

UNIVERSITY OF TWENTE.

Faculty of Behavioural, Management and Social Sciences
Department of Technology Management and Supply

Master thesis

Master of Science (M.Sc.) Business Administration
Purchasing and Supply Management

Reliable procurement cost estimation methodologies: A case study in complex environments

B.Y. Perluka

Examination committee:

Dr. K.P.M. Stek

Dr. E. Svetlova

Enschede, May 2024

Abstract

Background: Competitive bidding is being used to compare potential suppliers. For the supplier, it is important to have a competitive bid price. Otherwise, the supplier's actual cost needs to stay below the bid price to avoid a cost overrun. Therefore, organisations can use qualitative and quantitative estimation methodologies to determine the cost. Thereby, in complex environments, you must deal with complicated products that consist of standard products in combination with new product development (NPD), which complicates the estimation process. Additionally, there are internal and external factors that may influence the accuracy of the cost estimation; as a result, the estimation will be less reliable.

Purpose: This research aims to investigate how cost estimation methodologies for procurement parts can be enhanced to become more reliable. It will examine which kinds of methodologies are effective for both standard products and NPD. Furthermore, factors that influence cost estimates will be explored. In addition, a framework will be developed to provide a representation of the coherence of methodologies and factors for organisations in complex environments.

Method: For the analysis of this research, a qualitative multiple case study approach was used, focusing on organisations operating in complex environments. Data collection is done by semi-structured interviews ($n = 12$), which are held multidisciplinary in four different cases. The interviews were transcribed, coded, and analysed to identify themes and categories in the collected data.

Findings: The results show that organisations in complex environments employ an analytical breakdown approach for the cost estimation of procurement parts for standard products. When organisations deal with NPD, the same approach is used, where estimations are made based on assumptions. It is, therefore, important to use multiple and appropriate estimation methods to strengthen estimation accuracy and to have the ability to challenge potential suppliers on their costs. Furthermore, the outcome has shown various internal factors, which are procurement-, technical-, or estimation-related factors. Regarding external factors, these are described as market-related factors. These factors need to be considered to enhance the reliability of cost estimations for procurement parts.

Keywords: cost estimation, reliability, influencing factors, complex environments, new product development (NPD)

Management summary

Competitive bidding is being used to compare potential suppliers. For the supplier, it is important to have a competitive bid price. Otherwise, the supplier's actual cost needs to stay below the bid price to avoid a cost overrun. Therefore, it is important to have a reliable estimation. Organisations can employ qualitative and quantitative estimation methodologies to determine the cost of bids. Thereby, in complex environments, you must deal with complicated products that consist of standard products in combination with new product development (NPD), which complicates the estimation process. Additionally, some factors may influence the cost estimation, which will affect reliability. Prior literature has shown several calculation methodologies that can be employed and identified factors that influence cost estimations. However, there is limited empirical research on how these factors can be considered to create a reliable cost estimation. This gap will be addressed by conducting research into examining the influence of factors on cost estimation methodologies for procurement parts in complex environments to enhance reliability.

This research aims to provide an answer to the following main question: *How can organisations in complex environments enhance the reliability of their cost estimation methodology for procurement parts?* This question is divided into two sub-questions: *1. What are the most effective procurement cost estimation methodologies employed by organisations focusing on both standard products and new product development (NPD)? 2. Which internal and external factors need to be considered in cost estimations to improve predictability and become more reliable?* This research aims to investigate how cost estimation methodologies for procurement parts can be enhanced to become more reliable. It will examine which methodologies are suitable for use with both standard products and NPD. Furthermore, factors that influence cost estimates will be explored. Additionally, a framework will be developed to provide a representation of the coherence of methodologies and factors for organisations in complex environments.

Previous literature describes which methods can be used to perform estimation. Cost estimation methodologies can be divided into two different categories: qualitative and quantitative methods. Qualitative methods can be divided into two different types: intuitive techniques and analogical techniques. These techniques use data from previous product designs or expert knowledge to arrive at an estimate. On the other hand, quantitative methods can be divided into parametric and analytical techniques. These techniques are based on data from the characteristics of a product design or a manufacturing process. Because standard products are fully developed, a lot of information is available to perform a cost estimation. However, in complex environments, you also have to deal with NPD (new product development). For NPD projects, when an NPD develops further in the process, the information will become more reliable, which enables the use of cost estimation techniques that are more accurate and result in more reliable cost estimations. In the early stages of development, only qualitative techniques are applicable to perform a cost estimation. Once a product or process design has been developed, only detailed quantitative techniques can be used for cost estimation.

Also, previous literature has shown that there are many factors that can influence cost estimation. These factors can be divided into two groups: internal factors and external factors. The internal factors occur within the organisation or project, which means that an organisation can influence these types of factors. On the other hand, there are external factors that occur outside the organisation and can be influenced minimally. This literature has shown that it is important that these factors are identified, and an assessment of these factors should be conducted. After that, the department responsible for cost estimation will have to consider the influence of this factor on the estimation.

For the methodology of the research, a multiple case study is employed as a qualitative study approach. To get a general perspective on cost estimations in complex environments, it is necessary to engage various companies about their cost estimation processes. For this, four different companies were interviewed, and respondents from different departments (such as buyers, cost estimators, and project managers) were approached to get a broad perspective on this process, which resulted in a total sample size of twelve interviewees ($n = 12$). To collect data, semi-structured interviews were used to gather information on the following topics: current practices, challenges and opportunities, internal and external practices, and best practices. Using the Gioia methodology, grounded theory was developed as an inductive approach. This method consists of several rounds of coding to connect different concepts to describe a phenomenon.

The first results of the study focused on the estimation methodologies used in organisations in complex environments. For this purpose, a distinction was made between methodologies for standard products and for NPD. For standard project estimations, it has become evident that cost estimations are based on the BOM structure, making it clear which parts are needed for a project. For component prices, companies use the principle of updating prices to obtain recent prices by requesting quotations from the supplier. It also uses so-called reference prices, where prices are updated by a percentage to estimate a current price. For NPD projects, organisations use a high-level breakdown structure based on assumptions. This helps identify requirements that enable the calculation of cost estimations. For new products, which are like existing products, organisations reuse those quotations to estimate costs. Also, should cost analysis be used to challenge the cost of suppliers to determine whether the price asked is a reasonable price to pay. For the same reason, manufacturing costs are calculated for the outsourcing of components.

Furthermore, the results of the study showed that several factors play a role in the reliability of an estimation. The study showed that there are four different categories of factors. Within the technical-related factors category, two factors were identified: a lack of a clear definition of the project and a lack of technical knowledge. Due to a poor definition of a project, misconceptions can occur in cost estimation. Thereby, poor technical knowledge can cause difficulties in reviewing the accuracy of the information that engineering departments provide. A second category focuses on procurement-related factors: frequently changing prices by suppliers and long waiting times to receive quotations from suppliers were identified. The procurement department is responsible for requesting new quotations from the supplier. However, due to market conditions, these prices change frequently and are therefore inconsistent. It also shows that suppliers often do not have time to make quotations, which causes long waits for quotations. Market-related factors were a third category identified: poor availability of materials due to supply issues and high increases due to market forces were the identified factors. While materials are sometimes not available, this will affect the costs to be incurred that were not considered in the estimation. In addition, market forces also increase the price of materials, which has a major impact on the reliability of cost estimations. Finally, three factors were identified within the category of estimation-related factors. These factors are a lack of updating input data for the estimation, a lack of estimation time, and poor transparency of input data for the estimation. As the data from estimations is not updated, this will directly affect the reliability of the cost estimation. The transparency of the data supplied will also have an impact, as poor transparency will make it more difficult for the estimator to determine whether the data are correct. Finally, it is important to take enough time to carry out estimations so that it can be checked whether all facets have been included in the estimation.

The theoretical implications of this research show that the choice of methodology depends on the state of development. It has become evident that the analytical breakdown approach applies to both standard products and NPD. However, the methodology is highly dependent on the availability of cost data from historical data. Standard projects already have a structured product and process design, while NPD projects need a more adaptive approach to determine which methodology is appropriate for the situation. It became evident that multiple methodologies should be used to eliminate uncertainties and strengthen reliability in NPD cost estimations. Furthermore, the research identified procurement-, technical-, estimation-, and market-related factors that influence cost estimates. These factors can be divided into internal factors within the organisation, which can be influenced. In comparison, external market-related factors can hardly be influenced by organisations. These outcomes have strengthened existing literature on cost estimations and factors that may influence predictability, which undermines reliability.

The practical implications of this research give organisations guidance on how to improve cost estimation predictability to become more reliable. First, methodologies are uncovered during the research, which will give organisations guidance on which methodologies can be employed for the estimation of procurement costs. The research made evident that the analytical breakdown approach is the most effective approach to estimating procurement costs for both standard and NPD projects. However, the methodology cannot be used in the same way in both cases. This study emphasises the necessary adaptability to choose appropriate estimation techniques based on the circumstances. For NPD projects, an organisation cannot rely solely on one technique, as the project description is not fully established during the development stage. Organisations need to consider which estimation technique is suitable for the specific situation by examining project requirements and constraints. Next, influencing factors were revealed during the research. The factors give direct practical guidance to organisations on factors that they can improve. These results will show organisations how they can improve the predictability of cost estimations, making them more reliable. To visualise this, a thematic framework was developed based on the uncovered themes shown in Figure 4. The respondents described a general process for how cost estimation is performed, which is shown in this framework. This describes the necessary collaboration between procurement, the estimation department, engineering, bid, project, or sales management. The framework also shows estimation methodologies, which are used in standard projects and new development projects. At last, it presents the influencing factors where they occur within the cost estimation process. Table 6 shows which department is responsible for the factors, which gives practical guidance on which actions to take to improve processes and ultimately enhance the overall estimation process.

In conclusion, the research results have shown how organisations can enhance the reliability of their cost estimations for procurement parts. Using interviews, this study revealed how organisations perform cost estimations and what factors influence them. These results have thus given organisations practical guidance on improving the cost estimation process. The study also enriched existing literature with new insights regarding the cost estimation principle.

Table of contents

ABSTRACT	2
MANAGEMENT SUMMARY	3
LIST OF FIGURES	7
LIST OF TABLES	7
1. INTRODUCTION: ENHANCING THE RELIABILITY OF THE COST ESTIMATION METHODOLOGY, ESPECIALLY FOR PROCUREMENT PARTS	8
2. LITERATURE REVIEW: A CONSTRUCTIVE REVIEW OF ACADEMIC LITERATURE	10
2.1 COMPLEX PRODUCT SYSTEMS: HIGH-VALUE PRODUCTS WITH NON-LINEAR PROPERTIES AND PROJECT-BASED PRODUCTION	10
2.2 COMPETITIVE BIDDING: COST ESTIMATION IS CRITICAL IN PROJECT BIDDING FOR SUCCESSFUL PROJECTS AND THE AVOIDANCE OF COST OVERRUNS	11
2.3 COST ESTIMATION METHODS: QUALITATIVE OR QUANTITATIVE METHODS FOR THE ESTIMATION OF COST	12
2.3.1 <i>Qualitative methods: Intuitive or analogical techniques based on historical data or the experience of experts</i>	13
2.3.2 <i>Quantitative methods: Parametric or analytical techniques based on product design and process characteristics</i>	14
2.4 NEW PRODUCT DEVELOPMENT: VARIOUS COST ESTIMATION METHODOLOGIES ARE REQUIRED AT DIFFERENT STAGES OF PRODUCT DEVELOPMENT	16
2.5 INFLUENCING FACTORS ON COST ESTIMATIONS: INTERNAL AND EXTERNAL FACTORS AFFECTING THE ACCURACY OF ESTIMATIONS ..	17
2.5.1 <i>Internal factors: Project and estimation-related factors influencing the cost of procurement parts</i>	19
2.5.2 <i>External factors: Market conditions influencing the cost of procurement parts</i>	20
3. METHODOLOGY: CONDUCTING A MULTIPLE CASE STUDY TO ENHANCE COST ESTIMATION RELIABILITY	21
3.1 RESEARCH DESIGN: MULTIPLE CASE STUDIES EMPLOYED AS A QUALITATIVE STUDY APPROACH.....	21
3.2 CASE SELECTION: RECRUITING VOLUNTARY PARTICIPANTS IN COMPLEX ENVIRONMENTS IN THE PROFESSIONAL NETWORK WHILE SECURING INFORMED CONSENT	22
3.3 DATA COLLECTION: SEMI-STRUCTURED INTERVIEWS AS A DATA COLLECTION METHOD TO EXPLORE THE PRACTICES OF MULTIPLE CASES	23
3.4 DATA ANALYSIS: QUALITATIVE DATA ANALYSIS SOFTWARE IS EMPLOYED TO CODE INTERVIEW TRANSCRIPT.....	24
4. RESULTS	24
4.1 COST ESTIMATION TECHNIQUES FOR COMPLEX ENVIRONMENTS.....	25
4.1.1 <i>Standard product: Cost estimations based on the BOM structure</i>	26
4.1.2 <i>Standard product: Updating prices for familiar parts using supplier quotations</i>	26
4.1.3 <i>Standard product: Use of reference prices to calculate contemporary costs</i>	27
4.1.4 <i>New development: Utilisation of breakdown structure based on assumptions for procurement parts</i>	27
4.1.5 <i>New development: Reuse of a quotation for a product similar to a new product</i>	28
4.1.6 <i>New development: Employing should cost analysis to challenge supplier costs</i>	29
4.1.7 <i>New development: calculation of manufacturing costs for outsourcing</i>	29
4.1.8 <i>overall conclusion</i>	30
4.2 INFLUENCING FACTORS FOR COST ESTIMATION	31
4.2.1 <i>Technical-related factors: Lack of a clear definition of the project</i>	32
4.2.2 <i>Technical-related factors: Lack of technical knowledge</i>	32
4.2.3 <i>Procurement-related factors: Frequently changing prices by suppliers</i>	33
4.2.4 <i>Procurement-related factors: Long waiting time to receive quotations from suppliers</i>	33

4.2.5 Market-related factors: Poor availability of materials due to supply issues.....	34
4.2.6 Market-related factors: High price increases due to market forces	34
4.2.7 Estimation-related factors: Lack of updating input data for the estimation	35
4.2.8 Estimation-related factors: Lack of estimation time.....	35
4.2.9 Estimation-related factors: Poor transparency of the input data for the estimation.....	36
4.2.10 Overall conclusion	36
5. DISCUSSION AND CONCLUSION	37
5.1 THEORETICAL IMPLICATIONS.....	38
5.1.1 Effective methodologies for standard products and new product development (NPD)	38
5.1.2 Internal and external factors affecting the cost estimation	39
5.2 PRACTICAL IMPLICATIONS	40
5.3 LIMITATIONS	42
5.4 FUTURE RESEARCH	43
6. CONCLUSION.....	43
REFERENCES	45
APPENDIX.....	48
APPENDIX A: INTERVIEW GUIDE.....	48
APPENDIX B: QUOTATIONS SUBSTANTIATING FIRST-ORDER CONCEPTS	49

List of Figures

Figure 1 Bid structure in projects (Tayefeh Hashemi et al., 2020)	12
Figure 2 Cost calculation techniques (Huang et al., 2012; Niazi et al., 2006)	13
Figure 3 Cost estimation in NPD (Chwastyk & Kołosowski, 2014).....	17
Figure 4 Thematic framework	41

List of tables

Table 1 Cost estimation techniques: advantages and disadvantages (Niazi et al., 2006).....	16
Table 2 Literature summary factors affecting cost estimation accuracy	18
Table 3 Sample overview	23
Table 4 Coding structure.....	25
Table 5 Utilised cost estimation technique among cases	31
Table 6 Influencing factors by department	42

1. Introduction: Enhancing the reliability of the cost estimation methodology, especially for procurement parts

Competitive bidding is a procurement method that ensures cost savings, transparency, and fair competitiveness in the selection of potential suppliers for contracts and projects. This method relies on suppliers that submit bid prices to secure projects. This winning bid is contingent on their ability to deliver their project within the estimated cost (Takano et al., 2018). In complex projects, there is high responsibility for suppliers who signed the contract; accuracy of the estimation is crucial to avoid cost overruns of the project, while on the other hand, it is important to have a competitive bid price to secure the project (Ishii et al., 2014; Takano et al., 2014). For the supplier, it is important to ensure that the actual project cost remains below the bid price to maintain profitability. Otherwise, the project may lead to financial losses for the supplier. Hence, an estimation for procurement parts is a crucial element for cost estimation, which is the foundation for ensuring project profitability.

To arrive at an accurate cost estimate, it is important to have access to a reliable methodology with accompanying tooling. Several methodologies can be distributed using either qualitative or quantitative techniques, and the literature describes several cost calculation methods (Huang et al., 2012; Niazi et al., 2006). However, the estimation is always based on two possible components or a combination of both: (1) the use of historical data or experience can leverage this knowledge to generate cost estimates, or (2) the level of design and process knowledge is sufficient for conducting a bottom-up cost calculation (Hueber et al., 2016). This implies that the effectiveness of any cost calculation method is influenced by the availability and relevance of existing data and the experience of appropriate people.

However, in complex manufacturing environments, you must deal with complicated products that consist of standard products in combination with new product development (NPD), which requires specialised acquaintance for cost estimation. Accuracy of information is a crucial factor in the accuracy of the cost estimation; during the NPD process, the information will get more reliable as the development process progresses (Chwastyk & Kołosowski, 2014). Respondents in the research by Doloi (2011) emphasised that project and design complexity are crucial factors in cost estimation in project management.

Next to choosing an appropriate cost estimation methodology, there are also internal and external factors that influence the costs of procurement parts. Internal factors are related to factors within the organisation and project. The most important internal factor mentioned in the literature is project complexity (Akintoye, 2000; Hatamleh et al., 2018; Odusami & Onukwube, 2008). The complexity of a product consisting of many different purchase parts makes it more difficult to determine the exact cost. The root cause is that this factor has the most significant impact on cost estimation and, therefore, causes cost overruns because the complexity of the project is often underestimated (Kujala et al., 2014).

External factors are usually related to changes in market conditions (Akintoye, 2000; Odusami & Onukwube, 2008). 2022 European sanctions imposed against Russian exports caused a major impact on supply chains in the global market; as a result, energy prices were at their highest level since 2013 (Sokhanvar et al., 2023). In addition, COVID-19 and the war between Russia and Ukraine have played a major role in the increase in inflation; because of this, the Russia-Ukraine war inflation applies mainly to countries that are relying on Russian energy supplies (Zheng et al., 2023). Also, considering the events, this shows that these are complications that are taking place today, which emphasises the relevance of the research.

Prior literature has shown which calculation methodologies are available and which factors influence cost estimations. However, there is limited empirical research on how these factors can be considered to create a reliable cost estimation. This gap will be addressed by conducting research into examining the influence of factors on cost estimation methodologies for procurement parts in complex environments to enhance reliability. Therefore, the following research question is asked:

How can organisations in complex environments enhance the reliability of their cost estimation methodology for procurement parts?

Sub-questions:

1. What are the most effective procurement cost estimation methodologies employed by organisations focusing on both standard products and new product development (NPD)?
2. Which internal and external factors need to be considered in cost estimations to improve predictability and become more reliable?

Currently, the literature on how factors affecting cost estimation can be integrated into the estimation process is limited. In the literature, several papers are focused on factors that affect cost calculation (Akintoye, 2000; Alumbugu et al., 2014; Hatamleh et al., 2018; Hueber et al., 2016; Mahamid et al., 2014; Odusami & Onukwube, 2008; Trost & Oberlender, 2003). However, these factors are not linked to the process of cost estimation described in the literature (Huang et al., 2012; Hueber et al., 2016; Niazi et al., 2006; Tayefeh Hashemi et al., 2020). This research intends to bridge the gap between how these factors can be integrated into the estimation process.

The research has both practical and theoretical contributions. The research focuses on the practical challenge of maintaining project profitability in complex procurement environments. By improving the reliability of cost estimates, organisations can avoid cost overruns and financial losses. The research further recognises the complexity of projects and the associated risks. External factors, such as market conditions, can also significantly affect procurement costs. The research offers insight into adapting cost estimation methodologies to these changes and provides practical guidance for organisations dealing with project complexity and dynamic external environments. Organisations can adopt the results of this research to improve their internal processes, which increases the predictability of cost estimates.

The theoretical contribution of this research lies in bridging the existing gap in empirical knowledge by examining the influencing factors in cost estimation methodologies for procurement items in complex environments. Prior literature has described available calculation methodologies and identified factors influencing cost estimations. There is limited empirical research conducted to understand how these factors are considered in the estimation methodology that is employed. The research focuses on the challenges that occur in complex environments, where the combination of standard products and new product development (NPD) causes difficulties in cost estimation. This research seeks to identify the most effective methodology for estimating procurement cost and which internal and external factors should be considered to provide insights that contribute to the development of a framework for the estimation of cost in complex projects, which contributes to the theoretical foundations of cost estimations in procurement.

The first part of this research contains a systematic literature review on cost estimation in procurement, including related topics. The second part will be focused on the methodology, which contains the data

collection method and analysis of the data in this research. In the third part, the outcome of the data collection findings will be presented. The fourth part presents the discussion and conclusion, where findings will be linked to existing literature and give both theoretical and practical limitations with suggestions for future research.

2. Literature review: A constructive review of academic literature

In the literature review, there will be a constructive review of academic research. Therefore, academic research will be consulted to see what is already known in the literature. The goal of the literature review is to give a comprehensive overview of existing literature to get a better understanding of the subject of cost estimation and related topics that are necessary for the research. Based on existing literature, a theoretical framework will be developed, which will serve as a guideline for the analysis of this research.

2.1 Complex product systems: High-value products with non-linear properties and project-based production

Due to the complexity of products, there are various obstacles that companies face when operating in complex environments. In the literature, several articles focus on products in complex environments, also called Complex Product Systems (CoPS) (Hobday, 2000; Hobday & Rush, 1999; Ren & Yeo, 2006), which can be seen as high-value products, services, networks, and constructs. CoPS are products intended for an individual customer that are produced as on-off projects or in small batches (Hobday & Rush, 1999; Ren & Yeo, 2006). Adding to that, CoPS is very important because 11% of a nation's value-added GDP is due to CoPS (Moody & Dodgson, 2006). An example of CoPS are automated production systems, frigates, aircraft for passengers, and yachts. According to Hobday and Rush (1999), three characteristics make the distinction between CoPs and mass production. The first characteristic is based on the valuation of a product. CoPS are highly valued and often include customised parts that are produced for specific customers. Second, CoPS shows non-linear properties after some time, which results in small improvements in one component leading to the need for improvement in larger components, which means developing parts does not work but entire product solutions need to be developed. The third characteristic Hobday and Rush (1999) describe is production volumes. CoPS is mostly produced in projects or small batches, which allows close user involvement during the production process.

For CoPS-related projects, there are several capabilities required for the preparation of the bid and the execution of the project. Therefore, the bid phase activities include collecting supplier requirements, specifying conceptual designs, estimating costs, level of service, risk management, project planning, selecting subcontractors, and emerging all activities mentioned in a bid document (Davies & Brady, 2000). These activities will be the responsibility of bid managers, who need to ensure a successful, substantiated bid to secure projects. In the project phase, the following activities are included: integrating organisational functions; purchasing resources, which need to be managed and reallocated; working in teams; and the use of specific tools and techniques (Davies & Brady, 2000). In the project phase, the project manager is responsible for the management of the project to ensure cost will be within budget and on-time delivery according to project planning.

According to Davies and the authors, cost estimation is one of the related processes in CoPS for both the bidding and project phases. Kujala et al. (2014) describe the eight key challenges in cost management in CoPS, which are important:

- Due to the unique characteristics of projects, there is no accurate information about pricing and management contingencies known in the bid phase, such as the cost of purchasing unique parts that are difficult to estimate.
- Due to the long project timeline, estimating the cost of resources is difficult because of the variations in prices during the project.
- Due to the high complexity of projects, project management and integration engineering costs are costs that occur more often, which hinders cost estimations.
- Many different stakeholders need to calculate their profit margins.
- The calculation of the profitability of a project is difficult to do because it requires price agreements between the holding company and the daughter company when a project is implemented by different companies within the holding company.
- A cost overrun can result in challenges for the holding company when very large projects are involved.
- Due to the large contingencies in different parts of the project, determining the total value of the contingencies is difficult.
- Projects with a long duration and high value require the use of the percentage of completion (POC) method. This method requires the release of contingencies due to the recognition of accrued value during the project.

2.2 Competitive bidding: Cost estimation is critical in project bidding for successful projects and the avoidance of cost overruns

While working on projects, it is usually applicable that prior price agreements are made with a customer. Competitive bidding is based on placing bids to secure a project, where the supplier with the lowest bid will execute the project (Takano et al., 2018). In this method, “the bid price of each contract is determined based on the estimated cost, and consequently, a cost estimation error makes the bid price inaccurate and may even cause a deficit from the contract” (Takano et al., 2014, p. 132). In connection with this, procurement has a significantly large share; manufacturing companies spend 50% to 80% of their revenue on procurement activities (Johnson et al., 2021; Sobhani et al., 2014). This indicates that it is very important that procurement parts that are part of the project are calculated with great accuracy. Accuracy is of great importance to avoid cost overruns, but on the other hand, the bid must also be competitive to secure the project (Ishii et al., 2014; Takano et al., 2014). The project cost needs to stay below the price agreement for the project to be profitable; otherwise, the project will lead to financial losses. So, it is important to have a well-substantiated cost pricing structure to know what the limits are for price agreement negotiations.

The bid price is based on cost, which can be distinguished into direct and indirect costs, and a markup, which is shown in Figure 1. According to Tayefeh Hashemi et al. (2020), the markup that will be merged with costs to formulate the bid price is structured as follows:

- Profit is based on the objectives of the company, the level of competition during the bid, and the willingness to win the project over competitors. This represents the profit that a company is willing to make on a project, which will be merged with the cost.
- Unexpected risks are based on identified and unknown risks. This part of the markup is set aside to cope with uncertain situations that will affect the performance of the project.

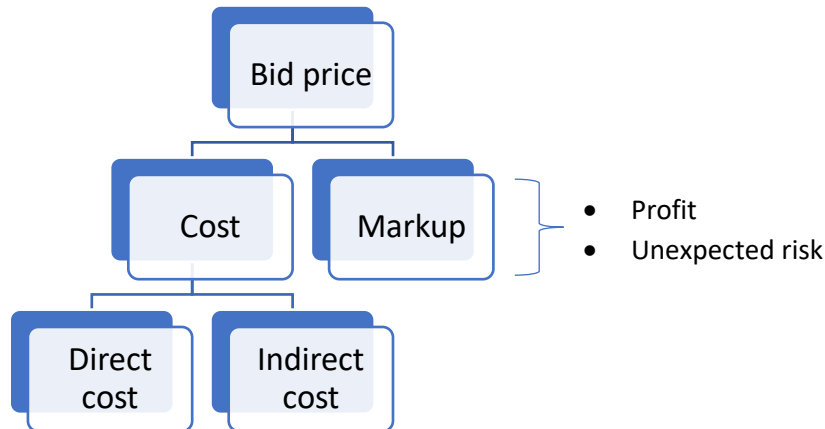


Figure 1 Bid structure in projects (Tayefeh Hashemi et al., 2020)

2.3 Cost estimation methods: Qualitative or quantitative methods for the estimation of cost

Cost estimations are fundamental components of decision-making and serve as a foundation to support crucial business decisions. It is therefore important that a calculation be reliable and accurate to make important decisions related to project budgeting or financial management. Therefore, an appropriate cost estimation method is required to perform a cost estimation. To make a distinction between different cost estimation methods, there are various ways to distinguish them from each other. A common way to indicate the difference between the methods is to divide them into qualitative or quantitative methods (Layer et al., 2002; Niazi et al., 2006; Tayefeh Hashemi et al., 2020).

Niazi et al. (2006) and Tayefeh Hashemi et al. (2020) make the distinction between four different techniques: intuitive techniques and analogical techniques, which are qualitative methods. For quantitative techniques, they make the distinction between parametric techniques and analytical techniques. However, not every technique is applicable in every situation; which technique can be used depends on what information is available about the product in question. The basis is that data from historical products or expert knowledge is required to make a cost estimation or that the product design and production process are defined in such a way as to perform a cost estimation; this applies to both qualitative and quantitative techniques (Hueber et al., 2016). The total overview of techniques is shown in Figure 2. All techniques are explained in the following chapters, with Table 1 briefly listing their advantages and disadvantages.

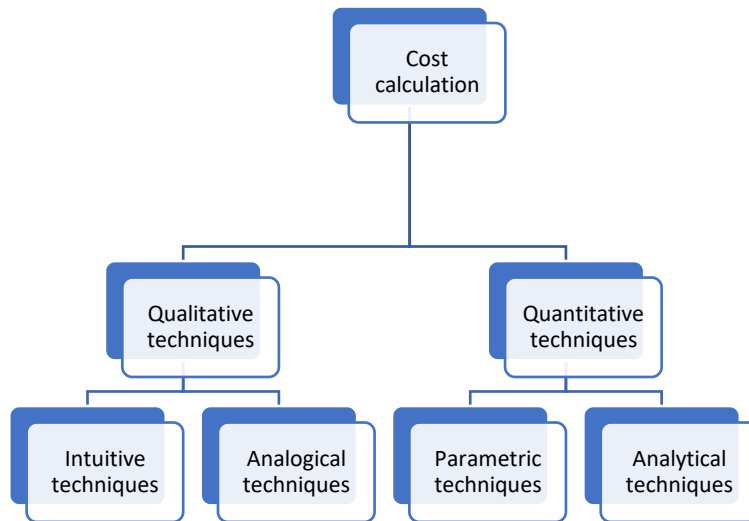


Figure 2 Cost calculation techniques (Huang et al., 2012; Niazi et al., 2006)

2.3.1 Qualitative methods: Intuitive or analogical techniques based on historical data or the experience of experts

Qualitative methods are mainly used for cost estimations regarding new products; by comparing previously produced products with the new product, similarities between the products can be used as part of arriving at a cost estimation for a new product (Huang et al., 2012; Niazi et al., 2006). This technique can be used in situations where limited detail about the product design or production process is available. Huang et al. (2012) emphasise that this method requires historical data on comparable products or experts who are experienced with comparable products to perform cost estimation and is convenient to use when estimation time is limited. Qualitative techniques can be distributed in two ways: intuitive techniques and analogical techniques, where intuitive techniques are based on expert knowledge, which is stored as rules that support decision-making (Niazi et al., 2006). For analogical techniques, historical data on products is needed with corresponding costs.

Intuitive techniques

One of the intuitive cost estimation techniques is case-based reasoning. This method is based on the historical design of a product, which partly matches the new product design (Huang et al., 2012; Niazi et al., 2006). This case-based reasoning technique “enables cost estimation of a new product through combining the past results of existing products with modifications referring to the newly designed components and/or assemblies of a new product” (Relich & Pawlewski, 2018, p. 41). Using historical designs will reduce the cost and time required for NPD projects and will provide cost estimations in a shorter time. The downside of case-based reasoning is that it relies highly on historical data and only often provides innovative designs; therefore, this technique is not applicable if historical or cost data are limited (Huang et al., 2012). Another intuitive cost estimation technique is decision support systems, which support the cost estimator, which can use a database with knowledge to select the best product design (Niazi et al., 2006). This technique can be divided into a rule-based system, a fuzzy logic system, and an

expert system. In rule-based systems, limitations of product design or manufacturing processes are utilised to select the optimal process to calculate product cost; however, the downside is that calculation for every process of components takes a long time (Huang et al., 2012). A fuzzy logic system offers system rules that check the relationship between the input and output of the fuzzy logic system, which is used to handle the uncertainty of the cost estimation (Niazi et al., 2006). Expert systems are techniques that are based on rule-based programming that convert expert knowledge into a knowledge database that ensures that estimation can be done faster and more accurately (Huang et al., 2012). A downside of expert systems is that it is sometimes necessary to programme complex programmes.

Analogical techniques

Qualitative methods, which are analogical techniques, are based on the assumption that similarities between different products have the same cost (Huang et al., 2012; Roy & Kerr, 2007). This technique can be distributed in two ways: regression analysis models and back propagation neural network methods (Huang et al., 2012; Niazi et al., 2006). For these methods, historical data on the cost of products is required.

Regression analysis models are based on the linear relationship between historical data and selected parameters, so the relationship between the past design data and selected variables can be used to estimate the cost of new products (Niazi et al., 2006). However, when a new product has a non-linear relationship with past similar products, the regression analysis method is not applicable. Back propagation neural network methods can be used to obtain answers to questions that were not seen by the model before (Niazi et al., 2006). This method adopts AI for the use of cost estimation, which allows neural networks to store and use data like the process of human thought (Huang et al., 2012). This method can also work in uncertain situations and with non-linear relationships across products, which overcomes the limitations of regression analysis models (Niazi et al., 2006).

2.3.2 Quantitative methods: Parametric or analytical techniques based on product design and process characteristics

Quantitative methods are more focused on the design of the product; these techniques involve the variation of several parameters or resources that are part of the product and the process that belongs to the production of the product (Niazi et al., 2006). Qualitative techniques can be divided into parametric techniques or analytical techniques, as shown in Figure 2. In contrast to qualitative techniques, which focus only on past data and the knowledge of experts, quantitative methods are focused on the characteristics of product design and manufacturing processes (Huang et al., 2012). However, to perform such a cost estimation, the time required will be longer, but this will provide more accurate cost estimations.

Parametric technique

The parametric techniques described by Niazi et al. are based on “applying the statistical methodologies and by expressing cost as a function of its constituent variables. These techniques could be effective in those situations where the parameters, sometimes known as cost drivers, could be easily identified” (2006, p. 567). In these techniques, cost drivers are mostly set as parameters that are focused on the characteristics of a product and do not require a detailed description. By using this technique, more cost

drivers can be considered by adding more parameters; in contrast to simply linear regression analysis techniques, this overcomes the limitations of utilising more parameters (Huang et al., 2012; Niazi et al., 2006). However, the downside of this technique is that the estimation relies on statistical assumptions regarding the cost-driver relationship towards the cost, the estimation should not only rely on statistical analysis (Roy & Kerr, 2007). Because of this, the common sense and experience of experts are not exploited in this technique.

Analytical techniques

Another quantitative technique is the analytical technique. This technique is based on the breakdown of a product into elementary parts, operations, and activities, which are resources that are utilised during the product life cycle, where the sum of all these components represents the total cost of a product (Huang et al., 2012; Niazi et al., 2006). This technique can be divided into five different categories, which are: operation-based cost models, break-down cost models, cost-tolerance models, future-based models, and activity-based cost models. The operation-based cost model requires a high level of information, so it is usually used in the final design stage. This model allows the calculation of manufacturing cost divided by material cost and machining time, which include productive production time, non-productive time, and setup times (Niazi et al., 2006). This model is based on times related to production to arrive at the manufacturing cost. In contrast to the operation-based model, which focuses only on production costs, the breakdown cost model is also focused on material, labour, and overhead costs, which require more details of the product design and process (Hueber et al., 2016). Hence, the breakdown cost model is only applicable at a later stage of product and process development because of the requirement for detailed information. Cost-tolerance models are based on the design tolerance of a product, which is used as a function of the product cost (Niazi et al., 2006). Another method similar to this is feature-based estimation, in which the features of a product are used as a function of the product cost. Activity-based costing models estimate the costs that are required to perform processes related to the manufacturing of a product (Huang et al., 2012). In activity-based costing models, “it is assumed that resources are consumed by the activities needed to produce the products or services. In the first phase, the resources are allocated to the activities, and in the second phase, the activities are allocated to the products” (Almeida & Cunha, 2017, p. 934). A downside of this model is that costs are allocated to activities; however, not all costs have a clear activity, which means that not all costs can be linked to an activity.

Cost estimation techniques					
			Advantages	Disadvantages	
Qualitative technique	Intuitive technique	Case-based reasoning		The design approach is innovative.	Mainly based on historical data and past experience.
		Decision support technique	Rule-based system	It is possible to provide optimised results.	It is usually time-consuming.
			Fuzzy logic system	Considers uncertainty to arrive at an estimation.	The calculation of complex features is difficult.
			Expert system	It is possible to calculate a faster and more accurate estimation.	It requires complex programming.
	Analogical technique	Regression analysis		The method is easy to use.	It is possible to solve non-linear cases.
		Back propagation neural network		It is possible to deal with uncertain and non-linear situations.	This model is fully dependent on data, and setup cost are high.
Quantitative techniques	Parametric techniques		Cost drivers are taken as the main definers of the cost.	unusable when cost drivers cannot be identified.	
	Analytical techniques	Operation-based cost models		Different process plans can be evaluated to get optimal cost estimations.	Time-consuming and detailed product design and production processes are required.
		Break-down cost models		An easy method to employ without software.	dependent on cost data for resources that are utilised.
		Cost tolerance models		It is possible to estimate cost by applying design tolerances.	Dependent on detailed design.
		Feature-based cost models		Features with higher costs can easily be identified.	It is difficult to determine costs for small and complex features.
		Activity-based cost models		The method uses activity costs, which result in an easy and effective cost estimation.	Dependent on lead time in the early design stages.

Table 1 Cost estimation techniques: advantages and disadvantages (Niazi et al., 2006)

2.4 New Product Development: Various cost estimation methodologies are required at different stages of product development

In complex manufacturing companies, products as well as production processes are of high complexity. In addition to the standard complex products that a company makes, NPD will also be part of the product and life cycle. The NPD process is important for companies because of the dynamic market changes and the maintenance of competitiveness in the market (Kazimierska & Grębosz-Krawczyk, 2017; Relich &

Pawlewski, 2018). Due to the high complexity of products, “formal vertical and lateral mechanisms are required during NPD to reduce the potential negative impact of information uncertainty on costs” (Ellram et al., 2020, p. 3). Therefore, Griffin (1997) describes the following mechanisms required during NPD: a lateral relationship mechanism is related to cross-functional teams needed during an NPD process; a vertical information mechanism is related to the stage-gate process and platform approaches during an NPD process. These mechanisms will reduce the uncertainty of information and can reduce the cost of an NPD project (Ellram et al., 2020).

Adding to that, when an NPD develops further in the process, the information will become more reliable, which enables the use of cost estimation techniques that are more accurate and result in more reliable cost estimations (Chwastyk & Kołosowski, 2014). Because, during an NPD, there is not yet complete information about the product design and process design, which makes precise calculation difficult. This emphasises that it is difficult to make cost estimations due to the scarcity of information available from an NPD. Chawastyk and Kołosowski (2014) describe different techniques in several stages of the NPD, where intuitive or analogical techniques can be used in the planning stage, and for the product design stage, parametric techniques can be used for the product cost. Analytical techniques can be used for manufacturing costs and, lastly, cost accounting in the production stage, which is visualised in Figure 3.

The visualised techniques across the several stages are discussed in Chapter 2.3 Cost estimation methods: Qualitative or quantitative methods for the estimation of cost, where an in-depth explanation is given about the differences between the techniques. As seen in the techniques presented by Niazi et al. (2006) and Huang et al. (2012), quantitative techniques can only be used when the product or process design is detailed enough to estimate cost, which means they can only be used in a later stage of projects. Qualitative techniques can be used to estimate costs during the planning stage of projects. In conclusion, the estimation of costs for an NPD depends on the stage of its development to use a corresponding methodology.

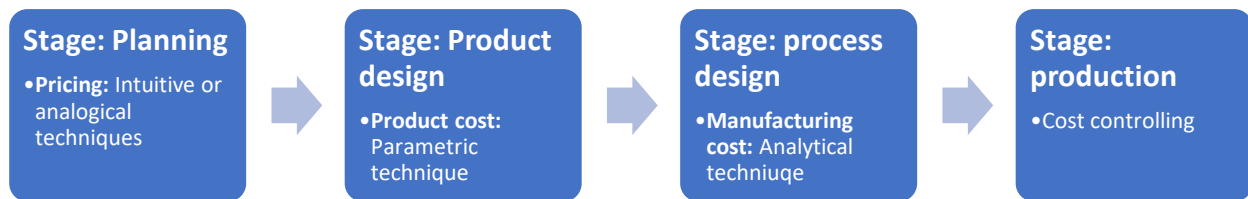


Figure 3 Cost estimation in NPD (Chwastyk & Kołosowski, 2014)

2.5 Influencing factors on cost estimations: Internal and external factors affecting the accuracy of estimations

The importance of cost estimates is that they are accurate, so they become more reliable. Besides the employed cost estimation methodology, other factors may influence the actual cost in comparison with the estimated cost. For factors that can escalate project costs, it is crucial to be identified, and an assessment of these factors should be conducted (Hatamleh et al., 2018). The department that is responsible for the estimation should examine what factors will affect the cost of the project (Akintoye,

2000). This should provide a good overview of risks that should ensure that actual costs are equal to the estimated cost so that there are no cost overruns.

Hatamlah et al. (2018) made a distinction between factors as follows: (1) factors related to the estimator and available information; (2) factors related to market conditions; and (3) factors related to the project. Idrus et al. (2011) made a distinction between factors that are internal and external related to the project cost contingency. To properly distinguish between the factors, they will be divided into internal and external factors, where all internal factors will be related to processes within the project and the organisation. External factors will be related to geopolitical or macroeconomic factors. The influencing factors will be taken into account in the estimation by including these as contingencies, which together with the profit margin form the markup on top of the costs (Tayefeh Hashemi et al., 2020). However, when dealing with CoPS, projects are split into different parts within the project. Due to large contingencies in different parts of the project, determining the total value of contingencies is difficult (Kujala et al., 2014).

To see what factors have been examined in past literature, a comprehensive review of factors affecting cost estimations has been made in Table 2 to gain insight into influencing factors. The table lists several studies with factors they see as relevant regarding the accuracy of the cost estimation. For internal and external factors, the following chapters will provide further exploration of the factors that are mainly considered important in the literature.

Literature	Factors affecting cost estimation accuracy
Akintoye (2000)	Project complexity, technological requirements, project information, project team requirements, contract requirements, project duration, and market requirements.
Trost and Oberlender (2003)	Process design, experience of the team and information on costs, available time to prepare estimates, site requirements, and bidding and labour conditions.
Odusami and Onukwube (2008)	Experience of the estimator, quality of information and requirement of flow, experience of the project team on a specific project, the tender period and market condition, degree of development of the pre-contractual design, and the complexity of the design.
Alumbugu et al. (2014)	Experience and skills of the estimator, experience of the project team in a specific type, clear and detailed project specification, cost information availability and the accuracy, and reliability of cost information.
Mahamid et al. (2014)	Number of competitors in the tendering stage, changes in material prices, communications between the executor, and client, and the methodology that is employed for the cost estimation.
Hatamlah et al. (2018)	Clear and detailed project specifications, estimation experience in specific projects, perception of the importance of the estimation, equipment, complexity of the project, clear definition of the scope, accuracy of the estimation data, site constraints, availability of materials, clients' financial capabilities, and availability of a database of historical data from similar projects.

Table 2 Literature summary factors affecting cost estimation accuracy

2.5.1 Internal factors: Project and estimation-related factors influencing the cost of procurement parts

Within companies, some factors play a role in exceeding the budgets drawn up for the procurement parts of a project. Internal factors can have a negative effect on cost estimations, which leads to inaccurate estimations. Looking at Table 2, the majority of the listed factors that affect cost estimation accuracy are due to factors that are internally related.

The most discussed factor in the literature is project complexity (Akintoye, 2000; Hatamleh et al., 2018; Odusami & Onukwube, 2008). Kujala et al. (2014) emphasise that the major reason for cost overruns is caused by the complexity of the project and the underestimation of its complexity. Due to the high complexity of projects, project management and integration engineering costs are more common, which complicates cost estimates for products (Kujala et al., 2014).

One other major factor discussed in the literature is project duration (Akintoye, 2000; Kujala et al., 2014), which manifests itself in an extensive period between the start of the bid phase and the end of the execution phase of the project. In the research of Kujala et al. (2014), they identified a cause that could cause a cost overrun on procurement parts:

“In the execution phase, the uncertainty of complex projects causes problems in procuring resources from suppliers without long-term contracts that outline prices. The uncertainty and uniqueness of the purchase prevent the responsible person from estimating the cost of the purchased product. Thus, he or she does not enter an estimate of the costs into the ERP system. As a result, the cost estimate for the entire project is no longer reliable, and cost overruns occur when the costs of the purchase are actualized” (p. 52).

In the absence of long-term contracts, estimates are based on predictions of future prices and not on actual prices. Therefore, this is more likely to happen when it comes to unknown products where suppliers are not identified than when it comes to standard products where overall supply chains are well-known.

Clear and detailed project specifications are also an important factor that ensures accuracy in cost estimation (Alumbugu et al., 2014; Hatamleh et al., 2018; Odusami & Onukwube, 2008). Due to the unique characteristics of projects in CoPS, there is no accurate information about pricing and management contingencies known in the bid phase, such as the cost of purchasing unique parts that are difficult to estimate (Kujala et al., 2014). Since every project has unique characteristics, it is important to have a clear and detailed project specification so that this gives clarity to each party to adhere to the project plan and so the estimator knows what needs to be calculated. When project specifications are not clear and detailed described, this will lead to changes in the "requirements during production, leading to unclear goals, uncertainty in production, and un-predictable, unquantifiable risks. Success and failure are multifaceted and hard to measure" (Hobday, 2000, p. 874). Due to changes during the execution of the project and deviation from the intended plan, which will lead to a cost overrun of the project. This describes that complex projects require clear and detailed project specifications that should be well thought out in advance before the execution of a project to avoid problems in the implementation of the project.

Lastly, there are often named factors that are directly related to the estimation namely, the reliability and availability of the cost estimation data (Alumbugu et al., 2014; Hatamleh et al., 2018; Odusami & Onukwube, 2008; Trost & Oberlender, 2003), the choice of an appropriate methodology to perform the

estimation (Mahamid et al., 2014), and a suitable executor with enough experience to perform the estimation (Alumbugu et al., 2014; Hatamleh et al., 2018; Odusami & Onukwube, 2008). This means that the chosen methodology to perform the cost estimation itself is also a factor that can influence the accuracy of the cost estimation. Alumbugu et al. (2014) conclude that the "experience and skill level of the estimator is the most influencing factor affecting the accuracy of pre-tender cost estimate. This implies that to produce an accurate estimate encompassing available of detail information, skill, and requisite experience of the estimator" (p. 24).

In conclusion, assessing the challenges posed by these internal factors, it becomes clear that a holistic approach, combining clear project specifications, consideration of project complexity, and adoption of estimating methodology, is essential for improving the accuracy of cost estimations for procurement parts. As organisations strive for more accurate estimates, recognising and addressing these factors will contribute to better project planning and successful cost management.

2.5.2 External factors: Market conditions influencing the cost of procurement parts

External factors in the context of cost estimation for procurement parts are influences from outside organisations, which makes controlling or mitigating the factor difficult. The factors are mostly beyond the organisation but can have a significant impact on the accuracy and predictability of cost estimates. However, eliminating the risk may be impossible. Keeping awareness of these external factors is important, so the probability that a risk may occur can be calculated in a cost estimation. As seen in Table 2, external factors are underrepresented. The most important factor listed in Table 2 is related to market conditions (Akintoye, 2000; Odusami & Onukwube, 2008).

Changes in market conditions can lead to cost overruns, making it an important factor to take into consideration in cost estimations (Doloi, 2011). Therefore, it is crucial to keep track of market conditions and include this as a factor in the cost estimation. Akintoye (2000) states that "the cost estimator in the estimating process must take into account the trends in market conditions and the implications on the costs of the resources for the project" (pp. 85-86). These factors need to be considered by the estimator to prevent a cost overrun for the project due to unforeseen costs caused by factors related to market conditions.

Looking at recent events, the Ukraine-Russia war is such an event that causes fluctuations in market conditions. Due to European sanctions on the export goods of Russia, they had a major impact on the global market, which caused supply chain disruptions and also caused the highest energy prices since 2013 (Sokhanvar et al., 2023). For companies with high energy consumption, these sanctions have a greater negative impact on financial performance than for companies with low energy consumption (Ferriani & Gazzani, 2023). Zheng et al. (2023) emphasise that due to the Ukraine-Russia war, energy prices increased, which caused inflation, especially for countries that rely on Russian energy supplies. They further describe that the breakout of COVID-19 also has a significant impact on inflation rates.

The events that have happened recently indicate that external factors can cause major consequences for market conditions, which underscores the interplay between market conditions and material prices. While the consequences of these external influences may be substantial, avoiding them is as minimal as possible, which necessitates adaptability in cost estimation practices. The importance of a forward-

looking and externally aware approach to cost estimation becomes not only evident but also needs sustained success in the continuously changing economic environment.

3. Methodology: Conducting a multiple case study to enhance cost estimation reliability

This chapter will give insights into the methodology used to perform this research, and in the first place, the research design is described. Second, there is a description of the case selection, which includes the participant selection. Last will be an explanation of the method that is used to collect data, and the last chapter will clarify which analysis method is used to get a better understanding of the collected data.

3.1 Research design: multiple case studies employed as a qualitative study approach

For this research, a qualitative study approach will be employed, a systematic approach to social phenomena that includes how people experience dimensions in life, the behaviour of individuals and groups, processes in organisations, and how relations are shaped (Teherani et al., 2015). The method allows for the extraction of answers to questions related to the experience, meaning, and perspective of the participant within the research (Hammarberg et al., 2016).

To understand and explore procurement cost calculation methodologies that are utilised within complex manufacturing environments, a multiple case study will be used to get comprehensive insights. A case study is described as “an intensive study about a person, a group of people or a unit, which is aimed to generalize over several units” (Gustafsson, 2017, para. 1). Case studies contribute to knowledge about individuals, organisational, political, and social phenomena; hence, case study is widely used among others, in psychology, sociology, and political science (Yin, 2014). To apply this method, a case needs to be defined to conduct a single case study or a group of similar cases can be defined to perform a multiple case study. The advantages of a multiple case study are that it allows the researcher to analyse data within each case and across the different cases, which allows the researcher to provide valuable differences and similarities to the literature (Gustafsson, 2017; Heale & Twycross, 2018). Additionally, the evidence is often strong and reliable, which allows the researcher to explain why the results are valuable or not.

The first part of this research is focused on a literature review, which gives a good understanding of existing literature. The literature review serves as a base “for knowledge development, create guidelines for policy and practice, provide evidence of an effect, and, if well conducted, have the capacity to engender new ideas and directions for a particular field” (Snyder, 2019, p. 339). The literature review is performed through the analysis of appropriate academic literature obtained from literature databases, namely Google Scholar and Scopus. In addition, snowballing and citation searches are used to obtain relevant literature related to the research framework.

The first component that needs to be described within a case study is to formulate a research question (Yin, 2014). Yin also emphasises that “how” and “why” questions are used to formulate research questions within case studies. In Chapter 1. Introduction: Enhancing the reliability of the cost estimation methodology, especially for procurement parts, a research question is formulated, which is: *“How can organisations in complex environments enhance the reliability of their cost estimation methodology for procurement parts?”* First, the cases will give insight into the cost estimation methodologies used for procurement parts that are employed in complex environments. Next to that, the challenges and opportunities of the employed methodologies will give insight across the cases. Third, the cases will give insights into internal and external factors that are influencing different actual costs compared to cost

estimation. The reviewed literature in Chapter 2. Literature review: A constructive review of academic literature, will be linked to the outcome of the case study to determine if these outcomes are represented in academic literature. Last, the cases in the case study might expose best practices that companies can adopt in complex environments to improve the accuracy and predictability of cost estimation for procurement parts.

3.2 Case selection: Recruiting voluntary participants in complex environments in the professional network while securing informed consent

For the case study, multiple cases representing organisations in complex environments will be selected that involve procuring both standard products and/or new development products. Cases will be selected based on industry relevance, diversity in size, and willingness to participate in this research. To select cases, purposeful sampling will be used; within this method, criterion sampling will be employed to assess cases if they comply with the purpose of the research (Suri, 2011).

Participants within the organisations will be selected based on the relevance of their positions related to procurement, cost engineers, supply chain, finance, and other relevant stakeholders. In addition, participants need to have expertise and involvement in cost estimations of procurement parts. To get a broad understanding, a diverse range of roles will be ensured. Therefore, to contact potential participants, the professional network will be used to approach candidates working for organisations that are known for their involvement in complex environmental projects in which the procurement department has an important role in cost estimations.

By getting in touch with potential participants, the purpose of the study will be explained, and the willingness to volunteer to participate in the study will be discussed. Also, informed consent will be ensured for the participants who will contribute to this research, which is focused on voluntary participation in the research. The identity of the participants in the interview will be confidential; therefore, the names of participants and the organisation of the interviews will be anonymised. Further sensitive information will remain confidential and will be handled with care.

In Table 3, the different participants are mentioned across four different cases. The cases operate in different markets, which are: defence, industrial machinery, and construction engineering. The sample of interviewed participants was made up of four participants in case ALPHA, three participants in case BETA, three participants in case CHARLIE, and two participants in case DELTA ($n=12$). The participants in the cases all had different roles associated with cost estimation. The interview duration had a minimum time of 27 minutes and a maximum duration of 50 minutes.

CASE ID	OPERATING MARKET	RESPONDENT ID	DISCIPLINE INTERVIEWEE	INTERVIEW DURATION
ALPHA	Defence	R1A	Procurement	42 min
		R2A	Supply chain	36 min
		R3A	Finance	30 min
		R4A	Bid management	40 min
BETA	Industrial machinery	R5B	Procurement	31 min
		R6B	Sales	27 min
		R7B	Cost engineering	44 min
CHARLIE	Construction engineering	R8C	Procurement	30 min
		R9C	Responsible cost engineering department	41 min
		R10C	Project management	38 min
DELTA	Defence	R11D	Procurement	46 min
		R12D	Cost office	50 min

Table 3 Sample overview

3.3 Data collection: Semi-structured interviews as a data collection method to explore the practices of multiple cases

To come up with relevant data for this research, data collection will be done through semi-structured interviews as the primary approach to obtaining data for this research. The method is chosen because it gives an in-depth exploration of participants' experiences related to the procurement calculation method in complex environments, which include standard products and NPD. Because "flexibility both in designing and refining the interview guides and in actually conducting the interviews is probably the most important key to success in using this technique" (Horton et al., 2004, p. 340).

The semi-interviews will be conducted in person or via video conference appointment, which depends on personal preference and the geographical location of the interviewees. To collect data, interviews are recorded to enable them to be used for data analysis. For the semi-structured interviews, an interview guide will be made to give guidance during the interviews. The interview guide will be focused on the following dimensions:

- 1. Current practices:** Participants will be asked about the procurement cost estimation methodologies in their organisations, which will be focused on both standard product projects and NPD projects.
- 2. Challenges and opportunities:** participants will be asked about the challenges and opportunities that occur in their current cost estimation methodology, which is focused on the accuracy and predictability of cost.

3. **Internal and external factors:** Participants will be asked how factors that influence the cost estimation are considered in the cost estimation to mitigate them. There will be a distinction between internal factors (project characteristics) and external factors (market constraints) that cause deviations in actual costs.
4. **Best practices:** Participants will be asked about the best practices and strategies that they consider proven in the context of procurement cost estimations to ensure accuracy and cost predictability.

An interview guide is made based on the dimensions described above in Appendix A: Interview guide.

3.4 Data analysis: Qualitative data analysis software is employed to code interview transcript

To analyse the obtained data during the interviews, an audio/video recording will be done to store the data. From these audio/video recordings, a transcript will be made to make analysis possible across the interviews.

To analyse the transcript, qualitative data analysis (QDA) software will be used. Therefore, the software program ATLAS.ti will be used to organize the data to get a good overview and to make coding possible out of quotations within the transcript. In a practical sense, ATLAS.ti is software that saves time and makes work easier. From an empirical perspective, this will improve credibility, which makes the research process more transparent (Hwang, 2007). The software will be used to code the transcript of the interviews, which can be used to compare cross-case examples to come up with relevant results for the research.

An inductive coding approach will be used to develop a grounded theory from the interviews. To structure the data, the Gioia methodology will be utilised (Gioia et al., 2012). This method consists of a first-order analysis, which searches for possible categories in which to quote in an interview. In a second round, similarities and differences will be considered between the first-order concepts to determine if they are in the same category to ensure data reduction. In the second-order analysis, possible themes that can be linked to the concepts will be considered that make it possible to describe a phenomenon (Gioia et al., 2012). Finally, after the theme's development process, it will be examined whether a second-order emerges from the second-order, also called aggregate dimensions. The outcomes of this process will be displayed in a data structure figure to visualise the results.

4. Results

This chapter will present the results of the research. The results of the interviews will be presented to answer the research question and the accompanying sub-questions. The chapter will present the first-order concepts, second-order themes, and aggregate dimensions. The concepts and themes found in the data analysis are shown in Table 4. The paragraphs of the results are divided by the aggregated dimensions, which include underlying themes and concepts grounded with obtained quotations from the participants in the interviews. The additional quotes obtained from the interviews which support the concepts and themes can be found in Appendix B: Quotations substantiating first-order concepts.

First-order concepts	Second-order themes	Aggregate dimension
Cost estimation based on the BOM structure	<i>Standard project estimations</i>	Cost estimation methodologies in complex environments
Updating prices for familiar parts using supplier quotations		
Use of reference prices to calculate contemporary costs		
Utilisation of breakdown structure based on assumptions for procurement parts	<i>New development estimations</i>	
Reuse of a quotation for a product similar to a new product		
Employing should cost analysis to challenge supplier costs		
Calculation of manufacturing costs for outsourcing		
Lack of a clear definition of the project	<i>Technical-related factors</i>	Influencing factors estimation
Lack of technical knowledge		
Frequently changing prices by suppliers	<i>Procurement-related factors</i>	
Long waiting time to receive quotations from suppliers		
Poor availability of materials due to supply issues	<i>Market-related factors</i>	
High price increases due to market forces		
Lack of updating input data for the estimation	<i>Estimation-related factors</i>	
Lack of estimation time		
Poor transparency of the input data for the estimation		

Table 4 Coding structure

4.1 Cost estimation techniques for complex environments

The interviews revealed what estimation techniques companies use to arrive at a cost estimate. The second-order themes are divided into standard product estimations and new development estimations. The corresponding first-order concepts found in the interviews are described below in the different chapters.

4.1.1 Standard product: Cost estimations based on the BOM structure

There are many different methods for estimating costs for procurement parts. It became evident from the interviews that for standard project estimations, respondents in several cases emphasised the use of cost estimation based on the BOM structure. *“What I'm starting with is a spin of costs from the [ERP system]. A printout of costs contains the routings of operations (I'm talking purely about the supply chain part) and a BOM of all materials. [...] Then the order of the purchase parts is examined; if there is a current blank purchasing agreement, then it is the first based on which the value of the material is determined. If there is none, the last purchase order is examined” (R2A).* The respondent's approach emphasises the consolidation of prices for all procurement items based on the BOM. They emphasise that since the BOM contains a structured list of all materials required for the standard product, it simplifies the process of determining costs for each component. This method allows a comprehensive assessment of the total project cost by adding up the costs of the individual procurement parts included in the BOM.

Overall, respondent descriptions emphasise the use of the BOM structure as the methodology for estimating costs in standard projects. The use of detailed information in the BOM is complemented by price data from procurement agreements or, if there are none, by quotations. This enables organisations to calculate project costs and ensure effective budget management during the project.

4.1.2 Standard product: Updating prices for familiar parts using supplier quotations

The interviews also highlighted updating prices for familiar parts using supplier quotations from the different cases. *“What we do to purchase parts within standard products is request new quotations from the suppliers and negotiate them. They will also be placed in the system in the form of a blank purchasing agreement, and they will then be reviewed in [a review], where you will see the cost increases, decreases, etcetera, and they will then be reviewed [...]” (R3A).* The respondent emphasises a review process in which cost changes are monitored during periodic reviews. This review process should cause cost data to remain current and meet current market conditions. By regularly updating cost data through quotations from suppliers, organisations can ensure the accuracy of their cost estimation process is maintained.

Another respondent describes how they keep the system up to date with recent prices. *“[...] Those cost engineers also need that structure, and we also prefer to work with the bill of materials. Because that is, of course, a very tight structure that you have. Well, then you can indeed update that periodically, and we do have a system in place that says that products that have not been ordered in our ERP system for more than a year are automatically set to block. We can no longer order them directly. There, a buyer must then take action to remove that item from the blockade” (R5B).* Both respondents underscore the importance of keeping systems updated by periodically reviewing and updating prices for the procurement part. They emphasise the use of the BOM structure to organise and structure the updates. They further describe a system function that is automated, where products that are not ordered within a certain time are automatically blocked from procurement activities unless action is taken by a buyer to prevent the blockage.

The strategies that are described by the respondents highlight the importance of relying on supplier quotations to ensure the accuracy and reliability of cost estimation and show a proactive approach that is necessary in the estimation process. Organisations can lower the risk of cost overruns to ensure

profitability by including supplier prices in the cost estimation. It was additionally described by respondents that the review of estimates and update processes are very important processes to maintain the effectiveness of the cost estimation process within the organisation.

4.1.3 Standard product: Use of reference prices to calculate contemporary costs

Another costing strategy mentioned during the interviews is the **use of reference prices to calculate contemporary costs**. “[...] *The reference price is only an indication that this is there now, but you know it's old; what should it be? As a result, we sit down with purchasing to arrive at a price. If the amounts are not very high, I will of course not approach procurement to request quotes for everything because that is time-consuming, then we escalate it*” (R2A). Due to the high complexity of projects in complex environments, it is often difficult to request prices for all costs of procurement parts in a project. Companies use reference prices, which means using prices from previous quotes with an escalation percentage to arrive at an estimation of cost for the current situation. The respondent describes that requesting prices from suppliers for all components is time-consuming. Therefore, they use reference pricing for low-cost components.

For this method, it is necessary to determine a reference percentage. This will be done by looking at historical data to determine the percentage by which an old price should be multiplied. This method can save a lot of time on quotation retrieval, which avoids the need to request quotations for each component. This approach enhances cost estimation efficiency by making it possible to use a reference price for low-priced items.

4.1.4 New development: Utilisation of breakdown structure based on assumptions for procurement parts

In parallel with the standard project estimations, respondents also discussed **new development estimations** that apply to projects with new developments. Therefore, the **utilization of breakdown structure based on assumptions for procurement parts** is named by several respondents. “*This is based on high-level requirements, very high-level requirements. [...] Aren't we missing certain qualification requirements that we set for the product? Have we made the right assessment? Some of us simply don't know. We can't apply for it because the technology isn't there yet. [...] Based on the high-level requirements, we can request quotations. Whether those quotations are the actual outcome, then you are dealing with scope creep*” (R1A). The respondent emphasises the reliance on high-level requirements, which provide the basis for setting up cost estimates in the early stages of development. Because certain technologies may not yet be available, they recognise that it is challenging to have all the necessary requirements for the product to be entirely considered. Due to this uncertainty, scope creep may occur when the project becomes larger than previously expected; because of this, the project can have cost overruns.

“[...] *We prefer to do that based on the bill of materials. Our cost engineer keeps it as a guideline because then you also know whether you have to buy parts at the mono-level or sub-assembly level and in what quantities. If that is not there, because the bill of materials is not there yet, because we make and do NPI projects, then we buy based on assumptions. Then we don't buy yet, then we ask for prices based on*

assumptions that we make, and mainly, of course, for the customer-specific manufactured parts [...]" (R5B). For projects during the development phase, another respondent also emphasises the importance of using a breakdown structure to estimate cost. However, during NPD projects, they emphasised that a full BOM is not always available. In the case of no full BOM structure, assumptions are made regarding the procurement parts, which enables the procurement department to request quotations from suppliers based on these assumptions.

For projects that are in the development phase, both respondents emphasised challenges related to cost estimation. These challenges are linked to the requirements of a product and the availability of components. It enables the organisation to prepare cost estimates, which makes it possible to request relevant cost information on procurement items from suppliers, which will all be possible by using this approach. Because of this, it also allows decisions for the project to be made based on these estimations at the early development stage of the project.

4.1.5 New development: Reuse of a quotation for a product similar to a new product

Besides using quotations based on assumptions, the **reuse of a quotation for a product similar to a new product** will be used to arrive at an estimation. It became evident that multiple cases use quotations from similar parts to determine the cost of new development parts. *"In that situation, I am highly dependent on our engineers, who also sit down with purchasing, and then they often look at an [article number] that is already known from which a price can come. Then purchasing can get started with quotations. Or it is checked whether a part is similar to another part. If you don't have the price of it, we know another product that also has a [part]. The large ones are not equal to each other, so you can apply a multiplication factor there. In this way, you can also arrive at a new calculation"* (R2A). The respondent emphasizes that during a new development project, there is a high dependence on the engineers because estimates can be made based on the design and project specifications. When the procurement parts of the new development project are similar to the procurement parts of a previous project, a previous quote with a factor can be used to arrive at an estimate for the procurement part of the new development project.

However, the feasibility of reusing supplier quotations depends on the technical solution and the availability of relevant historical data. *"It depends on the technical solution. If you have some experience, you can reuse a supplier's offer from a previous year if you don't have enough time. I think reuse is the only solution for building something with the team because they have the expertise to estimate all the major items of the product"* (R11D). The respondent emphasises that the reuse of supplier quotations from previous years can help when an estimate needs to be made quickly so that there is no time to wait for quotations from suppliers. Also, the respondent emphasises that this then needs to be done in consultation with the development team since they know the details of the engineered parts.

In general, when time is limited or detailed specifications are not available directly, the reuse of quotations from similar products could provide a solution for the estimation of cost in new development projects. Organisations can enhance the estimation process and make decisions on cost estimates for new development projects by using historical data and working together with engineering and procurement teams.

4.1.6 New development: Employing should cost analysis to challenge supplier costs

Another methodology for the estimation of cost that became evident during the interviews is **employing should cost analysis to challenge supplier costs**. It emerged in the interviews that should cost analysis can be used to challenge supplier costs. “[...] *We have a department in the [country] that does should cost analysis. That's just a programme or tool that we can use to challenge whether a product quoted by a supplier has the right should cost. We have these tools, and I see them as successful; we can really get this sub-assembly of sheet material of parts, or you name it, we can put it all in that tool. [...] Are these the costs we should pay? So yes, I see it as very successful*” (R1A). The respondent explains the use of should cost analysis, which the organisation uses to verify the accuracy and competitiveness of suppliers' quotations. They describe a department within their organisation that deals with the estimation of should cost analysis. They are using specialised tools to evaluate whether quoted prices match what can be expected based on various factors such as material, labour, and overhead costs. This process ensures that the organisation is not overpaying suppliers for components or subassemblies.

Another respondent clarified how this case uses a special department responsible for this so-called should cost analysis. “[...] *The goal of the cost office is to provide solutions for challenging costs throughout the whole life cycle, from bids to production and maintenance. So, there are different disciplines, so in terms of cost, you have two big categories. The first is macro should cost, while the second is detailed should cost. Macro should cost is also called parametric should cost. Parametric or macro should cost is the same idea. Detailed should cost is also called analytic should cost*” (R12D). This respondent explained that this case uses a special department responsible for challenging costs throughout the life cycle of a product. Also, the respondent highlights the distinction between macro should cost and detailed should cost methodologies. Macro should cost, also called parametric should cost, involves a broader assessment based on involved factors of a part. On the other hand, detailed should cost, which is also called analytical should cost, is based on a more detailed assessment of individual components or subassemblies, which considers specific features and characteristics that are unique to a part.

In this case, it is necessary to have a department that constantly questions the costs of the entire product life cycle of a given component. By employing the methods of macro- and detailed should cost, an organisation can analyse and address the prices of suppliers, making it possible to assess and negotiate prices with suppliers, which ultimately helps optimise costs and lead to increased market competitiveness.

4.1.7 New development: calculation of manufacturing costs for outsourcing

Finally, one case involved the use of a **calculation of manufacturing costs for outsourcing**. Due to their expertise in these products, they can use their calculation models when they outsource their work to calculate what it should cost. “*But we buy a lot of mechanical parts because we just don't have the capacity to make everything. So, we also calculate all the parts that we can calculate, and we just have calculation programmes for that. [...] We can calculate what a manufacturing part costs. We also know that if we were to outsource, the maximum price should be approximately in the region where you buy it*” (R7B). The respondent explained how they use their calculation programs to calculate the manufacturing cost of their outsourced products. By using their calculation models, the organisation can estimate the expected costs associated with outsourcing and provide insights into fair pricing, which serves as a benchmark for a

specific component. This proactive approach puts the organisation in a better negotiating position with suppliers and ensures that procurement costs remain within reasonable levels.

For outsourcing production, the respondent stresses the importance of considering factors related to geographical location when deciding where to buy. The organisations, therefore, consider regional differences in labour rates, material costs, and other relevant factors since those costs can vary significantly depending on the location of the supplier. The organisation can improve their cost estimation process and calculate the expected cost for the outsourced components by taking these geographical factors into account. The organisation presents a methodology to calculate production costs for outsourcing components, which allows them to make better decisions based on their calculations to remain competitive in a complex environment.

4.1.8 overall conclusion

The interviews have made it clear that there are different methodologies to determine the cost of procurement parts in complex environments. However, between standard projects and new development projects, a similar methodology is used to estimate the costs of procurement parts. Partly because we work with complex projects, it is difficult to make a very precise estimate of the purchase price. This has also strongly emphasised that the choice of methodology used depends heavily on the time available for this particular methodology. Table 5 gives an overview of the approaches employed within the various cases according to the estimation techniques of Niazi et al. (2006). Standard project cost estimations are not applicable for case CHARLIE since construction engineering almost always involves new development within the estimation.

Standard projects are projects that have already been developed and have been produced at least once. This means that the structure of procurement parts within the project is well known. Throughout the interviews, it became evident that all cases employed the analytical breakdown approach to calculating the cost for standard project estimations. In all cases, interviewees stated that a build of material is used as a guideline for the estimation of standard projects. To link the cost to the materials within the structure, companies use quotations or price agreements from suppliers to indicate the price at a certain moment. The use of recently requested quotations from suppliers makes the input of cost highly reliable; however, this makes the company dependent on the willingness of suppliers to provide a quote. Since you are dealing with complex projects that contain many purchase parts, it isn't easy to request quotes for each procurement part. Therefore, it can be seen in the interviews that respondents indicated that for low-priced parts, a percentage is used to estimate a price by today's standards.

In new development projects, a similar cost estimation structure is used for standard products. Here, an analytical breakdown approach is also used to distinguish all procurement parts of the entire project. However, the level of detail depends heavily on how much engineering work has been done. Based on the engineering work done, quotations can be requested from suppliers to get an indication of how much certain purchase parts should cost. In addition, in some cases, should cost analysis should be used to test whether these costs are the value of the product to be purchased. This should cost analysis causes the suppliers' price to be calibrated against the actual value of the procurement part, thereby driving down

the price. Also, it became evident that companies also use quotations from comparable parts to arrive at the cost of a new development part using a conversion factor.

CASE ID	STANDARD PROJECT COST ESTIMATIONS	NEW PROJECT COST ESTIMATIONS
ALPHA	Analytical breakdown approach where price agreements or offers are used as input data or outdated offers with reference percentage.	Analytical breakdown approach to enable requesting quotations from suppliers for new parts. Intuitive case-based reasoning to arrive at costs via comparable parts of the new parts. Analytical cost tolerance models are used for new parts to challenge the cost of quotations.
BETA	Analytical breakdown approach where price agreements or offers are used as input data.	Analytical breakdown approach to enable requesting quotations from suppliers for new parts. Analytical operation-based costing models are used for new parts that are in their expertise field to challenge the cost of quotations.
CHARLIE	<i>(Not applicable)</i>	Analytical breakdown approach to enable requesting quotations from suppliers for new parts. Intuitive case-based reasoning to arrive at costs via comparable parts of the new parts.
DELTA	Analytical breakdown approach where price agreement or offers are used as input data or outdated offers with reference percentage.	Analytical breakdown approach to enable requesting quotations from suppliers for new parts. Parametric approach and analytical cost tolerance models are used for new parts to challenge the cost of quotations.

Table 5 Utilised cost estimation technique among cases

In conclusion, the results show that the analytical breakdown approach is the main methodology used among the respondents. It also reveals that this methodology is highly dependent on the input data available to perform the estimation. This is more difficult for NPD projects since they do not yet have a complete structure. Therefore, many different methodologies are used to fill in the gaps. It shows that in this situation, multiple methodologies are often used to estimate the costs. This is because this type of project uses assumptions that result in uncertainties arising.

4.2 Influencing factors for cost estimation

In the interviews held, various factors were discussed that strongly influence cost estimation. The second-order themes that are revealed during interviews are technical-related factors, procurement-related

factors, market-related factors, and estimation-related factors. The corresponding first-order concepts found in the interviews are described below in the different chapters.

4.2.1 Technical-related factors: Lack of a clear definition of the project

The first theme that became evident was technical-related factors. The first concept that became evident from the interviews is the lack of a clear definition of the project, which means that the scope of what needs to be estimated is not clear either. *“My personal experience is when I see how many times, we have made assumptions based on information built by another team. Then I see that we must source certain products with certain assumptions about, for example, requirements and specifications that are so different in the project. There you see costs that go by a factor of 10” (R1A).*

The respondent describes the problem of assumptions made by different teams because the project specification is not clear enough, causing misconceptions to be made. This problem creates variation in consistency, resulting in large costs. Because of the variation, costs become significantly more expensive due to the outcome of the project.

To improve the accuracy of an estimate, it is necessary to ensure that project specifications are more obvious so that they cannot be misunderstood. By improving the project specification and making it more evident, it is easier to understand during cost estimation what the scope is and therefore what should ultimately be calculated.

4.2.2 Technical-related factors: Lack of technical knowledge

On the other hand, respondents emphasised a lack of technical knowledge to be able to understand technical features to make a proper cost estimation. *“One of those challenges that I do face is because we work on multidisciplinary projects [...] Each discipline of engineers is responsible for a certain part of the design, who also does it in his own way, to the best of his knowledge and ability, and provides that input for that cost estimate. But it is often so complex that, as a project manager but also a cost engineer, I cannot see in detail whether the input you get for making a cost estimate is completely complete or whether there is still some room in it. That also plays a big part in confidence in the input that is provided, which really takes as a basis for your cost estimate that it is good” (R10C).*

The respondent indicated that there is difficulty in reviewing the information that the engineering department provides. Because of the complex projects, other departments besides the engineering department have difficulty reviewing the accuracy of the information that engineering provides. Because of the moderate technical knowledge that other departments have, this can affect the reliability of the estimation.

This barrier makes it difficult to assess engineering inputs. Therefore, organisations should look at how to avoid this barrier so that input data can be better assessed, and the final cost estimation can become more reliable.

4.2.3 Procurement-related factors: Frequently changing prices by suppliers

In addition to technical-related factors, another theme identified by respondents relates to procurement-related factors. Respondents acknowledge the frequently changing prices of suppliers, which complicates the reliability of cost estimation. *“But if you look at the past 2 years, they have been very intense. The price increases went sky-high through the roof. No one dared to make any predictions anymore. Suppliers also felt very reluctant to give prices for a longer period (R2A)”*. As a consequence of this, the validity of quotations has changed. *“At that moment you look at, for example, after the validity of quotations, how long is a quotation valid? Some quotations are valid for fourteen, 30, 45, or 60 days. I know a lot of situations where you have a certain period of days that such a quotation is valid. Well, at that time we also had quotes that were valid for one day, right, or were valid for two days, purely because there were continuous changes in material prices that varied greatly, so that was not very useful at that time” (R8C)*.

Respondents describe that suppliers no longer want to make long-term arrangements due to changing market conditions that cause prices to change regularly. The validity of quotations has been greatly reduced. One respondent describes that quotations are only valid for a day or two so that the supplier can always respond to the changed market. Because prices have risen sharply, suppliers are reluctant to issue quotations for longer periods.

It is therefore important to consider how to deal with them. Because the validity of quotations is limited, suppliers may keep changing their prices, making the input data unpredictable. When prices are predictable, the overall cost estimation will be more stable, which will ultimately help in calculating a more accurate cost estimation.

4.2.4 Procurement-related factors: Long waiting time to receive quotations from suppliers

Furthermore, respondents acknowledge that there is a long waiting time to receive quotations from suppliers, which makes it challenging to include them in cost estimation. *“The biggest challenge is often the lead time that something can take. If you need to request quotes from a supplier, [...] you just hope that procurement can have such an influence that it still happens. If it does take a dramatically long time, you still must make assumptions” (R3A)*. The respondent describes the long wait time for quotations requested from suppliers. Because of the long waiting time, stakeholders are forced to make assumptions instead of using prices from suppliers. Because of these long waits, the accuracy of the input data will be less accurate because you must make a calculation based on your assumptions. Further, the respondent describes that the purchasing department can play a role in this to still ensure that the quotation comes in in time to do the estimation. This can be a potential risk factor when relying on assumptions rather than supplier cost information.

“Suppliers were also very busy just making offers. There are several people for that, and at some point, those people are all full, so they don't really have time to make another offer. And if I want to have an offer from someone in three or four weeks because it fits into our schedule, they can't because they don't have time again for another six or eight weeks. Then I must look at whether I am going to wait for that, or am I going to go to the next party? Who might be able to help me? So those are challenges right now; we also run into them” (R8C). Another respondent describes the difficulty of receiving quotations on time. This respondent mainly exposes the problem that the organisation's and the supplier's timetables do not match because the supplier needs more time to make a quotation. If the supplier does not have time to

make a quotation, the respondent describes the possibility of asking another supplier for the quotation to still get input data.

It is important to look at the quotation process from suppliers to see how the time to receive a quotation can be reduced. So, to ensure that quotations come in on time so that they can be included in an estimation. This will avoid having to rely on assumptions and ensure that estimation is done within the time frame.

4.2.5 Market-related factors: Poor availability of materials due to supply issues

Another emerging theme from the interviews is market-related factors. Respondents emphasised that poor availability of materials due to supply issues can cause what you have calculated to be unavailable in the execution phase. *“Talking about an external factor, it's the inaccuracy, what's going to do with time, what's going on, the economy, and how hard materials are to be available at once. These can be factors such as war or shipping lanes that are blocked. Almost anything can affect the final price. The moment you start with a calculation, you don't know what will happen in the future” (R2A).* The respondent emphasises the difficulty of available materials as an external factor. Due to factors such as war or blocked supply chains, materials will not be available on time. This certainly affects the final price of a product. The respondent also described that it is difficult to estimate such events during the estimation phase because you don't know what will happen in the future.

“The price itself, and especially the delivery times, are the most difficult things at the moment. You still have certain component groups that have doubled in terms of delivery time, or more like doubled, where we used to be with six months and now, we are with a year of delivery time” (R8C). Another respondent confirms this problem, describing that delivery times have doubled in recent years. In this, he indicates that the delivery time of a product has changed from 6 months to a year.

Both respondents describe this as a crucial difficulty now. Because products are not available on time, this will cause delays in the product. When this is due to a factor not overlooked in the estimation, it can have a great deal of impact on project results. It is therefore important to consider how such factors that cannot be foreseen in advance can be included in the cost estimation. This is to ultimately maintain reliable estimations.

4.2.6 Market-related factors: High price increases due to market forces

In addition to the availability of materials, respondents also made evident that there are high price increases due to market forces, making costs more expensive in the execution phase. *“In any case, what we have seen is that the predictability for the entire inflation stimulus was much greater, but that was 2/3 years ago when we did meet inflation issues” (R4A).* This respondent emphasises the problems that occur due to the inflation problems of the past years. Due to the inflation fluctuations of the market, the predictability of procurement costs is therefore difficult to estimate. Because the inflation rates were much higher than expected, this affected the cost estimation because other assumptions were made.

Besides the fact of price increases, another respondent describes the difficulty of including them in the estimation. The uncertainty of various events makes it difficult to take them into account in estimation. *“I couldn't have overseen Corona; I couldn't have overseen the misery in Ukraine that the aluminium price*

went through the roof. Now the Suez Canal is closed, and I could not have foreseen that. So yes, then I can, so I never actually go in advance, and I take there, I can't estimate that" (R6B). This respondent emphasises the fact that disruptions or events have a significant influence on the pricing of materials. Events such as Corona, the Ukrainian War, and the closing of the Suez Canal all have an impact on the pricing of materials. The respondent here indicates the difficulty of including these events in the calculation because they happen in the future.

This shows that external factors can have a huge impact on the reliability of cost estimations. Although these events cannot be addressed directly because they do not occur during the estimation process, it is important to consider how these risks can still be included in the estimation. In this way, when an unexpected event occurs, it does not become a significant cost and cause cost overruns.

4.2.7 Estimation-related factors: Lack of updating input data for the estimation

Finally, the last theme that emerged in the interviews was estimation-related factors. Respondents affirmed that the lack of updating input data for the estimation is disastrous for making a cost estimation. *"If we don't do this for one year, it means that we are dealing with data that was collected two years ago. We can update this with an escalation factor or with new hourly rates that apply that year to update the hours accumulated last year with the then-expected costs. But you are always less reliable when it was calculated even longer than a year ago. I think there is a real risk that we will be confronted with the unexpected"* (R4A). An escalation factor can be used to update the input data; however, this is not reliable because, in today's times, there are highly dynamic market forces. Therefore, it is important to update prices often enough so that you can make calculations based on reliable data.

"What we do is keep our database up to date, which is actually a continuous improvement. If you now only have prices from 2021, they are no longer current; that is not only normal inflation but also market forces" (R9C). The respondents emphasised the critical importance of updating input data to maintain accuracy for cost estimates. Also, they emphasized that relying on outdated data can lead to unreliable estimation because external factors can affect it. In doing so, both respondents stress that data from more than a year ago is not reliable enough to include in an estimation. One respondent describes the method of using an escalation factor to bring the cost data up to date, but this will always be less reliable due to the rapidly changing market.

Updating cost data is very important because it is highly influenced by external factors. Therefore, it is important to update the prices of input data often enough. This is done by requesting quotations directly from suppliers and not just using an escalation factor. Continuous improvement of cost data is important so that cost estimates can be made at all times based on reliable data.

4.2.8 Estimation-related factors: Lack of estimation time

It was also evident from the interviews that there is a lack of estimation time, preventing the assessment of all facets with the time necessary. *"So actually, we always have a bit too little time to draw up a cost estimate, and we have been happy for a long time that we have a cost estimate with substantiation. Actually, we just have to spend more time on that and take more time for it, so that you can also think about it calmly and think: Have we really done the right thing, have we reviewed everything properly, have*

we thought everything through properly” (R10C)? One respondent emphasized the pressure to produce cost estimates quickly and mentioned that this rush can negatively affect the quality and accuracy of estimates. They stressed the importance of spending more time in the estimation process so that all facets involved can be carefully considered and assessed. The respondent describes another approach, which involves reviews to validate if all requirements are met. Evaluating estimations too quickly can lead to lower reliability, which can lead to decisions being made on unreliable data.

“I think that involvement is important, but I don't think that one can always spend enough time on it because, firstly, there are a lot of bids running all the time, and secondly, because they are also just busy with ongoing projects” (R3A). Another respondent describes the challenges of having too many bids and projects that are ongoing at the expense of the focus of a specific estimation. This shows that there is not always enough focus on one estimation to bring its quality to a high level.

This shows that there is too little validation for cost estimation because too little time is taken for it. This is because estimation is done quickly. After all, there are other ongoing projects. It is therefore important to take more time for estimations and their validation to increase reliability.

4.2.9 Estimation-related factors: Poor transparency of the input data for the estimation

Finally, respondents acknowledged poor transparency of the input data for the estimation. *“But I think it's important that you're transparent. Everyone who contributes to the calculation can assess it. [...] Too often, person-dependent, I do get costs, but to be able to assess them, because this is what you want to also assess how realistic this is or not” (R4A).* According to the respondent, transparency in the estimation process is critical to enabling all stakeholders involved to assess the reliability and validity of the data used. Ensuring transparency allows individuals contributing to the estimation process to access the underlying data and assess its realism and accuracy. The respondent emphasises the lack of transparency about input data, which ensures that the input data cannot be assessed for accuracy or the source of the data.

“In my opinion, that input can really be improved, and that is also in communication, in transparency, that engineering is also just transparent in how they arrive at certain quantities and also inform the project manager and the cost engineer of which choices and what consideration I have made to arrive at a certain amount of state” (R10C). Another respondent confirms the same problem. By being transparent, it is possible to see what assumptions and choices have been made so that they can be reconsidered. This can serve as an additional check, which should provide more reliable data.

Both respondents describe the challenge associated with the lack of transparency in input data. By making the input data transparent, the accuracy of the data can be better examined and reassessed. In doing so, one respondent described that this could be done through improved communication between departments to promote transparency. This is to increase the reliability of the estimation.

4.2.10 Overall conclusion

In conclusion, this chapter shows multiple factors in different facets that influence cost estimation. It became evident from the interviews that many different factors significantly influence the accuracy of cost estimation, thereby undermining reliability. Most of the factors mentioned can be addressed as

internal factors within the organisation. However, various respondents have mentioned the high influence of external factors on the accuracy of the cost estimations. These results acknowledge that consideration of the named influencing factors is important.

First, technical factors such as unclear project definitions and a lack of technical knowledge have emerged. Because there is an unclear project specification, misconceptions may be made due to incorrect assumptions. As for the lesser degree of technical knowledge, assumptions may be made that are incorrect. Second, procurement-related factors, such as fluctuating supplier prices and long waiting times for quotations, have a key role in providing accurate data. Suppliers often change prices or fail to provide timely data, and the accuracy of the input data can be compromised. Moreover, market-related factors, such as the availability of materials and price increases due to external events, have a great impact on estimation but are uncertain. Because market-related factors are difficult to estimate due to their uncertainty, they often have the greatest impact because they were not anticipated. In addition, estimation-related factors, such as the lack of updated input data, the lack of estimation time, and the lack of transparency of the data, have a direct influence on the accuracy of cost estimates. The updated input data is highly important to ensure reliability. In addition, transparency of data allows estimators to assess input data based on their accuracy and the assumptions that were made. At last, additional time is required for estimation to determine if all requirements are considered.

In conclusion, this indicates that there are a wide range of factors that can influence estimation. The results show that the factors emerge both inside and outside the organisation. While internal factors are easier to address, external factors will hardly be influenced by the organisation. It can also be argued that different departments are involved and influence them. This means that it is important to consider these factors so that the accuracy of cost estimation is promoted, which should ensure that it ultimately becomes more reliable.

5. Discussion and conclusion

The results presented in Chapter 4 showed which methodologies are employed in standard projects and new development projects. It also provided insight into what factors influence cost estimates. This chapter aims to look for links in the broader context to uncover findings to answer the research question: "*How can organisations in complex environments enhance the reliability of their cost estimation methodology for procurement parts?*".

The research employed interviews to obtain data, and the findings reveal how organisations utilise cost estimation methodologies to calculate costs for procurement parts in standard projects and new development projects. The finding reveals that different methods are used to estimate costs for standard projects and new development projects. While standard project calculations have the advantage of a fixed structure of data, in development projects, the structure is often unknown, and assumptions must be made to arrive at an estimate. In addition, it also emerged that it is important to test costs, which are input figures, against assumptions to arrive at an estimation. This can help challenge the supplier against the quotation they have given to avoid overpaying for procurement parts. Next to methodologies to estimate cost, it emerged that factors influencing the cost estimation process have been discovered. These factors can be divided into technical-related, procurement-related, market-related, and estimation-related factors that may influence the estimation accuracy. Therefore, organisations in complex

environments will have to consider the factors to see the benefits reflected in the accuracy of the cost estimates. This will help them enhance their estimation process, which will ensure the reliability of their cost estimations.

5.1 Theoretical implications

5.1.1 Effective methodologies for standard products and new product development (NPD)

This chapter addresses the first sub-question: "What are the most effective procurement cost estimation methodologies employed by organisations focusing on standard products and new product development (NPD)?" Based on the model of Chawastyk and Kołosowski (2014), as a project progresses through its development stages, the availability and quality of information improve, which affects the selection of estimation techniques. Their analysis shows that during the production phase, referred to as standard projects, cost accounting appears to be the dominant method for estimating procurement costs. Considering the estimation techniques described by Niazi et al. (2006) and Huang et al. (2012), the analytical breakdown approach appears as the primary technique for cost accounting of standard projects revealed by interviews.

It is evident from the findings that for standard projects, characterised by a known product structure and relatively predictable procurement requirements, the analytical breakdown approach proves to be the most effective method for determining procurement costs. This approach involves a systematic allocation of the components and processes of a project, followed by a detailed assessment of the costs of each procurement component. The method has the advantage that it is an easy approach that can be used without software; on the other hand, it depends heavily on the cost data of the parts in question (Niazi et al., 2006). However, given the stability and familiarity of standard projects, the analytical breakdown approach allows procurement professionals and cost estimators to accurately predict costs by updating prices as the primary variable in the estimation process. It became evident that this mainly consists of making price agreements with suppliers, requesting quotes, or converting outdated prices into a reference price.

While standard projects benefit from a well-known component structure and established procurement processes, the analytical breakdown approach is, for this purpose, the best method to use to make an accurate cost estimation. By employing this methodology, organisations can enhance their procurement costs by optimising resource allocation and enhancing cost efficiency in cost estimations.

However, delving further into the analysis, for new development, this method will have to be adapted to include unique characteristics and the uncertainties of a development project in a cost estimate. Unlike standard projects, new development projects deal with other dimensions of information facilities. Since CoPS has to deal with the unique characteristics of projects for which no accurate information is available, it complicates the estimation of procurement parts (Kujala et al., 2014). As projects are still under development, the structure of the product is not yet known. Looking back at the model of Chawastyk and Kołosowski (2014), it can be seen that not every technique can be used, but this depends on the degree of development. The results show that many different techniques are used to estimate costs during the development stage.

The investigation into identifying which method for estimating procurement costs is the most effective for NPD projects reveals a similar cost estimation methodology as for standard projects. In both project

types, an analytical breakdown approach is the basic methodology for defining procurement components and assessing cost towards the associate component. However, this method is highly dependent on how much engineering work has already been done, as this determines how detailed calculations can be made. Due to this uncertainty, adaptability and flexibility are needed to make an estimation when calculating NPD projects.

The interviews with respondents reveal different methodologies to underpin the defined components of the breakdown structure. Furthermore, it is evident that companies do not rely solely on one specific methodology. Because the structure of the project is not yet fully established, you must deal with uncertainties. As a result, quotations can be requested from suppliers based on assumptions. Hence, companies also use proprietary estimation methods such as intuitive case-based reasoning, parametric approaches, analytical-operational costing models, and analytical cost tolerance models. The advantage of making your own estimates is that you have the opportunity to test the suppliers' quotations against your own assumptions. The goal here is to find the gap with the supplier to both get the solution clear and ensure you don't overpay for procurement parts. However, a dedicated department with appropriate knowledge and experience is needed to enable these estimation methodologies.

The results show that the choice of a methodology strongly depends on the state of development. It has become clear that the analytical breakdown approach applies to both standard products and NPD projects. However, this method is highly dependent on the availability of cost data. Since a standard project already has a component structure, it is easier to calculate, but an NPD project faces uncertainties because the full structure is not yet known. Therefore, an NPD project needs a more adaptive approach to determine which methodology is appropriate for the situation. For this, it became clear that multiple methodologies would have to be used to eliminate uncertainties and strengthen reliability. Through the assessment of methodologies used, this research helped to provide insights for cost estimation in complex environments. The outcomes have thereby expanded existing literature.

5.1.2 Internal and external factors affecting the cost estimation

The following addresses the second sub-question: "Which internal and external factors need to be considered in cost estimations to improve predictability and become more reliable?". The outcome has shown various internal factors, which are procurement-, technical-, or estimation-related factors. Regarding external factors, these are described as market-related factors. Examining these factors provides insight into refining estimation practices for greater reliability and effectiveness.

As for the first factor, focusing on frequent changes in prices by suppliers is one of the identified procurement-related factors of the research. Indeed, this factor is supported by existing literature; the long duration of complex projects means estimations in the execution phase are no longer accurate (Kujala et al., 2014). Also, Mahamid et al. (2014) emphasised that the change in material prices is a factor influencing estimation accuracy. This makes the market-related factor focusing on high price increases due to market forces also supported by the literature. Also, Akintoye (2000) and Odusami and Onukwube (2008) have shown that market conditions are a key factor that can influence cost estimation. The other market-related factor focusing on poor availability of materials due to supply issues can, therefore, also be seen as supported by the literature. In doing so, the research of Hatamleh et al. (2018) also directly shows that this is a major factor affecting cost estimation accuracy.

As for the second procurement-related focus on long waiting times to receive quotations from suppliers, the existing literature does not directly mention this factor as a crucial factor influencing estimation. However, indirectly, Alumbugu (2014) named the availability of estimation data and the accuracy and reliability of information as influencing factors in the estimation process. Alongside this, other existing literature also describes the essence of the accuracy of data for cost estimations (Hatamleh et al., 2018; Odusami & Onukwube, 2008; Trost & Oberlender, 2003). This has made it evident that data accuracy is an important issue. This makes estimation-related factors focused on the lack of updating input data for the estimation and poor transparency of input data for the estimation, which is strongly supported by existing literature. Furthermore, the estimation-related factor focuses on the lack of estimation time, also mentioned in prior literature. Trost and Oberlender (2003) have found in their research that time spent on estimation can directly affect accuracy.

For the technical-related factor focusing on the lack of a clear definition of the project, several existing pieces of literature substantiate this factor. Prior literature has proven that a clear and dated project specification is needed to improve estimation accuracy (Alumbugu et al., 2014; Hatamleh et al., 2018; Odusami & Onukwube, 2008). Also, prior literature has underlined that the estimator's skills and experience are important factors in accuracy (Alumbugu et al., 2014; Hatamleh et al., 2018; Odusami & Onukwube, 2008). The uncovered technical-related factor focusing on the lack of technical knowledge strengthens the existing literature. The results showed that not only the estimator's knowledge is important, but also for all other stakeholders. This outcome is supported by Trost and Oberlender (2003) and Odusami and Onukwube (2008), which describe the experience and knowledge of the entire project team as factors.

In conclusion, the analysis has identified several procurement-, technical-, estimation-, and market-related factors that have a significant impact on cost estimates. Looking at the results of the study, these factors play a crucial role in the reliability of cost estimation. Thereby, on the one hand, internal factors emerged within the organisation that can be influenced a lot, and on the other hand, factors external to the organisation can hardly be influenced. Through the analysis of these factors, practical guidelines for organisations are given. Hence, existing literature is also further strengthened about factors that potentially influence the predictability of cost estimations, which undermines reliability.

5.2 Practical implications

The study aimed to provide organisations with guidance on how to improve cost estimation to be more predictable and enhance reliability in complex environments. Therefore, a thematic framework shown in Figure 4 is developed to link estimation methodologies and influencing factors to the general cost estimation process.

The thematic framework shown in Figure 4, based on the uncovered themes, gives a visual representation of the underlying relationship between the estimation methodologies and the factors that influence the cost estimation process for procurement parts in complex environments. The developed structure gives guidance for understanding the complexities accompanied by the cost estimation process. Also, the framework reveals the interplay between the departments to arrive at a cost estimate. It presents a general process that is used in each examined case organisation, where several departments collaborate to achieve a cost estimation. In this process, the procurement department is responsible for the cost of

procurement parts that are necessary for the estimation, while the engineering department is responsible for defining a project definition so that it becomes clear which parts procurement costs should be retrieved. A bid, project, or sales department is responsible for keeping an overview of the entire project so that it is managed in the right direction. Lastly, an estimation department is responsible for performing a cost estimation based on the input data using an appropriate cost estimation methodology.

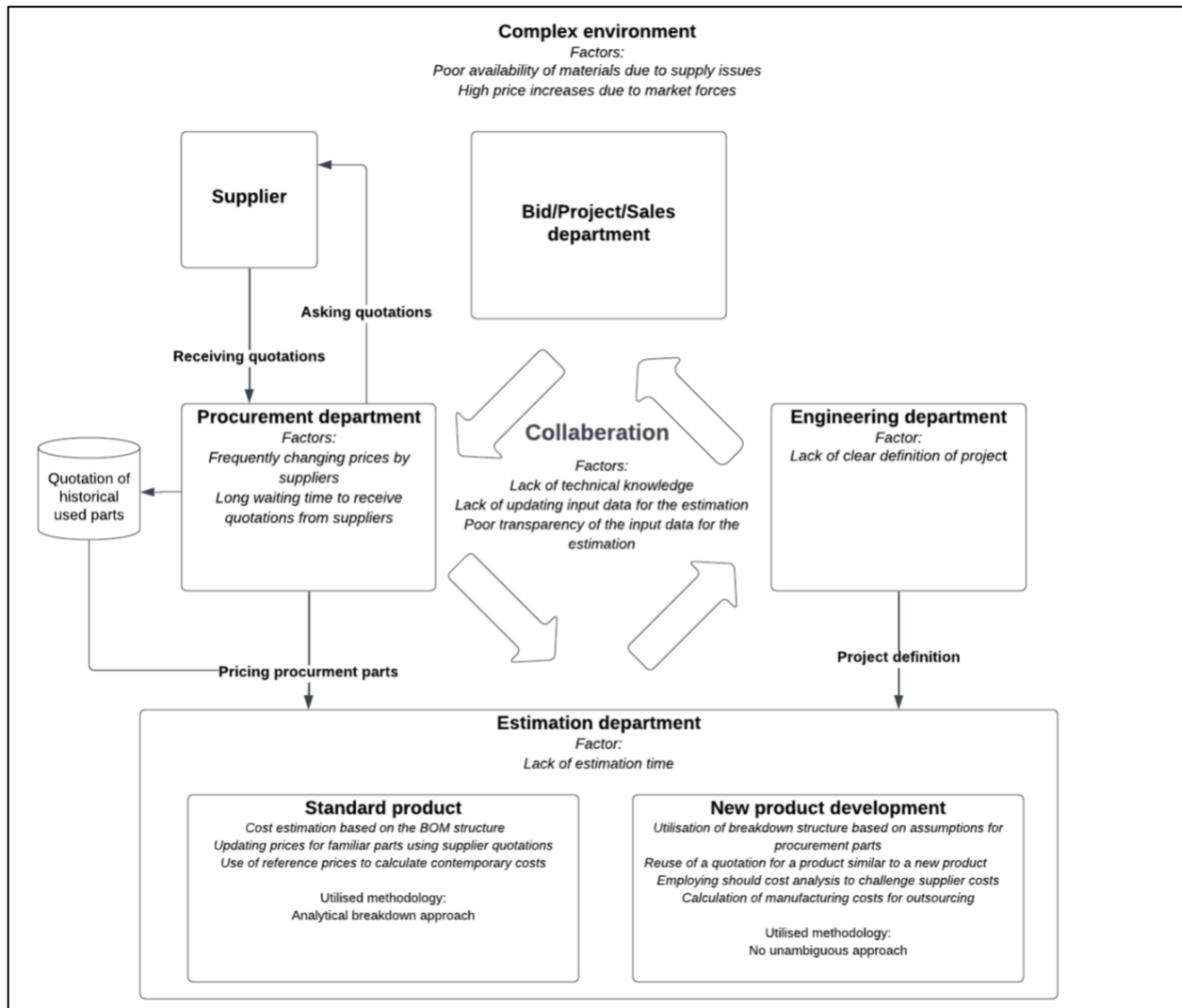


Figure 4 Thematic framework

The methodologies that are uncovered during the research will give organisations guidance on which methodologies can be employed to determine the costs of procurement parts in complex environments. Firstly, the findings highlight the effectiveness of the analytical breakdown approach in estimating procurement costs for both standard products and NPD projects. This approach, characterised by the allocation of procurement estimation components, allows organisations to perform detailed assessments and improve accuracy in estimating costs. However, this method cannot be used for new product

development in the same way as for standard products. This study emphasises the necessary adaptability to choose appropriate estimation techniques based on the circumstances. Organisations should not rely solely on a single estimation technique, as the project's direction is not yet fully established and assumptions are used. Therefore, organisations need to weigh up which estimation method is suitable to use in the given situation based on project requirements and constraints.

Next, influencing factors are included in the thematic framework. These factors give guidance to organisations on what the key factors are to improve the reliability of cost estimations. From the thematic framework, the influencing factors were assigned to a particular department; these are adopted from the framework and shown in Table 6. This gives organisations practical guidance on which actions to take to improve processes in departments and eventually enhance the overall estimation process.

Overall, the insights gained from the research on factors affecting the predictability and reliability of cost estimates offer a practical contribution to the practice of organisations. Organisations can use these findings to improve their estimation processes and ultimately improve decision-making. By systematically addressing the identified factors, such as market dynamics, procurement challenges, and technical complexity, organisations can refine their estimation practices and reduce the uncertainties associated with cost estimates.

<i>INFLUENCING FACTORS</i>	DEPARTMENT
<i>Lack of a clear definition of the project</i>	Engineering
<i>Lack of technical knowledge</i>	All departments
<i>Frequently changing prices by suppliers</i>	Procurement
<i>Long waiting time to receive quotations from suppliers</i>	Procurement
<i>Poor availability of materials due to supply issues</i>	General
<i>High price increases due to market forces</i>	General
<i>Lack of updating input data for the estimation</i>	All departments
<i>Lack of estimation time</i>	Estimation department
<i>Poor transparency of the input data for the estimation</i>	All departments

Table 6 Influencing factors by department

5.3 Limitations

This research addressed the question of how organisations can improve their cost estimation. However, there are several limitations associated with this research.

The first limitation is focused on the limited number of cases involved. The research utilised multidisciplinary interviews to gather insights from different professionals about the entire estimation process. For this purpose, twelve interviews were conducted across four different cases. Because there

were few cases involved in the research, only a limited range of insights and perspectives were included. To overcome this limitation, more cases should be involved in the research to gain more perspectives on the methodologies used and influencing factors on cost estimations.

The second limitation is based on generalisation. The study chose a specific group of cases involved in this research. These four different cases, of which two operate in the same sector, represent only three different sectors in total in this research. While these cases provided valuable insights, the results may not be applicable in a broader context. Due to the unique characteristics of companies, they may not be representative of other cases or sectors. Therefore, caution is required when generalising the results of this research in different settings, such as variations in industry or organisation structure.

5.4 Future research

In this study, a specific problem was examined to arrive at worthy insights. However, there are aspects not included in the study that could potentially lead to future research.

This research was focused on identifying factors influencing cost estimates. Since the research mainly focused on identification, further research may explore how these factors can be mitigated to minimise the influence of these factors on the accuracy of estimations. In future research, researchers can examine the identified factors of this research to assess strategies for mitigating those factors. To do so, potential future research can propose methodologies that can be adopted by organisations to enhance estimation accuracy, which makes them more reliable.

Second, considering the previously stated limitation regarding generalisation, future research could focus on more diverse cases by expanding the number of organisations operating in different industries or sectors. Therefore, researchers can include more cases in the research to get a better understanding of the methodologies employed and influence factors. Also, future research could explore whether the identified methodologies are applicable in different organisational settings or other industries. Researchers could increase the generalisability of the findings and provide stronger evidence for organisations and literature by examining these aspects to improve their cost estimation processes.

6. Conclusion

The purpose of this study is to identify how organisations that operate in complex environments can improve their cost estimation methodology for procurement parts to become more reliable. Therefore, the following research question was formulated: *How can organisations in complex environments enhance the reliability of their cost estimation methodology for procurement parts?*

To answer the research question, qualitative research has been conducted through interviews. The results of the interviews show that organisations in complex environments employ an analytical breakdown approach for the cost estimation of procurement parts for standard products. When organisations deal with NPD parts, the same approach is used, where estimations are made based on assumptions. While standard products have the advantage of a known structure of procurement parts, no full structure is known for NPD projects. It is therefore important to use multiple and appropriate estimation

methodologies to strengthen estimation accuracy and to have the ability to challenge potential suppliers on their costs.

Furthermore, procurement-, technical-, estimation-, and market-related factors were identified, which are influencing cost estimations. It became evident that attention is needed from various departments to address these factors. Organisations should consider these factors to enhance the reliability of their cost estimations.

Additionally, a framework is developed to provide a representation of the coherence of methodologies and factors for organizations in complex environments. This gives organisations practical guidance on how to deal with cost estimation in complex environments. Furthermore, the research has strengthened existing literature about influencing factors by providing a comprehensive overview of factors that influence the reliability of the cost estimation.

References

- Akintoye, A. (2000). Analysis of factors influencing project cost estimating practice. *Construction Management & Economics*, 18(1), 77-89.
- Almeida, A., & Cunha, J. (2017). The implementation of an Activity-Based Costing (ABC) system in a manufacturing company. *Procedia Manufacturing*, 13, 932-939. <https://doi.org/https://doi.org/10.1016/j.promfg.2017.09.162>
- Alumbugu, P. O., Ola-Awo, W., Saidu, I., Abdullahi, M., & Abdulmumin, A. (2014). Assessment of the factors affecting accuracy of pre-tender cost estimate in Kaduna state, Nigeria.
- Chwastyk, P., & Kołosowski, M. (2014). Estimating the Cost of the New Product in Development Process. *Procedia Engineering*, 69, 351-360. <https://doi.org/https://doi.org/10.1016/j.proeng.2014.02.243>
- Davies, A., & Brady, T. (2000). Organisational capabilities and learning in complex product systems: towards repeatable solutions. *Research policy*, 29(7-8), 931-953.
- Doloi, H. K. (2011). Understanding stakeholders' perspective of cost estimation in project management. *International Journal of Project Management*, 29(5), 622-636. <https://doi.org/https://doi.org/10.1016/j.ijproman.2010.06.001>
- Ellram, L. M., Tate, W. L., & Choi, T. Y. (2020). The Conflicted Role of Purchasing in New Product Development Costing. *Journal of Supply Chain Management*, 56(1), 3-32. <https://doi.org/https://doi.org/10.1111/jscm.12217>
- Ferriani, F., & Gazzani, A. (2023). The impact of the war in Ukraine on energy prices: Consequences for firms' financial performance. *International Economics*, 174, 221-230. <https://doi.org/https://doi.org/10.1016/j.inteco.2023.04.006>
- Gioia, D. A., Corley, K. G., & Hamilton, A. L. (2012). Seeking Qualitative Rigor in Inductive Research: Notes on the Gioia Methodology. *Organizational Research Methods*, 16(1), 15-31. <https://doi.org/10.1177/1094428112452151>
- Griffin, A. (1997). PDMA research on new product development practices: Updating trends and benchmarking best practices. *Journal of Product Innovation Management: An International Publication of The Product Development & Management Association*, 14(6), 429-458.
- Gustafsson, J. (2017). Single case studies vs. multiple case studies: A comparative study. In.
- Hammarberg, K., Kirkman, M., & de Lacey, S. (2016). Qualitative research methods: when to use them and how to judge them. *Human Reproduction*, 31(3), 498-501. <https://doi.org/10.1093/humrep/dev334>
- Hatamleh, M. T., Hiyassat, M., Sweis, G. J., & Sweis, R. J. (2018). Factors affecting the accuracy of cost estimate: case of Jordan. *Engineering, Construction and Architectural Management*, 25(1), 113-131.
- Heale, R., & Twycross, A. (2018). What is a case study? In (Vol. 21, pp. 7-8): Royal College of Nursing.
- Hobday, M. (2000). The project-based organisation: an ideal form for managing complex products and systems? *Research Policy*, 29(7), 871-893. [https://doi.org/https://doi.org/10.1016/S0048-7333\(00\)00110-4](https://doi.org/https://doi.org/10.1016/S0048-7333(00)00110-4)
- Hobday, M., & Rush, H. (1999). Technology management in complex product systems (CoPS)-ten questions answered. *International Journal of Technology Management*, 17(6), 618-638.
- Horton, J., Macve, R., & Struyven, G. (2004). Chapter 20 - Qualitative Research: Experiences in Using Semi-Structured Interviews1. In C. Humphrey & B. Lee (Eds.), *The Real Life Guide to Accounting Research* (pp. 339-357). Elsevier. <https://doi.org/https://doi.org/10.1016/B978-008043972-3/50022-0>
- Huang, X. X., Newnes, L. B., & Parry, G. C. (2012). The adaptation of product cost estimation techniques to estimate the cost of service. *International Journal of Computer Integrated Manufacturing*, 25(4-5), 417-431. <https://doi.org/10.1080/0951192X.2011.596281>

- Hueber, C., Horejsi, K., & Schledjewski, R. (2016). Review of cost estimation: methods and models for aerospace composite manufacturing. *Advanced Manufacturing: Polymer & Composites Science*, 2(1), 1-13. <https://doi.org/10.1080/20550340.2016.1154642>
- Hwang, S. (2007). Utilizing Qualitative Data Analysis Software: A Review of Atlas.ti. *Social Science Computer Review*, 26(4), 519-527. <https://doi.org/10.1177/0894439307312485>
- Idrus, A., Fadhil Nuruddin, M., & Rohman, M. A. (2011). Development of project cost contingency estimation model using risk analysis and fuzzy expert system. *Expert Systems with Applications*, 38(3), 1501-1508. <https://doi.org/https://doi.org/10.1016/j.eswa.2010.07.061>
- Ishii, N., Takano, Y., & Muraki, M. (2014). An order acceptance strategy under limited engineering man-hours for cost estimation in Engineering–Procurement–Construction projects. *International Journal of Project Management*, 32(3), 519-528. <https://doi.org/https://doi.org/10.1016/j.ijproman.2013.07.009>
- Johnson, F., Leenders, M. R., & Flynn, A. E. (2021). *Purchasing and supply management*. McGraw-Hill Companies, Inc.
- Kazimierska, M., & Grębosz-Krawczyk, M. (2017). New product development (NPD) process an example of industrial sector. *Management Systems in Production Engineering*(4 (25), 246-250.
- Kujala, J., Brady, T., & Putila, J. (2014). Challenges of cost management in complex projects. *International Journal of Business and Management*, 9(11), 48.
- Layer, A., Brinke, E. T., Houten, F. V., Kals, H., & Haasis, S. (2002). Recent and future trends in cost estimation. *International Journal of Computer Integrated Manufacturing*, 15(6), 499-510. <https://doi.org/10.1080/09511920210143372>
- Mahamid, I., Al-Ghonamy, A., & Aichouni, M. (2014). Factors affecting accuracy of pretender cost estimate: Studies of Saudi Arabia. *International Journal of Applied Engineering Research*, 9(1), 21-36.
- Moody, J. B., & Dodgson, M. (2006). Managing complex collaborative projects: Lessons from the development of a new satellite. *The Journal of Technology Transfer*, 31, 568-588.
- Niazi, A., Dai, J. S., Balabani, S., & Seneviratne, L. (2006). Product cost estimation: Technique classification and methodology review.
- Odusami, K., & Onukwube, H. N. (2008). Factors affecting the accuracy of pre-tender cost estimate in Nigeria. *COBRA 2008 - Construction and Building Research Conference of the Royal Institution of Chartered Surveyors*.
- Relich, M., & Pawlewski, P. (2018). A case-based reasoning approach to cost estimation of new product development. *Neurocomputing*, 272, 40-45. <https://doi.org/https://doi.org/10.1016/j.neucom.2017.05.092>
- Ren, Y.-T., & Yeo, K.-T. (2006). Research challenges on complex product systems (CoPS) innovation. *Journal of the Chinese Institute of Industrial Engineers*, 23(6), 519-529.
- Roy, R., & Kerr, C. (2007). Cost engineering. *International journal of Production economics*, 109(1), 1-1.
- Snyder, H. (2019). Literature review as a research methodology: An overview and guidelines. *Journal of Business Research*, 104, 333-339. <https://doi.org/https://doi.org/10.1016/j.jbusres.2019.07.039>
- Sobhani, M., Malarvizhi, C. A., Al-Mamun, A., & Jeyashree, S. (2014). Strategic procurement and financial performance of Iranian manufacturing companies. *Asian Social Science*, 10(1), 250.
- Sokhanvar, A., Çiftçioğlu, S., & Lee, C.-C. (2023). The effect of energy price shocks on commodity currencies during the war in Ukraine. *Resources Policy*, 82, 103571. <https://doi.org/https://doi.org/10.1016/j.resourpol.2023.103571>
- Suri, H. (2011). Purposeful sampling in qualitative research synthesis. *Qualitative research journal*, 11(2), 63-75.

- Takano, Y., Ishii, N., & Muraki, M. (2014). A sequential competitive bidding strategy considering inaccurate cost estimates. *Omega*, 42(1), 132-140. <https://doi.org/https://doi.org/10.1016/j.omega.2013.04.004>
- Takano, Y., Ishii, N., & Muraki, M. (2018). Determining bid markup and resources allocated to cost estimation in competitive bidding. *Automation in Construction*, 85, 358-368. <https://doi.org/https://doi.org/10.1016/j.autcon.2017.06.007>
- Tayefeh Hashemi, S., Ebadati, O. M., & Kaur, H. (2020). Cost estimation and prediction in construction projects: A systematic review on machine learning techniques. *SN Applied Sciences*, 2, 1-27.
- Teherani, A., Martimianakis, T., Stenfors-Hayes, T., Wadhwa, A., & Varpio, L. (2015). Choosing a qualitative research approach. *Journal of graduate medical education*, 7(4), 669-670.
- Trost, S. M., & Oberlender, G. D. (2003). Predicting accuracy of early cost estimates using factor analysis and multivariate regression. *Journal of construction Engineering and Management*, 129(2), 198-204.
- Yin, R. K. (2014). Case study research. In: Thousand Oaks, CA: Sage.
- Zheng, T., Gong, L., & Ye, S. (2023). Global energy market connectedness and inflation at risk. *Energy Economics*, 126, 106975. <https://doi.org/https://doi.org/10.1016/j.eneco.2023.106975>

Appendix

Appendix A: Interview guide

1. Current practices

- Can you describe which methodologies your organisation currently uses for cost estimation of procurement costs, specifically for standard product procurement?
- How do your methodologies for cost estimation of procurement costs differ regarding New Product Development (NPD) procurement?
- Can you elaborate on which key steps are involved in your current procurement cost estimation process?

2. Challenges and opportunities

- What challenges do you face when it comes to the reliability of cost estimations for procurement parts?
- Can you identify any specific opportunities for improving cost predictability and accuracy in the current procurement cost estimation process?
- How have these challenges and opportunities impacted the overall efficiency of related processes?

3. Internal and external factors

- What adjustments are made to include internal factors such as project complexity in the cost estimation?
- What adjustments are made to include external factors such as market conditions in the cost estimation?
- Can you provide experiences or examples of how internal and external factors have affected the accuracy and predictability of procurement cost estimates?

4. Best practices

- What are the best practices in the organisation which are effective and related to the accuracy and predictability of cost estimation of procurement parts?
- What kind of methodology, tooling or technology which is used to arrive at a cost estimation for procurement parts would you describe as proven successful?
- Could you provide examples of best practices implemented in the process which has shown that cost estimation for procurement parts has become more reliable and accurate?

Appendix B: Quotations substantiating first-order concepts

Respondent	Quote	First-order concepts
R2A	<i>What I'm starting with is a spin of costs from the [ERP system]. A printout of costs contains the routings of operations (I'm talking purely about the supply chain part) and a BOM of all materials. [...] Then the order of the purchase parts is examined; if there is a current blank purchasing agreement, then it is the first based on which the value of the material is determined. If there is none, the last purchase order is examined.</i>	
R4A	<i>[...] we use [ERP system] to get a picture of all materials based on a released engineering Build of material (BOM). How are they defined, what numbers? [...] Then I ask you to assess the known costs based on that list, because that list, because they are existing parts, costs are already known. If it is a standard product it will have been bought sooner, otherwise it would not be a standard of course. Those costs are then verified to what extent they are still current, if not, the buyer will come up with a delta that will be processed.</i>	Cost estimation based on the BOM structure
R7B	<i>When it comes to cost engineering, we always ask for a bill of material, what does the product look like? [...] What will you see when such a package arrives with a whole system, we split it into packages, a piece goes to assembly, a piece goes to mechanical parts manufacturing, a piece to sheet metal, a piece to purchasing and a piece to outsourcing. So everyone gets a package.</i>	
R3A	<i>What we do to purchase parts within standard products is request new quotations from the suppliers and negotiate them. They will also be placed in the system in the form of a blank purchasing agreement, and they will then be reviewed in [a review], where you will see the cost increases, decreases, etcetera, and they will then be reviewed [...]</i>	
R5B	<i>if we're talking about the so-called shelf items, OEM items, then you can do that on an annual basis where prices are agreed upon. This is useful because it saves both of us, but also the supplier time in the end. Then you don't have to constantly request quotes or get started with price changes. You already have it.</i>	Updating prices for familiar parts using supplier quotations
R5B	<i>[...] Those cost engineers also need that structure, and we also prefer to work with the bill of materials. Because that is, of course, a very tight structure that you have. Well, then you can indeed update that periodically, and we do have a system in place that says that products that have not been ordered in our ERP system for more than a year are automatically set to block. We can no longer order them directly. There, a buyer must then take action to remove that item from the blockade.</i>	
R2A	<i>[...] The reference price is only an indication that this is there now, but you know it's old; what should it be? As a result, we sit down with purchasing to arrive at a price. If the amounts are not very high, I will of course not approach procurement to request quotes for everything because that is time-consuming, then we escalate it.</i>	Use of reference prices to calculate contemporary costs
R8C	<i>[...] it's never exactly the same, so then you can say okay, it's 60 or 80 per cent about compared to this project. But it may have been three years, four</i>	

	<i>years ago. Huh, so even then you have to put margins over that. Or you have to check again in the market of what some differences are compared to a few years ago. But that's where you have the engineering basics. We've had the past, with projects we did for [company], for example. They were similar projects and then you can just use part of your engineering or cost calculation from a previous project. But you still have to challenge against the current situation.</i>	
R1A	<i>This is based on high-level requirements, very high-level requirements. [...] Aren't we missing certain qualification requirements that we set for the product? Have we made the right assessment? Some of us simply don't know. We can't apply for it because the technology isn't there yet. [...] Based on the high-level requirements, we can request quotations. Whether those quotations are the actual outcome, then you are dealing with scope creep.</i>	
R5B	<i>[...] We prefer to do that based on the bill of materials. Our cost engineer keeps it as a guideline because then you also know whether you have to buy parts at the mono-level or sub-assembly level and in what quantities. If that is not there, because the bill of materials is not there yet, because we make and do NPI projects, then we buy based on assumptions. Then we don't buy yet, then we ask for prices based on assumptions that we make, and mainly, of course, for the customer-specific manufactured parts [...].</i>	Utilisation of breakdown structure based on assumptions for procurement parts
R7B	<i>Normally we always request a bill of material and technical product document because actually you just want to have a drawing or an order specification for purchasing, then it's very easy, I have to have that thing from a shelf. How much does this cost? But if it becomes special, then it becomes more difficult. If I want to have a [part], but then some things have to be removed or it has to be able to work in vacuum, then you already get it in special from a supplier. Then you will have to ring the doorbell again: purchasing, they will just ask for prices.</i>	
R10C	<i>I think we're just doing a detailed breakdown of all the elements, multidisciplinary and by just peeling everything down to some kind of work breakdown structure, you can just put a price behind everything. So I think we're doing a really good job of just peeling everything off completely and getting to a total in that way substantiated.</i>	
R2A	<i>In that situation, I am highly dependent on our engineers, who also sit down with purchasing, and then they often look at an [article number] that is already known from which a price can come. Then purchasing can get started with quotations. Or it is checked whether a part is similar to another part. If you don't have the price of it, we know another product that also has a [part]. The large ones are not equal to each other, so you can apply a multiplication factor there. In this way, you can also arrive at a new calculation.</i>	Reuse of a quotation for a product similar to new product
R11D	<i>It depends on the technical solution. If you have some experience, you can reuse a supplier's offer from a previous year if you don't have enough time. I think reuse is the only solution for building something with the team because they have the expertise to estimate all the major items of the product.</i>	

R1A	<i>[..] We have a department in the [country] that does should cost analysis. That's just a programme or tool that we can use to challenge whether a product quoted by a supplier has the right should cost. We have these tools, and I see them as successful; we can really get this sub-assembly of sheet material of parts, or you name it, we can put it all in that tool. [..] Are these the costs we should pay? So yes, I see it as very successful.</i>	
R11D	<i>From our supplier, it's very difficult. We have the estimation but only for the three major items, only their purchase parts, their people and maybe the margin, but we have no more information. So, with [cost office] information, we can challenge it.</i>	Employing should cost analysis to challenge supplier costs
R12D	<i>So, we use as an input file, the detailed should cost we made before and we go to the supplier facilities to ask questions on their hypotheses in terms of process, time of process, and cost of raw material. We compare with our hypothesis to understand where the gap is and to give the opportunity to the supplier to optimize their process or their hypothesis</i>	
R12D	<i>[..] The goal of the cost office is to provide solutions for challenging costs throughout the whole life cycle, from bids to production and maintenance. So, there are different disciplines, so in terms of cost, you have two big categories. The first is macro should cost, while the second is detailed should cost. Macro should cost is also called parametric should cost. Parametric or macro should cost is the same idea. Detailed should cost is also called analytic should cost.</i>	
R7B	<i>But we buy a lot of mechanical parts because we just don't have the capacity to make everything. So, we also calculate all the parts that we can calculate, and we just have calculation programmes for that. [...] We can calculate what a manufacturing part costs. We also know that if we were to outsource, the maximum price should be approximately in the region where you buy it.</i>	Calculation of manufacturing costs for outsourcing

Respon dent	Quote	First-order concepts
R1A	<i>My personal experience is when I see how many times, we have made assumptions based on information built by another team. Then I see that we must source certain products with certain assumptions about, for example, requirements and specifications that are so different in the project. There you see costs that go by a factor of 10.</i>	Lack of a clear definition of the project
R2A	<i>For NPIs, of course, you don't have a bill of materials. So, when you talk about materials, for an NPI you don't know exactly what to price. That's an extra dimension that makes it more difficult. [...] So, when you make a calculation, you must know first, what requirements do I set for my product. Must be very clear to be able to make a good request for your suppliers. In practice, you sometimes see that we regularly miss that.</i>	
R3A	<i>So, the translation of: what is in the contract and what we have to do to be able to deliver that 100 per cent to the customer, that is not always quite right in my experience.</i>	
R5B	<i>But some packages can sometimes be very dated. Well, some packages are sometimes from the 80s. Then the information is very old and then</i>	

	<p><i>unfortunately we can't just assume that it's still common. It can really contain 40-year-old information. Well, certainly in the electronic world, you can assume that that information is outdated, and then you have to find out if it is still possible and what the intention was.</i></p>	
R3A	<p><i>When I see that part of the new products, I sometimes feel very dependent on what engineers have on paper. For me, it is quite difficult because it is not technically understandable for me. They have to be able to transfer it to me in terms of knowledge and what it represents.</i></p> <p><i>One of those challenges that I do face is because we work on multidisciplinary projects [...] Each discipline of engineers is responsible for a certain part of the design, who also does it in his own way, to the best of his knowledge and ability, and provides that input for that cost estimate. But it is often so complex that, as a project manager but also a cost engineer, I cannot see in detail whether the input you get for making a cost estimate is completely complete or whether there is still some room in it. That also plays a big part in confidence in the input that is provided, which really takes as a basis for your cost estimate that it is good.</i></p>	Lack of technical knowledge
R10C	<p><i>I think we need to have a purchasing department with more technical experience. [...] Purchasers do not have enough experience on the technical part. And it's one of the major points for me because it's very difficult to have the details of the cost. When you don't know about the product when you are talking about the product.</i></p>	
R12D		
R2A	<p><i>But if you look at the past 2 years, they have been very intense. The price increases went sky-high through the roof. No one dared to make any predictions anymore. Suppliers also felt very reluctant to give prices for a longer period.</i></p> <p><i>So, some suppliers say, I change the price every month. So, if you call tomorrow, it just happens to be the next month, I guess. Yes, then you have a chance that you will get a different price tomorrow, because yes, we do the price per month.</i></p>	Frequently changing prices by suppliers
R6B	<p><i>We see that our buyers receive a lot of e-mails: everything will be 5 per cent more expensive in the future, or 10 per cent. That's what I call price warnings, then we register them, and we translate them into what they have said, 5 per cent more expensive as of January 1st. And when will we have the prices of these for that period or after that period? And then we say, okay, we have this price, we can add a few per cent to that given his comments.</i></p>	
R7B	<p><i>At that moment you look at, for example, after the validity of quotations, how long is a quotation valid? Some quotations are valid for fourteen, 30, 45, or 60 days. I know a lot of situations where you have a certain period of days that such a quotation is valid. Well, at that time we also had quotes that were valid for one day, right, or were valid for two days, purely because there were continuous changes in material prices that varied greatly, so that was not very useful at that time.</i></p>	
R8C		
R3A	<p><i>The biggest challenge is often the lead time that something can take. If you need to request quotes from a supplier, [...] you just hope that procurement can have such an influence that it still happens. If it does take a dramatically long time, you still must make assumptions.</i></p>	Long waiting time to receive

R4A	<p><i>What I am experiencing now is that we do update annual price agreements with our suppliers. But this almost always leads to a cost price increase. We are not able to make agreements with a supplier over a much longer period and keep the increase limited.</i></p> <p><i>Suppliers were also very busy just making offers. There are several people for that, and at some point, those people are all full, so they don't really have time to make another offer. And if I want to have an offer from someone in three or four weeks because it fits into our schedule, they can't because they don't have time again for another six or eight weeks. Then I must look at whether I am going to wait for that, or am I going to go to the next party? Who might be able to help me? So those are challenges right now; we also run into them.</i></p>	quotations from suppliers
R1A	<p><i>What we have noticed during COVID is happened, inflation was already growing, availability of materials, we know very well from those chip shortages all what impact that has had.</i></p> <p><i>Talking about an external factor, it's the inaccuracy, what's going to do with time, what's going on, the economy, and how hard materials are to be available at once. These can be factors such as war or shipping lanes that are blocked. Almost anything can affect the final price. The moment you start with a calculation, you don't know what will happen in the future.</i></p>	Poor availability of materials due to supply issues
R2A	<p><i>The price itself, and especially the delivery times, are the most difficult things at the moment. You still have certain component groups that have doubled in terms of delivery time, or more like doubled, where we used to be with six months and now, we are with a year of delivery time.</i></p>	
R8C	<p><i>So if you're talking about an external factor, it's the inaccuracy, what's going to do with time, what's going on, the economy, how hard materials are to be available at once. These can be factors such as war, or shipping lanes that are blocked. Almost anything can affect the final price. The moment you start with a calculation, you don't know what will happen in the future. In any case, what we have seen is that the predictability for the entire inflation stimulus was much greater, but that was 2/3 years ago when we did meet inflation issues.</i></p>	
R2A	<p><i>So if you're talking about an external factor, it's the inaccuracy, what's going to do with time, what's going on, the economy, how hard materials are to be available at once. These can be factors such as war, or shipping lanes that are blocked. Almost anything can affect the final price. The moment you start with a calculation, you don't know what will happen in the future. In any case, what we have seen is that the predictability for the entire inflation stimulus was much greater, but that was 2/3 years ago when we did meet inflation issues.</i></p>	High price increases due to market forces
R4A	<p><i>I couldn't have overseen Corona; I couldn't have overseen the misery in Ukraine that the aluminium price went through the roof. Now the Suez Canal is closed, and I could not have foreseen that. So yes, then I can, so I never actually go in advance, and I take there, I can't estimate that.</i></p>	
R6B	<p><i>yes, what we did a few years ago, for example, you got a lot of signals, with the war, with Corona, everything became more expensive. So then the challenge was: how are we going to translate that? So, what are you also doing in addition to cost engineering that is more quotation part, of course,</i></p>	
R7B	<p><i>if there is an order, the cost control part.</i></p> <p><i>The price itself and especially the delivery times, that is the most difficult thing at the moment. You still have certain component groups that have doubled in terms of delivery time or more like doubled, where we used to be with six months and now, we are with a year of delivery time.</i></p>	
R8C	<p><i>The price itself and especially the delivery times, that is the most difficult thing at the moment. You still have certain component groups that have doubled in terms of delivery time or more like doubled, where we used to be with six months and now, we are with a year of delivery time.</i></p>	
R3A	<p><i>Actually, all costing parameters that have an impact on such a cost calculation must always be up to date, they regularly are not.</i></p>	Lack of updating input

<p>R4A</p> <p>R9C</p>	<p><i>If we don't do this for one year, it means that we are dealing with data that was collected two years ago. We can update this with an escalation factor or with new hourly rates that apply that year to update the hours accumulated last year with the then-expected costs. But you are always less reliable when it was calculated even longer than a year ago. I think there is a real risk that we will be confronted with the unexpected.</i></p> <p><i>What we do is keep our database up to date, which is actually a continuous improvement. If you now only have prices from 2021, they are no longer current; that is not only normal inflation but also market forces.</i></p>	<p>data for the estimation</p>
<p>R3A</p> <p>R10C</p>	<p><i>I think that involvement is important, but I don't think that one can always spend enough time on it because, firstly, there are a lot of bids running all the time, and secondly, because they are also just busy with ongoing projects.</i></p> <p><i>So actually, we always have a bit too little time to draw up a cost estimate, and we have been happy for a long time that we have a cost estimate with substantiation. Actually, we just have to spend more time on that and take more time for it, so that you can also think about it calmly and think: Have we really done the right thing, have we reviewed everything properly, have we thought everything through properly?</i></p>	<p>Lack of estimation time</p>
<p>R4A</p> <p>R10C</p>	<p><i>But I think it's important that you're transparent. Everyone who contributes to the calculation can assess it. [...] Too often, person-dependent, I do get costs, but to be able to assess them, because this is what you want to also assess how realistic this is or not.</i></p> <p><i>In my opinion, that input can really be improved, and that is also in communication, in transparency, that engineering is also just transparent in how they arrive at certain quantities and also inform the project manager and the cost engineer of which choices and what consideration I have made to arrive at a certain amount of state.</i></p>	<p>Poor transparency of the input data for the estimation</p>