costs (Dagostino and Peterson, 2011).

The deterministic or risk-based approach focuses on setting an appropriate contingency reserve to cover the project risks by taking into account the likelihood and severity of the materialized risk event. The inaccuracy of this method amplifies with the size of the project, making the method more applicable to small projects (Queensland Government, 2017). One of the examples of risk-based cost estimation is Monte Carlo simulation, which is widely utilized in cost estimation and risk management (Zhu et al., 2016). Monte Carlo simulation is a relatively complex mathematical method of calculating the expected value as an integral against a probability density function (Joshi, 2003, p.191). The method requires an abundance of processed historical data to be fitted to a distribution model (Peleskei et al., 2015). Fitting is commonly done using specialized computer software and afterward, the correlation of the elements is evaluated.

A three-point estimate is another technique belonging to the cost estimation through risk factors. The technique that takes into account the most likely, optimistic and pessimistic values and calculates the estimate based on the assumed distribution of the values. A visual example of a three-point estimate is presented in Figure 17.

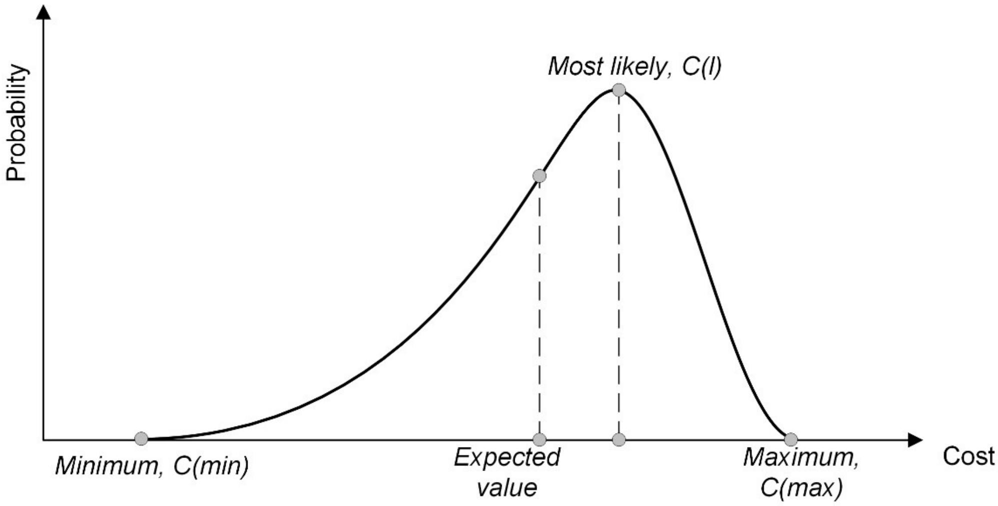

Figure 17. *Three-point estimation.*

The figure illustrates the distribution of possible values and is a visualization of a program evaluation and review technique (PERT), which calculates a weighted average using the formula for beta distribution, shown as Formula 1. In the formula, *C(min)* stands for the minimum value, *C(l)* stands for the most likely value and *C(max)* is the maximum value. If the estimate is calculated based on a different probability distribution, the formula will also differ, and so will the assumed accuracy of the estimate, according to the confidence level of the distribution.

$$Estimate = \frac{C(min) + 4 \cdot C(l) + C(max)}{6} \qquad (1)$$

The cost estimation techniques can be subdivided into two categories: quantitative and qualitative. Quantitative estimation techniques are comprised of parametric and analytical types of estimates and qualitative types include intuitive and analogical (Budiono et al., 2014). The examples of parametric techniques were provided in Table 6, and they include statistical and functional estimates. Analytical quantitative estimates are represented by top-down and bottom-up cost estimation methods as well as deterministic approaches. These techniques include some level of analysis on top of the mathematical calculation. Expert opinion and guesstimates are classified as intuitive qualitative estimation techniques, where the estimation is rough and quick to produce. Analogous and project comparison estimating are variations of analogical qualitative estimation techniques.

Most organizations use multiple cost estimation methods at varying stages of the project lifecycle since the purpose of the cost estimate varies throughout the project preparation phase and more information becomes available when the scope of the project is specified in more detail. The purpose of the cost estimate is at first strategic, gradually transforming into operational. The rough cost estimates help the organization to position itself in the mind of the customer among the competitors and roughly assess whether the offering is competitively attractive and profitable enough (Rajkumar and Kerr, 2013). After the go/no-go or bid/no-bid decision, cost estimation becomes central to setting cost objectives in the form of project budget and a cost management plan, which lay out a groundwork for final project profitability. As was discussed in Chapter 4.1, a significant share of total project costs (about 70 to 80%) is committed already at the conceptual stage of the project's lifecycle, thus it is crucial to set an appropriate cost objective as well as establish a realistic cost management plan to complete the project successfully within the established budget.

4.4 Budgeting and project control

When referring to budgeting, the author considers project-level budgets, rather than company-level or department-level budgets. Budgeting is the next step in cost management after cost estimation. Budgeting is a process of gathering individual cost estimates to compute a total cost baseline for a project (PMI PMBOK, 2017). A cost estimate approximates the project's expenditures and a final budget is a baseline determining how much can be spent during the project in order to attain the target profit levels. Another distinction between the budget and the cost estimate is manifested as the project enters the implementation phase. The final budget or sales budget becomes the cost baseline after the deal is negotiated with the customer and the contract is signed, but the cost estimate should be updated throughout the whole projects' lifecycle (PMI PMBOK, 2017). In other words, the budget becomes the cost objective of the project (Artto et al., 2011).

The budget includes additional costs besides the activity and work package costs. Contingency costs and management reserves are estimated to cover the expenses in the light of unforeseen events. Management reserve is a monetary sum assigned to cover unplanned work that is within the scope of the budget (PMI PMBOK, 2017). In case the management reserve is used throughout the project, the cost baseline is adjusted (increased) according to the planned management reserve. Contingency is similar to the management reserve, except the contingency reserve is determined based on the risk analysis. In a sense, management reserve addresses the "unknown-unknowns" and contingency reserves are set to cover the "known-unknowns" (PMI PMBOK, 2017). There is a distinction between the cost baseline and the budget. The cost baseline contains cost estimates as well as the contingency reserves. The project budget, on the other hand, includes the management reserve as well. Additionally, as the project budget is approved and authorized, it cannot be changed (PMI PMBOK, 2001). The aggregation process of the project budget is shown in Figure 18.

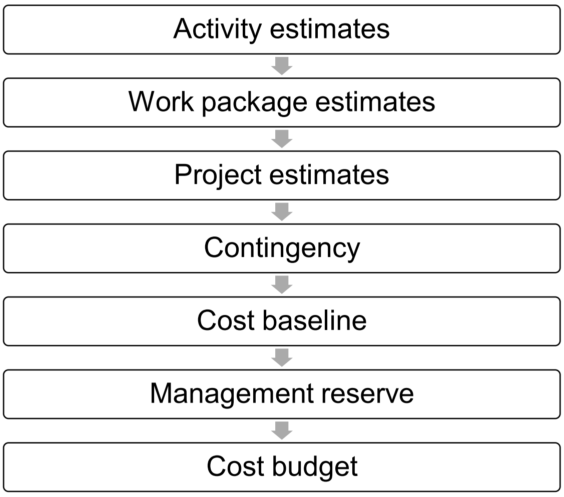

Figure 18. *Aggregation of costs in a project (PMI PMBOK, 2017)*

The figure demonstrates the differences between a project estimate and a budget. A budget requires assessment and assignment of contingencies, which are carried out through risk evaluation. One of the project objectives is to execute the scope of the project within an assigned cost baseline (Kerzner and Kerzner, 2013, p.7). Kerzner and Kerzner (2013, p.750) state that a project budget must be reasonable, attainable and based on contractual costs and WBS. Thus, it is imperative that a realistic schedule and a cost baseline are established for a project in addition to the project manager’s ability to assess the state of the project in terms of performance with respect to the established baselines.

Contingency is defined as a monetary sum added to the estimate to cover the consequences of risk events in case of them materializing (Stewart and Wyskida, 1987, p.667). Contingency is set based on the risk evaluation and the probability and impact of the risk event manifestation. Risk is quantified via expected monetary value (EMV) technique, which is calculated as a product of the probability of the risk event and the severity of impacts (PMI PMBOK, 2017). When the cost estimate is aggregated into the project estimate, a risk analysis regarding the overall budgetary and schedule contingency reserves in the event of the identified risks is carried out. For example, if the historical data is available, PERT technique may be used to determine the contingency reserves. The application of PERT in contingency evaluation is shown in Figure 19.

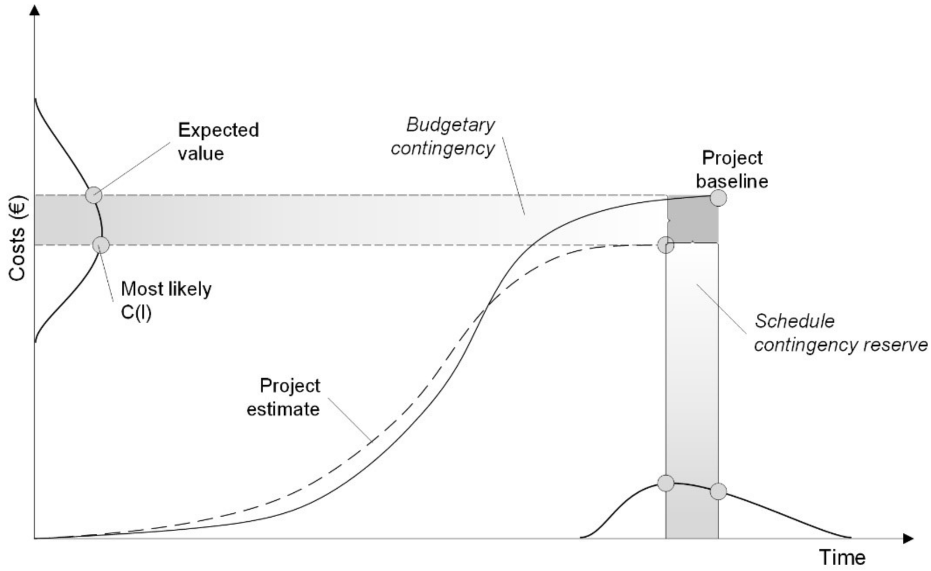

Figure 19. *Setting budgetary and schedule contingency.*

The figure illustrates that the project baseline is set through determining cost and schedule baselines, according to the contingency reserves (PMI PMBOK, 2017). When the project baseline is established, the management reserve, which is typically determined on the organizational level, is added on top of the baseline to form the project's budget (Venkataraman and Pinto, 2008). The project baseline serves as the performance benchmark for project controlling.

Assessing the project performance by comparing the planned progress and value to the actual timetable and earned value is called project controlling (Taylor, 2007, p.161). Project controlling is not restricted to progress monitoring, it includes managing activities to maintain the planned schedule as well as minimize the variations from the baselines. Venkataraman and Pinto (2008) describe the course of project control as a 4-step process: (1) establishing the baselines: project planning, (2) tracking the progress, (3) comparing the actual performance to the plan, and (4) taking corrective action. The schedule and cost baselines are established during the planning stage of the project. Goh and Hall (2013) emphasize the involvement of project managers in project planning and associate some methodology of planning and control with project management.

One often-used managerial control methodology is earned value management (EVM), which is a quantitative way to evaluate a project's performance (Hazir and Shtub, 2011). Earned value management approach was developed by the DoD as a way of monitoring their own and contractors' progress and financials (Taylor, 2007, p.161). The key concepts of EVM are planned value (PV), earned value (EV), actual cost (AC) and budget at completion (BAC). PV represents the cost baseline authorized for the project. EV is an expression of the work completed so far compared to the work that was planned to be completed by that time and is calculated using Formula 2 (Taylor, 2007, p.167; Artto et al., 2011, p.200).

$$EV = \%\ of\ work\ complete\ \cdot PV \qquad (2)$$

Actual cost (AC) is an expression of the costs incurred throughout the project and corresponds to the cost of the work performed to the measured EV point. BAC is budget at completion, which is the authorized total planned value for the project. As was mentioned, cost estimates are updated throughout the project lifecycle in the light of changes or availability of new or more accurate information. The probable cost estimate at the phase of project completion can be produced via trend analysis based on the AC (PMI PMBOK, 2017). The adjusted cost estimate that is based on the actual costs and the forecasted trends is called estimate at completion (EAC).

The project budget is represented as an S-curve as the relationship between expenditures and the elapsed time is typically non-linear and S-shaped (Venkataraman and Pinto, 2008, p.77). Additionally, cost and schedule indicators can be used to evaluate the performance of the project. Some of the indicators relevant to this work include:

- cost variance (CV),
- schedule variance (SV), and
- variance at completion (VAC).

Cost variance is calculated by subtracting actual costs from the earned value. Positive CV indicates that the project is progressing under the planned costs and the negative CV indicates that the project is exceeding the cost objective. When the project implementation is complete, the total cost variance is calculated by subtracting the total expenditure from the project’s budget. Schedule variance is calculated by subtracting the planned value from the earned value. Positive SV suggests that the project is ahead of schedule and negative SV signifies the delays. Variance at completion is calculated by subtracting the estimated costs at completion from the budget at completion. The calculation logic is shown in Figure 20.

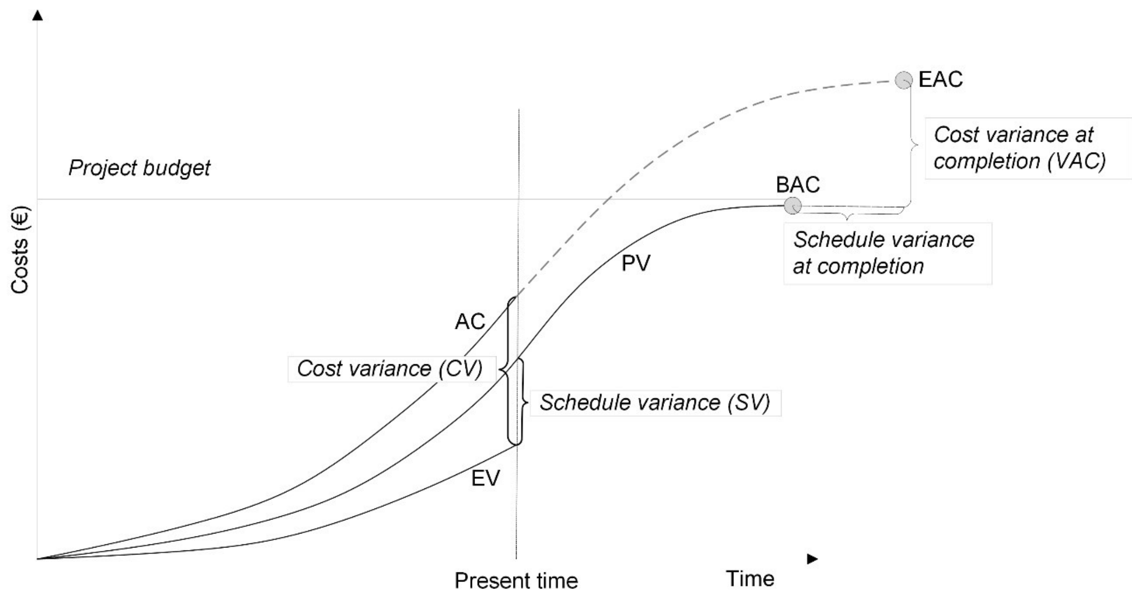

Figure 20. *EVM analysis (Taylor, 2007, p.164 and PMI PMBOK, 2017).*

The figure shows the planned value, earned value and actual costs incurred throughout the project. The figure demonstrates a scenario where at the time of the analysis the earned value curve is situated below the plan, meaning that less work was completed percentally than was initially planned. At the same time, the actual costs exceed the budgeted costs, indicating the presence of cost overruns. The curves shown on the graph are an example of progress tracking and analysis in a quantitative form.

4.4.1 Cost variance

Cost variances are expected in project business since the projects are rarely implemented according to the established plan (GAO, 2009, p.209). Additionally, Pinto (2016, p.279) remarks that the planned conditions are rarely encountered throughout project implementation and the project's scope is subject to change. Cost variances, however, cannot be attributed solely to the unforeseen circumstances. Unrealistic planning and budget setting may lead to financial deviations between the cost baseline and the actual costs. GAO (2009) clarifies that variances are a signal of unrealistic or incomplete planning, lack of change management and control during the project, and/or the quality of project execution.

As was described in Chapter 4.1, cost estimates are used for bidding and tendering. Realistic cost estimates, thus, become imperative to the project's success and the overall organizational success. Cost variance can be classified into favorable and unfavorable, signifying costs overrun and underrun respectively (Broyles and Lay, 1982). The standard of performance, in this case, is the project's sales budget. The favorable and unfavorable variances may further be subdivided into controllable and uncontrollable. Although, one might ask whether there is such a thing as a favorable variance.

A favorable variance may entail cost savings as well as overestimation. Overestimates may lead to higher bidding prices compared to those of the competitors, leading to potential loss of business and customers. Underestimates may lead to the firm's inability to execute the scope of deliverables within the designated budget, thus, leading to financial losses on the company level (Kesavan et al., 2009, p.100). Additionally, a tighter budget may imply compromised quality of the execution subsequently leading to customer dissatisfaction and causing reputational hazards. Thus, before concluding whether the variance is favorable, the root cause of the cost savings is to be determined.

The triple constraint of project management can be used to demonstrate the effect of abnormal performance in one aspect on the other constituents of the project's success. The relationship is demonstrated in Figure 21.

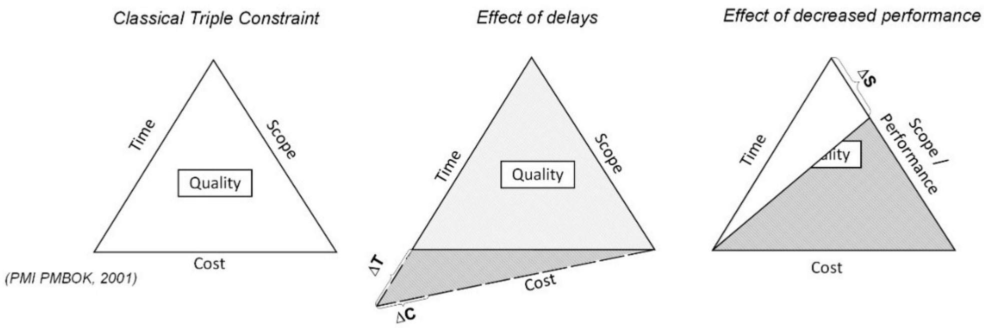

Figure 21. *The effect of deviations from the project plan.*

The figure demonstrates that the schedule and costs are interconnected. In the event of delays, additional costs are likely to be incurred assuming that quality is to remain unchanged. The scope in the triple constraint represents the tasks associated with the execution of the project scope (PMI PMBOK, 2001, p.29), and, can be thought of as performance. In case of lower than planned performance levels, the quality of the deliverables will suffer if the project is ordered to be completed within the schedule and cost baselines. Other variations of the CTC model may be used to illustrate the effect of change of one or more of the variables and their impact on the project's success.

It follows that the variance monitoring and control is a vital part of project management and ensuring the project's success in terms of customer satisfaction and profitability. Cost variances are a standard occurrence in project business, as in reality, the actual expenditure will rarely be equivalent to the planned budget (Kaplan, 1975). As a reference, about 35 per-cent of the software projects are completed within the schedule baseline (Goh and Hall, 2011), meaning that 65% face delays. Shehu et al. (2014) find that cost overruns are a fundamental and frequently observed problem for construction projects. Kwon and Kang (2018) in their review found that over 90 per-cent of construction projects encounter the issue of cost overruns of between 50 and 100 percent. Flyvbjerg et al. (2002) conducted a fundamental study of cost overruns in public projects and found that cost overruns occur due to cost underestimation in 9 out of 10 projects. The projects under investigation included railway, bridge and road construction. Bhargava et al. (2010) collaborate that cost overruns are oftentimes encountered in infrastructure and road construction projects.

Kaplan (1975) also emphasizes that variance investigation is demanding and resource-consuming, implying that it is cost-intensive. Hence, it is important to know whether the variance is insignificant and caused by random factors, or the root cause of the variance lies within the organizational procedures. In general, the cost-benefit analysis may serve as a guideline for the need to carry out variance investigation, as the investigation should be undertaken if and only if the benefits of the investigation outweigh the costs (Kaplan, 1975). Dean (1937) further confirms that it is important for the firm to identify the controllable portion of the cost variances in order to make use of the costing system and *"maximize managerial usefulness"*. Variations, random or controllable, may be a cause for project failure (Goh and Hall, 2011), hence it is of the utmost importance to identify the root causes of and decrease controllable variances, as well as prepare for the uncontrollable ones.

5. PROMOTING COST ESTIMATION QUALITY

5.1 Challenges in cost estimation and budgeting

Cost estimation and cost budgeting are a part of project planning, which means that both are carried out prior to the project's implementation and produce more of a forecast rather than a definitive output. Accurate cost estimation, based on which the sales and implementation budgets are set, is vital for the project's success (Love et al., 2013). An accurate budget ensures that the company will attain target profitability as well as serves as a performance control baseline for the project. Additionally, an accurate cost estimate establishes a valid ground for decision-making, and cost and schedule management within an organization (Doloi, 2013). However, project business is notorious for changes and it is known that cost and schedule variances are inevitable. Nonetheless, identifying and managing variance, as well as creating realistic and attainable estimates are instrumental in attempting to reduce the controllable variance.

Venkataraman and Pinto (2008, p.83) conclude that in project business cost estimation is by default more difficult due to the unique nature of each project. That, coupled with the unpredictable changes in scope and other circumstances, make variance at completion almost inevitable. As was discussed in Chapter 4.3.1, analogous estimating is a widely-used technique in cost estimating, however, since no two projects are identical, the estimate obtained by analogous estimating is merely a rough guideline. Venkataraman and Pinto (2008, p.84) and Taylor (2007, p.125) additionally emphasize that the estimation is even more challenging in "multi-year projects", as the scope of the project, external and internal environment, and resource requirement and availability are subject to change over the years. Artto et al. (2011, p.136) and PMI PMBOK (2001, p.32) bring up a managerial technique called the rolling wave principle, which is an iterative planning technique. The general principle of the rolling wave is to make use of the new, more accurate information as the project progresses and conduct cost estimation at a more detailed itemization level. The activities that are barely specified and are described on a highly general level are estimated at the cost account level.

Other challenges in cost estimation exist when it comes to itemization and timely cost allocation to a correct work package in the correct cost account (Venkataraman and Pinto, 2008, p.84). Accurate cost tracking and being able to trace the costs related to a specific cost item or work package is vital in earned value management, variance analysis at completion as well as future estimation. Taylor (2007) discusses the novelty of technology and technological requirements characteristic to project business as a reason for difficulties in cost estimation. As each project is unique in scope, the solutions provided to the customers are most likely also unique and tailored to the customer's needs. This makes the availability of historical data a challenge, as it is highly unlikely to find a project with comparable parameters.

Another variable that affects cost estimation is the size of the project. Jørgensen et al. (2012) found a correlation between the project size and the planning accuracy in projects. The researchers conclude that the larger and more complex the project is, the more likely cost overruns are to occur. The researchers were able to definitively state that the size affects the project no matter how rational the cost estimation procedures are, although, the patterns of the most and least successful cost estimating techniques were not clear. Shane et al. (2009) concur on the likelihood of cost overruns in larger projects. The researchers additionally state that the projects can be delivered within the assigned budget, however, that requires an extreme awareness of cost-incurring factors as well as a good cost estimate.

Love et al. (2013) confirms that cost estimating is more challenging in larger projects due to increased complexity and the likelihood of change orders throughout project implementation. Doloi (2010) elaborates on the particular aspects brought by increased project complexity and modern reliance on the supply chain. One of the features of the modern industrial environment is increased reliance on the supply chain and, hence, increased tendency to outsource some activities (Kujala et al., 2010; Zhu et al., 2001). Outsourcing is a strategy that companies use to differentiate their offerings in the market place by acquiring extra capabilities or capacity without investing in their development and differentiation. Outsourcing can be regarded as a survival tool for manufacturers in modern competitive and developed industrial environment. The firm acquiring cost estimates from the contractors relies on the estimates being accurate, however, deviations often occur due to factors affecting contractors' performance or inaccuracies in the initial cost estimation on their behalf (Doloi, 2010). The researcher points out that contractors' documentation quality and efficiency are sometimes inappropriate for setting a budgetary baseline.

Shane et al. (2009) additionally bring up the challenge of misinterpretation and reporting, in other words, impaired and incomplete information flow. Ferris (1976) attributes human personality as a challenge to cost estimation processes. The researcher states that the personality traits have a positive correlation to certain estimating tendencies, namely that there is a positive correlation between the optimistic personality and overestimation as well as pessimistic personality and underestimation. Challenges in cost estimation that are attributed to human factors are typically difficult to interpret. Shane et al. (2009) investigate the concept of optimism bias, which is associated with unrealistic schedules and budget baseline setting during the project planning phase. The effect of human factors on the estimate is unclear and cannot be easily mitigated with de-escalation factors, thus indicating that a degree of formalization and standardization is required to be applied to the process to eliminate the effect of personality bias.

Tanaka et al. (1993) discuss another challenging issue associated with cost estimation. Due to the estimating process being so time- and resource-consuming, it may be challenging to evaluate and compare design alternatives from the economic perspective. The uncertainty involved in the conceptual stage of project planning adds to the difficulty of reliable cost estimation. Additionally, the individual producing the cost estimation is of relevance. Tanaka et al. (1993) see it as a problem if the solution engineers and designers are responsible for the cost estimate. Taylor (2007) collaborates the previously mentioned and concludes that cost estimation should not be assigned to technical employees as an extra duty to avoid problems. Coupled with Stewart's and Wyskida's (1987) identified skill requirements for cost estimation, it follows that the estimator should possess expertise in finance and industrial management, as well as a technical understanding of the product portfolio. The challenges involved in the cost estimating procedure are summarized in Table 7.

Table 7. *Challenges in cost estimation: summary.*

Challenges in cost estimation	The nature of project business
	Lack of historical information
	Itemization and allocating costs to cost accounts
	Novelty of technology and custom-made solutions
	Project's size
	Reliance on supply chain
	Human factor
	Resource-consuming - costly to compare alternatives
	Assigning the task of cost estimation to technical staff

The table provides a summary of the challenges involved in cost estimation. Some of the challenges are of the controllable character and some, such as the nature of the project business cannot be controlled. Some methods, however, can be identified to mitigate the overall inaccuracy or other effects resulting from the uncontrollable challenge factors.

5.2 Pitfalls of cost estimating and cost overruns

Project variance at completion can be attributed not only to the planning stage of the project life-cycle but also the implementation stage. The role of the project manager is to undertake the necessary pre-defined actions or design a new course of action that aim at alleviating the effects of project variance. Nonetheless, no matter at what stage of the project lifecycle, the importance of an accurate initial cost estimate cannot be overemphasized. Hicks (1992) portrays the role of a cost estimate as a key element ensuring the project's success and claims that…

"…without an accurate cost estimate nothing, short of an act of God, can be done to prevent a loss, regardless of management competence, the financial strength of the contractor, or know-how".

Venkataraman and Pinto (2008, p.46) conclude that one of the most common reasons for cost overruns in a project is an unrealistic, low and unattainable cost estimate. Other causes of project variance, which are attributed to the pre-contractual stage of a project are misunderstanding the customer, inadequate planning, incomplete WBS, skill deficiency and personnel availability (Havranek, 2017). Misunderstanding the customer leads to incorrect technical requirement interpretation and subsequently to incomplete or faulty WBS development. Inadequate planning is a root cause of flawed schedule development and budget setting. Shane et al. (2009) emphasize that in order to attempt project completion within the assigned budget, project estimate, and planning should be carried out accurately. Tanaka et al. (1993) identify that one of the fundamental pitfalls of cost estimation is that it is carried out solely after product specification. The authors emphasize the importance of target costing and design-to-cost approaches since in order for the product to be competitively priced, the market analysis is necessary to evaluate the price levels of the competitors.

There are other reasons for cost deviations throughout the project lifecycle, but the ones discussed are the most relevant to this work, as the causes are internal and controllable. From the literature (Venkataraman and Pinto, 2008; Havranek, 2017; Shane et al., 2009; Hicks, 1992) it is apparent that the key reasons for cost overruns are incorrectly established cost baseline, which is a product of cost estimation. Incorrect cost estimation is, in turn, a result of inadequate planning, misunderstanding the customer and internal communication. The importance of the accurate cost estimate can be illustrated with a Freiman curve (Asiedu and Gu, 1998; Chang, 2013), which demonstrates the relationship between the estimated costs and the actual costs. The Freiman curve is shown in Figure 22.

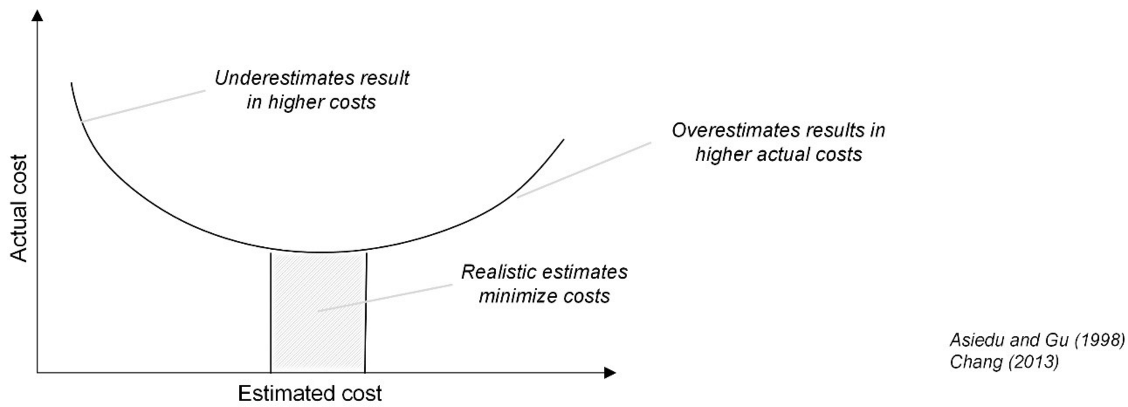

Figure 22. *Freiman curve.*

According to the curve, underestimates result in higher actual costs, due to unachievable schedule and resource planning. In order to compensate for inadequate planning, more costs are incurred during the project's lifecycle (Asiedu and Gu, 1998). Asiedu and Gu (1998) additionally state that overestimates are like "*self-fulfilling prophesies",* resulting in higher actual costs after the projects' completion. Shane et al. (2009) collaborate that cost overruns occur due to defective estimation, which is in turn rooted in erroneous design and planning. Attaining a realistic cost estimate is challenging during the early design phase of the project's lifecycle, which is associated with many uncertainties (Asiedu and Gu, 1998; Torp and Klakegg, 2016).

Budget planning requires specified technical aspects and project scope. The budgetary estimate is used in business decisions, such as go or no-go milestone decisions. Hence, it follows that the project uncertainties are interconnected and may trigger a cycle of invalid and unrealistic decisions and estimates, if not recognized. Accurate design and technical specifications are imperative prerequisites for a realistic cost estimate. Failure to recognize technological uncertainty during the planning phase may have serious consequences during the project's implementation. Design flaws and incompleteness cause order and scope changes during project implementation, which were unaccounted for during the planning phase, resulting in cost overruns (Chang, 2002). The relationship between the process and product engineering, sales and cost estimating organizational functions is one of the reasons for the thorough and high-quality stakeholder communication throughout the cost estimating process.

The first step in developing a corrective plan of action is understanding the root cause of the problem. A cause-effect relationship between the organizational aspects of carrying out a cost estimating process is instrumental in ensuring that the cost estimate is accurate. As was described before, the information requirements can be subdivided into historical and operational. The preceding operational information input for the cost estimation is WBS. In order to create a WBS, the project's scope and schedule must be defined, which in turn requires clear customer understanding as well as organizational understanding in terms of capabilities and resource availability.

Naturally, the information is specified with time throughout the project lifecycle, however, the estimates are already required at the earliest stages of the project planning for the milestone decisions, such as whether to proceed with the project. Cost estimate computation may be a costly process depending on the desired degree of accuracy. Some estimating techniques are more time-consuming than others, furthermore, some estimating techniques are accepted to be more accurate. If cost estimating is treated as a continuous and iterative process, rather than a singular independent event, the accuracy requirement may be adjusted and optimized according to the resource availability, which is deemed necessary for attaining a cost estimate.

5.2.1 Qualities of a good estimate

Taylor (2007) discusses the successful cost estimation practices and infers on the steps that are to be undertaken to create a quality estimate. The first steps according to the author are to determine the purpose of the estimate and assess the available information and resources for the estimation process. It is also emphasized that when sharing the estimate within the organization, the accuracy and the detail level of the estimate should be clearly stated and understood by the user of the estimate (Taylor, 2007). If the estimate is rough and unprecise and it is misused in customer negotiations, the seller organization may encounter financial losses or dismantle its reputation in the eyes of the customer by revoking the offer and altering the contract price.

Taylor (2007, p.109) proposes a set of recommendations for carrying out a successful cost estimation. The recommendations include:

- using the most accurate method and a combination of methods if possible,
- involving internal project stakeholders and experienced employees in the estimating process,
- recording all assumptions,
- basing the estimates on the evaluation and assessment of previously conducted estimates,
- communicating the level of precision to the party, who is using the estimate, and
- provide estimates based on the available information and do not pad them.

GAO (2009) identifies their requirements for a credible estimate. The requirements include clear task identification, internal stakeholder involvement in the estimation process, reliable data, standardized estimating procedure, identification and accounting for uncertainties, considering inflation, and reviewing, adjusting and revising the estimates throughout the project's lifecycle (GAO, 2009). If the recommendations are followed, the estimates that are obtained in the end is comprehensive, accurate, credible and well-documented. GAO's complete list of recommendations for attaining a high-quality cost estimate is attached in Appendix A.

Kerzner and Kerzner (2013, p.680) specify that a good estimate is based on the recent experiences from similar work, is supported by reference material and market surveys as well as is carried out by a knowledgeable person. Ideally, the estimate should be supported by data from a database accumulated from previous cases and computerized software (Kerzner and Kerzner, 2013). The role of the computerized software could, for example, be data fitting into probability density or distribution functions, as well as running statistical simulations.

5.3 Estimation accuracy

The cost estimation at the earliest stages of the project's lifecycle is of strategic importance and is used in sales to acquire customers. The role of sales organizations in the modern industry becomes increasingly important and it serves as a strategic tool for many companies (Nigel and Nikala, 2009). The sales organization is a tool to screen the market for potential customers and competitors as well as interpret customers' preferences. The suppliers compete for customer acquisition during the preparation phase of the project's lifecycle, where the customers are assessing their needs, preparing for the investment decision and choosing the best suppliers to fulfill the needs. The process of customer acquisition is illustrated with a sales funnel framework, illustrated in Figure 23.

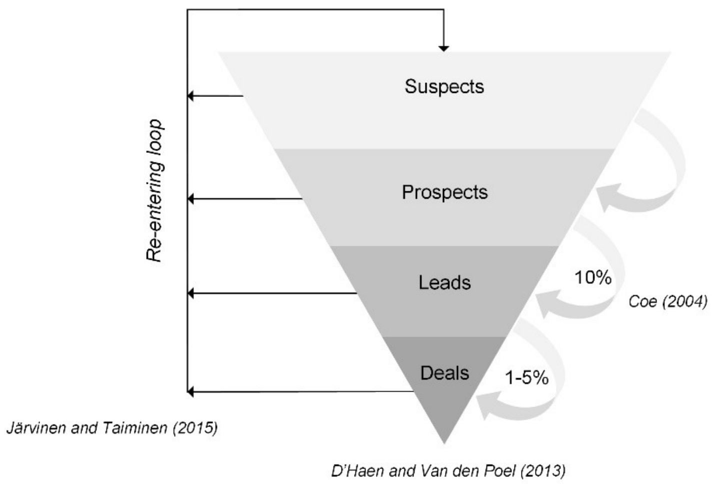

Figure 23. *Sales funnel.*

The figure demonstrates the customer acquisition process, starting from suspect identification, which is then converted into prospects, some of which turn into qualified leads and subsequently customers (D'Haen and Van der Poel, 2013). According to Coe (2004), the conversion rate of prospects to leads is about 10% and out of this 10 %, only 1-5% become customers. Raising the conversion rates, i.e. identifying prospects more accurately leading to a higher number of qualified leads and deals, is a practice to decrease the cost of customer acquisition (Järvinen and Taiminen, 2015) also in terms of the expenditure required for cost estimation.

Being a sales tool, accurate estimation is a key to successful tendering since an accurate cost estimate ensures that the project is not sold at a lower price than the total project's cost. Overestimates can cost the company its market share as well as the relationship with their customers (Chang, 2013). The most accurate estimation methods, however, are time- and resource-consuming for the organization, making it financially unfeasible for the organization to estimate the cost for every lead. There exists a correlation between the time required to execute an estimate and the accuracy of the final estimate. Typically, most time-consuming estimates are produced at a detailed level, making the aggregated estimate more accurate.

Dagostino and Peterson (2011) rank the estimates on a graph of estimate accuracy versus the time required to complete the estimate. The least accurate and the least time-consuming estimate is analogous or project comparison, followed by parametric, assembly and detailed estimate. Analogous estimating tends to be less accurate, since no two projects are identical, and hence the analogy cannot be perfect. Additionally, parametric estimating relies on a set of data gathered from previous projects, while analogy resembles a one-point-estimate technique. The analogous method, however, can be applied even in the absence of specific project data and the estimate is quick to carry out. Assembly and detailed estimates require extensive information availability as well as more prolonged time to complete. The detailed estimate is the most accurate of all since the costs are estimated for each work package on the lowest levels of WBS, although, it doesn't provide as good traceability of cost drivers as the parametric technique (GAO, 2009, p.108). Supporting detail is needed in combination with a detailed estimate to compensate for the lack of transparency of cost drivers. The other estimation techniques are ranked based on their stipulated accuracy and the ranking is shown in Figure 24.

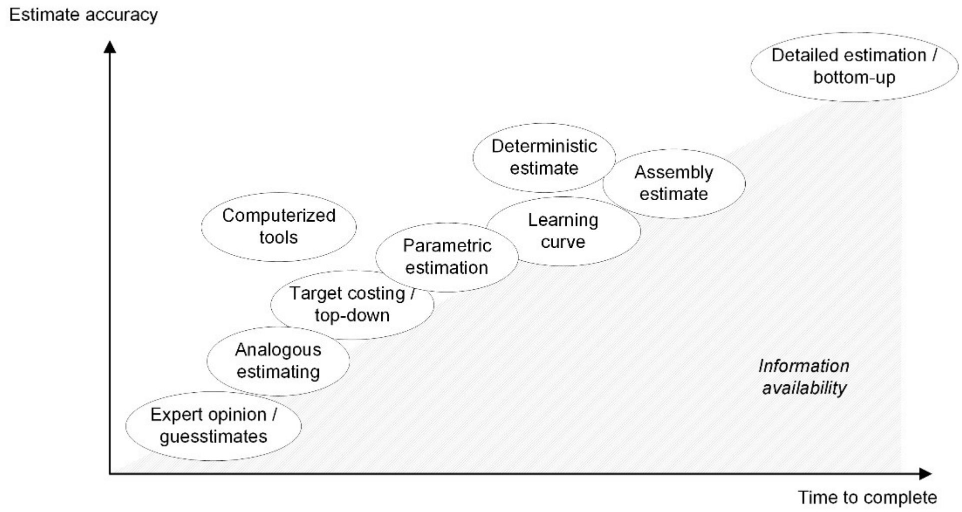

Figure 24. *Accuracy of cost estimation versus time required for the estimation.*

The figure shows that expert opinion is stipulated to be less accurate than the analogous estimating. Perhaps coupling expert opinion and analogous estimating would be a valid technique for obtaining a more accurate comparative estimate with consideration of case-specific implications, which are produced by experienced workers, who have encountered similar cases and can identify the uncertainties involved in the case.

Top-down estimation is ranked as the next most accurate, where the estimate is determined through the market and competitor analysis and the work package costs are assigned based on the total target cost. That technique guides the product development efforts to design the solution according to the established target cost. Top-down estimation may also be carried out based on the earlier sold similar products, which implies that a large amount of information about similar products is needed. Even with the available information, the top-down estimate is not the most accurate due to the uniqueness of each project. Computerized tools are comparable to the parametric estimation and are quicker and more accurate if the data archives are maintained properly. The learning curve, assembly estimate and deterministic estimate are stipulated to take a longer time than the parametric estimate, although resulting in a more accurate result, due to consideration of risks and case-specific factors, as well as experiential factors. A detailed estimate is considered to take the longest time to complete and the information input is required to be quite complete and accurate, thereby ensuring that the aggregated detailed estimate is indeed viable.

Using the most accurate possible estimating technique as well as using a combination of methods were outlined as good cost estimation practices. However, the balance between the desired accuracy and resource availability should be found, as the more detailed the cost estimation gets, the more costly the estimating process becomes. According to NASA (2015), there are two types of estimates throughout the project's lifecycle –

gross estimate and detailed estimate. Analogy and parametric estimates belong to the category of gross estimates and occur throughout the concept and early design stages in the project's lifecycle (NASA, 2015, p.14). Engineering build-up (bottom-up estimating) and cost tracking are defined as detailed estimation techniques and are implemented throughout the later stage of project planning.

If the estimation techniques are bundled with one another, the reliability of the attained cost estimate is supposed to be higher, as various methods of estimation serve to support and validate each other. The methods that can be bundled with one another should require approximately the same time and rely on a similar grade of project scope specification (information availability). The proposed bundles of cost estimation techniques are illustrated in Figure 25.

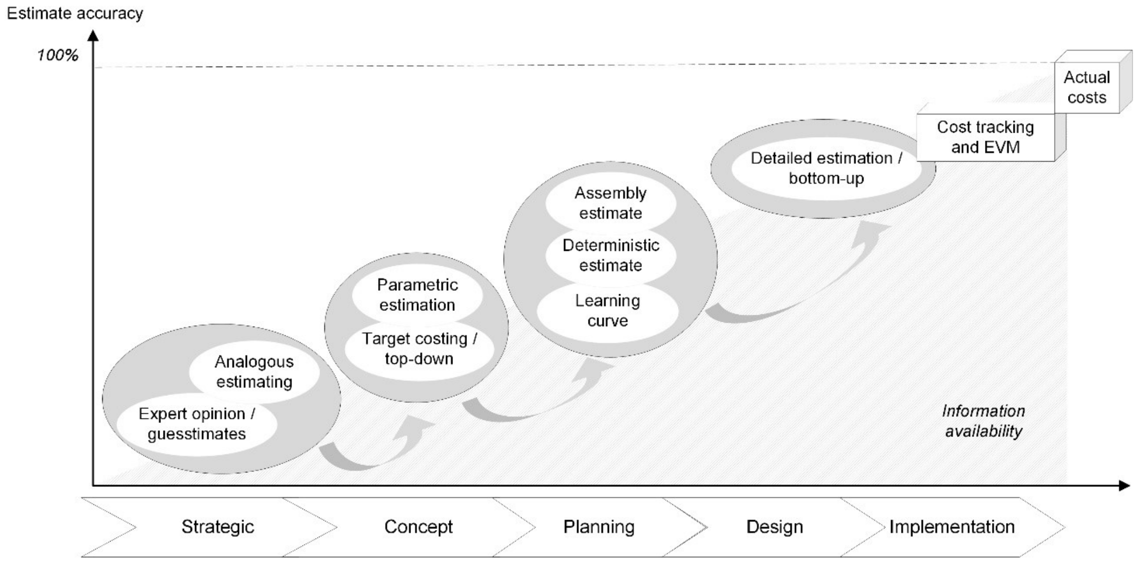

Figure 25. *Bundles of estimation techniques correlated with project's stage.*

As is demonstrated in the figure, there are four distinct technique bundles defined. The bundles are a collective summary of the techniques that are mentioned in literature as the guideline techniques for cost estimation at a certain project stage (NASA, 2015; MOTI, 2013, GOA, 2009; Queensland Government, 2017; DOE, 2011). The first suggested bundle is comprised of the qualitative techniques of expert opinion and analogous estimating. Utilizing these two techniques together still provides only a rough estimate (NASA, 2015), although a more accurate one than if the techniques were used independently. The bundle adds more credibility to the expert's opinion with the support of the data from previous projects, as well as sheds a light on possible specifics and uncertainties associated with the project, which cannot be easily identified from the data.

The second bundle is comprised of parametric estimation and top-down estimation. This is a good combination of techniques to estimate the company's own price level as well as evaluate whether the price is competitive in the market. Additionally, this bundle allows for a comparison of alternative design and price levels, which happens to be one of the pitfalls of cost estimating (Tanaka et al., 1993). The next bundle contains deterministic, learning curve and assembly estimates, which require more time to complete, although provide a more accurate estimate since the risks and uncertainties were taken into account. These estimation techniques do not allow for effective design comparison since they would be too costly to carry out for multiple alternatives.

The final and the most accurate estimate level is a detailed estimation, which is carried out for the firm proposal stage in customer negotiations. Since that technique involves cost estimation for each of the elements and work packages in the WBS, it is the most challenging and time-consuming estimation technique to carry out. It becomes even more challenging in multi-divisional projects, where various business units must combine their efforts to plan and price the deliverables. Communication and division of responsibilities quite frequently become an issue in such cases (Dietrich et al., 2002). It is noteworthy, that cost estimation is an iterative process, which means that the bundles of techniques are not mutually exclusive, on the contrary, the information acquired throughout the process is built up, revised and validated as the estimation process advances (GAO, 2009).

The cost estimation bundles are followed by cost tracking and EVM, which is a project management technique of project control. The actual costs and complete information become available only after project completion, which is the last block shown in Figure 25. EVM and actual costs are not excluded from the cost estimating techniques, as they become a part of cost analysis, which is then used in cost analysis to complete the cost estimation process and evaluate the accuracy of cost estimation for future estimations (Stewart and Wyskida, 1987; Rush and Roy, 2001; GAO, 2009).

5.3.1 Importance of historical information in cost estimation

The literature emphasizes the need for organized and retrievable historical information for obtaining a more precise cost estimate, however, sometimes the information is not available. The lack of information may be based on the novelty of the product or incomplete cost estimating procedures. As was discussed in Chapter 4.3, the cost estimate process is completed with the supporting detail, including the cost analysis and the lessons learned from the estimating process. Processing and accumulating the cost estimate and cost variance data at the end of the project are the necessary constituents for the cost database, which is an invaluable tool in cost estimation (Stewart and Wyskida, 1987, p.15).

Without historical data, most of the estimation techniques would not be possible. Historical data is used in analogous estimating, parametric estimating, deterministic estimating, learning curve and detailed estimating (Venkataraman and Pinto, 2008, p. 52). Thus, it follows that not a single one of the estimation bundles would be complete without the reliance on historical data. The importance of historical data to the cost estimation process was brought up as one of the elements of commonality in various cost estimation processes employed across different industries (see Figure 16). The quality and reliability of the data must be ensured in order for the historical data to be a prerequisite for excellence. Historical data is a key component for the basis of estimate, which is an integral step of the cost estimation process. In project business, especially, the internal cost estimate information is crucial, since the offerings that the project-based firms provide to their customers are never unique and are most often tailored to a specific case and customer.

Rush and Roy (2000) discuss an approach to project comparison technique solely based on historical data – case-based reasoning (CBR). This technique is based on forming a case and comparing and adapting the solution in accordance with observed historical trends. The previous cases and the information obtained and processed from the previous cases serve as a knowledge database, according to which the new solution is developed. Moreover, the information stored in the knowledge database is being continuously verified through application to the new cases. The researchers call this utilization of historical data as a learning process. CBR is an approach that is related to a projection technique widely applied in industry, called the learning curve (Stewart and Wyskida, 1987; Venkataraman and Pinto, 2008; Mislick and Nussbaum, 2015).

There are two schools of learning curve theories - a cumulative average theory and a unit theory. A cumulative average learning curve was developed by Wright (1936) and the incremental (unit) learning curve was developed by Crawford in 1947 (Stewart and Wyskida, 1987; Mislick and Nussbaum, 2015). Both theories are based on the assumption that the organization learns from the tasks performed and the more times a task was performed in the past, the less time it will require in the future. The repeatedly incurred costs in the organizational context are recurring costs, thus it can be concluded that the learning curve concerns only the processes which incur recurring costs. Unfortunately, learning curves are applicable only to direct labor (DOE, 2011).

For a project-based firm, the manufacturing learning curve may not be as instrumental, based on the degree of outsourcing. However, the idea of experiential learning and standardization may be useful in terms of evaluating the uncertainty involved in project planning. Lowe and Skitmore (1994) investigate the effect of experience and learning on the quality and effectiveness of task completion when it comes to cost estimation. The researchers found that if the individual is reflecting on their experiences and are able to convey their experience and identify development needs, the accuracy of their estimation work is higher. Thus, it is imperative for the cost estimator to follow through the whole process of cost estimation, including the estimation review and lessons learned from estimating.

Portfolio standardization and repetition of the tasks serves also as a mechanism for decreasing uncertainty, caused by the novelty or custom-made nature of the offering (Lorenz et al., 2019). Ulonska and Welo (2014) address the same issue from a different perspective, stating that the organizations, whose operations are based on custom-made solutions must be able to increase their learning capabilities. In other words, it is imperative for the organization to be able to convert the acquired tacit knowledge into explicit form, which required a systematic approach to collecting, processing and archiving data. Clear and systematic organization of product portfolio and project deliveries enables a clear overview of variances and unifies all the experience and tacit knowledge into one holistic database (Ulonska and Welo, 2014). It follows, that the learning curve phenomenon cannot be completely discarded when it comes to indirect work, although the application of the learning curve is not as literal as outlined by Wright or Crawford. The systemization of acquired knowledge is a pathway to deal with the uncertainties in a project-based business, where the projects and the offerings are unique.

5.4 Review of existing estimation accuracy boundaries

The accuracy of the cost estimate was found to positively correlate with the stage of project planning, seemingly due to more accurate scope specification and more extensive data availability. Furthermore, the project organization should define the purpose of the estimate and the resources that can be allocated for the process of cost estimation. Considering that such a small share of “suspects” is converted to customers (Figure 20), the firms cannot afford to produce a detailed customer solution design and detailed estimate. AbouRizk et al. (2002) conducted a case study of the estimation accuracy boundaries at different stages of project planning in construction projects. The result of their study is shown in Figure 26.

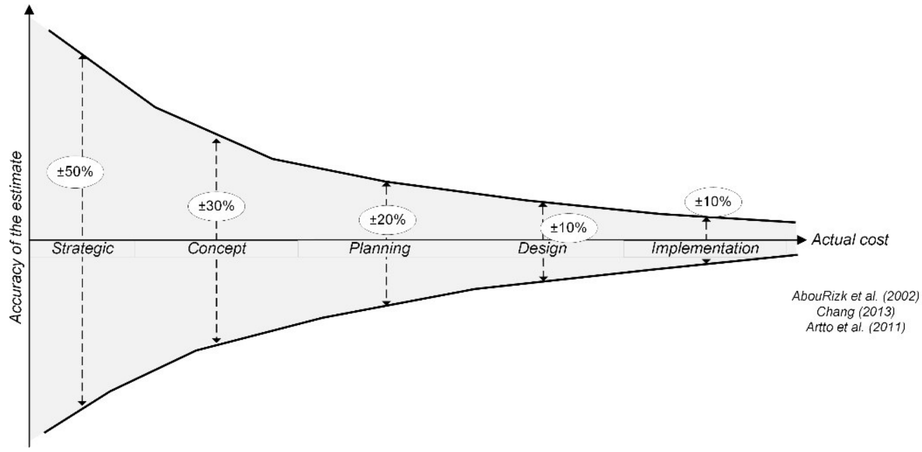

Figure 26. *Accuracy of cost estimation at different stages of project planning.*

The figure shows the observed accuracy boundaries at the stages of project planning. The strategic estimate is used in managerial purposes, for example in a milestone “go/no-go” decision (Doloi, 2013), and the observed accepted accuracy at that stage was ±50%. At the conceptual stage of the planning process, the accepted accuracy was about ±30%. At the planning, or so-called pre-design stage of the process, the accepted accuracy range was observed to be ±20%. Later, at the design and the implementation stages of the project, the accepted variance corridor was calculated to be ±10%. The implementation phase of project lifecycle does not belong to the preparation phase, but us often used in accuracy boundary setting, since the benchmark value for actual expenditure is obtained only after the project completion. The study was carried out based on the data from 213 construction projects, and the construction industry is notorious for cost overruns (Shehu et al., 2014; Kwon and Kang, 2018). The investigation on varying industrial standards is to be undertaken to gain an understanding of acceptable cost estimation accuracy boundaries with respect to the stage of the project lifecycle.

Canadian Ministry of Transport and Infrastructure classifies their cost estimates based on the idea of accuracy boundaries into estimate levels. The estimate levels are conceptual, planning, preliminary, design and pre-tender, which are associated with the level of completeness of project development (MOTI, 2013). The conceptual stage is associated with 0-2% of development completeness, planning – 1% to 15% completeness, preliminary – 10% to 40%, design – 30-90% and pre-tender – 80% to 100% development completeness. The accuracy ranges are defined with a 90% confidence level and are ±35% for conceptual and planning estimate level, ±20% for preliminary and design estimate levels and ±10% for pre-tender estimate level (MOTI, 2013). The accuracy boundaries for the earliest stages of project development are stricter than the ±50% observed by

AbouRizk et al. (2002). The two reasons for a narrower accuracy range may be the industrial differences as well as the evolution and computerization of cost estimation practices.

Taylor (2007, p.108) published the accuracy boundaries for the project data analyzed by the Project Management Institute. The three estimate categories that the author defined are a rough estimate, budgetary proposal, and definitive estimate. The accuracy ranges for the three classes respectively are -25% to +75%, -15% to +25% and -5% to +10%. The same ranges are collaborated by Kerzner and Kerzner (2013, p.681), whose guidelines are also based on the PMI's data. However, Kerzner and Kerzner (2013) additionally emphasize that the acceptable accuracy boundaries depend on the organization and the industry they operate in and are to be determined case-by-case. Humphreys (2005, p.59) carried out a review of standardized cost estimate classifications and accuracy boundaries. The author describes that the American National Standards Institute in 1991 defined three classes of estimates – order-of-magnitude, budget estimate, and definitive estimate. The respective accuracy boundaries of the classes are -30% to +50%, -15% to +30% and -5% to +15%.

Washington State Department of Transport employs a different set of guidelines for their estimation accuracy ranges. WSDOT (2015) defines five different estimate levels corresponding to the stage of the design completion. Planning includes stages of completion from 0-2% and 1-15%, scoping is a stage at 10-30% of development, design stage corresponds to 30-100% design completion and PS&E (plans, specs, estimate) is the last stage of project development with 90%-100% degree of completion. The five accuracy ranges that correspond to each stage of the project design development are:

- Planning (0-2%): -50% to +200%,
- Planning (1-15%): -40% to +100%,
- Scoping (10-30%): -30% to +50%,
- Design (30-90%): -10% to +25%,
- PS&E (90-100%): -5% to +10% (WSDOT, 2015, p.4-14).

As can be noticed, the ranges defined by WSDOT are not symmetrical, indicating that the projects are more prone to cost overruns. Additionally, the magnitude of the range of accuracy is substantial, compared to that defined by MOTI (2013) and AbouRizk et al. (2002). The reason behind the larger spread is the length of forecasting. Compared to the investigated construction projects that lasted around 3 years (AbouRizk et al., 2002), the forecast at the planning level of estimate carried out by WSDOT is 20- and 10-year plans respectively. It follows, that the accuracy of the estimate is dependant on the length of the project.

Queensland Government (2017) sets yet again a different standard for the accuracy of their cost estimation for transport and main roads related projects. The four levels of cost estimate accuracy boundaries are defined at the four stages of project development: concept, early design, design, and implementation. The concept phase has an estimation accuracy boundary of -15 to +20%; the early design stage is expected to range in accuracy from -10% to +15%. The design stage has boundaries from -5% to +10%, and at the implementation phase, the range of estimates is set at -2.5% to +5% (Queensland Government, 2017, p.5). The intervals set by Queensland Government are also asymmetric, expecting more cost overruns rather than cost savings.

Department of Energy (DOE, 2011) presents another classification employed in the cost estimate classification and accuracy range boundary setting. DOE defines five classes of estimates corresponding to the degree of the project definition. Each of the classes is assigned with a low and high range of expected accuracy, which is defined at a 50% confidence level. The accuracy levels are set as follows (DOE, 2011, p.15):

- Class 5 (0-2%): Low range -20 to -50%; High range +30 to +100%,
- Class 4 (1-15%): Low range -15 to -30%; High range +20 to +50%,
- Class 3 (10-40%): Low range -10 to -20%; High range +10 to +30%,
- Class 2 (30-70%): Low range -5 to -15%; High range +5 to +20%,
- Class 1 (70-100%): Low range -3 to -10%; High range +3 to +15%.

This performance standard is generalized, thus is includes the high and low ranges of estimation accuracy, instead of a single accuracy range. The guidelines are provided for energy and construction projects, although, it is mentioned that the guidelines are of a recommendatory character rather than mandatory. The ranges of estimation accuracy were developed in 1997 by AACE International as an elaboration of the previous standard proposed by ANSI in 1991. AACE International is the Association for the Advancement of Cost Engineering and has issued a series of recommended practices for cost estimation (AACE International, 2016). The summary of all the reviewed accuracy boundaries is presented in Appendix B.

Overall, the asymmetric range of estimation accuracy boundaries suggests that in general, the projects tend to face uncertainties leading to cost overruns rather than cost savings. Love et al. (2013) state that normal distribution is not applicable to model the cost overruns since normal distribution assumes that the values are symmetrically situated around the mean. Cost overruns are somewhat random and in order to model cost overruns, probability density functions are often used (Love et al., 2013). The probability density function is a basis of the Monte Carlo method, which is used in cost estimation. The deduced tendency of cost overruns being more likely than cost underruns, GAO

(2009, p.38) collaborates that the cost estimate tends to increase throughout the project's lifecycle. It is noteworthy that Taylor (2007) defines an acceptable variance corridor of ±10% deviation from the baseline. Taylor (2007) claims that if the cost variances throughout the project exceed 10%, it typically cannot be recovered to attain the variance at completion of less than 10%.

The accuracy boundaries are required for setting contingencies. Contingency and management reserve are used to alleviate the negative effect of anticipated project variance. Venkataraman and Pinto (2008, p.97) express contingency as "a cushion against time and money variances", although, the researchers also mention that the customers often see contingency as additional expenditure rather and may get an impression that the seller organization is incapable of carrying out a high-quality estimation nor producing a detailed design on time. Hence, it becomes of utmost importance for the seller organization to make sure that the contingency percentage is established correctly and correspondingly to the degree of uncertainty associated with a particular stage in a project's lifecycle.

5.5 Method for reducing variance through improved cost estimation processes

Peter Drucker in his work "The Effective Executive" (1967), describes the difference between effectiveness and efficiency in a memorable manner – "effectiveness is getting the right things done, while efficiency is getting the things done right". The definition of effectiveness and efficiency resonate with the definitions of lean and six sigma philosophies. Lean was developed as a quality control technique in Japan at the time of economic recession, which concentrated on eliminating production 'waste' or the 3Ms (Nicoletti, 2012, pp. 1-21). The 3Ms are *muda, muri, mura,* which from Japanese mean waste, unreasonable and illogical, and variation and poor management. Lean by itself is not a holistic process quality control method. The most evolved quality control method is lean six sigma, which integrates the essential ideas from both philosophies. Six Sigma philosophy concentrates on identifying the activities that lead to defects and variation and the root causes for these variations, subsequently adjusting and improving the process (Bradley, 2015, pp. 25-33).

The synthesized lean six sigma philosophy is a method for continuous process improvement in an organization by correcting flawed processes as well as making sure that the processes are carried out with the optimal lead times. One of the mechanisms to ensure that the "right things and being done right" within a project organization are to implement a systematic and standardized set of procedures. The systematic approach entails that the actions are carried out methodologically, i.e. based on pre-defined logic and logical correlations, which makes the attained knowledge organized and contributes to the overall increase in knowledge (Saunders et al., 2009, p.5).

Knowledge and information management are the starting point of managing uncertainty, as uncertainty is associated with the lack of information (Munier, 2014, p.2). Nonaka (1991) emphasizes the importance of knowledge in the modern economy, where “the only certainty is uncertainty” and knowledge is a source enabling organizations to sustain competitive advantage. Nonaka (1991) discusses the concept of knowledge spiral, which is based on the idea of organizational learning resulting from intersection and conversion of tacit knowledge to explicit knowledge and vice-versa. Ulonska and Welo (2014) emphasize that systematically converting tacit knowledge into explicit knowledge is beneficial for the efficiency of the organization, namely accessing the information and reducing uncertainty.

Grant (1996) discusses the foundation of knowledge management (KM) and some of the core principles are – transferability, the capacity of aggregation and knowledge acquisition. Transferability refers to the ability to codify tacit knowledge to the form of explicit knowledge, so that other individuals will be able to apply that knowledge. Knowledge aggregation potential refers to the compatibility of different forms of knowledge through expressing that knowledge in a similar form. Although, there is a type of knowledge, called idiosyncratic, which cannot be easily aggregated, due to its circumstantial and highly specific nature (Grant, 1996). Knowledge acquisition is based on the idea that human has a limit to storing and processing knowledge, hence, requiring various experts to take care of the necessary areas of competencies within the organization. It follows, that on the organizational scale, it is important to ensure that there is a systematic approach of data gathering, reporting and archiving. This, added to the research of Nonaka (1991) and Ulonska and Welo (2014), emphasizes a need for an information system architecture within an organization. Systematic knowledge sharing via reporting and archiving leads to knowledge accessibility, which is a mechanism of uncertainty reduction.

Uncertainty is one of the characteristic challenges in cost estimation. The uncertainty can be managed with systematic knowledge management and procedures, defining a set of requirements and procedures for the cost estimation process can potentially alleviate the effect of uncertainty on the quality of the cost estimate. An inadequate and inaccurate cost estimate leads to cost overruns in projects (Shane et al., 2009; Hicks, 1992, Venkataraman and Pinto, 2008; Jørgensen et al., 2012; Flyvbjerg et al., 2002). Although cost variance can be controlled during project preparation and implementation phases, if the cost baseline is unrealistic, then the project manager will be unable to meet the targets throughout the implementation phase (Hicks, 1992). The cost baseline is a component of the aggregated project estimate and contingency. England and Moreci (2012) break down contingency into risk-related costs and estimate uncertainty costs, as shown in Figure 27.

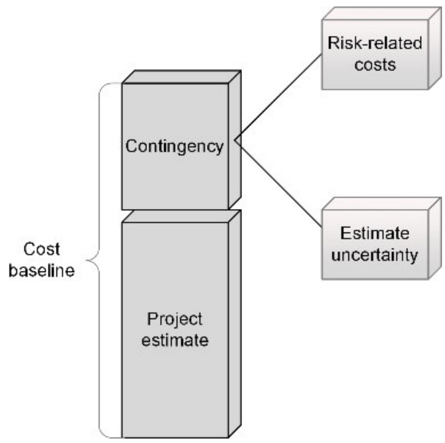

Figure 27. *Project contingency (adapted from England and Moreci, 2012).*

Typically, contingency and management reserves are used to soften the effect of variances that are bound to occur throughout the project (Venkataraman and Pinto, 2008, p.97). Venkataraman and Pinto (2008) note that the customers tend to be sceptical towards the contingency reserves, as it may come across that the seller company is not capable of designing and pricing their own offering. Additionally, customer satisfaction may be impacted, if the cost estimate keeps increasing throughout the project planning phase. Thus, it is of importance to set the contingency levels appropriately, not to present higher than competitors' prices to the customer, while at the same time not risking your own profit. In order to provide a realistic estimate at the required time, the organization and the cost estimator should be aware of the degree of uncertainty associated with the estimation technique used.

Skitmore and Lowe (1992) state that the high-quality estimate depends on the correctly chosen estimating technique, availability of design and cost information, size of the project and utilization of feedback from past cases. Taylor (2007) advises using the most accurate technique available and a combination of methods, if possible. The most accurate method, however, may be unfeasible and too expensive, besides being unattainable due to the degree of project specification and information deficiencies. Information availability is guided by project definition, at the same time allowing for a more accurate cost estimation technique to be used.

The accuracy of the estimate is associated with the class of the cost estimate as well as the estimating methodology used, meaning that the accuracy boundaries of cost estimation are determined by the accuracy of the cost estimation technique as well as the stage of the project development. To create a common understanding of choosing the method and specifying the degree of uncertainty involved in the estimation, a skewed distribution uncertainty model, accounting for cost overruns being more probable, is introduced and presented in Figure 28.

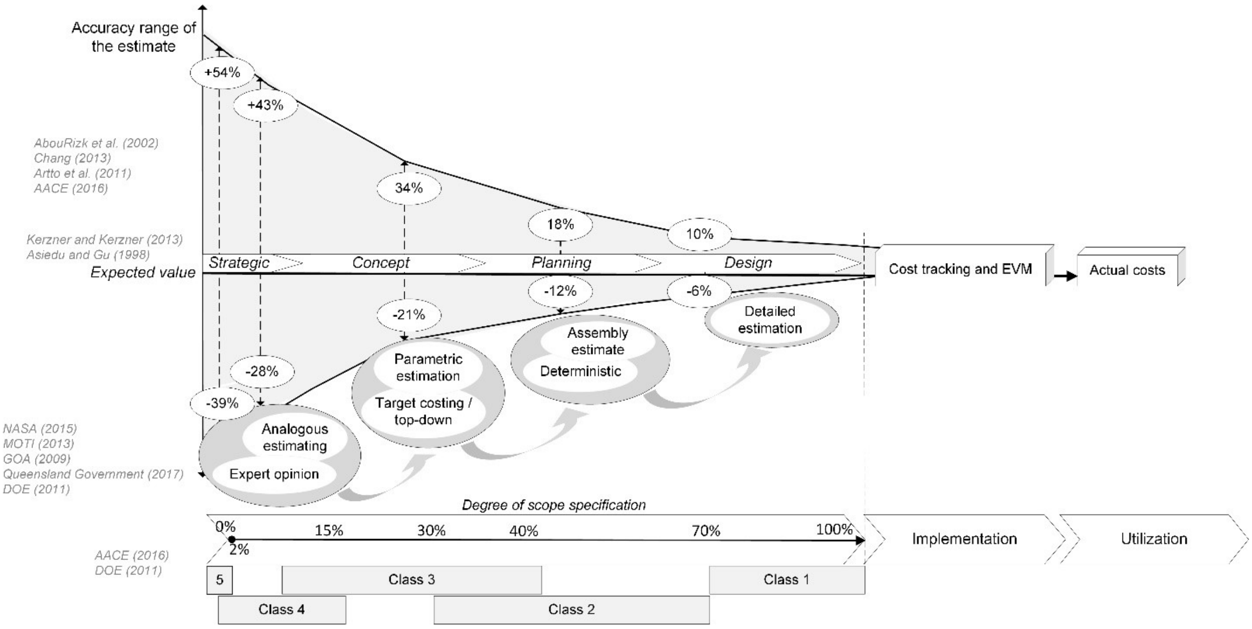

Figure 28. *Uncertainty model of cost estimation during project preparation.*

The figure illustrates the five classes of cost estimates and their accuracies correlated with the technique bundles that are fitted to the project development stage based on the information requirements. The accuracy boundaries are averaged from the reviewed boundaries of projects in construction, infrastructure and transportation industries (see Chapter 5.4 and appendix B: Estimation accuracy boundaries). The averaged accuracy boundaries correlated with the estimation technique and project development phase are shown in Table 8.

Table 8. *Cost estimation techniques and their accuracy boundaries.*

Development stage:		***Low***	***High***	***Estimate class***	***Estimation method***
Strategic	0-2%	-39 %	54 %	Class 5	Expert opinion & analogous
Strategic	1-15%	-28 %	43 %	Class 4	Expert opinion & analogous
Concept	10-40%	-21 %	34 %	Class 3	Parametric & top-down estimating
Planning	30-70%	-12 %	18 %	Class 2	Assembly & deterministic
Design	70-100%	-6 %	10 %	Class 1	Detailed estimation

The table shows that the recommended estimation techniques vary based on the stage of the project preparation, and the accuracy of the estimate classes also varies. The more information is available regarding the project, the more accurate the estimation can be. The accuracy boundaries that are presented in the table are averaged across the reviewed existing accuracy boundaries. However, Kerzner and Kerzner (2013) specify that for each industry, the boundaries differ based on the business- and operations-related specifics.

Choosing the correct method of cost estimation is only a part of managing uncertainty involved in the process. As was discussed in Chapter 3.3, cost overruns are the manifestation of risk, which in turn, is a successor of uncertainties. The scope of this work is to evaluate the controllable factors internal to an organization involved in the process of cost estimation, excluding uncontrollable and external influences. For this purpose, a separate category of risks was defined as internal foreseen risks. Inadequate resource planning and unrealistic schedule are both precursors of inadequate project baselines, leading to cost overruns. Lack of information is a characteristic problem to cost estimation. Project prioritization and conflict of resources are the risks to be mitigated at the organizational level by coordinating the projects and departments and ensuring adequate resource planning and availability. Lack of systematic procedures is an element facilitating business operations through knowledge management, which ideally should be homogenous on the organizational level, and without a doubt, homogenous on the department level.

It was earlier suggested that contingency constitutes of risk-related costs and estimate uncertainty. To avoid the interference of the two types of contingencies, the cost estimates should be based on the available information and not padded (Taylor, 2007). Such interference can cause double-counting the risks, which is a commonly occurring malpractice in risk management. Risk double-counting is a result of poor understanding of complexity and interactions between the elements in the risk analysis (Roger and Petch, 1999, p.6). Separate risk evaluation and documentation for risk-related costs and cost uncertainties is a useful tool to consider. When thinking about aggregating a cost database, it would be beneficial to know the historic trends of cost overruns and whether they were caused by insufficient contingency reserves to account for the risk factors or cost uncertainties. Having a historical database for the cost uncertainty ranges is instrumental in setting the estimation accuracy boundaries.

The internal foreseen risks, unlike the external, pure, technical and other typically identified risks (see Table 3) should not be mitigated via assigning contingency reserves in order to prevent the danger of double-counting. The internal foreseen risks identified in this work can be managed by implementing a systematic estimating procedure, which decreases, if not eliminates, this type of risk from the organization's operations. It is possible to avoid the internal foreseen risks because they originate from within the organization and are controllable in nature. GAO (2009) collaborates that a systematic standardized procedure for cost estimation leads to higher quality estimates and a higher rate of success throughout the projects. Chapter 4.3 discusses the procedures of cost estimation in project organizations, each based upon the identified commonality factors and each containing twelve steps. A synthesis of the reviewed procedures that accounts for the characteristics of high-quality estimates is presented in Figure 29.

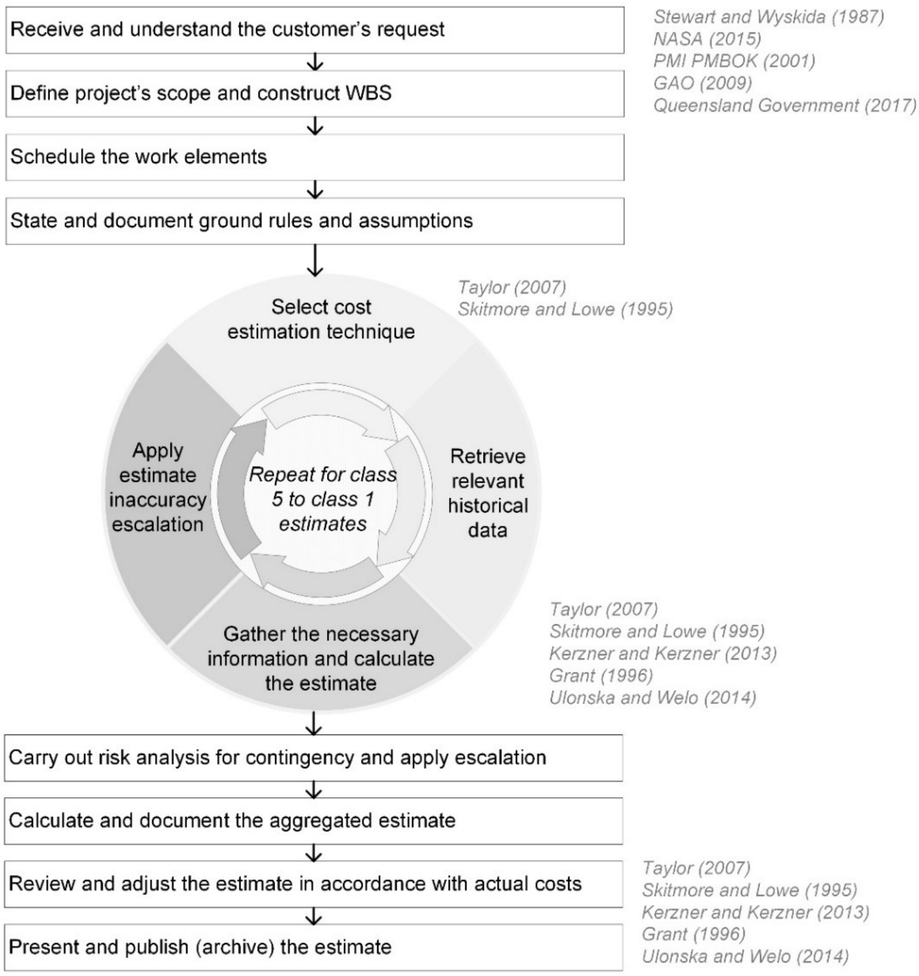

Figure 29. *Systematic cost estimation promoting estimation quality and KM.*

The figure shows the twelve steps of systematic cost estimation that incorporate prerequisites for a high-quality estimate as well as promote knowledge management within an organization. The process is initiated with receiving and understanding the customer's request, defining technical specifications and constructing WBS. These steps form the information prerequisite that is needed for an accurate cost estimate, as poor design, misunderstanding the customer and inadequately constructed WBS lead to cost overruns (Havranek, 2017; Venkataraman and Pinto, 2008; Shane et al., 2009; Hicks, 1992). If the first three steps are carried out properly, some of the internal foreseen risks are avoided. Understanding the customer, defining the technical specifications, constructing

WBS and scheduling activities, if done adequately, ensure appropriate resource planning and realistic schedule, as well as information availability.

The lack of information can be furthermore tackled with creating and maintaining an appropriate archive of historical data. In the case of cost estimation, the data may be related to the unit cost of activity, supplier costs, transportation costs, sizes and weight of equipment delivered and their cost, and others. A database is also a form of transforming tacit knowledge to explicit, as it entails documenting project specifics by the stakeholders involved in the project. A cost estimate report, containing the actual costs and the reflection on the accuracy of the estimate is an invaluable element of determining the estimation inaccuracy for future projects undertaken by the organization. A template for a cost estimating report is shown in Table 4. The complete schematic representation of the recommended cost estimation process for the project organization is schematically shown in Figure 30.

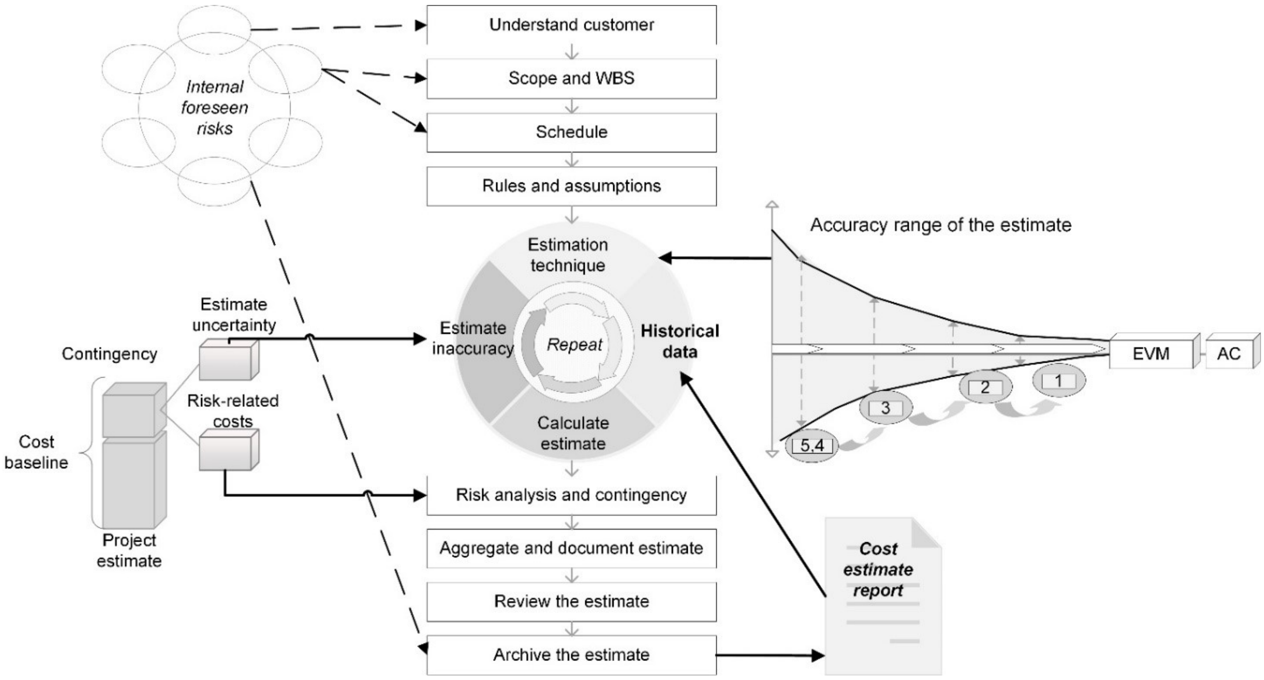

Figure 30. *Method for cost estimation in a project-based firm.*

The figure demonstrates a systematic cost estimation process with a guide for selecting a cost estimating technique appropriate for the stage of the project preparation process. In addition, the method suggests how the internal foreseen controllable risks can be mitigated and contingency reserves assigned without double-counting the risks. A crucial part to the accuracy of cost estimation is the follow through the whole process and create a cost estimating report, which is then archived. The report should contain the initial cost estimate and all the adjusted estimates, including the final actual cost, which serves as a performance indicator of the initial cost estimate.

6. CASE COMPANY

6.1 Sales organization in the case company

The case company is a Finnish industrial company, which provides a range of solutions and services around the world. The competencies of the organization include engineering and automation solutions as well as services and the product portfolio of each of the business units of the company is vast. The case company identifies the experience in the industry and its wide product portfolio as strengths since the company is able to provide their customer with a completely customized and tailored to customer's needs system solution, including engineering services, automation, process technology, and service contracts. The scale and the nature of the case company's operations, as well as a diverse product portfolio, creates challenges when it comes to project planning and cost estimation.

The projects within the case organization can be subdivided into three categories: sales projects, delivery projects, and warranty projects. Each project normally follows through all three stages, the earliest being the sales project phase. To avoid confusion, it is noteworthy that the earlier discussed delivery project differs from what is called a delivery project in the case company. In the case company, the project's classification changes throughout its lifecycle, as shown in Figure 31.

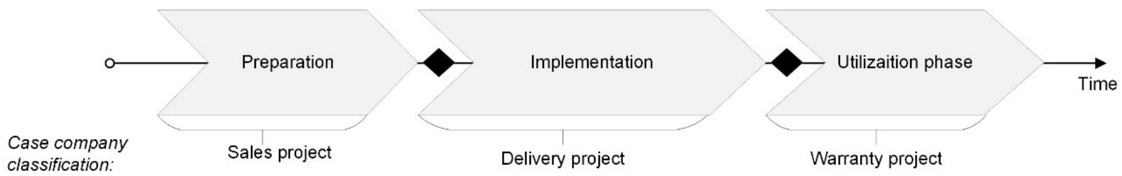

Figure 31. *Project classification in the case company.*

As the figure shows, at a pre-contractual phase, projects are classified as sales projects. After the contract was signed, the project's status changes to a delivery project and at that stage, the scope of the project is executed. After the project is handed over to the customer, its status changes to a warranty project, which lasts according to the specified contractual terms. The case organization is in its core a project-business firm, which consists of multiple departments that sell and deliver their own projects as well as collaborate to deliver a larger in scope offering. The multi-unit projects, which are sometimes called multi-divisional, bring their own challenges. At times, it may be difficult to coordinate the activities on a multi-divisional scale, which calls for a systematic approach to project planning and delivery. The systematic procedures and code of conduct are instrumental also for the situations when the departments deliver projects independently. The process standardization is an approach of ensuring that the departments' activities are aligned with the organizational strategy and follow the code of conduct.

To unify and standardize the sales processes between the departments and enable more effective collaboration, especially during the multi-divisional projects, a universal set of sales procedures is established within the company. Sales organization in the case company is organized correspondingly to the idea of the sales funnel in B2B marketing (see Figure 23). The details of the sales processes within the organization may differ based on the department and the delivery scope of a business unit, but the backbone of the process follows the same principles and the same targets. The general targets of the sales process are to increase the sales volumes and margins, develop a common sales methodology with a customer-centric approach, harmonized selling process between the departments and overall to establish an effective sales organization according to the company's guidelines and principles.

Besides the sales funnel, the company's sales approach is trying to mirror the customer's buying process. The customer's buying process consists of three stages – solution development, evaluation, and commitment. It is recognized that sometimes the sales efforts begin only at the evaluation stage of the customer buying process, bypassing the opportunity identification and validation stages alongside one of the gates in the process. If some of the stages of the sales process are skipped, there is a danger of not laying down all the necessary groundwork for the successful project implementation. The company's sales formula relies on the fact the progress and data aggregation throughout the preparation stage of the project's lifecycle is cumulative, implying that the milestones throughout the set the information requirements for the process. Furthermore, the milestones provide process systematization, ensuring that the required activities were carried out and the required information was gathered. Such an approach to activity management with activity phases and intermediate milestones is called the stage-gate process.

The sales process formula is comprised of five general phases: (1) opportunity screening, (2) indicative proposal, (3) budget proposal, (4) firm proposal and (5) negotiations. The sales process of the case company is schematically represented in Figure 32.

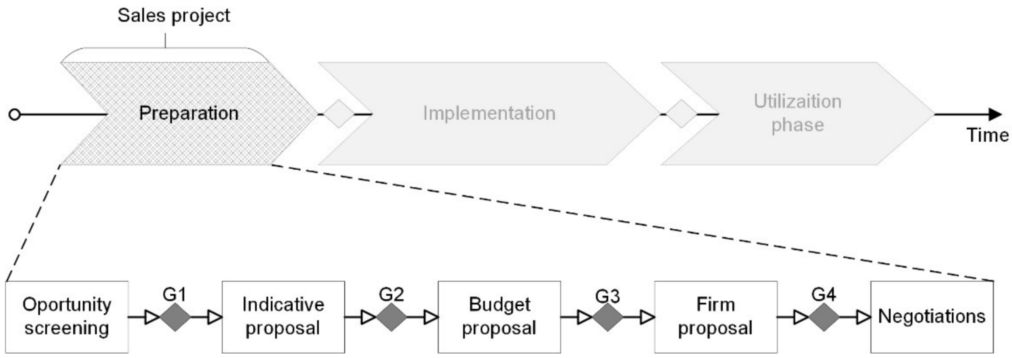

Figure 32. *The sales process in the case company.*

The figure demonstrates the sequence of five phases of the sales process formula and the intermediate gates named from G1 to G4. The gates are the decision points, where managerial audits are conducted to determine whether to proceed with the sales efforts and to evaluate the state of the sales project. The stage-gate model is an effective tool to support quality management throughout the process (Wuest et al., 2014). Wuest et al. (2014) recommend positioning the gates in the process so, that the performance can be traced to the creator of the progress. The gates are recommended to be situated before the responsibility and liability shifts, implying that the stage-gate model could be beneficial in terms of dividing and clarifying responsibilities in addition to setting measurable targets. Since each of the steps throughout the sales process is associated with a certain milestone, there exists an information input and output requirement from each process.

The first milestone (G1) after the opportunity screening phase is of a strategic character, where the management evaluates whether there is a business opportunity in a certain sector as well as the feasibility of the opportunity to the organization in terms of strategy. The first phase and gate of the company's sales formula identify with the definition of the strategic project preparation phase. After the G1 milestone, the organization should have gathered information about the customer as well as determined if the company has the potential to cooperate with the customer.

The next phase is the indicative proposal phase, where the design alternatives are compared and the most promising one is selected. The output from that phase includes the concept of the offering as well as a very rough ballpark price estimate. The indicative proposal stage is followed by G2, where the technical requirements and competencies are assessed and whether the company possesses the necessary competencies. Additionally, the project opportunity is further assessed in terms of profitability. This is the first phase, where the company enters the tendering process, meaning that the focus shift to demonstrating and delivering the value to the customer.

During the budget proposal stage, the organization is concerned with how to deliver a competitively priced yet state of the art offering. At that stage the technical specifications are defined in more detail, however, they are still limited and the cost estimate is adjusted according to the newly emerged technical specifications. Since the aim of the stage is to create a competitive offering, the technical specifications may be adjusted to decrease the price, which is, in essence, the DTC approach. G3 aims at identifying whether the budgeted price is attractive for the customer and whether the offering is competitive compared to others in the market.

The firm proposal is a stage that requires the seller organization to produce detailed technical specifications and a detailed price. This process is very work-intensive and time-consuming, making it costly for the company. The general guideline is that the case company should not enter the firm proposal phase if the customer is not definitely prepared to invest in the project. G4 follows the firm proposal phase, where the company can make the final revision of the proposed scope and price as well as decide whether to proceed with the project or not. Final negotiations are the phase, where the project delivery is discussed and confirmed with the customer, including the contractual terms. The customer still must make the decision which supplier to award the project to. After the negotiations phase is concluded, if the case company is chosen as a supplier, the budget is finalized, the scope is documented, and the contract is prepared. The division of responsibilities in the case company throughout the sales process is shown in Figure 33.

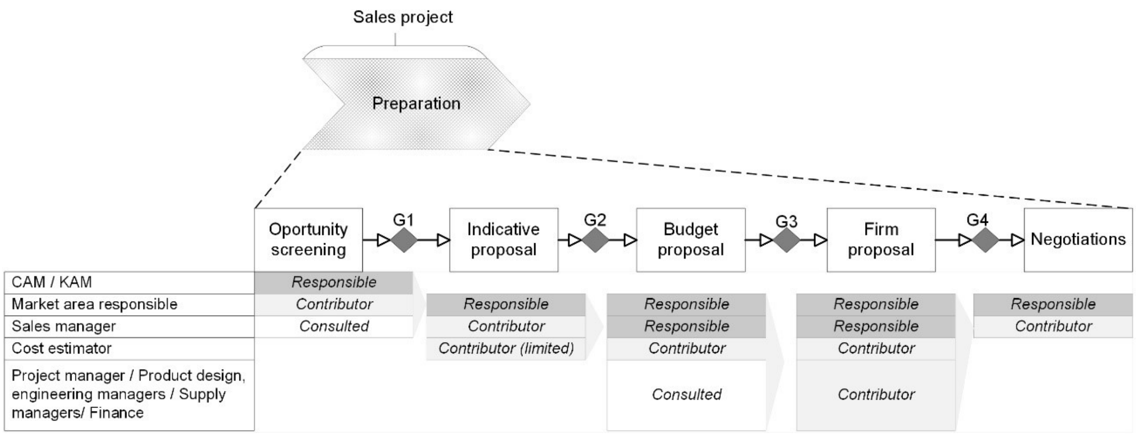

Figure 33. *Division of responsibilities throughout the sales process.*

The figure illustrates the shift of responsibilities among the internal project stakeholders throughout the sales process. The role distribution is classified as responsible, contributor and consultant. Corporate and key account managers are responsible for the strategic phase of the sales process, where the market area responsible is a contributor and the sales manager serves as a consultant. The market area responsible becomes and remains responsible for the rest of the sales process starting from indicative proposal all the way to negotiations. The sales manager is a contributor at the indicative proposal stage and is responsible for the budget and firm proposal stages. The cost estimator is a limited contributor at the indicative proposal stage and a contributor at the budget and firm proposal stages. The project, engineering, product, supply, and design managers, who are responsible for the planning stage of the project are consulted at the budget proposal stage and contribute during the firm proposal stage. It follows that the estimator's involvement starts from the indicative proposal stage and ends with the firm proposal. The stages from indicative proposal to form proposal are going to be considered in the context of cost estimation in the case company.

The case company's sales formula indicates that the cost estimation follows through the sales phases and gets more accurate with each phase as the scope of the project is specified. Additionally, it was confirmed from the cost estimator in the case company that…

"…the estimate should not increase throughout the sales process unless the technical specifications are changed, otherwise it creates a bad impression for the customer".

The cost estimator elaborated that the customer satisfaction is impaired because, throughout the sales project, the customer and the case company usually negotiate a discount and aim to reduce the final price of the solution, hence the increases in price will negatively affect customer satisfaction. Thus, it is important to communicate the purpose of the estimate and the accuracy of the estimate to the salespeople, so that the salespeople know how to properly utilize the estimate and not make premature promises to the customer.

The accuracy of the final cost estimate is relevant for the projects' success since one of the performance criteria that is used to evaluate the project is the cost baseline, which is based on the cost estimate. Realistic and attainable cost estimates and cost baselines are fundamental to ensuring the project's success. When it comes to underestimates, if the cost baseline is too low, it is outside the project manager's power to keep the project within the assigned budget. The overestimates are dangerous during the sales phase, as an unrealistically high price might lose the whole case for the firm. Furthermore, according to the Freiman curve, overestimates tend to lead to higher than necessary project expenditure. Hence, it is imperative to prepare the cost estimate that is appropriately accurate, which, as was concluded, has prerequisites in the form of information.

6.2 Cost estimation in the case company

The cost estimation process as a part of the sales process within the case organization has a unified backbone set of guidelines that each business unit should follow. However, the cost estimation procedures vary between the business units due to the differences in pricing product offerings compared to service offerings and systems offerings. The differences occur based on the cost-incurring processes and unit costs that are offering-specific. For example, in some cases, the work is partially outsourced and partially completed in-house, in some cases all the work is outsourced. For some projects, only the labor costs are estimated and for some projects, estimating labor and material costs is necessary. The department where the researcher is involved carries out cost estimation of own and contractor's work and well as purchased materials and miscellaneous items. The scope of cost estimation of the case company is illustrated in Figure 34.

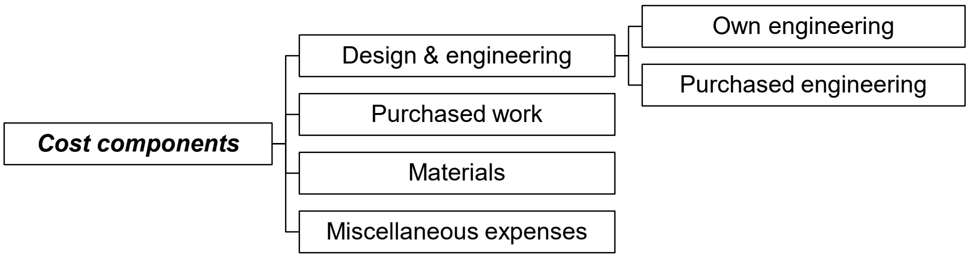

Figure 34. *Cost components in the case company.*

The cost component classification shown in the figure includes the categories of cost incurring objects in a typical project carried out by the case company. Different cost components require different sources of information for successful cost estimation. The costs of purchased engineering and materials are computed from the contractors' quotations based on the technical specification provided by the company. For the less accurate cost estimating, the previous contractor price lists and quotations can be used to estimate the cost of work and materials for a similar project. The price of work and materials can be estimated using reference market price levels and the unit costs from previous similar projects. To sum up, the core information sources for cost estimation include engineering and planning documentation, reference cases, historical data, market prices, and expert opinion.

The unit cost data may constitute, for example, the price per kilogram of material (€/kg), a diameter of pipes, the volume of parts and similar. The estimation is then carried out by estimating the quantity of materials and work required in the project and multiplying with the prices according to the market price levels or the incurred costs of similar wok in previous projects. This approach to cost estimation is called elemental parametric and it is a commonly used method in the case company. The elemental parametric cost estimation can be as accurate as the available information allows, gradually turning into the detailed estimation method (MOTI, 2013, pp.17-18). The reliability of the estimate depends upon the accuracy of the information gathered from the previous projects as well as the suitability of the unit costs selected for the elements. Additionally, the unit cost should correspond to the market price format, if possible, i.e. if the market price of steel is given as a price per mass (€/kg), the data in the cost database should not be accumulated as a price per length (€/m).

All the cost components, including purchased work, own work, materials, and miscellaneous costs can be estimated through elemental parametric modeling, which requires a systematically compiled database of historic cost-per-unit information. When the historic and market-based information is not available, the assumptions for the parametric modeling can be carried out as a one-point estimate or a three-point estimate based on the reference projects, or expert opinion. It is crucial to document the basis of the estimates so that the reliability of the estimate can be assessed and adjusted according to the stage of the project lifecycle.

The cost estimator in the case company commented on the challenges of cost estimation in the organization. The challenges they identified are the nature of project business, large projects, reliance on supply chain and the human factor in cost estimating. These challenges were drawn from the literature review and reported in Table 7. The unique scope of each project and tailor-made technical solutions make the application of historical data in cost estimation challenging since there are no identical projects and the figures need adjustments. It is difficult to estimate the costs for larger projects. The larger the project, the more prone it is to cost overruns. Modern tendency to outsource and hire contractors to perform a share of workforces the cost estimator to rely on the contractors' estimates, which may not be reliable. The human factor implies possible inaccuracies caused by the individual's personality as well as calculation or planning mistakes. The cost estimator identified another challenge related to no means of storing historical data in a harmonized manner and occasional ineffectiveness of the cost review process. The researcher identifies the problem as a lack of systematic procedures.

Some of the challenges that were identified from the literature are not manifested in the case company. For example, there is an abundance of historical data, it is just scattered across the digital storage locations. The cost estimator did not attribute the challenges in cost estimation to issues regarding itemization and cost allocation nor to the novelty of the technology. The process being resource-consuming and assigning cost estimation to technical staff were not identified as problem-causing factors in the case organization.

Two cost estimators from other departments were interviewed to get an insight into the cost estimation challenges and whether the identified challenges are department-specific or rather are common on the organizational scale. One of the cost estimators attributed the difficulties in cost estimation to the custom-made solution, reliance on supply chain and the human factor. The other cost estimator said that the project uniqueness, lack of historical information, unclear cost account structure and custom-made solution are the main aspects hindering the cost estimation. Both cost estimators added that they experience challenges with the technical specification and supply plan changes in the late sales phase and early delivery phase. Information flow, lack of resources for design and engineering, delays in technical specification and misinformation from the customer's end were additionally identified as challenges in cost estimation.

The process of cost estimation becomes more complex in multi-divisional projects, especially when it comes to the division of responsibilities – every element should be planned and accounted for, and double-counting should be avoided. Each department has its own cost estimator or even several, that possess the technical competencies and understanding of their departments' product portfolios. The division of responsibilities in the company is pre-determined on the organizational level. Depending on the scope of the deliverables, departments are allocated with the responsibility for the connecting structures and supporting structures related to the elements. Cost estimation strategy meetings are organized before the firm proposal stage to create and confirm the common understanding of the responsibility areas of each department.

It does sometimes happen that the elements are not included in the cost estimation, due to miscommunication, changes in project design or project scope, according to the case department' senior sales & technology manager as well as the cost estimator. It follows, that in the multi-unit projects, a systematic approach to process coordination as well as unambiguous communication is required. Timely and relevant communication helps the cost estimators to include all the necessary changes into their calculations. There exists a process to mediate the communication and division of responsibilities between all the parties involved in the process of cost estimation, as well as ensure that the latest information regarding technical specifications, design, and costs is available to everyone. Without conducting the cost review, the proposal is not allowed to move to the negotiation stage of the sales process, serving as a quality check of the cost estimate and the proposal. The cost estimator's feedback regarding the cost review process is lack of effectiveness and output documentation. Upon further observation, it is concluded that the cost review process is indeed lacking systematic structure and a considerable amount of time is spent on contemplation and deliberation.

6.3 Cost variance analysis

The case company is a project-based firm, and unlike in standard manufacturing, project-based firms encounter cost variance issues during and after project implementation. The initial step towards problem identification was a straight-forward variance analysis based on the data from two or three projects. After conducting the preliminary data analysis and discussing the results with the steering group, a new course of action was elected. Instead of concentrating on two projects, collective data from a set of projects is to be used in the investigation, allowing for a more holistic analysis. The element-specific cross-project variance analysis could be beneficial for tracing the cost history for an element and constructing the learning curves based on that data. Additionally, the element-specific analysis can reveal the commonality between projects, where cost overruns occur, which will assist in a more appropriate contingency setting and risk management procedures.

The department has access to project-specific variance data, meaning that the variance figures presented are usually the total variance between the budgeted cost for the project and the actual cost of project implementation. The researcher identified that it would be beneficial for the company to analyze data on the element-specific basis across multiple projects. Element in this context means an element of a work breakdown structure, which is a typical way of organizing schedules and resources in project business. Such an analysis could potentially bring out a new perspective and reveal systematic cost overruns in certain types of projects or systematically underprized or overprized elements. The element-specific analysis additionally is an attempt to distinguish between systematic and random variances. The hypothesis is that the systematic variances indicate cost overruns or underruns due to incorrect cost estimation and random variances indicate that cost overruns were caused as a result of a risk event. Analyzing the cost variance by element across multiple projects can reveal the most problematic elements causing a variance in the projects and determine if there is a need to adjust the cost estimating procedure and methods regarding these elements.

Project data used in variance analysis was retrieved on the 25th of July 2019 and was used throughout the analysis. The cost data was retrieved again on the 11th of October 2019 to confirm that no significant changes happened to the expenses of the chosen projects. The sample consisted of project budget and cost data from the case company's ERP system. The retrieval criteria for the data was that all the elements are budgeted and billed under the scope of the department, which has its own corresponding value in the ERP system. Altogether, 110 projects with 5 or more elements included were selected for the analysis. The newest projects were excluded with the advice of the senior sales manager and the cost estimator, as the implemented costs were not fully recorded, falsely indicating the positive variance in the projects' elements. Among the 110 projects, there were 167 elements in the fourth level of the WBS, which contained data and could be analyzed. The data analysis was carried out using MS Excel, where the variance percentages, costs, and relative importance were analyzed and compared.

Project-scale and element-scale variance percentages were calculated by subtracting actual costs from budgeted costs and dividing the difference by the budgeted cost, according to Formula 3. The negative variances signified cost overruns and positive variances stood for cost savings. To avoid compensation of positive and negative values for one another, the statistical analysis was conducted based on the absolute values of the element-specific variances, as the main point of interest of the analysis is the cost deviation itself, not only the cost overruns. To determine the elements that have the most variance, the %-variances were averaged by using mean (μ) and median functions in combination. Mean as a function was not suitable on its own, as the outliers skewed the average. Median was used to mitigate the skewing. The formula for calculating the population mean is presented as Formula 4. Median is obtained by arranging the data sample in increasing order and choosing the middle value. If there is an even number of values in the sample, the mean of the two middle values is taken as a median.

$$\%\,Variance = \frac{BC - AC}{BC} \cdot 100\% \qquad (3)$$

$$\mu = \frac{\sum_{i=1}^{N} x_i}{N} \qquad (4)$$

The percental variance analysis was conducted by keeping the data count in mind. The element count across the projects was computed using the *count* function in excel, which calculates the number of values in the selected array of cells. Low data count for an element is a result of the infrequent implementation of that element throughout the projects. The infrequent implementation signifies that the element is either new or not frequently ordered from the company's product portfolio, implying that the case department does not have much experience delivering the element in question. The effect of the variance was assessed for the elements with no restrictions imposed on the data count and with the element count of ten and over. In accordance with the principle of the learning curve, the more the activity is carried out, the better and more effective the execution is. Based on the learning curve theory, it is hypothesized that the elements with smaller count should have the largest percentual variances, and the elements with the higher count should on the opposite have consistently lower variances. Figure 35 shows the results of the element-based cross-project percental variance analysis. It is noteworthy that the sensitive company-related information will not be presented in this report, as the researcher signed an NDA with the case company. The information regarding the product portfolio and names and finances are substituted with example names and the values are not given accurately.

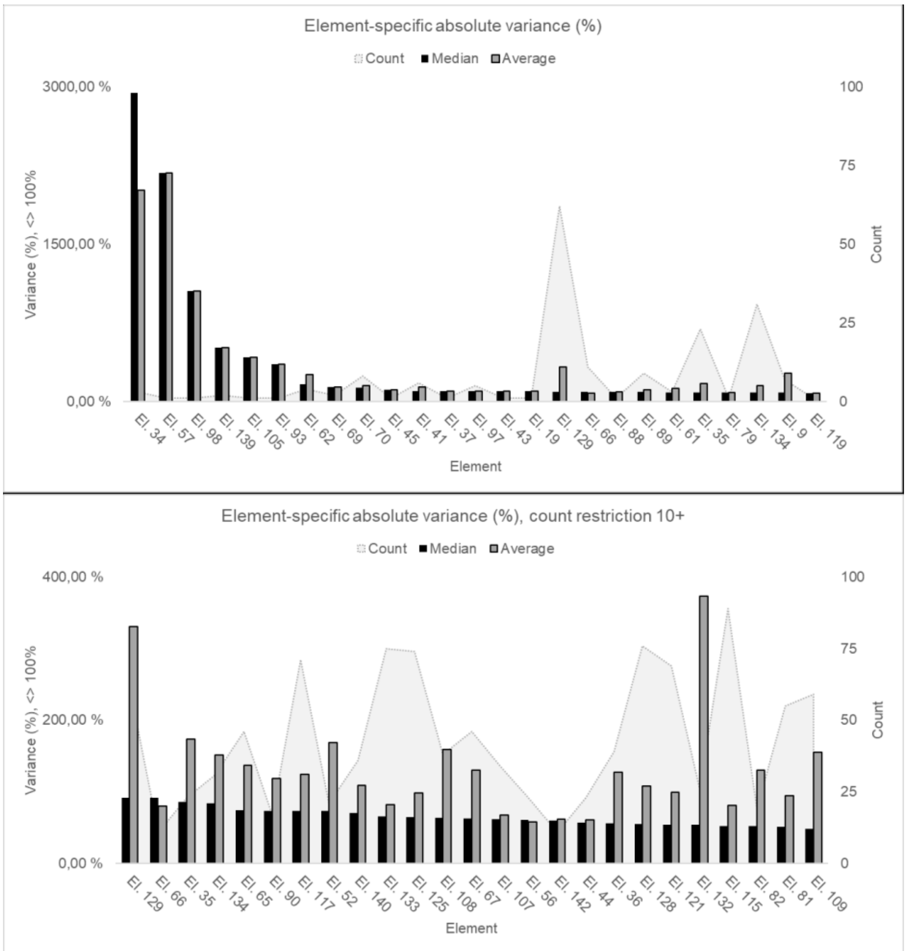

Figure 35. *Results of the variance analysis.*

The figure contains two graphs showing the top twenty-five elements with the largest median percentage variance independent of the element count and limited to the element count of ten and over. The top graph shows the elements with the largest percental variances from the whole sample without the count restriction and omitting the variances equal to 100%. Variances of 100% indicate that the costs were budgeted, but no spending was recorded. Out of the 25 elements with the largest percental variance, 21 of them have a count of lower than ten elements. Surprisingly, element 129 with a count of 62 has one of the highest percental variances in the whole sample. Element 129 has the largest percental variance in the sample with a count limited to 10 or over elements, followed by elements 66, 35 and 134, which are all on the list of the elements with the highest variance percentage. When comparing the graphs, it is noteworthy that the scale of the primary vertical axes differs on the two graphs. The top graph's scale reaches 3000%, while the bottom graph's scale is limited to 400 %. The secondary vertical axes scale on both graphs is identical. The graphs show, that the largest percentual variance can indeed be attributed to the elements with low count, as 84% of the elements with the lowest variance percentage have a count of 9 or less. The variance percentages of these elements are also significantly greater than these of the repeatedly implemented elements, shown on the bottom graph. The absolute cost variance does not reveal whether the cost is being systematically underestimated or overestimated. Further breakdown of cases by the negative and positive variances is required. Cost deviation breakdown into cost overruns and cost underruns are shown in Figure 36.

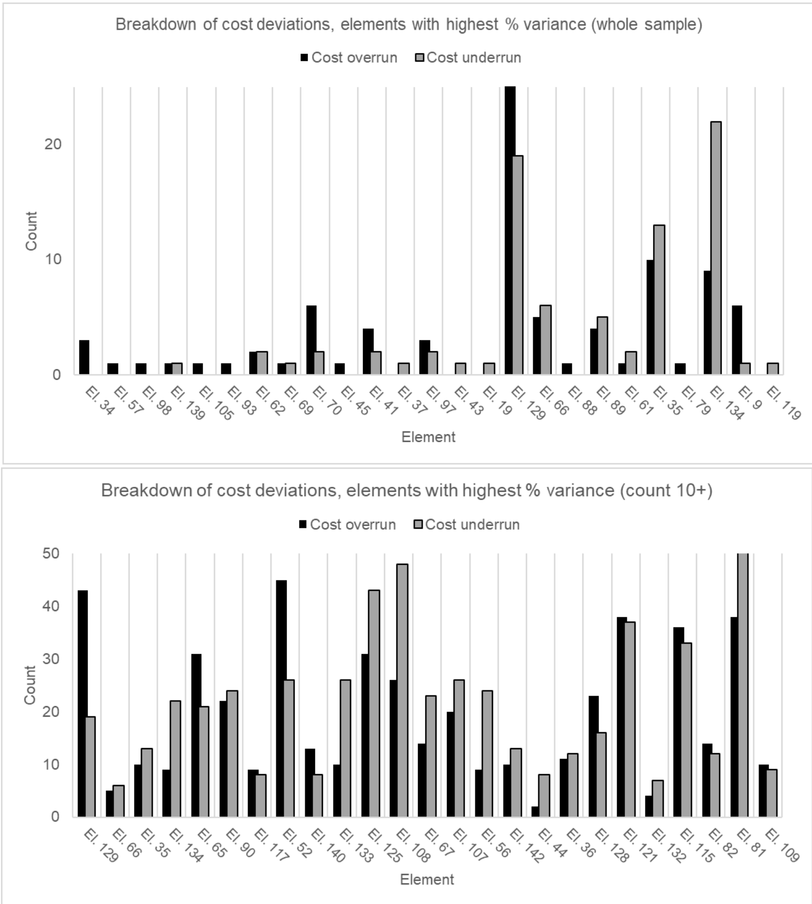

Figure 36. *Cost deviation breakdown into cost overruns and cost underruns.*

The graphs on the figure show the breakdown of the cost deviation cases from Figure 35 into cost overruns and underruns. The top graph corresponds to the elements with the highest variance without count restriction and the bottom one – to the cases with count restriction. In the cases without count restrictions, the cost overruns are prevalent over cost underruns and are demonstrated in 64% of the cases. In the cases with count restriction of 10 and over, cost overruns are observed in 40% of the cases. It can be concluded that cost overruns are more likely when it comes to the elements associated with less experience and infrequent implementation.

When defining the most problematic elements in terms of project variance, it was immediately noticed that a large variance percentage does not always cause disastrous cost overruns. Sometimes a large cost overrun percentage makes a difference of a hundred euros to the final project cost, on the other hand, a small variance percentage can make a difference of hundreds of thousands of euros. As a result, the percental variance analysis was combined with the effect of variance analysis for the identification of the most variance-causing elements. The magnitude of the effect of variance is calculated by multiplying the absolute value of percental variance with the budget cost of the element and dividing that product with the total project's budget cost. The formula used to calculate the magnitude of variance is shown as Formula 5. The results of the magnitude of the effect of variance analysis are presented in Figure 37.

$$Effect\ of\ variance = \frac{|\%\ Variance| \cdot element's\ BC\ (€)}{project's\ BC\ (€)} \cdot 100\% \qquad (5)$$

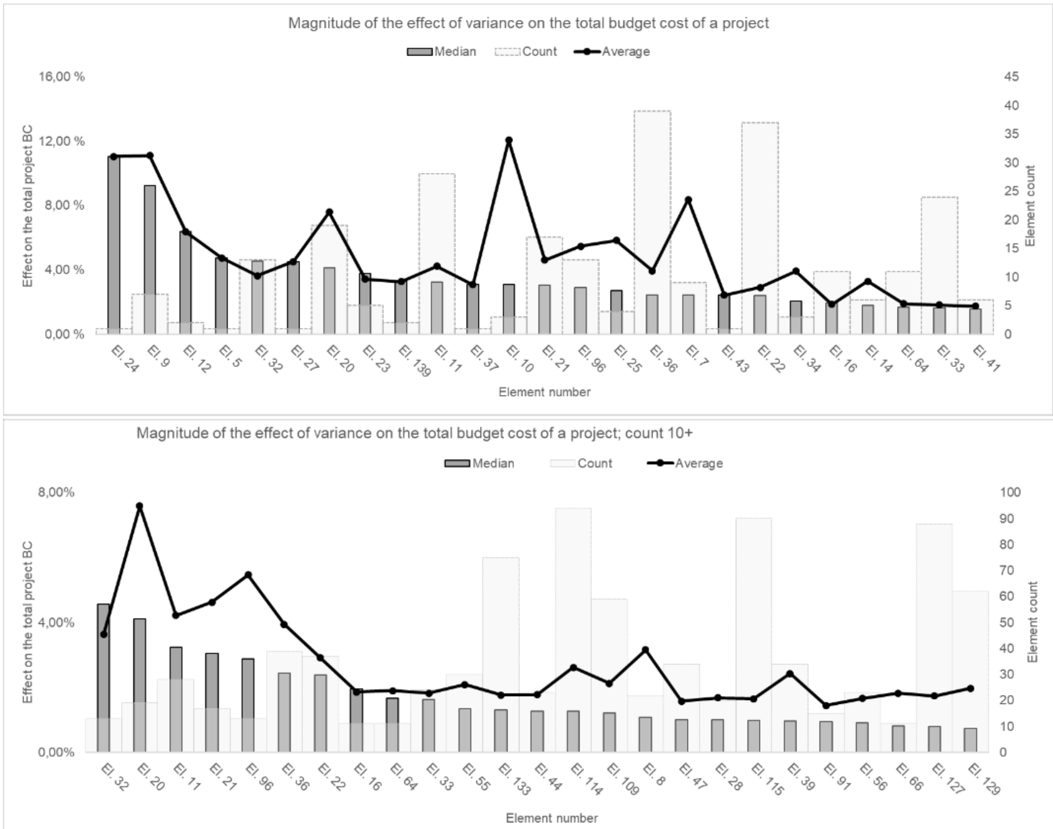

Figure 37. *The magnitude of the effect of variance on the total project's budget cost.*

The figure graphically shows the effect of variance on the project budget averaged with both median and mean functions. The top graph includes the elements within the scope of the case department without the count limit and the bottom graph shows the elements limited in the count to 10 and over. The variances of 100% were excluded from the analysis. The median and average functions are represented with respect to the primary vertical axis, while the element count is shown with respect to the secondary vertical axis. The figure shows the top twenty-five elements in terms of their effect on the total project budget. Both graphs contain the same ten elements, 11, 16, 20, 21, 22, 32, 33, 36, 64 and 96. The aforementioned elements are all with a high count, meaning that the effect they have on the project budget is systematic and more attention needs to be paid to cost estimation of these elements. The next step in the analysis is to identify whether there are such elements with a high variance that have a profound effect on the total project budget cost and classify these elements by cost components to identify potential root causes for estimation inaccuracies.

The magnitude of the effect of variance is ranged between 0,01% and 11,05% as a result of data analysis. A scale of values is developed by using statistical quartiles to assess the severity of the effect of variance on the total project budget. The three quartiles split the data set into four quarters corresponding to low, medium, high and very high classification of effect assessment. The scale for the assessment is shown in Table 9.

Table 9. *Scale for assessing the magnitude of the effect of variance on project's BC.*

Percentile	*Assessment*	*Data range*
0-25%	Low	0,01% - 0,24%
25-50%	Medium	0,25% - 0,53%
50%-75%	High	0,54% - 1,19%
75%-100%	Very high	1,20% - 11,05%

Considering the classification presented in the table, the magnitude of the effect of variance in the earlier discussed analysis (see Figure 37) can be assessed. The median effect of variance calculated on the element-specific cross-project basis is *very high* for the data set in the scenario without count limitation. In the scenario with the count of 10 and over, 60% of the top twenty-five elements have a *very high* effect on the overall project budget and 40% have a *high* effect. The elements with the highest variance percentage are assessed by the same scale of the severity of the effect on the total project cost. Further discussion with the case company's cost estimator revealed that the elements with the count of 10 and less, in this case, are not used in pricing from their experience and should not be emphasized. Table 10 shows the elements with the highest percental variance that have the most profound effect on the total project cost with element count 10 or higher.

Table 10. *Elements with the highest variance and effect on the project budget.*

Element number	*Count*	*The magnitude of the effect of variance*	*Cost component*
El. 35	23	high	own engineering
El. 56	23	high	materials
El. 65	46	high	miscellaneous
El. 66	11	high	miscellaneous
El. 115	89	high	own engineering
El. 129	62	high	own engineering
El. 140	36	high	materials
El. 36	39	very high	materials
El. 44	23	very high	materials
El. 109	59	very high	miscellaneous
El. 133	75	very high	purchased work

The table shows that there eleven elements falling under the criteria of high variance and severe effect. Additionally, the table presents the classification of the elements by the cost components. The case company's cost estimator mentioned that it is always challenging to estimate work hours. Material estimation is affected by the accuracy and quality of the technical specification and planning. A similar method can be applied in reverse to analyze the elements that have the most severe effect on the project budget. The element-specific variance values were split in percentiles and the following classification scale of percental variances was obtained:

- Absolute variance 0-25% → low,
- Absolute variance 25-50% → medium,
- Absolute variance 50-75% → high,
- Absolute variance of 75% and over → very high.

The scale is given for the absolute variance, meaning that the assessment for cost overruns and cost underruns needs to be carried out separately. The assessment scale merely provides information regarding the degree of cost deviation from the estimate. The scale is developed based on the available data, however, the question remains of what an acceptable variance on the element or work package scale is. Based on the conducted data analysis, the element-level variance cannot be compared to the project-level cost variance. The project-scale cost deviation from the estimate is lower than that on the element scale. The lower total project-scale variance is achieved by compensation of the cost savings for the cost overruns in some elements and the actions undertaken by project managers in attempting to control the project spend. This scale for assessing the degree of deviation is adopted for further analysis since it is derived from years' worth of historical data gathered from implemented and active projects.

The cost deviation assessment is then applied to the elements with the highest impact on project budget and the overlap of classifications indicated the areas that can be most potentially affected by improving cost estimation procedures. A combination of high cost variance together with the severe effect of that variance on the total project budget indicates that the element is to be paid attention to and the cost estimation strategy has room for further development. The analysis also reveals that the individual cost of some of the elements is very high, making the effect of cost deviation more severe on the project scale, even though the element-level cost variance is acceptable. The elements with low count were not considered, as the potential of reducing their variance is not high. The classification for recommendations alongside the basis for the recommendations is presented in Table 11.

Table 11. *Recommendations on the priority of element-specific variance reduction.*

Recommendation	***Basis for recommendation***		
	Effect of variance	*%-Variance*	*Count*
Very high priority	Very high / high	Very high /high	10 and over
High priority	Very high / high	Very high /high	6-9
Medium priority	Very high / high	Medium	10 and over
Priority-4	Medium	Medium / high/ very high	10 and over
Low priority	Low	Medium / high	6 and over
OK	-	Low	-
Needs more data	-	-	Count under 6

The table shows that the elements were divided into seven categories based on their potential for cost variance reduction on a project scale. The elements classified as the high priority elements indicate that if the element-specific cost deviation is reduced, then the cost variance of the whole project will be positively affected. The estimated cost of the elements with the low cost variances is considered as acceptably accurate, hence in these cases, there is no potential of improving the cost variance on a project scale.

Three parameters – magnitude of the effect of variance, percental variance and count were conjointly used to draw conclusions on the priority of improving the quality of cost estimation on the element-specific basis. The elements with high variance percentage indicate that there is room for improving the accuracy of cost estimation of these elements, meaning that there is potential for variance reduction. Coupling that with the effect of variance on the project budget, the element-specific variance reduction potential has an impact on the overall project cost variance. The count is an especially relevant parameter to the analysis. The random errors in the assessment are mitigated if the count of element-specific data is high. According to a project manager in the case company, the historical data cannot be fully relied on due to purposeful or unintended cost misallocation. However, if the amount of data is significant and the analysis does not yield contradictory findings, the data can be relied on as an indicator of direction for the actions, although not necessarily a source for definitive conclusions.

The elements from the WBS of the case department were analyzed by applying the priority classification to each of the elements. Table 12 shows the elements that were defined as the *“very high priority”* elements, meaning that the overall project variance can be reduced by improving the accuracy of the cost estimation of these elements.

Table 12. *Cases where improved estimating procedures can decrease project cost variance.*

Element nro.	***Magnitude of the effect of variance***	***%-Variance***
El. 35	High	Very high
El. 36	Very high	High
El. 44	Very high	High
El. 52	High	High
El. 56	High	High
El. 65	High	High
El. 66	High	Very high
El. 115	High	High
El. 129	High	Very high
El. 133	Very high	High
El. 140	High	High

The case company received a more detail table, where the elements need to be monitored. Additionally, there are cases, where there is not much potential to decrease the project variance with the improved cost estimation procedures. The case company was presented with a visual detailed WBS, where the elements with the most percental variance and the elements whose cost variance affects the total project cost the most are shown. The cost estimates for certain work packages in the case department’s WBS are carried out independently by the units responsible for these work packages. This is often the case with centralized resources, which are utilized by several departments in the case company. Some of the elements that have high percental variance as well as a high level of impact

The table shows the variance reduction potential, although it gives no direction on how to adjust the cost estimation for the elements in question. Historical data is the key to improving the accuracy of cost estimation by tracing the cost history through the implemented projects. If the element is more prone to cost overruns, then the estimate should be systematically increased. Further investigation into detailed cost incurrence and invoice history can reveal whether an integral component of the element has not been accounted for. On the other hand, if the element is systematically overpriced, then the estimate should be decreased to attain a more competitively priced offering, which could lead to increased sales.

The cost estimator and the senior sales manager had an observation that generally the purchased and own work and working hours are the hardest cost components to estimate, yielding the highest cost deviations. Most of the identified elements of concern are related to work hour estimation, but some also include the material costs. Material costs are usually exceeded due to incompetent planning and project engineering, indicating that some of the work packages cannot be analyzed in isolation in the light of project complexity. According to Dao et al. (2016) and Martinsuo (2011) project complexity entails the ambiguous nature of the interactions between project elements, making the identification of the root cause of cost variances less straightforward.

6.4 Current situation

6.4.1 Perception of the current situation in the case company

One of the integral steps of the situation analysis was quantifying the perception of the current situation by the project stakeholders. Four individuals, a senior sales manager, a product sales manager, a project manager, and a cost estimator were interviewed and were asked to choose 5 to 10 elements that are the most problematic and cause the most variance according to their opinion. The objective of that questionnaire was to interpret and validate quantitative findings to form the basis for a process improvement suggestion. Additionally, the perception of the problem areas could indicate the quality of the information flow within the case department through misidentified concerns and priority areas in different functions of the departments, through the emphasized concerns.

The interviews were carried out in December 2019. The interviewees were presented with a list of elements that was composed of the elements with the highest variance percentage, highest impact on the total project budget in addition to the elements with the lowest percentages and lowest impacts. Altogether, the list contained 57 elements. The interviewees were asked to select from five to ten elements that in their personal opinion have the largest variances in the department’s project and if there are such elements missing from the list, the participants were encouraged to add the elements. The interview was carried out for data triangulation and revealing the causes of cost variance in a form of element-specific cost variance. This is done by comparing the elements revealed by the quantitative analysis as the highest priority with those that are perceived as problematic by the case company’s stakeholders.

The cost estimator identified twelve elements, project manager and senior sales & technology manager both identified eleven and the product sales manager selected six elements from the list. During the interview the question was asked whether the elements should be identified based on their percentual variance or based on their cost variance in financial currency, indicating that there potentially exists a lack of a unified variance analysis format. The responses of each expert are summarized in Figure 38.

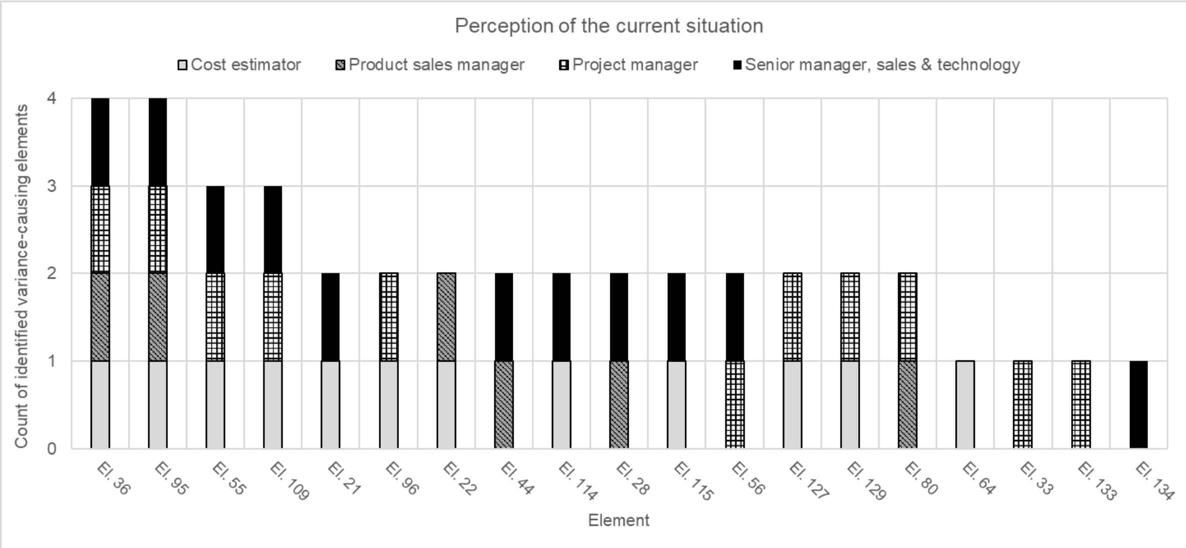

Figure 38. *Perception of the current situation: interview responses.*

The figure shows that elements 36, 95, 55 and 109 were the most popular choices. Element 36 is classified into the very high priority category regarding the potential of variance reduction, and elements 95, 55, and 109 are classified as medium priority elements. Overall, the elements that were identified as by the case company's stakeholders cover half of the elements identified as the highest priority elements in terms of variance reduction. The elements that were not mentioned in the qualitative interview are elements 35, 52, 65, 66 and 140.

Elements 35 and 36 are very close to one another according to their description, and, further, support the statement of questionable clarity of the cost account system implemented in the case company. One of the causes of the substantial deviation of actual costs from the budgeted costs is the difficulty in cost allocation throughout project implementation caused by unclear cost accounts, that can be interpreted as interchangeable. The estimates for the elements 52. 65 and 66 are provided by other departments within the case company, and the cost estimator in the case department cannot judge the accuracy of these estimates. The reasons for the cost variance, in that case, include lack of detail or incompatible format of the provided estimates, which makes the cost aggregation into a detailed estimate inadequate. The cost tracking becomes challenging, as some of the costs may not be present in the project budget due to the lack of detail supplied to the cost estimator. Element 140 does not anymore belong to the scope of the case department. The jurisdiction over the element has been transferred to another department, who is now responsible for the cost estimation and cost tracking of that element.

Overall, the interview is consistent with the quantitative findings of variance analysis and the respondents are aware of the development needs when it comes to the high priority elements, whose cost estimates are produced by the case department. Some additional problem areas in the cost estimation were identified and brought to the case department's attention, such as the estimates supplied by other departments. Systematizing the process across the organization by providing a uniform standard format for cost estimation and defining precise information requirements is instrumental when it comes to reducing the overall project variance. When aggregating the estimate, if the individual estimates are supplied in sufficient detail, the origin of the individual costs is clear to the project manager, who is the key stakeholder in cost tracking throughout project implementation. Making the cost allocation and cost tracking more reliable provides an opportunity for evaluating the accuracy of the cost estimate and potentially implementing adjustment factors, based on the lessons learned from the project implementation.

6.4.2 Process observations

The case company implemented a method to deal with project complexity in terms of specifying and reviewing the internal division of responsibilities when it comes to cost estimation. The division is carried out in the cost estimation strategy meetings and the review – in cost review meetings. Cost review is carried out in accordance with the cost estimation template that is in use in the case company. The cost estimation template contains all the elements of the WBS that belong to the scope of the case department, and the same template is used throughout all the stages of the cost estimation process. The cost estimator of the case company commented that the process does not seem to be as effective as it could be and there are no tangible results obtained from the cost review discussions. This could be tied to a lack of consistent quality documentation (Doloi, 2010).

The contingency reserve in the case company is set through a risk analysis, where the risk factors are identified, the risk management policies are selected for each factor. Then the risks are quantified in terms of plausible cost overruns and cost savings regarding each aspect. The researcher participated in risk review meetings and it was immediately noticed that the quality of the information presented by the responsible parties differed. For instance, one expert may provide information supported by the received quotation from the supplier and another expert has developed a ballpark estimate. Keeping the notion of project complexity in mind, it is a challenge to claim that all the estimates can be of the same quality during the early stages of the project lifecycle since the estimates are closely related to the specification of the project's design. Although, the process and the contingency estimate will be of a higher quality if the information provided is relevant and up-to-date, which should be systematically defined across the project organization and not subjectively interpreted by the project stakeholders.

It is hypothesized that cost overruns may depend on the competitive situation of the company. Under the pressure from competitors, the disciplines may tend to lower the prices too much for the final price to become more attractive to the customer. According to the case company's cost estimator and senior sales manager, each of the disciplines lowers their cost estimate unrealistically much in order to reach the target cost for the optimal price. In this case, a design-to-cost approach is advisable as instead of providing unrealistic cost estimates, the technical specifications and supply plan are tweaked to attain the desirable cost estimate. Additionally, having readily-available organized data from similar projects conducted in the past could provide a benchmark for sales managers in terms of evaluating how realistic their estimates are.

The literature also brings up that individual personality factors can affect the estimates, some may be of higher quality and some may be too optimistic (Skitmore and Lowe, 1992; Shane, 2009). As was discussed, the key to dealing with personality bias is implementing systematic approaches that are clearly defined on the organizational scale and no crucial information is left upon personal interpretation. Through participating in the daily processes within the firm it is concluded that there is a need for process development in terms of increasing efficiency and effectiveness.

Information availability throughout the project lifecycle was observed and identified as a definite improvement area. The cost estimators in the case company were interviewed with the purpose of confirming the observations and acquiring more information, and one example questionnaire is presented in Appendix C: challenges in cost estimation questionnaire. The case company's cost estimator stated that even if the historical information is available, it cannot be effectively utilized due to the lack of systematic archiving and difficulties regarding information retrievability. A newly-hired product engineer was interviewed several times regarding information availability. According to them, the relevant information is scattered across the storage databases, the format of the information is not standardized, and, in some cases, the information is outdated or missing altogether. The issues with systematically organized data archiving entail a high risk of knowledge and expertise loss whenever an expert leaves their position. In companies comparable in scale to the case company, employee mobility is high, making it imperative to codify and be able to utilize employees' tacit knowledge and expertise (Nonaka, 1991; Aliaga, 2000). The knowledge is a strategic resource that enables value creation in companies, making good knowledge management practices essential in terms of gaining competitive advantage (Meso and Smith, 2000).

Internal information flow is another process requiring attention and modification in the case department. A cost estimator from another department identified that one of the difficulties in cost estimation is insufficient information flow during the early phases of the project lifecycle. The design of the offering is prone to changes during the early phases and these changes need to be communicated across the project stakeholders, so that they are accounted for in all functions relevant to project preparation, including cost estimation. The estimate is very likely to change with the changes in technical specifications, making the communication of change crucial to the process. The interview with the case company's product engineer revealed that there are flaws in the methods selected for internal information management, as some of the data that is created by one party is being overwritten by a new document version from another party. The information about changes is not being sufficiently relayed resulting in occasional losses. The product engineer mentioned that there are superior information management systems already in use within the case organization and the training regarding the information management system is organized within the case organization, though the case department is somewhat reluctant to change.

Additionally, the product engineer in the case department mentioned that there are no standardized ways for external inquiries, making the inquiries a lengthy process. According to their expert opinion, the process would not take nearly as long and the information requirements would be met more effectively if there was a collection of inquiry templates, which could be slightly modified on a case-specific basis. In other words, the information requirements should be made explicit to ensure timely information availability. Another product engineer who was employed in the case department for over two years commented on the overall process execution in the case organization. In their opinion, the training information was not provided in a good format. instead of having a collection of standard methods and procedures, it was scattered across different storage locations and, as a result, some crucial to the job information was missed out on. In addition, both product engineers pointed out that the division of responsibilities is not always clear throughout the sales process in the case company. In most cases, when employees are given a task, they complete it without consideration of whether the task is a part of their responsibilities. Occasionally, the external to the job description tasks inhibit other activities belonging to the responsibilities of product engineers. Overall, the conclusion can be made that there is room to improve the sales process in the company towards being more effective and efficient, in other words, towards being more *lean*.

Throughout the quantitative analysis of cost variance, a problem in cost tracking and recording was identified. Some of the actual costs were allocated to the wrong cost accounts compared to the budgeted costs. According to the case company's controller and cost estimator, it can happen either purposefully or not. Intentional cost misallocation can happen due to the attempt of project managers to keep the project costs in check, for instance, by purchasing materials for other projects with the saved costs. Unintentional cost misallocation arises from occasional ambiguity of itemization in cost accounts. There are often several elements regarding a work activity, and it may not be clear to all the project stakeholders where the cost should be allocated. Additionally, sometimes the contractors bill the organization for several projects at once, and if the cost allocation to different projects is not visible from the invoice, then the cost allocation is not reliable. The indirect costs are challenging to allocate to projects. The workers are responsible for assigning their daily working hours to specific projects, however, depending on the job function and the regularity of reporting, the hour allocation is merely approximate.

6.4.3 Cost estimation process

Cost estimation is an integral part of the sales process. The process of cost estimation in the case department is compiled through interviews with the cost estimator in the case company as well as the researcher's process observations during the time of personal involvement in the case company. The process contains eleven steps:

1. indicative estimate,
2. project kick-off,
3. initial technical specification,
4. initial cost estimation strategy meeting,
5. limited design and specification,
6. budget estimate and cost strategy meeting,
7. detailed design, specification and project schedule,
8. detailed cost estimate for firm proposal,
9. cost review,
10. risk analysis,
11. aggregate the cost baseline and compute the project budget.

Indicative estimate, budget estimate and firm proposal estimate correspond to the phases of the sales process formula utilized in the case company. The intermediate steps are related to project planning, namely engineering, design, and scheduling. During the project kick-off, the internal project stakeholders are identified, and a rough design is developed based on the customer’s inquiry. That is followed by the development of preliminary specifications and the initial cost strategy meeting, where the responsibilities are divided among the departments. Based on that, the budget estimate is developed, simultaneously ensuring that the division of responsibilities has been followed thoroughly. Afterward, detailed design and schedule are developed, based on which the detailed cost estimate is computed. The cost baseline and project budget are set after the cost review and risk analysis was carried out.

Comparing the above-outlined process to the best available processes reviewed in Chapter 4.3, there are clearly noticeable deviations. The cost estimation process in the case company is treated as a sales phase and is not a continuous process throughout the project lifecycle, as is dictated by the best available practices (see Figure 29). The process cannot be completely adapted to that of the best available practices, due to differences in the company’s business and operations. When it comes to the first four steps identified as BAP, the case company conforms to the process well. The WBS exists, it needs to be limited to the defined project scope. The customer’s request is analyzed during the project kick-off and the preliminary schedule and specification are developed. The ground rules and assumptions are identified and documented.

When it comes to selecting the cost estimation technique, there is no existing distinction between the techniques available. The indicative estimate is a combination of analogical and expert opinion techniques. The cost estimator is not the main contributor during that stage, they are merely consulted. From there on, the cost estimation is carried out in the template for the detailed estimate. Elemental parametric estimation is used for certain elements, for which the unit cost parameters are available. The detailed estimate is computed based on the same principle, just in accordance with the more detailed design specifications and schedule available. The risk analysis is carried out and the cost bassline is developed alongside the project budget. This is where the cost estimation process is perceived to end in the case company. The cost estimate remains in the template, where it was created, and no separate reporting is done. The cost estimate is not adjusted according to the actual costs, nor the cost estimation is analyzed at the end of the project to identify the improvement areas for future cases. The ground rules and assumptions used in the process of estimation remain in the detailed estimate template, which is a large document, containing the whole WBS of the case department on the most detailed level. The cost estimation templates are scattered across the information management system locations, making it difficult to locate specific files and retrieve the unit costs and parameter one-by-one from the files.

6.5 Recommendations

Based on the identified and observed challenges present in the case company and the theory on cost estimation and the best available practices, a set of recommendations is issued to the case department that will potentially result in project cost variance reduction through an improved method of cost estimation. First, the cost estimation process should be carefully documented, and the estimate should be revised either throughout, or at least at the end of the project. Second, more attention needs to be paid to the cost estimation techniques used to promote lean thinking as well as balance resource utilization. Third, the inaccuracy involved at each stage of the cost estimate should be recognized and communicated to the party that utilizes the cost estimate. And last, when carrying out the risk review, the uncertainties associated with the risks and the uncertainties regarding the available cost data should be discussed and documented separately.

It is vital to follow through all stages of the cost estimation process to begin accumulating historical data and promote organizational learning. At the end of each project, a project manager holds a presentation, where the outcomes and the lessons learned from the projects are covered. It is instrumental for the cost estimator to participate in such meetings, getting feedback on the quality of the cost estimate as well as getting an overview of the process and the big picture of the project implementation. Based on the information presented as the analysis of the project outcomes, the cost estimator is to make the final adjustments to the cost estimation report and archive it for future use. A cost estimation report should be created, where the information regarding the project scope changes and the estimate adjustments is visible. Suggested content for the cost estimation report is shown in Table 4, and it includes the description of the case alongside the ground rules for the estimate, technical specifications and project schedule, and additional work-specific information. The detailed cost estimate can be referenced to as an appendix since the template is substantial in size and would overwhelm the cost estimate report. Pricing factors, previously referred to as unit cost are important to gather systematically in one location since they are utilized in elemental parametric estimation in future projects. Not having the archive of the unit costs, which can be sorted by the type of the project and other relevant factors, inhibits experiential learning.

It is advised to initiate the effort of archiving the unit costs, such as cost per hour or cost per kilogram, which can be sorted by the project type, location, scope, cost component and year. Upkeeping such an archive available will allow for harnessing the knowledge acquired from previous projects in a more effective manner as well as apply deterministic and learning curve cost estimation techniques. Furthermore, the information archive supports the expert opinion on cost estimation and prevents information losses due to employee mobility or personal bias. The report should include the details of the experts responsible for the cost estimation and be supported with materials that back-up the estimate, such as relevant invoices and explanations for non-standard events.

Selecting the appropriate cost estimation technique promotes effective resource utilization and prevents internal resource cannibalization. In the case company, the template for the detailed estimate is utilized all the way after the indicative proposal is done. It is worth exploring if acceptable cost estimates can be produced with less time-consuming techniques on a less detailed level, such as assembly estimates and deterministic estimates to free up the cost estimator's, engineer's and designer's time, so it can be dedicated to the projects of higher priority and in more advanced stages of development. The recommended techniques for cost estimation and their approximate accuracy level is shown in Figure 39.

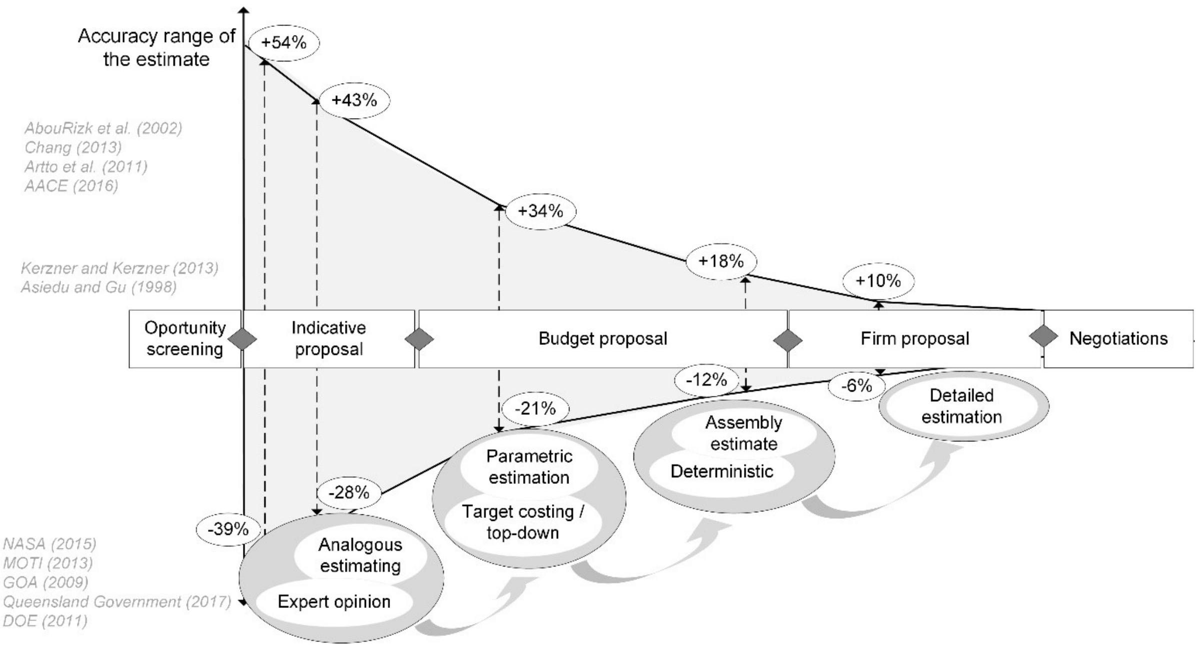

Figure 39. *Recommended estimation methods for project preparation stages.*

The figure shows that the budget proposal should make use of less time-consuming techniques, which could be made more reliable with upkeeping and maintaining the cost information archive. Additionally, it should be noticed that the projects are more prone to cost overruns, and the accuracy range is skewed towards the cost overrun direction. This should be noted while conducting risk reviews. Cost estimation may not always be realistic if carried out in a hurry. The cost estimation process is dependent upon scheduling and technical specification, meaning that it cannot be rushed out of proportion with respect to the other factors. The quality of the estimate is in line with the quality of the schedule and design. The process of cost estimation should be followed systematically, and the unavoidable uncertainties should be recognized and accounted for instead of being brushed off.

With appropriate cost estimation methods and good quality historical data archives, the process could be adapted to lean principle by decreasing the time required to produce the cost estimate without affecting the quality. The consequential additional resource availability can be utilized to increase the quality of the detailed estimate as well as to prevent carrying out the estimation in a hurry. Another advantage of historical information archive is the prevention of succumbing to competitive pressure and undervaluing projects. If there are clearly defined cost levels associated with certain elements, the cost of the element should not be estimated at a lower level than is historically observed from similar cases. This preventive approach is an example of six sigma philosophy, where the estimation mistakes are prevented with the relevant benchmark cost level.

It is important to communicate the inaccuracy of each of the cost estimates produced to the party utilizing the estimate so that the cost data is not misused. If the sales manager is hurried by the customer, they may mistakenly present a rough estimate as a reliable price level to the customer, hindering the chances of winning the project if the costs are overestimated, or risking company reputation and customer dissatisfaction in case the costs are underestimated. The benefit of quantifying risks of cost deviation due to risk events and due to uncertainty of the available cost data separately is the ability to track and assess the appropriateness of contingency levels. The tracked cost data uncertainty can be used to adjust the accuracy range of cost estimates, which should be done in any case, as the ranges differ based on the organization and its operations.

To facilitate the idea of lean process development, a stage-gate information requirement model should be incorporated into the process. There should exist a unified understanding of the information needed at each stage of cost estimation and the information should be available already at the specified point of time. A practical method to facilitate systematic information availability is to create inquiry templates for different elements included in the project scope and to specify at what time the templates are to be used. If the inquiry is sent to early, there is a risk of it expiring and if it is sent to late, the accurate information is not available to the cost estimator at the right time. The inquiry template should in itself contain the information that should be asked to eliminate the lengthy process of additional questions and support inquiries. Designing a stage-gate model for information requirement, which is supplemented by the inquiry templates is a path to lean six sigma process improvement, increasing the quality of information and decreasing the amount of rework and waiting time.

When it comes to six sigma philosophy, there is potential for reducing defects in cost estimation by improving cost estimation tools used for certain elements oftentimes included in the case company's project scope and causing high project variance. Such elements and work packages, with high cost estimation improvement potential, were identified in the cost variance analysis in Chapter 6.3. Some additional improvement possibilities include implementing modularity and standardize product portfolio. Portfolio standardization is a way to decrease variance, and if it is possible to standardize or at least have a handful of variants that the customer can choose from, the cost variance can be potentially reduced (Lorenz et al., 2019).

The variance reduction is based on more accurate initial planning of standardized products as well as the established cost database for that product. Nevertheless, projects are associated with unique custom-made solutions, so in order to facilitate organizational learning and prevent information and knowledge losses, the information should be effectively converted from tacit to explicit form via a standardized method of codification, meaning that the information should be available and accessible to every employee within the organization. Emphasis on knowledge management can address improving the quality of the historical information database and the quality of the information flow throughout the projects' lifecycle.

The challenge of multi-unit project planning and preparation is already being taken on in the company. Last autumn a new method of division of responsibilities was taken into use that tackles the division of responsibilities in a more organized manner to prevent omission of the elements from the cost estimate, or, on the opposite, double-counting of the elements. The tool works as a checklist for the scope of the project, supporting the process of cost estimation. Nonetheless, if the process itself is not organized, the tool is not going to bring the expected benefits. Similar to the sales formula, there needs to exist a formula for the cost estimation process, as the process is multifaceted, follows through the whole project life-cycle and involves many stakeholders. And to organize such a process in a systematic and efficient way, a set of guidelines is required, targeted at all the project stakeholders participating either directly or indirectly in the process of cost estimation.

Currently, the cost estimation process is not established as a system of its own, it follows the needs of the project. According to the cost estimator in the case department, there is not always a cost estimation strategy meeting, and the division of responsibilities is checked only at the cost review phase. The cost estimator earlier stated that the cost review meetings are not as effective as they could be and there are no documented results from that meeting. To alleviate the load of content that must be covered during the cost review meetings, it is advised to follow through with the cost estimation strategy meetings and document the results, so that this document could be used later in the cost review meeting. Furthermore, for the cost estimator, it is important to document the discussion that happens during the cost review, as the cost estimator must be able to obtain a holistic picture of the situation, possible changes in the specification or requested quotations. The extent of the quality of this information affects the quality of the aggregated cost estimate as well as the viability of the price issued to the customer.

6.6 Synthesis of the proposed process improvement

The goal of the intervention is to influence the case company's existing process of cost estimation and enhance common understanding on the cost estimation across the organization. Based on the comparison of the existing cost estimation practices and the best available practices, a process recommendation is suggested to the case company that will increase the quality of the cost estimate through promoting knowledge management as well as standardizing the process. The process recommendation is shown in Figure 40. The figure illustrates the systematic process of cost estimation, which corresponds to the stage of the project's lifecycle.

Additionally, the figure elaborates on the role of the cost estimator during the implementation phase of the project lifecycle. The systematic and clearly-defined process, as well as the clear definition of the roles, is currently lacking in the case department. In addition to that, the milestones from the sales formula of the case company are projected onto the developed process of cost estimation, and some additional milestones are defined based on the information requirements during the process. The information requirements are, for example, the detail and degree of completeness of the technical specification, the quotations received from the contractors and suppliers as well as the developed and revised project schedule.

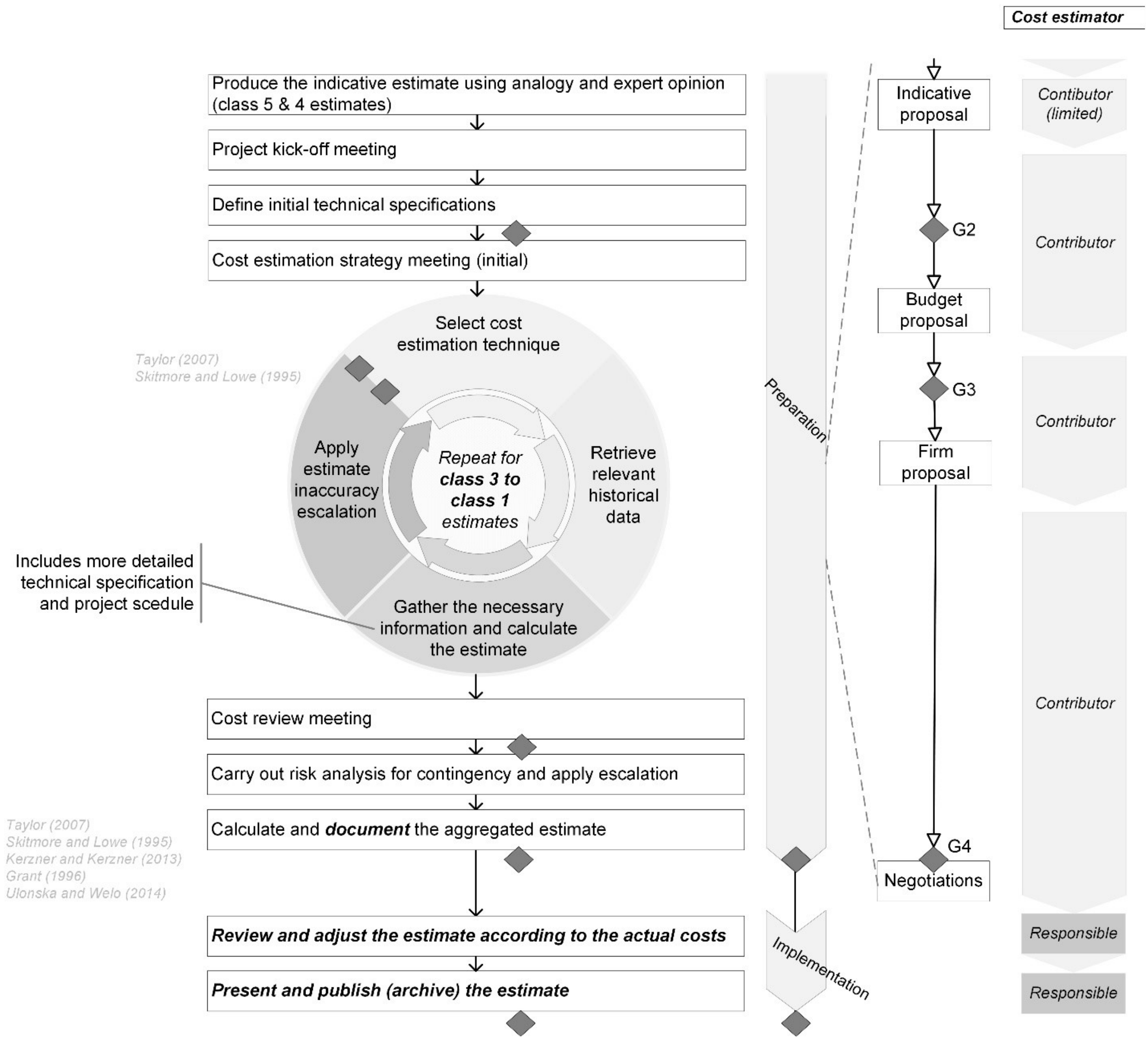

Figure 40. *Cost estimation process recommendation.*

The figure shows the recommended process of cost estimation consisting of thirteen steps. The recommendation is developed based on the existing processes in the case department as well as the best available practices regarding cost estimation. The first four steps of the recommended process follow the currently implemented process in the case department: (1) producing indicative estimate, (2) holding a project kick-off meeting, (3) defining initial technical specifications and (4) holding an initial cost estimation strategy meeting. The goal of the first four steps is to produce a limited technical specification as well as divide the responsibilities over the scope of deliverables within the case organization. It is advised that the case company starts utilizing class 5 and 4 estimate technique bundles for a more accurate initial estimate, which is especially important since the cost estimator is not always involved in the indicative proposal and the cost estimate serves a sales tool during that stage of the project specification. However, it is noteworthy that an output of class 5 and 4 estimation techniques is still a rough, order-of-magnitude estimate. Class 5 and 4 estimate technique bundle includes analogous estimating and expert opinion, which support one another. If a good cost data archive is available, a cost estimate from a similar in scope project can be attained and adjusted based on the case-specific information using expert opinion.

The next stages of the cost estimate process that are not so clearly defined in the case department include (5) selecting an appropriate cost estimate technique, (6) retrieving historical data, (7) gathering the necessary supplementary information and (8) applying the estimate inaccuracy escalation factor to the cost estimate. The selection of the estimation method is discussed in detail in the previous chapter (see Figure 39), where different estimation techniques are suggested to be used by the case company. Throughout the fifth to eighth stages of cost estimation, more precise, but at the same time, more time- and resource-consuming techniques of cost estimation are used. The cycle is repeated twice, once for the class 3 estimate and once for the class 2 estimate. More detailed technical specifications, as well as confirmation on the customer's willingness to invest in the project, serve as the justification for utilizing more resource-intensive estimation techniques. Class 3 estimates include techniques such as parametric estimation and top-down estimation, followed by class 2 estimates, which include assembly and deterministic estimates. Both class 3 and class 2 estimates can be used throughout the budget proposal phase, although class 2 estimates already require rather specified project design and schedule and take longer to compute, as both are bottom-down techniques and are computed using the existing estimation template.

The next two stages (9) cost review meeting and (10) risk review and contingency analysis and (11) calculating and documenting the aggregated estimate are followed through in the company. The recommendation regarding the cost review process is creating and utilizing a check-list or a formal standardized procedure for reviewing the cost estimate. Furthermore, if the cost strategy meeting is carried out and documented accordingly, the documented division of responsibilities can be used as a template for tracking the changes to the initial technical specification as well as checking whether each element has been priced or whether some elements have been double-counted. Furthermore, it is advised that the external project risks and the cost uncertainty risks are tracked separately, allowing for future analysis of the suitability of the assigned contingency reserves and the accuracy boundaries of the cost estimate at the firm proposal stage of the sales project. It is strongly advised to create a standard format for a cost estimate report, which should be used in the case department for archiving and analyzing historical data. Currently, there are no guidelines for creating a cost estimate report and all the reference data has to be retrieved one by one from overloaded detailed estimate templates, which are all dispersed across the data storage locations in the separate project folders. Moreover, there is no centralized source of reference project information, which would at least indicate which project to search for. Creating such a database of project information, including year, scope, status, location and budget cost (and actual cost if applicable), would make it easier for all the cost estimators, engineers, product managers, and sales managers to find a reference for their design and estimation work.

The concluding steps in the recommended process of cost estimation are (12) reviewing and adjusting the estimate according to the actual costs and (13) publishing and archiving the estimate. These steps are not currently followed in the case company, meaning that the cost estimator does not get feedback on the accuracy of their estimation, neither they get an overview of the cost incurrence processes throughout project implementation. Furthermore, there is no final cost estimate report that includes the reference project information, necessary unit cost data and pricing factors, case-specific assumptions, which are invaluable sources of information for the cost data archive and future cost estimates. The figure illustrates that according to the best available practices, the process of cost estimation should be extended to the implementation phase of the project's lifecycle, alongside the responsibilities of the cost estimator. The cost estimator becomes responsible for reviewing and adjusting the estimate according to the actual costs as well as reporting and archiving the cost estimate. A sales manager and project manager act as contributors during the adjustment and reporting stages of the cost estimate, as they are able to provide deeper insights into the assumptions and ground rules used for the estimate as well as the practicalities related to the actual costs, namely the reasons behind the cost savings and overruns.

The cost estimation process includes milestones, the criteria for which should be fulfilled before moving on to the next stage of the process. The stage-gate model, in that case, is a method to adapt the process towards lean philosophy, preventing rework through standardized process output requirements. The systematic standardized process responds to the challenge of information flow identified as a source of estimation inaccuracy by the case company's cost estimator. The project stakeholders should also be encouraged to obtain the highest quality information, by, for instance, introducing a set of element-specific or work-package specific inquiry templates. Clearly defined information requirements and milestones in the cost estimation process could assist in preventing technical specification changes after the estimate's completion. If the technical specifications are changed, then there is a clearly defined need for reworking the estimate. The changes to project scope are not avoidable, although, they can be mitigated, especially at the early stages of project implementation, by specifying the link between the design and the estimating process.

The quantitative cost variance analysis revealed the elements with the highest potential for reducing project variance through improving the estimation procedures. Furthermore, it became clear that it is practically impossible to trace the actual project costs from the existing database, because of the flawed cost allocation and cost tracking. The cost estimate report, created at the end of project implementation would allow for easier cost tracking, as the project manager and cost estimator collaborate to compare and analyze the estimated and actual costs, while the project is still fresh in the memory for all the project stakeholders. It would be beneficial for the cost estimator to participate in the final project review, where the project manager presents the outcome of the project and the areas, where delays and cost overruns occurred. This information is needed for the cost estimator to get an overview of the accuracy of their estimates and for adjusting future estimates. Additionally, the information from the project review meeting is a valuable input into the cost estimate report.

Keeping a systematic archive of the cost estimate reports, as well as the unit cost information, would reduce the time used to locate the information for the cost estimator, contributing to making the process of cost estimation more *lean*. Additionally, an easily-accessible archive with processed data makes the estimate more reliable in terms of setting the limits for risk reviews and bidding process, where the prices might be unrealistically low due to competitive pressures. Having a historical chart of actual costs, which is sorted by project type, scope, location and similar, could also serve as a learning curve for the organization, resulting in the subsequent decrease of cost deviation with time. The pricing factor archive, or unit cost archive also serves as a database to assess the reliability of contractor pricing, which was identified as a source of inaccuracy in cost estimating by the case company's estimators.

7. DISCUSSION AND LESSONS LEARNED

7.1 Application of the framework in the case company

The framework developed throughout the survey of the best available practices and the theory review (see Figure 30) consists of five elements that are worth considering in isolation before overviewing the method in its entity. The five elements are (1) the process of the cost estimation, (2) the internal foreseen risks, (3) framework for selecting a cost estimation technique, (4) the split contingency reserve and (5) the cost estimate report. First, the cost estimation process framework was used as a core for developing the cost estimation method for the case company. The theoretical framework was adjusted with respect to the business-specific features in the case company.

Second, the category of the internal foreseen risks, which was defined in Chapter 3.3, includes the pre-defined potential challenges relevant to the success of project execution, that are rooted within the organization. The internal foreseen risks include:

- Inadequate planning of resources,
- Unrealistic scheduling,
- Lack of information,
- Lack of systematic procedures,
- Lack of project prioritization, and
- Conflict of resources between the project within the organization.

These risks are gathered into one category from the surveyed existing and defined risk categories (see Table 3). It is discussed that these risks are not to be mitigated with contingency reserves, but with procedural improvements to the processes implemented in the organization. In the case company, the most relevant risks are lack of information, lack of systematic procedures and conflict of resources between projects. Lack of information and systematic procedures is mitigated with the introduction of a defined cost estimation process with milestones, that are to be completed before the next stage.

The conflict of resources is mitigated with a guideline to use an acceptable cost estimation method at a corresponding stage of the process, which is the third element in the developed framework. Utilization of less time-consuming methods at the stages, where the accuracy demand is met, balances the resource utilization allowing the employees to concentrate on other more pressing tasks. inadequate planning and unrealistic schedule are not to be omitted, as, without quality planning, project success cannot be reached in terms of meeting costs and schedule baselines. Quality planning is ensured by systematizing the process and defining the information requirements at each stage of the process. Furthermore, systematic archives of information from previously implemented projects, such as cost estimate reports and unit cost (or pricing factor) sheets reveal the similarities between the projects and their scopes and support the planning efforts with historical reference information.

Lack of information is mitigated by recognizing the importance of and implementing superior knowledge management practices, in the form of documentation and archives. In general, historical information is a prerequisite for a high-quality cost estimate, making it imperative to ensure the availability of up-to-date and easily accessible information. The fourth element of the framework suggests that the risk-related contingency costs should be tracked separately from the cost uncertainty related contingency, making the accuracy boundaries and costs deviations due to external risk more transparent.

The major difference between the developed process and the existing process of cost estimation in the case company is the latter steps, including adjusting and reporting the estimate at the time of project completion. The fifth element of the developed framework – cost estimate report, is an invaluable source of information for the cost estimator, as they receive an overview of the project implementation process and actual costs. The project review meetings, which are held by project managers, should include a brief analysis of the areas that were prone to cost overruns and cost savings and the reasons for the cost deviations. Such information will assist the cost estimator in adjusting his work and identifying focus areas during the project preparation phase.

7.2 Results of the intervention in the case company

The results were presented to the case company stakeholders to collect feedback and opinions regarding the outcomes of the work. The feedback form is presented in Appendix D: feedback collection form Altogether, six individuals provided their feedback regarding the procedural improvements suggested to the case company. The interviewed individuals are the case company’s cost estimator, senior sales and technology manager, project controller, engineering manager, and two product sales managers. Overall, the suggestions were perceived as very useful in the context of the case company. It was mentioned that some of the issues were presented in a new angle, raising thoughts. Additionally, it was mentioned that the positive impact of the implementation of the suggestions is achievable as long as the implementation is correctly enforced within the company.

The suggestions are perceived as likely to be implemented, as long as there is a concrete implementation plan as well as clearly defined responsibility for the implementation process. Prioritizing the issues was an emphasized aspect. There are multiple suggestions and the most fundamental ones should be defined within the company and implemented first. The researcher is to consolidate the research into a handbook-type material and present the findings to the whole department as well as to other departments within the case company to obtain department-wide feedback and commit the employees to implement the process.

Some of the suggestions were identified as more important by the interviewees. The case company's cost estimator listed three suggestions that in their opinion should be implemented:

1. *developing and using tools that match the target of each estimation phase,*
2. *developing a cost estimation summary that is easy to utilize throughout the project implementation and post-implementation,*
3. *determining the cost uncertainty range at the firm proposal stage in the sales process of the case company.*

The product sales manager emphasized the importance of the cost estimator getting feedback and information on the accuracy of the estimates and an overview of incurred costs throughout the project. The engineering manager emphasized the need for more systematic pricing and the ability to trace the origin of individual costs, whether they are estimates or figures received from the subcontractors. The project controller found interesting the idea of splitting the risks into internal and project risks and tracking the contingency for both separately and mentioned that this might help in cost tracking throughout the project implementation.

Some of the areas of interest that were not included in this work were additionally identified. The concrete process formula with the guidelines was identified as one development area. Improving the cost allocation throughout project implementation and making historical data more reliable was another area requiring further investigation. Tools needed to improve the effectiveness of cost estimation and aligning the cost estimation structure with the actual cost structure are in need of further development. Overall, the interviewed case company stakeholders found the work important and beneficial for the case company and would like to see the development suggestions finalized and taken into implementation.

7.3 Limitations of the paper and further research

Ali and Yusof (2011) examined trends and literature related to the quality of qualitative research. The positivistic school of qualitative research assessed the research quality across three aspects – validity, generalizability, and reliability (Ali and Yusof, 2011). Validity is concerned with selecting appropriate research questions, methods and ability to provide a basis for the reached conclusions (Leung, 2015). Reliability stands for replicability of the processes outlined in the research to reach the same conclusions and generalizability means the ability to extend the conclusions drawn from a sample to the whole population (Ali and Yusof, 2011).

The quality assessment by the aforementioned three parameters received considerable criticism, and another set of criteria for assessing the quality of qualitative research was proposed to promote epistemological and ontological philosophies (Baxter and Eyles, 1997). The criteria are credibility, transferability, dependability, and confirmability. Credibility stands for unbiased, transparent and authentic representation of findings. Transferability is similar to generalizability, which stands for how well the results of the research fit other cases outside the investigated sample. Dependability is similar to reliability and refers to how easily the construct of the research can be applied to other cases. Confirmability refers to the transparency of reasoning and a non-biased approach to reporting. Since the research philosophy employed in this study is pragmatism, which is a combination of philosophies, the schools of assessing the quality of qualitative research will also be combined.

To increase the overall quality of the research, the findings are reported in a transparent manner, and the validity of qualitative data is ensured by avoiding personal interpretation of the responses from interviewed members of the case company. The researcher employs the strategy of reflexivity by making a distinction between the personal observations and the information obtained through the interviews in order not to impact the validity of the results. Another method of ensuring data validity is through data triangulation. Triangulation of quantitative and qualitative data is used to increase the validity, reliability, credibility, and dependability of the research. The quantitative findings are confirmed by the qualitative interviews and surveys conducted with the case company's stakeholders. The surveyed material is also triangulated by seeking multiple references for the same claim. Theory triangulation was employed in this research to assess the evolution of the concepts as well as ensure the validity of the concepts. Increasing the validity and confirmability of the findings is attempted by gathering the feedback from the stakeholders in the case company as well as the professors in the university and making subsequent necessary adjustments.

Generalizability and transferability are the limitations identified throughout this research. The cost estimation processes, as well as the typical acceptable variance ranges, are industry- and company-specific. It is mentioned throughout the research that the developed process recommendations are general and need to be adapted on a case-specific basis, as was demonstrated on the example of the case company. The accuracy limits of cost estimate are averaged across the published data from industrial project-based firms. The limits are to be adjusted with experiential data as it becomes available. Context specification is the researcher's attempt to mitigate the generalizability and transferability limitations of this research. Additionally, the researcher provides a description of the reasoning behind the findings, making it easier for the developed method to be adapted to other contexts.

Another limitation of the paper relates to the nature of the information regarding cost estimating and pricing. The publicly available information is published by governmental organizations due to the budget and spend transparency criteria imposed upon them. This makes the availability of industry-specific cost and estimation information limited, thus the recommendation issued to the case company needs to be adjusted based on the experiential data.

The data analysis conducted for the case company is based on the data retrieved from the company's ERP. The data validation was carried out through the selection of an appropriate sample of project data. The projects included in the analysis had to have a certain degree of recorded implemented costs, otherwise, the cost savings would be falsely represented by the costs that are yet to be implemented. Excluding active projects altogether would result in sampling bias and significantly limit data availability, as quite a large share of relevant projects included in the analysis are still active. It follows that it has to be ensured that the spending was recorded, and no new costs are likely to be incurred. The quantitative analysis is validated through multiple reverse calculations as well as the repetition of the analysis.

An additional limitation of this analysis regarding data validation lies within the cost tracking, as it is next to impossible to trace whether the costs were allocated to a proper cost account or even to the correct project. Some costs may have been assigned to a wrong element, skewing the validity of the data. Additionally, some costs may have been purposefully distributed among the work packages or even other projects to decrease project variance on paper. In light of the challenges with data validity, the variance analysis is to be treated as a direction giving and not definitive. Substantial data availability increases the validity of processed information in terms of compensating for and eliminating random errors, however, in case of systematic cost misallocation, the data should be treated with a degree of skepticism. The information should be further validated from project managers and other project stakeholders with first-hand experience and knowledge of each project.

Due to the limitations of complete data validation in variance analysis, no definitive conclusions and recommendations were issued to the case company. The cost implementation data should be collected and recorded in an organized manner so that the variance analysis by cost component and by the work package can be carried out successfully. The variances can thereafter be classified by the type, scope or location of the project to identify whether there are any geographic risks or technology risks that prevail in certain areas. The organized cost data can be instrumental for creating learning curves by element or work packages. The learning curves provide a comprehensive overview of the cost data history as well as provide the direction for future pricing. According to the logic of learning curves, the costs of elements should decrease with repeated implementation, however, that is more applicable to the manufacturing industry. The validity of the learning curve method should be tested in the case company. Nonetheless, the learning curve would represent the pricing trends, which are suitable for aiding cost estimation.

The method is based on the best available practices and was applied in one case company, making it difficult to draw conclusions about the transferability of the method. The transferability of the method should further be tested in other project-based industrial organizations, and whether the small adjustments in the process will be sufficient to achieve working results. Additionally, further research regarding computer-aided cost estimation and cost estimation software are required to ensure the timeliness of the method developed in the paper. Literature suggested that computer software should be actively used throughout the cost estimation process (Kesavan et al., 2009, p. 96; Humphreys, 2005, p. 258; Dagostino and Peterson, 2011, p. 38; Stewart and Wyskida, 1987, p. 489; Zhu et al., 2016; Peleskei et al., 2015; Galuzzo, 1991; Chang, 2013). However, there is a lack of literature for such cost estimation software applicable in project business. Due to the nature of projects and the degree of customization of the deliverables, the suitability of existing cost estimating software for project business is to be studied further.

8. CONCLUSION

Nowadays, to survive the fierce competition in the industrial B2B markets, companies are seeking to differentiate their solutions through customizing and tailoring the offerings to the customer needs. The customer-centric approach widens companies' product portfolio and calls for a variety of expertise. A project is an organizational form supporting the mobility of the expertise and competencies across the organization. Project business is associated with challenges, namely due to the nature of projects as well as the non-permanent structures. Each project is unique, and each project is temporary, making the project planning challenging. For a successful sale of a project, it is imperative to maximize the customer's perceived value, which convinces them to invest in the supplier's solution (Kotler and Keller, 2012). The supplier's profitability, however, cannot be forgotten, as profits are essential for organizations to survive. The balance between the CPV and the supplier’s profit is essential, and it is achievable through cost reductions in the supplier’s operations, by ensuring the efficiency and effectiveness of the process and quality control (Nicoletti, 2012; Bradley, 2015). The concepts of efficiency and effectiveness lie in the heart of lean six sigma philosophy, aiming at eliminating ‘wastes’ and defects in the business operations.

This thesis is an exploratory case study, where the researcher faces a problem related to project cost variances. The senior sales and technology manager and the cost estimator in the case organization want to ensure that the project costs are estimated correctly since cost estimation is the core of determining the project’s success as well as the profitability of the organization. The main objective of this thesis was to develop a method for reducing project cost variance by improving the quality of the cost estimation process for a case company, which is an industrial project-based firm. A systematic method, allowing for increased quality and potentially increased accuracy of the cost estimation is a source of competitive advantage for the firm since it enables the company to present competitively-viable prices to the customer without risking or compromising its own profit margins.

The supporting research questions included identifying whether there exists a notion of acceptable cost variance, investigating existing accepted project variance limits as well as identifying concrete areas of improvement for the case company. The scope of the case study was narrowed down to one department within the case company and to the factors that are internal to the organization, rather than external and uncontrollable. The research specifically concentrates on the sales phase of the project and on the process of cost estimation as an area of project cost management. To reach the objectives of the investigation, the researcher needed to submerge themselves into the daily operations of the organization to gain a deep understanding of the current situation and processes as well as the product portfolio.

For the purpose of meeting the objective of the thesis, a new risk category was introduced. These risks are rooted within the firm and are not advised to be covered with contingency reserve. Instead, based on the typical pitfalls and challenges of cost estimation, root causes of project variance as well as the best available practices, a method that mitigates these internal foreseen risks is developed. The main contribution of this thesis is the proposed general method for increasing the quality of cost estimation and subsequently reducing the project variance in the context of the project business. The method addresses the challenges and pitfalls of the process of cost estimation described in the literature. The reliability of the method was tested by applying the method to the context of the case company.

The work emphasizes the importance of knowledge management for sustainable business development as well as the role of a methodological and systematic approach within a company. The importance of historical information in cost estimation and sales is highlighted, and historical information was deemed especially important in the early stages of cost estimation. With a good quality historical information archive, the initial estimates are more accurate and lay a good fundament for subsequent estimation techniques to build on. Furthermore, having the cost data archive eliminates the need to create an estimate from the very beginning, saving cost estimator a significant amount of time.

From a managerial perspective, this thesis sheds a light on the requirements for the cost estimation process as an integral part of the sales process. The management is encouraged to promote the idea of systematic documentation, reporting and archiving, as well as setting the information requirements for the stages of the cost estimation process together with the cost estimator. The case company already has guidelines for the sales and planning processes, but a comprehensive set of guidelines for the cost estimation process is yet to be introduced. Cost estimation is a multifaceted discipline, requiring a wide range of competencies, which in practice is achieved by gathering information from other project members. Thus, it is recommended to demystify the importance of cost estimation to all the internal stakeholders in the case organization in order to create an understanding of the common practices and the standard quality of information that the cost estimator needs. Making the process more *lean* requires elaborating on the information requirements within the case organization. Additionally, it should be monitored that the stages of cost estimation should be followed systematically and in order. Moving past a milestone implies that all the previous stages have been completed.

From the theoretical point of view, this research offers an insight into project complexity and ties together the individual elements of cost estimation methods, techniques and processes to create a holistic framework on managing quality of cost estimation and reducing the project variance. There is potential for further research in the areas of the computer-aided cost estimation and its role in the context of project business. In addition, the generalizability and transferability of the method are to be tested among other project-based industrial firms to confirm the validity of the method. Even though the researcher was able to adapt the method to the case firm, more context specification may be required.

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APPENDIX A: GAO'S RECOMMENDATIONS FOR A HIGH-QUALITY COST ESTIMATE

The figure is borrowed from GAO's handbook of cost estimation (2009, p. 180).

Table 25: The Twelve Steps of High-Quality Cost Estimating, Mapped to the Characteristics of a High-Quality Cost Estimate

Cost estimate characteristic	Cost estimating step
Well documented	
The estimate is thoroughly documented, including source data and significance, clearly detailed calculations and results, and explanations for choosing a particular method or reference ▪ Data are traced back to the source documentation ▪ Includes a technical baseline description ▪ Documents all steps in developing the estimate so that a cost analyst unfamiliar with the program can recreate it quickly with the same result ▪ Documents all data sources for how the data were normalized ▪ Describes in detail the estimating methodology and rationale used to derive each WBS element's cost	1. Define the estimate's purpose 3. Define the program 5. Identify ground rules and assumptions 6. Obtain the data 10. Document the estimate 11. Present the estimate to management
Comprehensive	
The estimate's level of detail ensures that cost elements are neither omitted nor double counted ▪ Details all cost-influencing ground rules and assumptions ▪ Defines the WBS and describes each element in a WBS dictionary ▪ A major automated information system program may have only a cost element structure	2. Develop the estimating plan 4. Determine the estimating approach
Accurate	
The estimate is unbiased, not overly conservative or overly optimistic, and based on an assessment of most likely costs ▪ It has few, if any, mathematical mistakes; its mistakes are minor ▪ It has been validated for errors like double counting and omitted costs ▪ Cost drivers have been cross-checked to see if results are similar ▪ It is timely ▪ It is updated to reflect changes in technical or program assumptions and new phases or milestones ▪ Estimates are replaced with EVM EAC and the independent EAC from the integrated EVM system	7. Develop the point estimate and compare it to an independent cost estimate 12. Update the estimate to reflect actual costs and changes
Credible	
Discusses any limitations of the analysis from uncertainty or biases surrounding data or assumptions ▪ Major assumptions are varied and other outcomes recomputed to determine their sensitivity to changes in assumptions ▪ Risk and uncertainty analysis is performed to determine the level of risk associated with the estimate ▪ An independent cost estimate is developed to determine if other estimating methods produce similar results	7. Develop the point estimate and compare it to an independent cost estimate 8. Conduct sensitivity analysis 9. Conduct risk and uncertainty analysis

Source: GAO.

APPENDIX B: ESTIMATION ACCURACY BOUNDARIES

Stage	*Uncertainty range*		*Source*
Strategic	-50 %	50 %	AbouRizk et al. (2002), construction projects
Concept	-30 %	30 %	
Preliminary design	-20 %	20 %	
Detailed design	-10 %	10 %	
Construction	-10 %	10 %	
0-2 %	-35 %	35 %	MOTI (2013), transport and infrastructure
1-15%	-35 %	35 %	
10-40%	-20 %	20 %	
30-90%	-20 %	20 %	
80-100%	-10 %	10 %	
0-2 %	-50 %	200 %	WSDOT (2015), transport
1-15%	-40 %	100 %	
10-30%	-30 %	50 %	
30-90%	-10 %	25 %	
90-100%	-5 %	10 %	
Concept	-15 %	20 %	Queensland Government (2017), transport
Development	-10 %	15 %	
Development stage II	-5 %	10 %	
Implementation	-2,5 %	5 %	
Rough	-25 %	75 %	Taylor (2007) & Kerzner and Kerzner (2013), studies from PMI
Budgetary proposal	-15 %	25 %	
Definitive	-5 %	10 %	
Order of magnitude	-30 %	50 %	Humphreys (2005) - ANSI guidelines (1991)
Budgetary	-15 %	30 %	
Definitive	-5 %	15 %	
0-2 % (Class 5)	-20 % -50 %	30 % 100 %	DOE (2011) and AACE (2016)
1-15% (Class 4)	-15 % -30 %	20 % 50 %	
10-40% (Class 3)	-10 % -20 %	10 % 30 %	
30-70% (Class 2)	-5 % -15 %	5 % 20 %	
70-100% (Class 1)	-3 % -10 %	3 % 15 %	

The averaging of the values was carried out by classes of the estimate. The order of magnitude estimate provided by WSDOT (2015) was omitted since it was deemed too inaccurate. WSDOT's rough estimate is carried out for 20-year programs.

APPENDIX C: CHALLENGES IN COST ESTIMATION QUESTIONNAIRE

The questionnaire was sent to the cost estimators in the case company to obtain an overview of the prevalent challenges of cost estimation. The questionnaire form is presented in the figure below.

QUESTIONNAIRE: CHALLENGES IS COST ESTIMATING

Do you agree or disagree with the following statements?

In your organization, it is difficult to carry out cost estimation because (of)…

1. the nature of project business: each project is different.

   a. Agree *b. Disagree* *c. Cannot say*

2. lack of historical information.

   a. Agree *b. Disagree* *c. Cannot say*

3. it is not always clear which cost item to allocate costs to.

   a. Agree *b. Disagree* *c. Cannot say*

4. the novelty of the technology and custom-made innovative solutions.

   a. Agree *b. Disagree* *c. Cannot say*

5. project's size: the larger - the more difficult to estimate.

   a. Agree *b. Disagree* *c. Cannot say*

6. reliance on supply chain: prices from contractors may be inaccurate.

   a. Agree *b. Disagree* *c. Cannot say*

7. human factors: people make mistakes, some people underestimate, some overestimate.

   a. Agree *b. Disagree* *c. Cannot say*

8. detailed estimates being too resource-consuming.

   a. Agree *b. Disagree* *c. Cannot say*

9. assigning the task of cost estimation to technical staff.
   (Engineers should have business competence to create a cost estimate)

   a. Agree *b. Disagree* *c. Cannot say*

10. Other reasons? (optional)

Thank you!

Figure 1. *Questionnaire for identifying the challenges in cost estimation.*

The outcomes of the questionnaire and the additional challenges identified in the process of cost estimation are presented in the figure below.

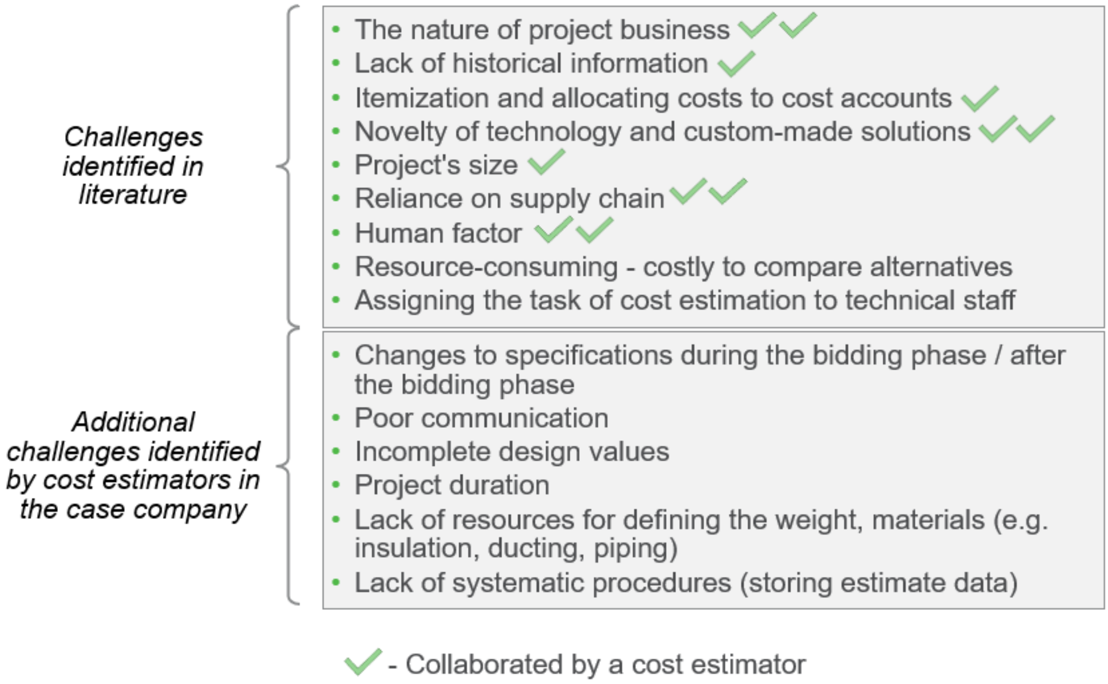

Figure 2. *Challenges in cost estimation.*

The tick-marks on the figure represent the challenges that were collaborated by the cost estimators within the case company. The additional challenges were collectively identified by the cost estimators in addition to those identified in the literature. Interestingly, the additionally identified challenges are of a procedural character and some of them correspond to the internal foreseen risks (see Figure 9).

APPENDIX D: FEEDBACK COLLECTION FORM

The findings were presented to the stakeholders in the case company to obtain feedback on the overall relevance and applicability of the findings. The session was held on the 17th of February 2020 and the feedback form, which was given out to the participants is presented in the figure below.

Please, provide short answers to the questions below. The questionnaire can be submitted anonymously if you prefer. The information regarding your position will be used in the thesis with the intent of clarifying priorities regarding the process of cost estimation in different parts of the sales organization.

Name / position: ***(optional)*** ____

1. Do you find the proposed suggestions useful in the context of the case company's current procedures?

2. In your opinion, how likely the suggestions are to be implemented?

3. Is there a particular aspect that you would like to be developed further?

4. Are there findings that you disagree with or find unnecessary?

5. Are there any topics that you would like to be investigated further or that are not mentioned in this work?

6. Do you have any other comments?

Thank you for your time and have a good day!

Figure 3. *Feedback collection form.*

The results were presented to the stakeholders in the case company in a form of a PowerPoint presentation, where the need for the research, as well as the challenges from the theoretical as well as the practical perspectives, were identified. Thereafter, the key theoretical findings were introduced, namely the accuracy boundaries of the cost estimation alongside the guidelines for selecting appropriate techniques of cost estimation as well as the process guidelines. Then, an overview of the challenges within the case department was introduced, after which the theoretically developed procedural improvement modified to the context of the case department was introduced and explained.

In addition, the methodology and the outcomes of the data analysis carried out through the research process were presented to the case company's stakeholders. The project manager, among others, mentioned that the historical data cannot be relied on since the cost tracking throughout the projects are not done in accordance with the account structure used to create the project's budget. Although, as was discussed, the data analysis is a direction-giving, rather than definitive as a result of analyzing a substantial amount of data.

The feedback provided by the case company stakeholders is listed below:

1. *Do you find the proposed suggestions useful in the context of the case company's current procedures?*

- Very useful
    - The three recommendations should be implemented:1) developing and using tools that match the target of each estimation phase; 2) developing a cost estimate summary for the ease of comparison of the budgeted and actual costs; 3) determining the cost uncertainty range at the firm proposal stage.
- Useful as long as the responsibility of implementing the changes and enforcing the changes is assigned within the case department
- Interesting suggestions, some of them from a new angle. Raised thoughts.
- Definitely useful, especially the estimation process and the techniques.

2. *In your opinion, how likely the suggestions are to be implemented?*

- Very likely
- Should be very likely
- Very likely, another question is enforcing the changes and getting everyone to work according to the improved procedures.
- Probably not all of them, but some.
- Should be 100%, but we should focus on priorities first.

3. *Is there a particular aspect that you would like to be developed further?*

- Cost review and follow up process, uncertainty ranges.
- The idea of splitting the risks into internal and project risks was a good idea and might help in following up on the costs.
- Tracking the individual costs and their origin: is it an estimate or is it an exact figure provided by a contractor.
- Feedback from project implementation to cost estimation.
- Pricing tools and ways of working. Using reference data instead of the guesstimates (where applicable). Focusing on the high impact and big variances – how to improve those.

4. Are there findings that you disagree with or find unnecessary?

- No

5. Are there any topics that you would like to be investigated further or that are not mentioned in this work?

- No, the most critical ones are presented in the work.
- Creating a process and guidelines to it, but that is another project.
- We cannot rely on historical data 100% because the cost allocation is usually not done correctly.
- How to make ways of working more effective? Improving the tools for cost estimation and the processes involved in cost estimation. Cost account structure in budgeting and throughout project implementation.

6. *Do you have any other comments?*

- Excellent work.
- Very good job and professional output.
- Very important work. I'd like to see the pricing done more systematically.
- The practical part of the thesis is very well done.