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Uncertainty analysis in competitive bidding for service contracts

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Uncertainty Analysis
in Competitive Bidding for Service Contracts

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"As I hurtled through space, one thought kept crossing my mind –

every part of this capsule was supplied by the lowest bidder"

John Glenn

Abstract

Sustainable production and consumption have become more important internationally, which has led to the transformation of market structures and competitive situations into the direction of servitisation. This means that manufacturing companies are forced to compete through the supply of services as opposed to products. Particularly the suppliers of long-life products such as submarines and airplanes no longer simply sell these products but provide their capability or availability. Companies such as Rolls-Royce Engines achieve 60% of their revenue through selling a service rather than the engine itself.

For a manufacturing company, the shift towards being a service provider means that they usually have to bid for service contracts, sometimes competitively. In the context of competitive bidding, the decision makers face various uncertainties that influence their decision. Ignoring these uncertainties or their influences can result in problems such as the generation of too little profit or even a loss or the exposure to financial risks. Raising the decision maker's awareness of the uncertainties in the form of e.g. a decision matrix, expressing the trade-off between the probability of winning the contract and the probability of making a profit, aims at integrating these factors in the decision process. The outcome is to enable the bidding company to make a more informed decision. This was the focus of the research presented in this thesis.

The aim of this research was to support the pricing decision by defining a process for modelling the influencing uncertainties and including them in a decision matrix depicting the trade-off between the probability of winning the contract and the probability of making a profit. Three empirical studies are described and the associated decision process and influencing uncertainties are discussed. Based on these studies, a conceptual framework was defined which depicts the influencing factors on a pricing decision at the bidding stage and the uncertainties within these. The framework was validated with a case study in contract bidding where the uncertainties were modelled and included in a decision matrix depicting the probability of winning the contract and the probability of making a profit.

The main contributions of this research are the identification of the uncertainties influencing a pricing decision, the depiction of these in a conceptual framework, a method for ascertaining how to model these uncertainties and assessing the use of such an approach via an industrial case study.

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List of Publications

Book chapters

Huang, X.X., Kreye, M.E., Parry, G., Goh, Y.M. & Newnes, L.B. (2012): ***The Cost of Service***. In: Electronic Systems Cost Modeling, Sandborn, P. (Ed.), accepted for publication with World Scientific Publishing, Singapore, pp. 385-399.

Journal papers

Kreye, M.E., Goh, Y.M., Newnes, L.B. & Goodwin, P. (2011): ***Approaches of Displaying Information to Assist Decisions under Uncertainty***. Omega - International Journal of Management Science*,* in print, Available under: http://dx.doi.org/10.1016/j.omega.2011.05.010.

Conference papers (peer-reviewed)

Kreye, M.E., Newnes, L.B. & Goh, Y.M. (2011): ***Uncertainty Analysis and its Application to Service Contracts***. In: IDETC/CIE 2011: International Design Engineering Technical Conferences & Computers and Information in Engineering Conference, 28-31 August, Washington, DC, USA.

Kreye, M.E., Goh, Y.M. & Newnes, L.B. (2011): ***Manifestation of Uncertainty - A Classification***. In: ICED'11 - International Conference on Engineering Design, 15-18 August, Copenhagen, Denmark.

Kreye, M.E., Goh, Y.M., Newnes, L.B. (2010): ***Information Display for Decisions under Uncertainty***. In: Design 2010 – International Design Conference, 17 – 20 May, Dubrovnik, Croatia.

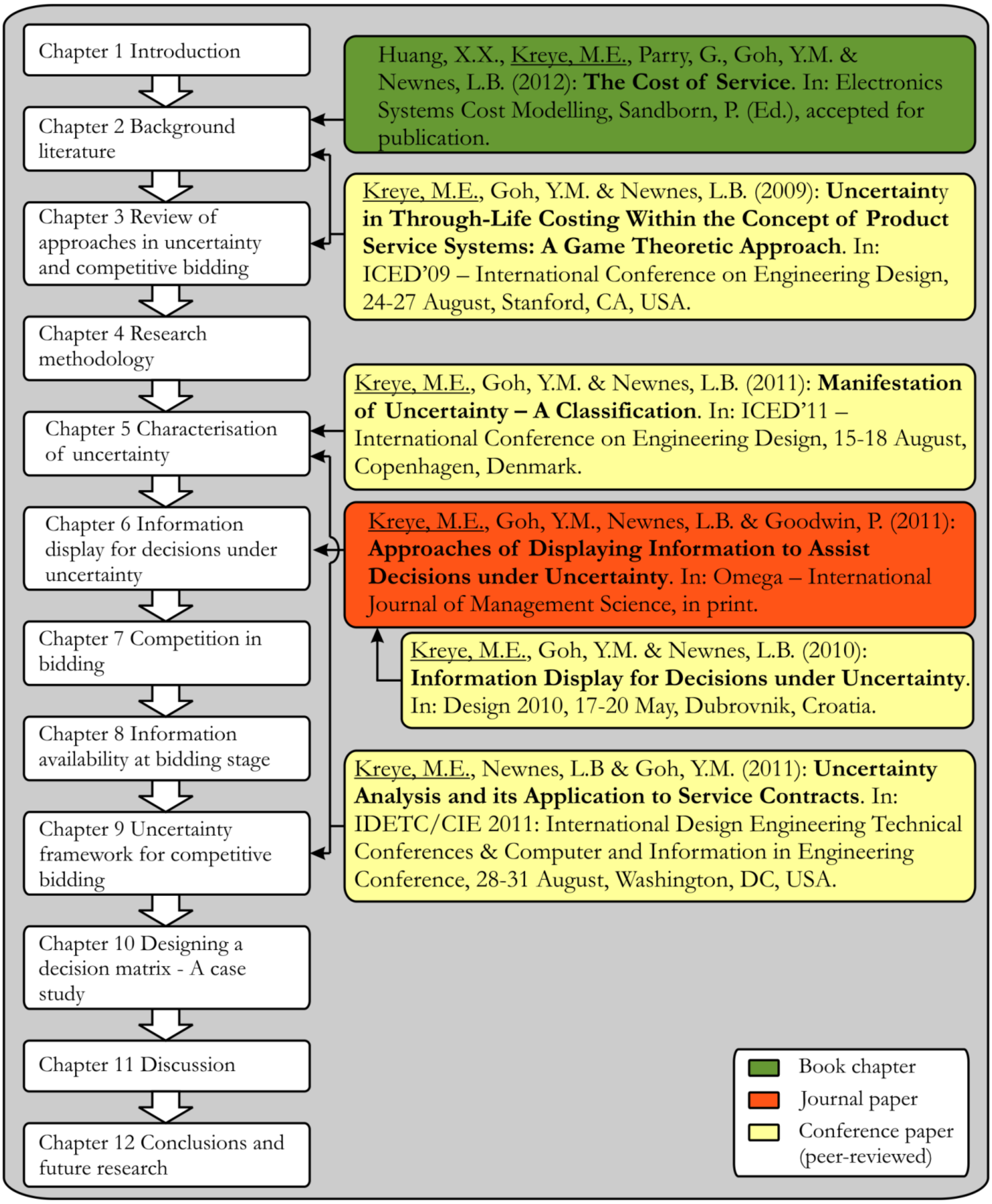
Kreye, M.E.; Goh, Y.M.; Newnes, L.B. (2009): ***Uncertainty in Through Life Costing Within the Concept of Product Service Systems: A Game Theoretic Approach***. In: ICED'09 - International Conference on Engineering Design, 24-27 August, Stanford, CA, USA.

Conference & workshop papers (not peer-reviewed)

Kreye, M.E.; Goh, Y.M., Newnes, L.B. (2009): ***Information Display for Costing Decisions under Uncertainty***. Presented at workshop *"Improving Value for Money"* of Society for Cost Analysis and Forecasting, 24 November, Bristol, UK.

Valerdi, R., Newnes, L.B., Goh, Y.M., Kreye, M.E. & Hihn, J. (2009): ***Mental Models of Cost Estimation: A Focus on Risk Assessment***. In: 24th International Forum on COCOMO and Systems/Software Cost Modeling, 2-5 November, Boston, MS, USA.

Publications and thesis chapters



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List of Abbreviations

ACostE	**A**ssociation of **Cost E**ngineers
AI	**A**rtificial **I**ntelligence
B2B	**B**usiness-**to**-**B**usiness
BS	**B**ritish **S**tandard
c	Estimated costs for fulfilling a contract
c_a	Actual costs for fulfilling the contract
CP	**C**ost **P**lus payment of a service contract. Specific values can be fixed (CPFF) or a variable (abbreviated as CPP for Cost Plus Percentage or CPM for Cost Plus Margin) payments
DS-I	**D**escriptive **S**tudy **1**, research phase to examine the current state of the examined situation
DS-II	**D**escriptive **S**tudy **2**, research phase to investigate the impact of the developed support
FP	**F**ixed **P**ayment for a service contract
IPS^2	**I**ndustrial **P**roduct-**S**ervice **S**ystems
ISO	**I**nternational **O**rganization for **S**tandardization
JCGM	**J**oint **C**ommittee for **G**uides in **M**etrology
MCS	**M**onte **C**arlo **S**imulation
p	price bid
$P_{acceptance}$	Probability of acceptance of a price bid
P_{lead}	Probability of being the lead bidder for a contract
P_{profit}	Probability of making a profit
$P_{winning}$	Probability of winning the contract
p-box	Probability box
PDF	**P**robability **D**ensity **F**unction which shows the frequency of occurrence of an uncertain variable over the domain of possible values
POF	**P**robability **O**f **F**ailure
PS	**P**rescriptive **S**tudy, research phase for development of a support for improving a situation
PSS	**P**roduct-**S**ervice **S**ystem
ROI	**R**eturn **O**n **I**nvestment
SCAF	**S**ociety for **C**ost **A**nalysis and **F**orecasting
TLC	**T**hrough **L**ife **C**ost
V&V	**V**erification and **V**alidation

List of Definitions

Ambiguity — Situation when the available information or problem description does not give a consistent or coherent picture.

Bidding — The act or process of making a bid or bids where the bid includes an offer of e.g. a price.[1]

Bidding process — Specifications that define how closely the bidding parties are connected to the customer in the time frame before the submission of their bids, i.e. it describes the level of allowed negotiation.

Confidence — The mental attitude of trusting in or relying on a person or thing.[1]

Cost estimate — Depicts the future cost values of a service or a product.

Decision — A commitment to an action with the constraint of serving the interest or value of the decision maker.

Imprecision — Situation before a decision about possible alternatives is made.

Method — Techniques or procedures for the collection and analysis of data.

Methodology — Interconnection between the applied methods in a research project.

Price — Monetary value the customer has to pay to receive the benefits associated with a service or product.

Product — An entity over which ownership rights can be established and from which its owner(s) derive some economic benefit.

Rational — A decision maker is (instrumentally) ***rational*** when s/he has priorities over the outcomes of his/her decision and selects actions that will best satisfy his/her preferences under the consideration of the information available for the specific decision problem.
A decision maker is ***bounded rational*** when there are bounds in his/her rationality such as the limited complexity of ascertainable information or the ability to learn.

Risk — The possible (positive or negative) effect of an uncertain event or situation.

Service — An activity or a process which is characterised by the triangular relationship between the service provider, the consumer and the service issue.

Service contract — An agreement between the parties about the technical details of the service; it is intended to be legally binding.

Servitisation — Transformation of market structures to the stage where manufacturing companies have to compete through offering services as opposed to physical products.

Uncertainty — A potential deficiency in any phase or activity of the process, which can be characterised as not definite, not known, or not reliable.

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[1] Definitions as found in the current edition of the Oxford English Dictionary SOANES, C. (2005): *The Oxford English Dictionary,* Oxford, UK, Oxford University Press.

1 Introduction

The suppliers of long-life products such as submarines and airplanes no longer simply sell these products but provide their capability or availability. Examples are the delivery of the so-called *power-by-the-hour* [Baines et al., 2007], the supply of the number of flying hours for an aircraft [BAE, 2010; 2006] and the support of a submarine through life [Rolls-Royce, 2011b]. This means that companies that traditionally design and manufacture long-life products now compete through the provision of a service [Baines et al., 2009]. For example, Rolls-Royce Engines achieve 60% of their revenue through selling a service rather than the engine itself [Rolls-Royce, 2011a].

These companies face a high level of uncertainty due to the novelty of the process and the long-term nature of services. For example, within the network of Alstom west coast mainline trains, service contracts for the Pendolinos 57 have been agreed until 2023. Another example of the long-term nature of service contracts is Rolls-Royce's Flotilla Support Programme for their submarines until 2017 [Rolls-Royce, 2011c]. As a consequence, it is difficult for companies to determine an appropriate price bid for the service, which will enable them to win the contract as well as make a profit [Wang et al., 2007; Chapman et al., 2000]. For example, companies performing maintenance work on roads have found that their profits were 50% less than predicted [Patel, 2011].

The overall aim of the research presented in this thesis is to support companies that offer these services in making the pricing decision under uncertainty in a competitive bidding situation. It provides an approach that enables service suppliers to identify the uncertainties that influence the pricing decision at the bidding stage, include them in the decision process and manage them. The following sections describe the context of the presented research, which is followed by a description of the problem statement and the research aim. Finally, the general thesis structure is presented.

1.1 Research context - servitisation

Servitisation means the transformation of market structures to the stage where manufacturing companies have to compete through offering services as opposed to physical products [Baines et al., 2009; Neely, 2008]. Within this development the delivery of a service is a central aspect. The term service has been defined is various ways over the past two centuries [Smith, 1776; Say, 1803; Hicks, 1942; Parasuraman et al., 1985; Fisk et al., 1993]. One approach is to compare it with the definition of a product. Products have been described as entities, over which ownership rights can be established, and from which its owner(s) derive economic benefit [Gadrey, 2000; Hill, 1999; Marshall, 1890; Senior, 1863]. As an entity, a product is separate from the producer or the owner and the production and consumption can occur at different locations and times.

In contrast to products, a negative view for a service can be defined as: they are non-entities, over which ownership rights cannot be established. Other authors have a positive view of services highlighting their *intangibility*, *heterogeneity* between different producers and consumers, and *inseparability* between point of production and consumption [Hicks, 1942; Fisk et al., 1993]. However, these do not provide a satisfying exclusive definition [Hill, 1999; Araujo and Spring, 2006]. This has been addressed by Gadrey [2000], who proposed an activity based definition that has received acceptance [Araujo and Spring, 2006]. Accordingly, the term service is defined as follows [Gadrey, 2000].

> A ***service*** is defined as an activity or a process, characterised by the triangular relationship between the service provider, the consumer and the service issue.

This is depicted in Figure 1-1.

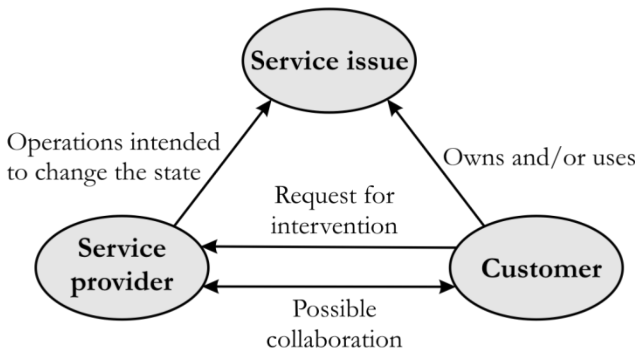


Figure 1-1: Service as a triangular relationship (adapted from Araujo and Spring [2006])

For the research presented in this thesis, this activity based definition is used. Thus, the service is aimed at the change of the state of the service issue, for example the repair of a car, the treatment of a medical problem of a person or the availability of an aircraft.

1.1.1 Product-centred services

Within literature, various types of services are differentiated depending on the focus of the research [Hytönen, 2005; Boyt and Harvey, 1997; Saurama, 2001]. These depend on the type of service issue that is considered (see Figure 1-1). For this research, product-centred services are considered, in other words the service issue is a product. These products can be tangible - such as airplanes, production machines, or buildings - or intangible. Intangible products feature all the characteristics of products, i.e. they are entities, over which ownership rights can be established, and from which its owner(s) derive economic benefit. But they were initially produced by persons (or enterprises) as a result of creative or innovative activities of a literary, scientific, engineering, artistic, or entertainment nature [Vargo and Lusch, 2008; Hill, 1999]. Examples include a new computer program, the text of a book, the formula for a new chemical, a new film produced by a studio, or a musical composition.

This thesis focuses on product-centred services with the following characteristics;

- ***Highly complex***: The complexity is the number of independent tasks necessary to complete the service [Skaggs and Youndt, 2004; Harvey, 1998; Olhager, 2003; Shostack, 1987]. For example, the maintenance of a machine requires the performance of various tasks that differ in their fundamental characteristics such as the exchange of broken parts, storage of replacement parts, their transport to the customer, and training of the servicing personnel.
- ***Long lived***: Examples of services of products with a long life expectancy include airplanes or buildings [Ferry and Flanagan, 1991; Oliva and Kallenberg, 2003; Cheung et al., 2007]. Literature does not offer a clear divisional rule to define a long-lived product as opposed to a short-lived one. However, one characteristic of long-lived products is the importance of the in-service phase in comparison to the design or manufacturing phase. Sometimes the operation costs can be 90% of the complete through-life costs (TLC) of these products [Wahl and Brueck, 2007].
- ***Business-to-business (B2B)***: For these services, both involved parties are businesses [Kärkkäinen et al., 2001; Gounaris, 2005]. This means that the customer is a business and not a private person or end consumer [Bolton et al., 2006].
- ***Competition***: The existence of competition for the delivery of a service is an important aspect of the bidding process [Grönroos, 2007; So, 2000]. However, this competition is usually imperfect [Caillaud and Jullien, 2003]. This is due to two main reasons. First, the service offers vary between suppliers in regard to their service specifications, which has also been defined as the heterogeneity of services [Say, 1803; Hicks, 1942; Parasuraman et al., 1985; Tsalgatidou et al., 2006]. Second, the number of competitors is small, in other words the market can be described as an oligopoly as opposed to a high level of competition [Badri et al., 2008; So, 2000].

Examples of these services include the provision of a set number of flying hours for an aircraft [BAE, 2010; 2006], the maintenance of a production machine, the through-life support of a submarine [Rolls-Royce, 2011b], the construction of a building, the investigation of a research project and the maintenance of a computer software. These examples are not to be seen as a complete definition but rather as an illustration of the services that are the focus of this research.

Some of the above mentioned examples have also been described as Product Service Systems (PSS) [Baines et al., 2007]. A PSS is a marketable, integrated combination of products and services, which extends the traditional functionality of a product by incorporating additional services [Mont, 2002; Baines et al., 2007]. It consists of two parts: a physical part (the product) and a non-physical part (the service), whose ratio can vary, either in terms of function fulfilment or economic value [Baxter et al., 2008]. Some authors have highlighted the importance of PSS in the context of sustainability with different emphases such as the environmental impact [Manzini et al., 2001; Wong, 2004], societal aspects of the development [Kates et al., 2001], the strategic adaptation of sustainability [Ny et al., 2006], and economic growth of business opportunities and market share [Dierickx and Cool, 1989; Schaltegger, 2008]. Baines et al. [2007] and Cook et al. [2006] offer a more detailed discussion of PSS and their contribution to sustainability.

The presented research is connected to the concept of PSS in the sense that the considered services can be interlinked with a product. For example, a maintenance contract is highly connected to the product that is to be maintained. However, the main focus of the presented research is on the service aspect as a contractual obligation. With this understanding, the presented research does not only focus on the service aspect of PSS but it also includes other product-centred services such as construction [Skitmore and Pemberton, 1994].

1.1.2 Service contracts

The delivery of a service is usually arranged through a contract. For the presented research, a service contract is defined as follows [Nellore, 2001; Rowley, 1997];

> A ***service contract*** is an agreement between the parties about the technical details of the service; it is intended to be legally binding.

Contracts can have different characteristics and impacts according to their scope and depth. The scope describes what is included in the contract, in other words the decision rights and organisational activities that are transferred to the service supplier. The contract depth characterises the number of organisational activities that are necessary to provide the service such as equipment specification and purchasing, installation, commissioning, monitoring and verification of performance or staff training [Sorrell, 2007]. A contract with a high scope and depth would potentially have higher costs, but also give the contractor higher control over the costs and, therefore, a higher potential for cost reductions.

Service contracts are often allocated through the process of competitive bidding [Albano et al., 2009]. In this process, the competing suppliers communicate their service specifications and price bids to the customer who then evaluates the bids [Shen et al., 2005; Bubshait and Almohawis, 1994]. For the presented research, the term price is understood as follows;

> The ***price*** is the monetary value the customer has to pay to receive the benefits associated with the service or product [Hytönen, 2005].

To make a decision about what price to bid, the supplier faces various uncertainties arising from e.g. their strategic aims, the aims of the customer, and the long-lived nature of the service contract. The following definitions of the terms uncertainty and decision are applied to this research;

> ***Uncertainty*** is a potential deficiency in any phase or activity of the process, which can be characterised as not definite, not known or not reliable [Soanes, 2005].
>
> A ***decision*** is a commitment to an action with the constraint of serving the interest or value of the decision maker [Yates and Tschirhart, 2006].

Based on the presented research context and definitions, the following problem statement can be made.

1.2 Problem statement

The pricing decision at the bidding stage for service contracts is influenced by various factors which leave the decision maker in a state of uncertainty. This uncertainty can be related to e.g. the cost estimate for fulfilling the contract. This may be based on different assumptions about the future which may hold true in reality. Examples are the price of spare parts and the inflation rate on the financial markets. Figure 1-2 shows an example of a cost estimate for fulfilling the contract requirements and the included uncertainty in the form of a forecast range [Tay and Wallis, 2000]. The forecast range can consist of the minimum, maximum and average value connected to different assumptions about the future [Giordani and Söderlind, 2003].

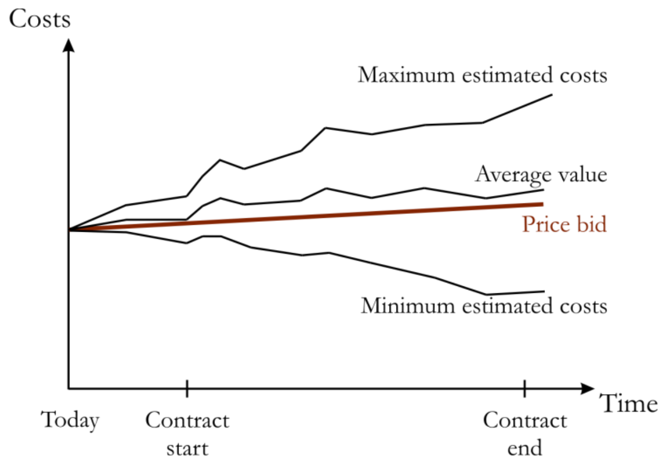


Figure 1-2: Example of a cost estimate and a possible price bid

At the bidding stage, the decision maker has to select one point within the given range as a price bid to communicate to the customer. One example is marked in Figure 1-2. Choosing a price that is too high may result in being underbid by competitors and, thus, potential loss of business [Rogers, 1990; Chapman et al., 2000]. A too low price may influence the customer's perception of the service quality and, thus, be rejected [Freedman, 1988], or result in the failure to recover the costs or produce a profit [Monroe, 2002; Chapman et al., 2000]. To make a pricing decision based on the previously estimated costs of the service contract, the decision maker has to understand;

- the uncertainty in the cost estimate, and
- other uncertainties that influence the bidding success and the fulfilment of the service contract.

Ignoring this uncertainty can result in the underachievement of profit as highlighted by Patel [2011] who found that companies offering road maintenance services face the problem of making 50% less profit than predicted.

1.3 Research aim

The intention of the presented research is to support the pricing decision under uncertainty. It describes a process from the identification of the inherent uncertainty in a pricing decision to its depiction for the decision maker. In particular it focuses on the trade-off between the probability of winning the contract and the probability of making a profit. This trade-off is included in a decision matrix showing the two probability values with subject to possible price bids.

Thus, the aim of the presented research is as follows.

> The aim of this research is to support the pricing decision by defining a process for modelling the influencing uncertainties and including them in a decision matrix depicting the trade-off between the probability of winning the contract and the probability of making a profit.

The decision matrix aims to support the decision maker in his/her awareness of the influencing uncertainties and their consideration in the decision process. In other words, the presented research delivers a support for the decision-making process; it does not focus on the optimisation of it. To investigate this research aim, objectives were defined, which are based on the reviewed literature. Thus, they are presented in Chapter 4 where the research methodology is described.

1.4 Outcomes and deliverables

The outcomes and deliverables of this research can be summarised as follows;

- ***An approach for characterising uncertainty:*** Based on literature, an approach was defined to characterise the uncertainty inherent in a situation. This approach was used to identify areas of application for existing uncertainty modelling techniques such as probability theory or interval analysis. It was validated through its application to the pricing decision in a competitive bidding environment as presented in this thesis.
- ***An uncertainty framework for competitive bidding:*** A framework was defined, which depicts and characterises the uncertainty within a competitive bidding situation. This was validated through an industrial case study.
- ***A guide for choosing a suitable uncertainty modelling technique:*** A method was defined to identify a suitable technique to model the uncertainty influencing a pricing decision. This guide is based on the approach for characterising uncertainty and the uncertainty framework of a bidding situation. This was validated through an industrial case study.
- ***A decision matrix:*** This shows the probability of winning the contract and the probability of making a profit. This decision matrix focuses on an industrial case study in competitive bidding and utilises the identified uncertainty modelling techniques by following the guide described above.

1.5 Thesis Structure

This thesis consists of twelve chapters as depicted in Figure 1-3.

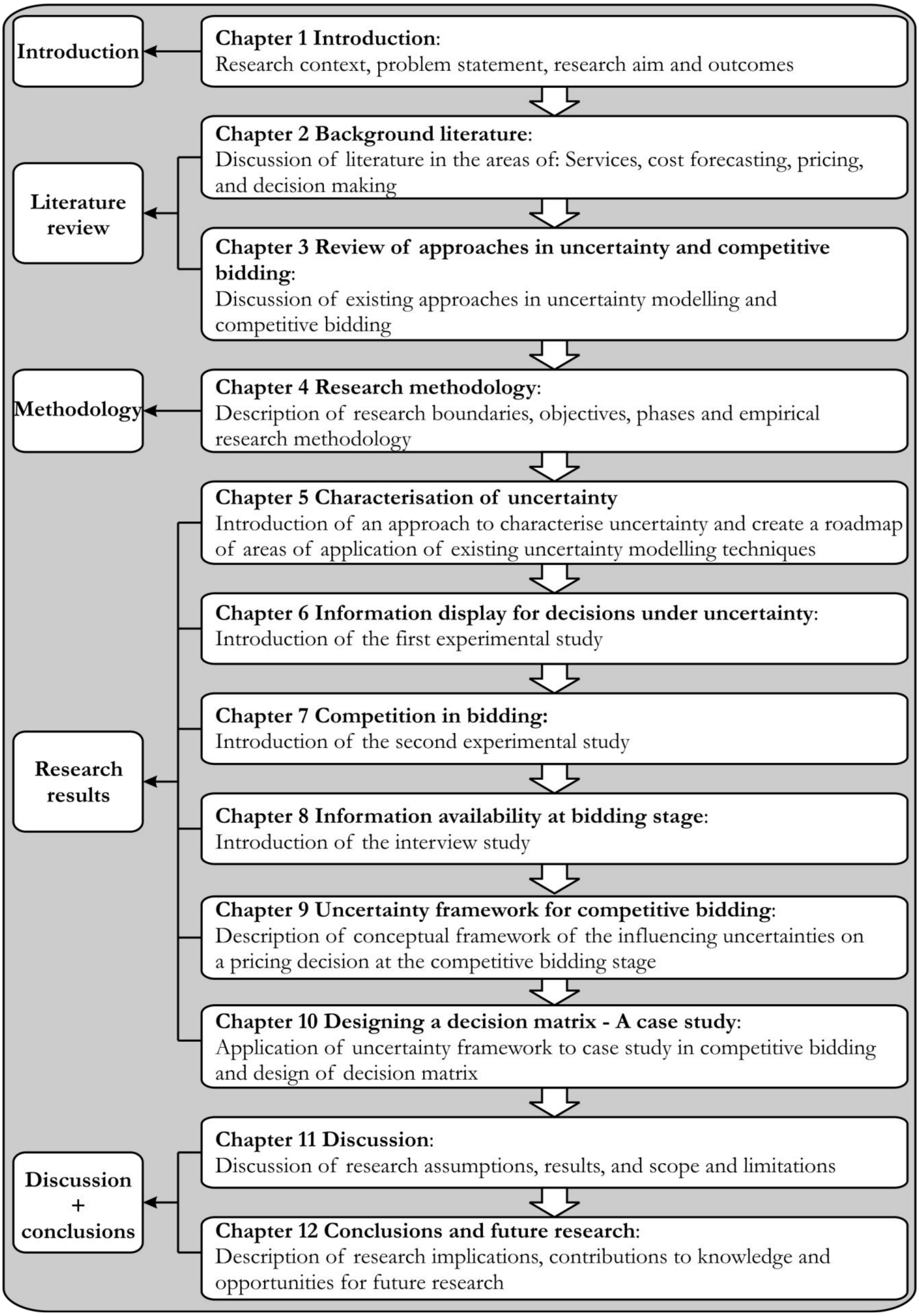


Figure 1-3: Thesis layout

The literature review was divided into two chapters according to their importance to the presented research. ***Chapter 2*** introduces the background literature and examines research approaches that form the basis of this research. ***Chapter 3*** describes existing approaches in the areas that are considered the core of the presented research, namely uncertainty and competitive bidding.

In ***chapter 4***, the research methodology is presented which includes the research objectives and the methodology of the empirical research.

Chapter 5 presents an approach for characterising the uncertainty inherent in a situation. This approach was used to create a roadmap of application areas for existing uncertainty modelling techniques. This formed the basis for the identification of suitable techniques to model the uncertainty within the competitive bidding process.

Chapters 6-8 introduce the empirical studies that investigated the uncertainties in a competitive bidding situation for service contracts. These studies examined the uncertainties that influence the decision maker at the bidding stage.

Chapter 9 describes the conceptual framework of the uncertainty influencing the pricing decision at the competitive bidding stage. This framework is based on the results of the empirical studies described in chapters 6-8. The uncertainty is characterised using the approach described in Chapter 5.

Chapter 10 illustrates application of the conceptual framework described in Chapter 9 on an industrial case study. Based on this case study, a decision matrix was derived which depicts the probability of winning the contract and the probability of making a profit.

Chapter 11 presents the concluding discussion of this research, particularly of the assumptions, results, and scope and limitations.

Chapter 12 draws the conclusions from the presented research and describes opportunities for future research.

2 Background literature

This chapter focuses on the background of this research. It describes the areas of services, cost forecasting, pricing, and decision making and gives an overview of current approaches in these areas.

2.1 Services

This section describes the state-of-the-art in the area of services, in particular service design and assessment of the service quality. It expands on the context of servitisation described in Section 1.1.

2.1.1 Service design

Service design is the formative stage of a service and is a necessary process to provide a suitable service to the customer [Akasaka et al., 2011; Sakao et al., 2011; Goldstein et al., 2002; BSI, 1994]. It can vary between different services and problems; however, this section sets the scene with some general descriptions of the design process. The current standard describing this process is BS 7000-3 [BSI, 1994]. Different international standards exist but they focus on the design of specific services such as construction [ISO, 2011].

In literature, the process of designing an innovative service is also referred to as service blueprint [Bitner et al., 2008]. This technique was introduced by Shostack [1982] and refers to the theoretical description of the steps that constitute the service. This means that the service blueprint describes the plan of executing the service, i.e. an action plan [Berkley, 1996].

The service design process can be described by a typical model, which identifies several important steps [BSI, 1994]. These steps can be internal to the company - such as the identification of a need or the creation of a design - or external - such as the operation and withdrawal of the service. Depending on the company, its market sector and the specific service, some of these steps can be more elaborate than others [Papazoglou and van den Heuvel, 2006]. Some approaches to service design include only the internal process to the company, i.e. the process from the idea to the specifications [Zeithaml, 1990; Gummesson, 1991; Goldstein et al., 2002]. For the presented research, all of the steps can be important due to the life-cycle orientation of the designed service [Aurich et al., 2004; Goldstein et al., 2002; Johnson et al., 2000].

Specifying the service idea for a specific problem can lead to a refined list of characteristics as depicted in Figure 2-1 [BSI, 1994]. This classifies the list of service specifications into four main areas: performance, cost, timescale requirements and other considerations.

Figure 2-1: Service specifications and characteristics (adapted from BS 7000-3 [1994])

For example, specifications regarding *availability* would belong to the area of timescale requirements, where particular time limits for the service performance may be specified. In case of a maintenance contract for a production machine, the specification could be, for example, that in case of a machine breakdown, the production process is guaranteed to continue within a pre-defined amount of time. It would then be dependent on the service provider, weather this would be achieved through repair or the provision of an exchanged machine.

Connected to this example, the service operation could be specified. To assure the availability of the production machine, servicing personnel may have to be transported to the customer's production site or a possibility to evacuate the machine from site and to deliver an exchange may have to be established. Depending on the specific service requirements, specifications regarding the service characteristics listed in Figure 2-1 have to be defined. This list is non-exhaustive and not all of the elements mentioned may be applicable to every situation. In other words, specific services may only need specification in some selected areas, while others may need additional areas.

2.1.2 Service quality

The main body of research focusing on service quality was done in the 1980s; however, the research results are still valid today [Chuang, 2010; Kuo et al., 2009; Shen et al., 2005]. Service quality is highly dependent on the perception of the concerned party (or parties) and can be understood as the *"conformance of requirements"* [Crosby, 1979]. This can include the service specifications considered in the service design phase as well as assumptions or expectations that may not be communicated between supplier and customer [Parasuraman et al., 1985]. It is influenced by the customer's perception of the delivered service and can be characterised as the fulfilment of customer's expectations on a consistent basis [Grönroos, 1983; Lewis and Booms, 1983; Chuang, 2010].

The customers compare their expectations to their perceptions of the service they receive [Grönroos, 1983; 1984; Parasuraman et al., 1985]. Thus, the level of satisfaction depends on the confirmation (or disconfirmation) of their expectations [Boulding et al., 1993; Smith and Houston, 1982][2]. The customer's expectations include their beliefs about the service that are formed in advance through information sourcing from e.g. prior exposure to the service, word-of-mouth, expert opinion, publicity, communication (advertisement, personal selling, price etc.) or prior exposure to competitive services and can be influenced through classical marketing instruments [Boulding et al., 1993; Zeithaml, 1990; Grönroos, 1983].

The service quality can occur on two dimensions [Grönroos, 1983; 1984]: the technical quality, i.e. *what* the customer receives, and functional quality, i.e. *how* the customer receives the service. For example, the technical quality can be the transport of the passenger, the given haircut, or the performance of a financial transaction. This can usually be assessed in an objective manner and has been described in international standards such as BS EN ISO 9001

[2] See also literature on product satisfaction such as SWAN, J. E. & COMB, L. J. (1976): *Product Performance and Consumer Satisfaction: A New Concept*. In: Journal of Marketing, 40(2), pp. 25-33.

[2008] or BS EN ISO 9004 [2009]. A satisfactory technical performance is essential for a positive consumer evaluation.

The functional or psychological level of the service quality is dependent on the buyer-seller interaction and can only be evaluated subjectively. This was described in the *gap model* which was introduced by Parasuraman et al. [1985; 1988; 1991]. The authors found five elements of functional service quality, namely;

- ***Reliability:*** Accurate and dependable performance of the promised service.
- ***Responsiveness:*** Willingness to help customers and to provide prompt knowledge.
- ***Assurance:*** Knowledge and courtesy of the service provider including the ability to convey trust and confidence.
- ***Empathy:*** Provision of caring and individualised attention to customers.
- ***Tangibles:*** Appearance of physical facilities, equipment, personnel, and communications materials.

Figure 2-2 summarises the two dimensions of service quality (technical and functional) and integrates the evaluation approaches as described by Grönroos [1983; 1984] and Parasuraman et al. [1985; 1988; 1991].

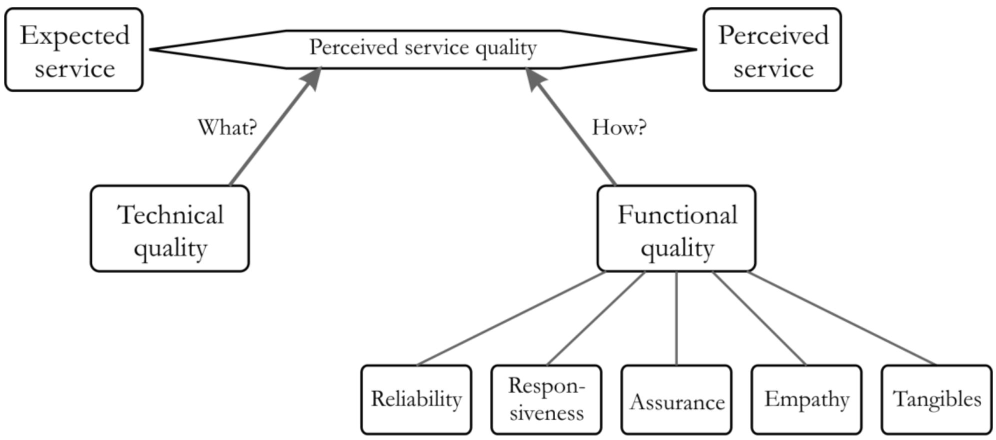


Figure 2-2: Dimensions of perceived service quality

There can be a significant difference between the intended service quality (from the supplier) and the perceived one (by the customer). The customer's perception can be influenced by the experienced service quality, the timing of the service delivery, and the variability in service levels [Bolton et al., 2006]. Further research in this area can be found for example in Tsikritsis and Heineke [2004], Hansen and Danaher [1999], Rust et al. [1999], Boulding et al. [1993] and Loewenstein and Prelec [1993].

2.2 Cost forecasting

Given the service design, the costs of offering and producing the service have to be estimated. Cost estimation is an important input for decision making [Skitmore, 1989]. Various influences (or uncertainties) can cause the actual costs to deviate from the estimated ones or the underlying assumptions of the estimate to be invalid [Bargelis and Rimasauskas, 2007]. This section gives a concise review of the literature on cost estimation and forecasting methods.

2.2.1 Forecasting and cost estimation

Forecasting is an important problem-solving and decision-making technique in project and production management [Armstrong, 2001; Adolphy et al., 2009]. It has been applied across a number of sectors and has been acknowledged in many areas, both in research and practice [Zotteri and Kalchschmidt, 2007; Hong, 2008; Hong-Dong et al., 2008]. Forecasting is a relevant technique when there are deficiencies in the availability or certainty of the necessary information due to e.g. limited resources [Courtney, 2001; Neugarten, 2006]. It is defined as the estimation of the future value of the variable under consideration [Lawrence et al., 2006]. It can be applied to estimate the future sales or demand of a product [Zotteri and Kalchschmidt, 2007], the costs of certain variables/products [Tay and Wallis, 2000], the outcome of a conflict situation [Armstrong, 2001], the effort of developing a new product [Jorgensen and Boehm, 2009], or the level of future macroeconomic values such as interest rates [McGuigan et al., 2005].

Different methods and models have been discussed to estimate the costs of products or systems [Newnes et al., 2008; Carpio, 2002; Asiedu and Gu, 1998]. These can be classified into qualitative and quantitative approaches, which can each be subdivided further as depicted in Figure 2-3 [Niazi et al., 2006; Ben-Arieh and Qian, 2003; Farineau et al., 2001].

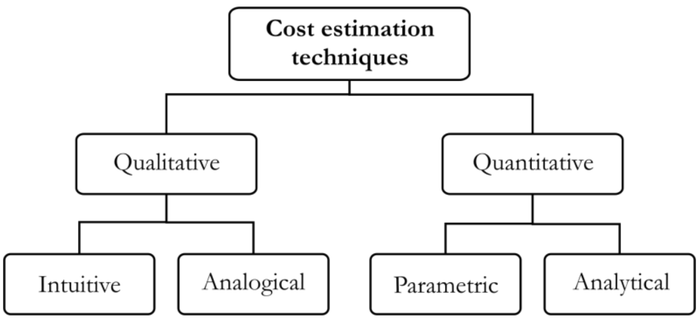


Figure 2-3: Classification of product cost estimation techniques (adapted from Niazi et al. [2006])

Qualitative cost estimation techniques use a comparison of the new product to previously manufactured products to derive differences and similarities. The similarities can then help to use past data as a basis to produce a cost estimate for the new product [Niazi et al., 2006; Goh et al., 2010]. An example of this process is the use of the volume and weight of a new product in relation to an existing one to estimate its costs [Newnes et al., 2007]. Qualitative cost estimation techniques can be further classified into intuitive and analogical techniques.

Quantitative techniques use a detailed analysis of the product features and manufacturing processes to derive the cost estimate. The costs are either calculated with the help of an analytical function of representative variables of different product parameters or as the sum of elementary units [Niazi et al., 2006]. Quantitative cost estimation techniques can be further classified into parametric and analytical techniques [Farineau et al., 2001].

The process of cost estimation is outside the scope of the presented research; however, insights from this process will be utilised. For a more detailed discussion of the different cost estimation techniques and their advantages and disadvantages, the reader is referred to Niazi et al. [2006] and Goh et al. [2010]. The outcome of this process is the cost estimate, which depicts the future cost values. This is described in the next section.

2.2.2 Cost estimate

A cost estimate can have the form of a point or range forecasts [Tay and Wallis, 2000; Zarnowitz, 1969]. A point forecast gives the most probable future value of the variable; a range or density forecast consists of a range of possible future values of the costs and the probability distribution of these values [Tay and Wallis, 2000]. To derive these ranges or intervals, the cost estimator typically uses an appropriate cost model as presented in Section 2.2.1 [Giordani and Söderlind, 2003].

The uncertainty connected to a cost estimate tends to increase with the forecasting span. Hence, the estimate range increases with increasing time in the future [Christoffersen, 1998]. A cost estimate for a service 10 years into the future can be expected to be more uncertain than the forecast for 1 year (see also Figure 1-2 in Chapter 1). One indication of this is also the occurrence of systematically larger errors in longer forecasts as the influence of under/overestimation is bigger [Zarnowitz, 1969; Goh et al., 2010]. It can therefore be expected that the longer the contract period,

- the bigger the range of the cost estimate for future values [Tay and Wallis, 2000] and
- the smaller the decision maker's confidence in the accuracy of the cost estimate [Hirst et al., 1999].

Based on the cost estimate, the pricing decision has to be made. The next section discusses approaches to pricing as described in literature.

2.3 Pricing

For the presented research, the price of a service (or product) is defined as the monetary value the customer has to pay to receive the benefits associated with the service (or product) [Hytönen, 2005]. Different terms can be used to describe the same issue, e.g. postage *fares*, *tuition* for education, *fares* for public transport, *fees* for doctors, *tolls* for crossing a bridge or *tariffs* for importing goods into another country [Monroe, 2002]; however, in this thesis the term ***price*** is used.

The service's price has to cover the costs incurred through producing the service as well as allowing for a suitable profit margin [Monroe, 2002; Dean, 1949]. This process is called cost-based pricing. Other methods include competitive-based or value-based pricing. This section gives an overview over each of these methods. The research presented in this thesis focuses on cost-based pricing, as it is the most frequently used method in practice [Avlonitis and Indounas, 2005; Hytönen, 2005] and most widely discussed in literature [Dean, 1949; Swann and Taghavi, 1992; Hansen and Banker, 2002; Courcoubetis and Weber, 2003].

2.3.1 Cost-based pricing

The cost-based approach is very common in pricing both products and services in practice [Avlonitis and Indounas, 2005; Hytönen, 2005]. In this approach the costs of producing and delivering the service are used to calculate the price. This is usually determined by adding a profit margin on top of the costs [Hytönen, 2005]. Hence, this method typically has a sound accounting background, which means it forms a good basis for negotiation processes with the customer. However, it also has shortcomings, particularly in the service context.

The costs are usually uncertain and may include possible variation according to different assumptions. Especially in the service context, the amount of necessary service incidents such as repairs is highly uncertain and can hardly be predicted [Zeithaml et al., 1985]. Furthermore, services can be characterised by a high fixed-to-variable cost ratio [Hoffman et al., 2002]. For example, if the service concerns the availability of a production machine for the customer (this example is also described in Section 2.1.1), the service provider may need to hold a pool of spare parts and specifically trained staff to guarantee the service. This means that the estimation of the demand is even more critical. In addition, the determination of a sufficient profit margin is not clear [Hytönen, 2005]. This will be described further in chapters 7 and 10.

2.3.2 Competitive-based pricing

The competitive-based approach bases the price on the market situation and the offers of competitors [Noble and Gruca, 1999; Rogers, 1990]. The starting point for this approach is the market price, which can include the closest substitute of the product/service or the average price of a similar product/service on the market. An example for competitive-based pricing methods is cooperative pricing, where changes in the market's price structure are made cooperatively between the competitors. Further examples are adaptive pricing, where the market price has to be accepted by a company with a small market share, and opportunistic pricing, where the price is used as a competitive weapon [Nagle, 1987].

Competitive-based pricing is an important method for services or products, where the market offers a high number of possible substitutes or alternatives for the service [Nagle, 1987]. These markets are characterised by the fact that the service providers act as price takers, i.e. they cannot influence the market price. However, services are heterogenic, which means they vary between different suppliers [Hoffman et al., 2002; Parasuraman et al., 1985]. Hence, the market price of similar services is adjusted according to how the supplier perceives to differ from the alternatives offered on the market. The research presented in this thesis focuses on services whose markets are usually not suitable for a competitive-based pricing method, due to e.g. their highly complex nature. Thus, this method is not discussed further in this thesis.

2.3.3 Value-based pricing

The value-based approach determines the final price according to the value or benefit the customer receives from the service [Hinterhuber, 2008]. It is driven by "*the measurable value provided to the customer*" [Monroe, 2002] as opposed to the customer's willingness to pay. The value (in the sense of an economic value) can be described with the utility received by the customer [Hytönen, 2005]. The value-based concept has been discussed in areas such as logistics services [Pirttilä and Huiskonen, 1996]. However, the economic value derived with this approach does not necessarily equal the customer's perceived value as this also depends on his/her perception of e.g. the service quality as described in Section 2.1.2 [Nagle, 1987].

The advantages of this method have been described as offering a fair and low price for a high-quality offer [Kotler, 2000]. However, it is based on the assumption that the price can be derived from the value the customer receives from the service, which can be problematic in practice [Reichheld, 1996], sometimes even impossible [Hinterhuber, 2004]. The perceived value of a service (also of a product) is a very subjective evaluation, which can differ between customers and is hard to assess by the supplier [Grönroos, 1984]. Thus, this method is not further discussed in this thesis.

2.4 Decision making

Decision making has been discussed in many domains especially in the field of economics and management [Clemen, 1991, p. 6; Abdellaoui and Hey, 2008; Yager, 2008]. As the term *decision* is used in everyday language, many research papers lack a definition or a clear distinction from other related terms [Arkes and Hammond, 1986; Smith et al., 2004; Xu et al., 2007; Radner, 2000]. Some approaches do give definitions such as the examples given in Table 2-1. What is intrinsic in all the papers reviewed is the interpretation of a decision as a final point or an action that separates two periods from one another [Hoffman and Yates, 2006]. A decision can be defined as *"making a choice of what to do and not to do, to produce a satisfactory outcome"* [Tang, 2006]. It can be interpreted as a commitment to an action with the constraint of serving the interest of the decision maker [Yates and Tschirhart, 2006]. This viewpoint is adopted in this thesis.

Table 2-1: Definitions of *decision* as described in literature

Definition	**Reference**
"A decision occurs when an organism, confronted by several discrete options, evaluates the merits of each and selects one to pursue. (… It is) mandated by (…) the subjective experience and preference of the individual."	Glimcher [2009, pp. 463-464]
"making a choice of what to do and not to do, to produce a satisfactory outcome".	Tang [2006]
"commitment to a course of action having the intention of serving the interests and values of particular people. (It is …) a mental event that occurs at a singular point in time—a psychological moment of choice—that leads immediately or directly to action."	Yates and Tschirhart [2006]
"the final and definite result of examining a question; a conclusion, judgement."	Oxford English Dictionary [Soanes, 2005]
"a specific commitment to action (usually a commitment of resources)."	Mintzberg et al. [1976]

This section describes the different types of decision before the influence of uncertainty on decision making is emphasised. Then, the decision maker is characterised.

2.4.1 Decision hierarchy

Different types of decisions can be distinguished, depending on the level they are made at [Dodgson et al., 2008; Gunasekaran et al., 2004]. Some decisions have a higher impact and are of higher importance in the given context than others [Mintzberg, 1979]. The different types can be illustrated in a hierarchy including the following decisions;

- ***Strategic:*** General directions of action to achieve long-term business goals.
- ***Tactical:*** Methodological decisions connected to a specific medium-term result.

- ***Operational:*** Decisions with a specific observable result.

Strategic decisions are the highest in the hierarchy, which means that they are the most important in regards to the committed actions and resources [García-Fernández and Garijo, 2010; Donaldson and Lorsch, 1983; Mintzberg et al., 1976]. They tend to be general directions of action and can describe areas of interest, such as the expansion to new markets or market segments. On the tactical level, decisions are more methodological, i.e. closer connected to a specific medium-term result. An example of a tactical decision is the starting of a research project in a specific area. On the operational level, decisions are connected to a specific observable result. An operational decision is connected to the implementation of the strategic decision with specific objectives [Rogers, 1990, p. 6]. An example could be to use Battery A instead of Battery B for a specific design problem.

A bidding decision as discussed in this thesis can be categorised as a tactical decision. This can also comprise strategic thinking and goals; however, it is of a more specific and project related character [Harrington Jr., 2009]. A tactical decision can have impacts over a medium time period into the future, in this case over the period of the service contract. This means that uncertainty can be highly important for the decision, which necessitates its consideration in the decision-making process. Thus, the following section discusses the influence of uncertainty in decision making.

2.4.2 Decision making under uncertainty

Decision making can be divided into sub-processes. For decision making under uncertainty, these sub-processes include the decision-making process, after which the decision is made, the implementation of the decision and the implementation of the decision object [Howard, 1992]. The outputs of these phases are the result and the outcome of the decision. This concept was introduced by Howard [1992]; however, it was refined for this research. Figure 2-4 illustrates the connection of the different decision phases.

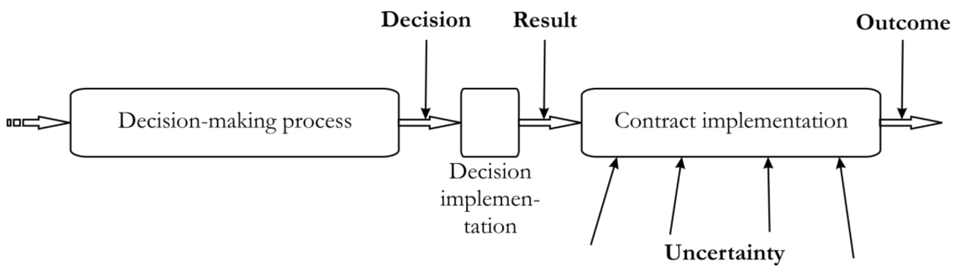


Figure 2-4: Result and outcome of a decision

This thesis focuses on competitive bidding for a service contract, i.e. the specific contract can be seen as the decision object. The decision process can include the collection of necessary information about, for example, the serviced product, service design and cost estimate, and the formulation of assumptions. Based on this, the decision regarding the price bid is made. This decision is implemented through its communication to the customer, which may include a presentation of the chosen approach. The result of the decision is either the acceptance or rejection of the proposed bid. If the price bid is accepted, the service contract is implemented. This phase is as long as the lifetime of the contract and can be influenced by uncertainty such as future developments of the market. The outcome can then be characterised by the actual costs of fulfilling the contract and the profit made. It can also include intangible aspects such as customer satisfaction [Cardozo, 1965; Cronin et al., 2000] or company reputation [Bikhchandani, 1988; Yoon et al., 1993; Argenti and Druckenmiller, 2004]. However, these intangible outcomes are outside of the scope of this research.

2.4.3 Decision makers

Some definitions of a decision as presented in Table 2-1 focus on one person and specifically exclude the possibility of multiple decision makers [Glimcher, 2009, pp. 463-464]. However, other literature highlights the importance of a team or group of multiple decision makers [Radner, 1962; Dooley et al., 2000]. While the consideration of the motivation and evaluation of the decision outcome for one person holds problems [Radner, 2000], the consideration of multiple aims and rationales multiplies these issues. Constraints have been described as different levels of available information to different team members [Radner, 1962], different competencies in different aspects of the overall decision aim [Radner, 1962; Marschak, 1955], and hierarchical sensitivity of the team [Hollenbeck et al., 1995].

For the research presented in this thesis, this dependence on the decision makers' identity is recognised. However, it is not the main focus because this research is primarily concerned with the influences and implications of uncertainty on the decision maker. Thus, the presented research treats the *decision maker* as a single unit whether individual or group. This means that the issues listed above are understood but not treated or solved by the presented research.

2.5 Summary and Conclusions

This chapter described existing approaches that form the background to the presented research. The research described in this thesis builds on these approaches where possible and appropriate. The main points drawn from the literature include;

- ***Services:*** The service design includes a list of specifications about the service and its delivery, based on the requirements. Furthermore, the customer may judge the service quality based on their experience. This judgement may differ from the supplier's intended service quality.
- ***Cost forecasting and estimation:*** The cost estimate can include specific uncertainties and assumptions about the performance of the serviced product and future developments. These may influence the pricing decision and the decision maker.
- ***Pricing:*** The research presented in this thesis applies the cost-based pricing approach, which means that the cost estimate is used as the starting point. However, other influences such as the existence of competition are recognised.
- ***Decision making:*** The bidding decision as discussed in this thesis is a tactical decision, which means that it can have economic impacts over a specific period into the future. Furthermore, the decision may be made by a single decision maker or a decision team, henceforth referred to collectively as the *decision maker*.

The consideration of uncertainty that may influence the pricing decision is essential for the success in the bidding process. The next section offers a detailed description of approaches to uncertainty modelling and a discussion of models for competitive bidding processes.

3 Review of approaches in uncertainty and competitive bidding

This chapter reviews the literature in the areas that are considered the core of the presented research based on the broader review presented in Chapter 2. These areas are uncertainty and competitive bidding. The purpose of this chapter is to give an overview of the state-of-the-art in these areas and identify the gaps in the current research. First, the area of uncertainty research is introduced by discussing the definition of the relevant terminology - particularly in contrast to risk - and subsequently by presenting modelling techniques. Then, the area of competitive bidding is introduced where the main focus is on the modelling approaches used to identify the probability of winning the contract and the probability of making a profit. This is of particular importance because these are the values that are to be included in the decision matrix (see Chapter 1, Section 1.3).

3.1 Uncertainty

The importance of uncertainty has been acknowledged in many areas such as management [Abdellaoui and Hey, 2008], policy and risk analysis [Arena et al., 2006; Bedford and Cooke, 2001a], physical sciences [Raizer, 2004; Pugsley, 1966], engineering [Agarwal et al., 2004; Grebici et al., 2008], and psychology [Kahneman et al., 1982; Kahneman and Tversky, 2000]. It has accordingly been examined from many different perspectives as summarised in Thunnissen [2003]. However, within the research community, the definition of the terminology itself appears to be inconsistent [Samson et al., 2009]. Most definitions are very context bound and cannot be applied to different situations [Thunnissen, 2003; Van der Sluijs et al., 2005]. In this section, the definition of uncertainty particularly in relation to risk is discussed followed by a description of modelling techniques.

3.1.1 Risk and uncertainty

Many opinions exist on what uncertainty is and how it can be defined [Samson et al., 2009; Hastings and McManus, 2004; Dubois et al., 2003; Zimmermann, 2000; BSI, 1997]. In particular, the boundary between risk and uncertainty is not clear from the different research perspectives, with some researchers using the terms interchangeably as highlighted by Samson et al. [2009]. In contrast, many authors have acknowledged the difference between risk and uncertainty especially in the areas of engineering, economics and finance, and operations research [Willett, 1901; Knight, 1921b; Morgan and Henrion, 1990; Bedford and Cooke, 2001a; Gray, 2006; ISO, 2009]. However, no consensus has been found as to what this difference is and how both terms are defined. Most of the definitions found in the literature are problem specific and cannot be adapted outside their originating contexts. This is particularly relevant in the areas of engineering and decision making, where a fundamentally different understanding of the two concepts can be observed in literature [Samson et al., 2009; Thunnissen, 2003].

The earliest distinction was drawn between risk as an objective and uncertainty as a subjective phenomenon [Willett, 1901; Knight, 1921c]. This general differentiation is no longer valid in the context of engineering or decision-making. For example, in the domain of risk assessment, the term has been discussed as subjective, which refers to its method of assessment [Stewart et al., 1995, pp. 267-285; Diebold et al., 1998]. Furthermore, the decision maker's attitude towards risk, i.e. if s/he is averse, neutral or seeking risk, is subjective and dependent on the person [Dickinson, 2009; Davies, 2006]. The following section presents different definitions of the relevant terminology as described in literature.

(1) Definitions of uncertainty and risk

Table 3-1 presents different definitions of the terminology of risk and uncertainty as described in literature. It is not an exhaustive list of the definitions that can be found in literature but the most common ones are summarised [Oehmen and Seering, 2011; Adams, 2010; Thompson, 2002; Ellsberg, 2001; Bell, 1982; Duncan, 1972].

Table 3-1: Definitions of *risk* and *uncertainty* as found in literature

Risk	**Uncertainty**	**Reference**
"effect of uncertainty on objectives. … An effect is a deviation from the expected - positive and/or negative. Objectives can have different aspects (such as financial, health and safety, and environmental goals)."	*"the state, even partial, of deficiency of information related to, understanding or knowledge of an event, its consequence, or likelihood."*	ISO 31000 [2009]
"a measure of the potential loss occurring due to natural or human activities" (p.1)	*"a measure of the 'goodness' of an estimate…Without such a measure, it is impossible to judge how closely the estimated value relates to or represents reality. Uncertainty arises from lack of or insufficient knowledge." (p. 197)*	Modarres [2006]
"risk is an uncertain event or condition that, if it occurs, has a positive or negative effect on project objectives." (p. 207)	*"The size and amount of contingency reserves depend on uncertainty inherent in the project. Uncertainty is reflected in the 'newness' of the project, inaccurate time and cost estimates, technical unknowns, unstable scope, and problems not anticipated." (p. 223)*	Gray [2006]

Table 3-1 (continued): Definitions of risk and uncertainty as found in literature

Risk	Uncertainty	Reference
"the possibility of loss, injury, or other adverse or unwelcome circumstance; a chance or situation involving such a possibility."	*"something not definitely known or knowable"*	Oxford Dictionary [Soanes, 2005]
"The definition of risk combines both of the above elements (i.e. hazard and uncertainty)." (p. 10)	*"is that which disappears when we become certain. We become certain of a declarative sentence when (a) truth conditions exist and (b) the conditions for the value 'true' hold." (p. 19)*	Bedford and Cooke [2001a]
"Risk involves as 'exposure to a chance of injury and loss'." (p.1)	*No definition given, but a list of examples: "uncertainty about technical, scientific, economic, and political quantities (…), about the appropriate functional form of (…) models (… 0, disagreements among experts about the value of quantities of functional form of models." (p. 39)*	Morgan and Henrion [1990]
"risk, therefore, involves both uncertainty and some kind of loss or damage that might be received."	*"you are not sure" about the exact value.*	Kaplan and Garrick [1981]
"a probability distribution over the set of states is known – or, better yet, the decision maker deems it suitable to act as if it were known" (p.277)	-	Luce and Raiffa [1957]
"We mean here risk in the sense of the worst that can happen under the given conditions." (p. 163)	*"The well known 'zone of uncertainty' (…) indicates that a broader concept of solution must be sought." (p. 35)*	von Neumann and Morgenstern [1944]
"E measures the net immediate sacrifice which should be made in the hope of obtaining (a …) good; q is the probability that this sacrifice will be made in vain; so that qE is the 'risk'." (p. 315)	*"The sense in which I am using the term is that in which the prospect of a European war is uncertain, or the price of copper and the rate of interest twenty years hence ... About these matters there is no scientific basis on which to form any calculable probability whatever. We simply do not know."*	Keynes [1921; 1937]
"It will appear that a measurable uncertainty, or 'risk' proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all." (p. 20)	*"We shall accordingly restrict the term 'uncertainty' to cases of non-quantitative type." (p. 20)*	Knight [1921c]

Some of the definitions listed in Table 3-1 are very generic [Bedford and Cooke, 2001a; von Neumann and Morgenstern, 1944] or consist of mere examples [Keynes, 1937]. There is also, as previously discussed, no clear distinction between risk and uncertainty. However, what seem to be intrinsic in most of the definitions and/or their use in literature is the inclusion of the term *impact* as discussed in the following section.

(2) Impact

Impact is the characteristic which offers a means of differentiating between risk and uncertainty. In general, when researchers describe uncertainty, they do not include the impact of the decision to be made or the problem to be assessed [Thunnissen, 2003; Bedford and Cooke, 2001b]. It describes, for example, the possible variation around an expected value, not the possible implications of this variation. The term risk usually includes the impact or outcome of the uncertain situation [Lough et al., 2009; Thunnissen, 2003; Nilsen and Aven, 2003; Bedford and Cooke, 2001a; Kaplan and Garrick, 1981].

It is usually an impact *on* something such as the impact *on* project cost, schedule and quality [Gray, 2006], the impact of additional costs *on* a project's return on investment (ROI) [Mohamed and McCowan, 2001], the impact *on* the technical performance of a system [Dezfuli, 2010], the impact *on* a company's performance [Aggarwal and Samwick, 1999; Busenitz, 1999], or the impact *on* the environment (in the ecological sense) [Sia et al., 2004]. Impact has also been described as the *exposure*, which means that a person cares whether or not their own expectation is true [Holton, 2004]. In summary, the term risk includes both the uncertainty and its impact.

The impact can be positive or negative, although the latter is more prevalent in the literature. An example of a negative impacts is the risk assessment or management such as the safety or performance analysis of a company's products or services [Lough et al., 2009; Bedford and Cooke, 2001a; Rechard, 1999; Thompson and Perry, 1992; Apostolakis, 1989; Houston, 1964]. The aim of the risk assessment is to ascertain the Probability Of Failure (POF) through a description of the natural variability of e.g. the strength of building materials such as timber and concrete [Pugsley 1966; Beck 1985; Raizer 2004]. The impact caused by uncertainty can, on the other hand, also be positive [Dawes, 1988]. For example, it can give an increased level of freedom to designers, the possibility for innovation and new ideas and the chance of (unexpected) positive outcomes [Lindemann and Lorenz, 2008; Courtney, 2001; Mavris and DeLaurentis, 2000].

(3) Definitions of risk and uncertainty used within this thesis

The definitions, which are used for this research, are as follows;

- Risk is the possible (positive or negative) effect of an uncertain event or situation [ISO, 2009].

- Uncertainty is a potential deficiency in any phase or activity of the process, which can be characterised as not definite, not known or not reliable [Soanes, 2005; Huyse and Walters, 2001].

To illustrate this difference, an example is introduced.

> **Example:**
>
> A fair coin can be expected to produce 50% heads and 50% tails when thrown multiple times but a decision maker cannot be certain about the outcome of the next throw. S/he faces uncertainty. If s/he puts a bid of e.g. £10 on the throw of tails in the next round, s/he faces a risk of losing this amount of money.

This thesis focuses on the existence of uncertainty, particularly in decision making. Thus, risk is not discussed further. Based on the definitions presented in this section and applied to this research, general attributes about uncertainty can be identified. These are listed in Section 3.1.2 in order to clarify the general meaning of the term uncertainty as discussed in this thesis.

3.1.2 Attributes of uncertainty

Uncertainty, as it is defined in this thesis, has the following three main attributes;

- ***Residual uncertainty:*** Uncertainty is what is left over after a process of information gathering and definition to separate the *"unknown from the unknowable"* [Courtney, 2001]. This means that the considered uncertainty cannot be reduced any further at the time of consideration due to for example economic constraints [Linder, 1999; Adolphy et al., 2009].

- ***Subjectivity and objectivity:*** Uncertainty can describe a subjective concept such as a decision maker's perceived level of control of a situation [Taylor and Brown, 1988; Seligman, 2006], or an objective concept such as the variation in the measurements of a physical part of a product [JCGM, 2008a]. This implies that uncertainty can exist independent from a decision maker's perception or attention to it. In other words, a situation can contain a level of uncertainty whether the person exposed to this situation is aware of this uncertainty or not. This has also been discussed as the ignorance of uncertainty [Bell, 1985; Courtney, 2001; Dewar, 2002; Ullmann, 2009] and will be discussed further in Chapter 6.

- ***Resolution over time:*** Uncertainty resolves over time [Lindemann and Lorenz, 2008] or in other words it *"is that which disappears when we become certain"* [Bedford and Cooke, 2001b]. If there is uncertainty about the occurrence of a definite event at a definite point of time, this uncertainty is resolved when this point of time has arrived. For example, the uncertainty involved in throwing a coin resolves when the coin is thrown and the outcome can be observed, the uncertainty of a machine component breaking during a production process is resolved when the production process is completed and the condition of the component can be examined.

The third attribute implies that one can avoid dealing with uncertainty simply by waiting [Courtney, 2001]. However, for specific decision problems it may not be possible or may even be detrimental to wait. Especially in business decisions, the *first-mover advantage* may dissipate with waiting too long [Courtney, 2001; Anderson et al., 2001]. In many situations, it is essential for the success of a product, project or even the whole company to deal with uncertainty and understand its possible consequences.

In order to improve the understanding of uncertainty, many modelling techniques and methods are described in literature. These are introduced in the following section.

3.1.3 Modelling techniques and methods

Various uncertainty modelling techniques exist that can be applied to different situations [Moeller and Beer, 2008; Duncan et al., 2008]. This section discusses the ones most frequently mentioned in the literature [Walley, 1991; Faucheux and Froger, 1995; Ben-Haim, 2001; Mohamed and McCowan, 2001; Nikolaidis et al., 2005; Krzykacz-Hausmann, 2006; Moeller and Beer, 2008]. These include approaches based on probability theory such as frequentist, subjective and imprecise probability, in addition to information gap theory, interval analysis, possibility theory, fuzzy set theory and evidence theory. The purpose of this section is to introduce the general concept of each of these techniques.

(1) Frequentist probability theory

Probability theory is a suitable method in situations, where aleatory uncertainty is present [Borgonovo and Peccati, 2008; Faucheux and Froger, 1995; Cornell, 1969]. Aleatory uncertainty is defined as the inherent variability of a system, such as the flow of a river during a year, or the weight of new-born infants in a specific area [Morgan and Henrion, 1990, p. 63-64; Moeller and Beer, 2008; Oberkampf et al., 2002; Bedford and Cooke, 2001b]. It is usually described in contrast to epistemic uncertainty, which is defined as the lack of knowledge about a system or the components of the process [Thunnissen, 2003; Vámos, 1990]. A more detailed discussion of these two types of uncertainty is presented in Chapter 5.

To apply frequentist probability theory, a statistically large number of sample sizes of the considered factor are tested and evaluated. The result is fitted with a Probability Density Function (PDF) that shows the frequency of occurrence of the uncertain variable over the domain of possible values [Goh et al., 2007; Moens and Vandepitte, 2004]. The most commonly used function is a Gaussian distribution [Miller, 1964]. However, other distributions are possible and can be dealt with using frequentist probability theory.

Examples for probability based modelling methods are the Monte Carlo Simulation (MCS) and Sensitivity analysis [Goh et al., 2010; García-Fernández and Garijo, 2010]. The MCS uses the law of large numbers to pseudo-randomly sample the problem of interest many times and the results are presented in a PDF. It is commonly used in areas such as business operations [Detemple and Rindisbacher, 2007], costing [Emblemsvaring, 2003], engineering [Dimov, 2008] and finances [Kaishev and Dimitrova, 2009]. Sensitivity analysis measures the relative effects of variables on the model outcome by varying their values within predetermined bounds [Christensen et al., 2005; Asiedu and Gu, 1998; Woodward, 1995]. It is used to identify the key influencing variables.

To apply frequentist probability theory, large amounts of data are typically required to derive the PDFs. This may not be available in certain situations due to economic or practical constraints [Davidson, 1991]. Most decisions, especially at the early design stages, have to be formed on the basis of a subjective assessment of the uncertainty involved [Tang 2006; Howard 1992; Kahneman et al. 1982]. Subjective probability theory is a suitable method to deal with these situations. This is discussed in the next section.

(2) Subjective probability theory

Uncertainty can be represented by a subjective judgment about the probability before/without observation of the actual occurrence of the event [Koopman, 1940]. It has also been discussed as intuitive probability [Koopman, 1940; Kraft et al., 1959; Abrahamson and Cendak, 2006]. Subjective probability is based on the same theory as frequentist probability, which defines the mathematical relationships. The major difference is that the distribution is not based on a repeated observation of an event, but on the belief or judgement of e.g. an expert [Shafer, 1994]. For example, the probability of a particular horse winning the next race cannot be sufficiently defined by the outcome of previous races, but has to be based on judgement [Anscombe and Aumann, 1963].

To prevent inconsistencies within the formulation of subjective probabilities, different approaches have been discussed in literature. The aim of these approaches is to help the expert to reason through a complex structure such as the causal relationship between various symptoms and the likelihood of a specific diagnosis of cancer [Cruz-Ramírez et al., 2007]. Amongst the most important ones are the Bayesian theory [Bayes, 1764] and Savage axioms [Savage, 1954]. These apply the theory of rational behaviour in the form of a prescriptive framework [Gilboa et al., 2009]. These rules and axioms can be utilised to construct, for example, Bayesian belief networks, which connect probability values of specific events to a mathematically consistent system [Pearl, 1988].

The subjectivity of the probability information means that it is an evaluation of one person at one point in time [Koopman, 1940]. This indicates that (i) the evaluation may differ between different points in time and (ii) it may differ between different persons [Merkle, 2010; Gilboa et al., 2009]. An example is the gambler's fallacy effect, which states that a recently occurred event is less likely to occur again in the near future [Dawes, 1988, p. 291; Parsons, 2001, p. 23]. Further criticism concerns the assumption that probabilities are never unknown, i.e. the decision maker can always form an opinion regarding a specific probabilistic value [Suppes, 1994; de Finetti, 1937]. This may not always hold true in practice, an alternative is the formulation of an inexact or imprecise probability [Suppes, 1994].

(3) Imprecise probability theory

Imprecise probability theory is applied in situations when the properties of the PDF such as the mean value cannot be observed or determined precisely [Walley, 1991; Nikolaidis et al., 2005]. As such it constitutes a more general and realistic application of probability theory [Zadeh, 2002]. It was first highlighted by Keynes [1921, Chapters 15 and 17] and has been described in the context of subjective judgement [Borel, 1962; Smith, 1961] and frequentist derivation [Huber and Strassen, 1973]. With the help of imprecise probabilities, vague statements such as *"very likely"* or *"about 0.2"* can be described and modelled [Walley, 1991, p. 216].

Within the theory, a set of underlying probability distributions is defined, which contain lower and upper probability bounds [Walley, 1991]. These can be observed in the price of an option with uncertain outcomes [de Cooman, 2005]. For example, the buying price of this option can be interpreted as the lower probability bound and the selling price as the upper bound. This means that the bounds of imprecise probabilities can (partially) be observed in the real world.

Criticism has been expressed regarding the assumption of smooth probability functions within the bounds, i.e. this modelling technique is not applicable to situations, whose information structure is not smooth [Nguyen et al., 1999]. An example was described by Zadeh [2002] as the consideration of an interval of numbers between 0 and 10, each of which can adopt a value between 0 and 1. If the average value of the interval is known, the decision maker is still unable to identify the function value at a specific point such as 3. A given average value for a reduced interval, e.g. between the numbers of 2 and 4, does still not allow the decision maker to identify the value of the point 3. In the case of non-smooth functions, the insight that the application of imprecise probability theory can offer in regard to the occurrence of a specific event is rather low unless the considered interval is 0. In other cases, the application of imprecise probability was found to be helpful to analyse and model the uncertainty inherent in a situation [Karanki et al., 2009; Jeleva and Bertrand, 2004; Ferson et al., 2003; Tucker and Ferson, 2003].

(4) Information gap theory

Information gap theory was introduced by Ben-Haim to offer an approach for robust decision making under *"severe uncertainty"* [Ben-Haim, 2001]. Its importance has been highlighted in the application to optimisation problems such as performance optimisation of uncertain loads [Ben-Haim, 2005], water resource management [Hipel and Ben-Haim, 1999], life cycle design decisions [Duncan et al., 2008] and the threat of forest destruction through fire [McCarthy and Lindenmayer, 2007]. With the help of this theory, a design can be found that offers a satisfactory level of performance and is robust to unknown influences as opposed to one that is performance-optimal but not robust to uncertain changes [Duncan et al., 2008].

The three important components of information gap theory include (i) the uncertain variable, which can be represented with an information gap, (ii) a performance model, which describes a function from the uncertain variable and design options, and (iii) a minimal performance value, which has to be considered throughout the optimisation problem [Duncan et al., 2008; Ben-Haim, 2001]. The uncertain variable can be described with a nominal value and an uncertainty interval around this value. The negative deviation from the nominal value is represented with the robustness function, the positive deviation by an opportunity function. For the robustness function, the maximum (negative) derivation from the nominal value of the uncertain variable is derived, for which the minimum performance value is still guaranteed.

Criticism of information gap theory includes the ability of the decision maker to set a minimum performance value and to adjust it in light of insights drawn from the application of this technique [Duncan et al., 2008]. Furthermore, the performance model, or in other words the mathematical connection between the uncertain variable, design options, and system performance, must be known, which may not be the case for specific situations or problems.

(5) Interval analysis

Interval analysis offers a mathematical background for situations when a specific value is not available (or not sensible to use) [Moore, 1966]. In other words, the uncertain variable x is described as a subset of all possible values it could take within an interval. The interval is the description of this variable with values including an upper and lower bound [Hansen, 1992]. Arithmetic manipulations can be applied, i.e. intervals can be, for example, added and subtracted [Moore, 1966, pp. 8-14; Nikolaidis et al., 2005, p. 9-5].

Interval analysis offers a more general framework than e.g. imprecise probabilities in the form that it is applicable to non-probabilistic information. As such, it forms the basis for many modelling approaches, particularly for computer modelling and simulation [Nikolaidis et al., 2005, p. 9-5]. It can be applied to represent the impact of rounding errors [Nakagiri and Suzuki, 1999] and to compute linear and nonlinear optimisation problems [Moore, 1979, Chapter 7]. With this technique, uncertainties such as input inaccuracies can be included in the modelling approach [Nakagiri and Suzuki, 1999].

A disadvantage of interval analysis is the possible overestimation of the interval range for a specific variable and the dependency on the mathematical expression particularly when repeated variables are used [Ferson and Hajagos, 2004; Moore, 1966]. An example is the calculation of a system output using $y=(x*x)-x$ or $y=x*(x-1)$ as described by Ugarte and Sanchez [2003]. If the input variable x can be defined in the interval [-2, 3], the output can be determined as [-9, 11] using the first equation and as [-9, 6] using the second one. However, both calculations overestimate the actual interval, which is [-1, 4.6] [Ugarte and Sanchez, 2003].

(6) Possibility theory

A possibility distribution describes the state of knowledge about the unknown and distinguishes the plausible from the less plausible, i.e. what is expected from what is surprising [Nikolaidis et al. 2005; Dubois et al. 2001; Yager 1979]. The possibility of an event is a measurement of the degree, to which the decision maker considers an event to occur and the degree, to which the available evidence does not contradict this evaluation [Nikolaidis et al., 2004]. A value between 0 and 1 is assigned to a specific event. If the possibility is suggested to be 1, there is no evidence to believe this event cannot occur; the possibility of 0 suggests the belief that the event cannot occur.

In general, it can be stated that any event, that has a probability larger than zero assigned, must have a possibility value of 1. In other words, an event that is probable also has to be possible

[Nikolaidis et al., 2004; Zimmermann, 1996]. The main difference between possibility theory and probability based approaches is that probability measures are additive whereas possibility is sub-additive [Nikolaidis et al., 2004]. In other words, the sum of the probability values connected to possible events equal one while the sum of possibility values can be larger than one.

Possibility theory can be used when there is not enough data or physical evidence to form a PDF. It has been described as a subjective approach in the choice of the possibility distribution by the designer [Walley, 1991]. Hence, an important criticism of this modelling technique is the possibility of obtaining different modelling outcomes from different designers.

(7) Fuzzy set theory

The theory of fuzzy sets was first introduced by Zadeh [1965] and emanates from the assumption that linguistic imprecision is an unavoidable aspect of communication [Morgan and Henrion, 1990; Antonsson and Otto, 1995]. It is a suitable method to describe linguistic, incomplete information in a non-probabilistic manner. Examples include expressions such as *"x is much larger than y"* or *"the cost of A should not be substantially higher than £200K"* [Bellman and Zadeh, 1970].

A fuzzy set is a class of objects with continuous grades of membership, meaning that it is characterised by a degree of membership, embodied by a membership function. The boundaries of the classes are usually not crisp, i.e. they are not clearly defined, as opposed to classical set theory [Cohen, 1966; Jech, 1978]. The degree of membership is assigned a value between zero and one, either in a subjective [Bellman and Zadeh, 1970] or an objective way [Civanlar and Trussel, 1986]. A quantity is assigned to a qualitative evaluation [Walley, 1991].

Fuzzy set theory has been applied in many domains, both in engineering and decision making [Jiang and Chen, 2005; Nikolaidis et al., 2005; Walley, 1991; Bellman and Zadeh, 1970]. However, there are shortcomings of the theory. Its aim is to model the ambiguity in ordinary language, which can also be represented using an interval statement [Walley, 1991]. Furthermore, the interpretation of the membership function is not clear [Dubois and Prade, 1989; Cooke, 2004]. In other words, the meaning of a degree of membership of e.g. 0.3 does not offer an interpretation value. It is not clear how to assess it, especially when this results from subjective assignment [Walley, 1991].

(8) Evidence theory

Evidence theory or Dempster-Shafer Theory was introduced by Dempster [1967; 1968] and Shafer [1976]. It is based on the formulation of belief functions, in other words on the decision maker's judgement about the uncertainty connected to a decision problem or a situation [Moeller and Beer, 2008; Elouedi et al., 2001]. It has been applied to areas such as Artificial Intelligence (AI) and expert systems [Beynon et al., 2000]. In particular, it has been used to model situations such as face recognition [Ip and Ng, 1994], target identification [Buede and Girardi, 1997], medical diagnosis [Yen, 1989] and plan recognition [Bauer, 1996].

In principle, a finite set of hypotheses is tested. For example, in the case of face recognition, the considered face can be compared to an existing database of different people, which offers a set of various different hypotheses [Beynon et al., 2000]. It involves two specifications of likelihood: belief and plausibility [Oberkampf and Helton, 2005]. The belief can be understood as the minimum likelihood of a specific event supporting one of the hypotheses while the plausibility is connected to the maximum likelihood that could be associated with a specific event. The difference or interval between the two can be interpreted as a value for the ignorance about the considered event. It is connected to other modelling techniques such as subjective probability because the subjectivity of the formulated belief [Walley, 1991, p. 272] or imprecise probability due to the fact that it originated from the discussion of lower and upper probabilities [Dempster, 1967]. In the special case of a difference between the belief and plausibility of an event of zero, the model offers the same result as the application of frequentist probability theory [Oberkampf and Helton, 2005].

Criticism concerning evidence theory includes the fact that it assumes the possibility of combining the information of the different sources of data through averaging the values [Oberkampf and Helton, 2005]. This means that it ignores possible inconsistencies or even conflicts between different sources of information [Agarwal et al., 2004]. Furthermore, this assumption implies that the sources of information are independent, which may not hold true [Agarwal et al., 2004].

3.1.4 Summary

In this section, various approaches to modelling uncertainty were described and discussed. However, their area of application is not clearly defined in literature. It has been shown that some of the modelling techniques have overlapping sets of assumptions and areas of application. For example, possibility theory and fuzzy set theory are closely connected. However, based on current literature, it is not clear how to find the modelling technique that is applicable and/or optimal for a specific uncertain situation. Current literature does not offer clear process to assist in the selection of suitable modelling techniques for a specific situation. For example, this research focuses on the uncertainty influencing the pricing decision at the competitive bidding stage. From literature, it is not clear, which technique should be chosen to model this uncertainty.

However, different approaches are described in literature that model the competitive bidding process. These are presented in the following section.

3.2 Modelling competitive bidding

As competitive bidding is not a fundamentally new concept, different approaches can be found in the literature, that model the available information in this process. These are described in this section and shortcomings for their applicability to the context of servitisation and competitive bidding for highly-complex services are highlighted. First, the definition of bidding strategy is introduced, particularly in comparison to business strategy. Then, existing approaches for modelling the probability of winning the contract and the probability of making a profit are outlined as these two values are to be included in the decision matrix as an outcome of this research.

3.2.1 Bidding and business strategies

A company's strategy can be defined as a pattern of activities, which impact the achievement of the individual's, organisation's or group of individuals' goals in relation to its or their environment [Håkansson and Snehota, 2006; Afuah, 2009]. A strategy can be seen as a background guide and it can be observed through the consistency of behaviour [Mintzberg et al., 2003]. Depending on the level of the goals, the strategy can be defined in different contexts, namely as business or bidding strategy. Figure 3-1 illustrates how these two are interlinked.

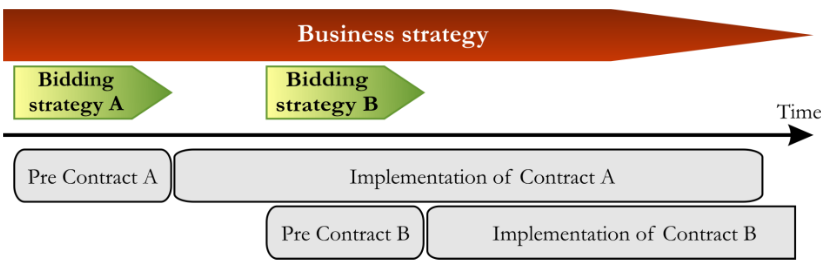


Figure 3-1: A company's business and bidding strategy

The top level depicted in Figure 3-1 is the business strategy. This can be defined as a pattern of activities, which has an impact on the achievement of business goals in relation to the environment. The business goals affect the company's overall direction and viability and can be connected to the strategic decision level described in Section 2.4.1. It defines the company's market position such as the type of product it supplies and the market share it aims for [Mintzberg et al., 2003; Arthur, 1992]. The business strategy is not only influenced by internal factors, such as the company's capabilities and limitations, but also external factors, such as the industry opportunities or political and economic conditions.

The bidding strategy occurs on a lower level, namely the contract level. It is influenced by the business strategy of the company. It can be characterised as a pattern of activities, which has an impact on the achievement of the bidding goals in relation to the environment. On this level, the bidding strategy describes one step towards achieving the business goals. Thus, it can be connected to the tactical decision level described in Section 2.4.1. The major goal of a bidding strategy is normally winning a contract that will yield a suitable profit. Other goals such as establishing a long-term relationship with customers are usually part of the business identity and, therefore, belong to the business strategy of a company [Harrington Jr., 2009; Afuah, 2009].

The presented research focuses on a company's bidding strategy as a basis for the pricing decision. Different approaches can be found in literature aiming at the provision of models of the two mentioned goals of a bidding strategy, namely winning the contract and making a profit with it. These approaches are discussed in the following sections.

3.2.2 Probability of winning a contract

The concept of modelling the probability of winning has received a lot of attention in research. Various approaches have been described in different areas including football games [Stern, 1991], horse races [Ali, 1977], combat [Brown, 1963], and contests such as tournaments or political campaigns [Skaperdas, 1996]. The approaches discussed in this section focus on modelling the probability of winning in the context of competitive bidding for service contracts.

The first approach, which highlighted the importance of the probability of winning, was described by Friedman [1956] in the context of bidding for property rights or the right to provide a service. However, this model considers the price bid as the sole decisive factor. Hence, the probability of winning the contract is the probability of submitting a lower price bid than any competitor. It is based on the assumptions that the competitors' identities, their previous price bids, and, thus, their bidding strategies in the form of a pattern of previous price bids, are known. This approach is applicable to only a few real world cases as the bidding company has to have enough information to derive a price bid pattern for each competitor [Skitmore and Pemberton, 1994]. Furthermore, it ignores the possibility that competitors may change their bidding strategy over time [King and Mercer, 1985] and that the acceptance of the bids may be based on other factors apart from the price bid. These other factors can include, for example, the service quality [Bolton et al., 2006].

Despite this criticism, various approaches can be found in literature, which are based on the model described by Friedman [Hanssmann and Rivett, 1959; Oren and Williams, 1975; Rothkopf and Harstad, 1994]. They generally loosen the assumptions and thus the amount of necessary information for the model, but still focus on the influence of competition and in particular the submitted price bids on the probability of winning. These are set in contexts such as the oil and gas industry where the product's price is subject to uncertainty [Oren and Williams, 1975] and in highly competitive service sectors with an unknown number of competitors [Hanssmann and Rivett, 1959]. All these approaches base their modelling efforts solely on the submitted price bids and allow no other uncertain influences.

In contrast, some researchers highlight the influence of other factors on the probability of winning [Simmonds, 1968; Bikhchandani, 1988; Seydel and Olson, 1990; Leopoulos and Kirytopoulos, 2004]. These can be summarised in e.g. bid valuations [McAfee and McMillan, 1987] or evaluation criteria [Wang et al., 2007]. In its simplest form, the bid valuation can be the trade-off between the price and the quality of the offered bid [Rothkopf and Harstad, 1994]. The bid evaluations can be expressed in monetary values [McAfee and McMillan, 1987] or utility values [Wang et al., 2007] and include other criteria such as the delivery date, special design features [Simmonds, 1968], reputation of contractor, financial specifications, or the location of the supplier [Ward and Chapman, 1988]. The probability of winning the contract is derived from the probability of offering the highest valuation to the customer [McAfee and McMillan, 1987; Klemperer, 1999].

One example of a model including the bid valuation in the probability of winning focuses on the competitive value of the submitted bid as described by Cagno et al. [2001]. This value is influenced by the competitors' bids, which are assumed to be random. This may, however, not be the case for specific bidding scenarios, in other words the competitors' bids may be constrainable using past information [Lin and Chen, 2004; Wang et al., 2006].

It can be summarised that many attempts have been made to depict the probability of winning a contract. Each of these approaches focuses on a specific aspect of the bidding process and the existent uncertainties. In the reviewed literature no approach was found, which lists the different uncertainties and discusses their relative influence or impact on the probability of winning the contract. Furthermore, the described approaches only give one side of the bidding process as the aim of a service contract. Within the current literature this is usually cost recovery and profit realisation [Chapman et al., 2000; Monroe, 2002]. The next section describes approaches, which model the probability of making a profit.

3.2.3 Probability of making a profit

Literature, which describes models of the probability of making a profit, is not as prolific as it is on the probability of winning although the concept of profit maximisation is implicit in many approaches [Wang et al., 2007; Klemperer, 1999; Ward and Chapman, 1988]. The approaches described in the literature focus on areas such as financial markets [Jiang et al., 2008], foreign exchange markets [Stein, 1963] or information provision and recommendation [Moreau et al., 2002].

The approach introduced by Friedman [1956] highlights that the optimum price bid also maximises the expected contribution to profit (in addition to the probability of winning as described in Section 3.2.2). The expected profit is calculated by the difference between the chosen price bid and estimated cost value with the assumption that the contract costs can be estimated accurately as a single value. This is often not the case as highlighted in Section 2.2.

The actual profit value is highly dependent on the uncertainty connected to the estimated costs [Chapman et al., 2000]. Different models can be found that focus on the realised profit value based on the costs and the connected uncertainty [Naert and Weverbergh, 1978; Skitmore and Pemberton, 1994; Albano et al., 2009]. Problems can arise from the fact that the uncertainty connected to the cost estimate of a service contract is very high in comparison to a product, and the limited amount of existing approaches for service cost estimation [Huang et al., 2009]. For these reasons, the research presented in this thesis does not include the profit value in the proposed framework for obtaining the decision matrix, but models the probability of making a profit. However, it is acknowledged that the determination of the expected profit value is also important.

In literature, the importance of modelling the probability of making a profit has been highlighted but very few approaches are available to model it. An example is the modelling of the price uncertainty connected to securities as described by Jiang et al. [2008]. Based on the present value of these securities, the probability of making a profit can be modelled relative to the one of making a loss. This is determined through the probability density function (PDF) of the security's past price values, which depicts whether the future value is more likely to be above or beneath the present value. Based on the tendency of the price value, qualitative statements can be made such as *"it is more likely to make a profit"* [Jiang et al., 2008]. A similar level of qualitative discussion regarding the probability of making a profit depending on the type of bidding process was provided by Rothkopf and Harstad [1994].

In the reviewed literature, no approaches were found that describe a model for the calculation of the probability of making a profit based on the characterisation of influencing factors and their uncertainty, even though there is a large body of research highlighting the importance of it [Wang et al., 2007; Monroe, 2002; Klemperer, 1999]. Thus, the research presented in this thesis will develop a novel approach for this purpose (see Chapter 10).

3.3 Summary and conclusions

This chapter described the state-of-the-art in the areas connected to the research presented in this thesis. In particular, literature on uncertainty and modelling of the competitive bidding process were described. The following points can be summarised;

- Current research lacks a clear process to assist in the selection of suitable techniques to model the uncertainty inherent in the bidding process. Existing approaches discuss their area of influences but lack clarity in their applicability to other situations.
- Current approaches do not offer a framework characterising the uncertainties that influence the decision maker at the bidding stage. The influence of uncertainty on the decision made at the bidding stage has been highlighted by various research approaches, which focus on different areas and contexts. However, they lack a holistic framework that depicts these uncertainties and their impacts on the decision process.
- Literature does not describe a process for including the uncertainties influencing the pricing decision at the bidding stage in a decision matrix displaying the probability of winning the contract and the probability of making a profit. The importance of these two valuations has been highlighted in literature but current research does not offer the following;
    - A quantitative approach to model the probability of making a profit.
    - An approach that depicts the trade-offs between the probability of winning the contract and the probability of making a profit.

The research described in this thesis aims at filling these gaps and as such the next chapter describes the research methodology adopted.

4 Research methodology

This chapter describes the methodology used to address the research aim. The aim of this research is to define a process for modelling the influencing uncertainties and including them in a decision matrix to support the decision maker. The presented research defines the term ***method*** as techniques or procedures for the collection and analysis of data and the term ***methodology*** as the interconnection between the applied methods in the research project [Saunders et al., 2009; Blessing and Chakrabarti, 2009; Tay and Wallis, 2000; Radner, 2000]. This chapter focuses on the research methodology, i.e. the way the different studies and methods interlink. The methods are introduced and described in more detail in the relevant chapters of this thesis. First, the research boundaries and focus are described before the objectives are outlined. Then, the research phases and approach are explained before the empirical approach is described.

4.1 Research boundaries and focus

The intention of this research is to support the cost-based pricing decision when competitively bidding for a service contract. Figure 4-1 shows the assumed pricing-decision process which is embedded in the competitive environment.

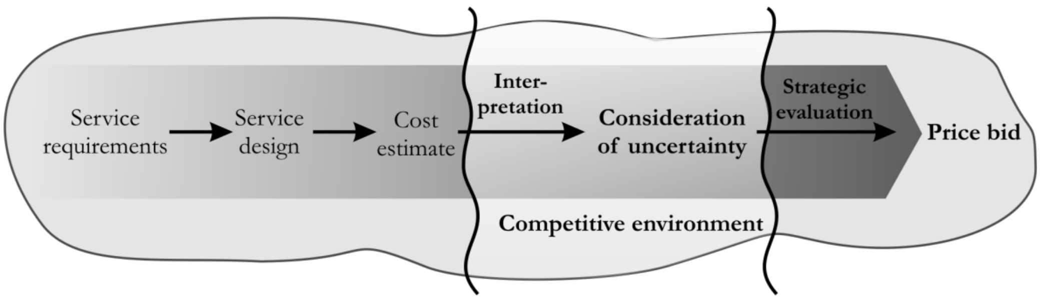


Figure 4-1: Assumed decision-making process of bidding for a service contract

For this research, the assumption was made that a service design exists and a cost estimate is available. This research assesses the decision process starting with the interpretation of the cost estimate, in other words it focuses on the use of the cost estimate in the decision-making process as depicted by the framed area in Figure 4-1. The applicability of this decision process to a pricing decision was investigated during this research and is highlighted in chapters 6, 7, 8 and 11.

4.2 Research objectives

The aim of this research is to support the pricing decision by defining a process for modelling the influencing uncertainties and including them in a decision matrix depicting the trade-off between the probability of winning the contract and the probability of making a profit. To fulfil the research aim, the following objectives were identified:

1) To define a holistic approach to characterise the uncertainty inherent in a situation as a basis for modelling.
    a) To identify a classification of the general characteristics of uncertainty.
    b) To identify suitable modelling techniques for different uncertainty characteristics.
2) To identify the uncertainties influencing the pricing decision in competitive bidding.
    a) To identify the decision maker's interpretation of uncertain costing information.
    b) To identify the influence of the competitive environment on the pricing decision.
3) To define the level of the identified uncertainties in the pricing decision process.
    a) To explore the availability of relevant information in the context of competitive bidding for a service contract on the supplier's side.
    b) To describe the subjective processes of the decision maker at the bidding stage.
4) To define a framework of the uncertainties influencing a pricing decision.
    a) To define the uncertainty characteristics influencing a pricing decision.
    b) To identify suitable techniques to model the uncertainties within the framework.
5) To create a decision matrix depicting the probability of winning the contract and the probability of making a profit for an exemplary case study.
    a) To define the logical relationships of the uncertainties to derive the probability of winning the contract and the probability of making a profit.
    b) To model the uncertainties and include the outcome in a decision matrix.

These research objectives were achieved through several research phases described in the following section.

4.3 Research phases

In literature, different approaches can be found, which describe the general course of a research project. Although they focus on different disciplines such as engineering design

[Blessing and Chakrabarti, 2009], social sciences [Robson, 2011], education [Cohen et al., 2011], business management [Saunders et al., 2009] and psychology [Shaughnessy et al., 2009], the general research process is similar and inherent in all these approaches. Accordingly, a research project typically follows three major phases [Blessing and Chakrabarti, 2009]:

- ***Descriptive Study 1 (DS-I):*** In general, in DS-I the current state of the examined situation is characterised.
- ***Prescriptive Study (PS):*** In this phase the obtained understanding of the examined situation is used to develop a support for improving the situation.
- ***Descriptive Study 2 (DS-II):*** Within the DS-II phase the developed support is investigated to detect if the desired outcome can be realised.

The research presented in this thesis was undertaken in these three main phases. The connection between the research phases and objectives presented in Section 4.2 is depicted in Figure 4-2.

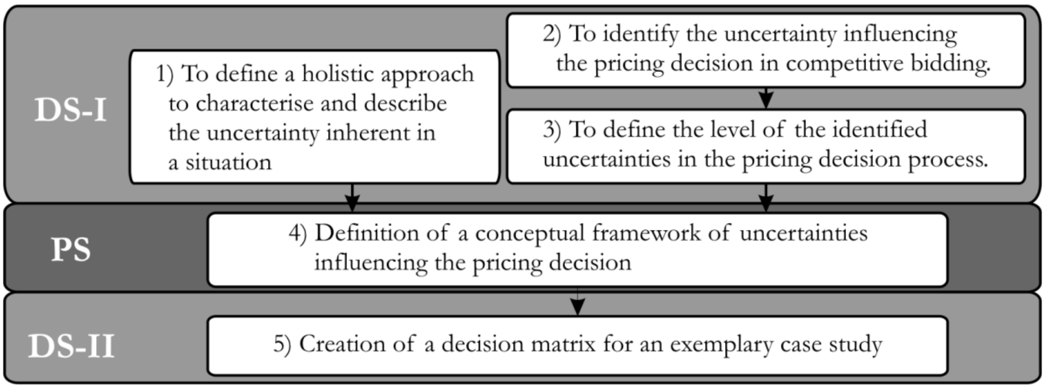


Figure 4-2: Research phases and objectives

The emphasis of the presented research is on the first descriptive study (DS-I) due to the novelty of the research in this area. This phase encompasses research objectives 1-3, namely the definition of a holistic classification for the characterisation and management of uncertainty, the identification of the uncertainty influencing a pricing decision and the characterisation of this influencing uncertainty. Based on the results, a framework was formulated which depicts the uncertainties influencing the pricing decision at the bidding stage (objective 4). This was used to identify suitable techniques to model these uncertainties in the decision matrix. This objective represents the prescriptive study (PS) of the presented research. Finally, the identified techniques were applied to create an exemplary decision matrix depicting the probability of winning the contract and the probability of making a profit for a case study, which allegorises the second descriptive study (DS-II).

4.4 Research approach

In general, the research approach can adopt the form of deductive or inductive research [Saunders et al., 2009]. This is depicted in Figure 4-3. Deductive research is concerned with the testing of a theory with the help of an operational hypothesis and examination resulting in a confirmation or a rejection/modification of the hypothesis [Robson, 2011]. Inductive research is defined as building a theory which usually occurs through the examination of a real world situation, the finding of a pattern in the collected data and formulation of a hypothesis and development of a theory from this examination [Easterby-Smith et al., 2008].

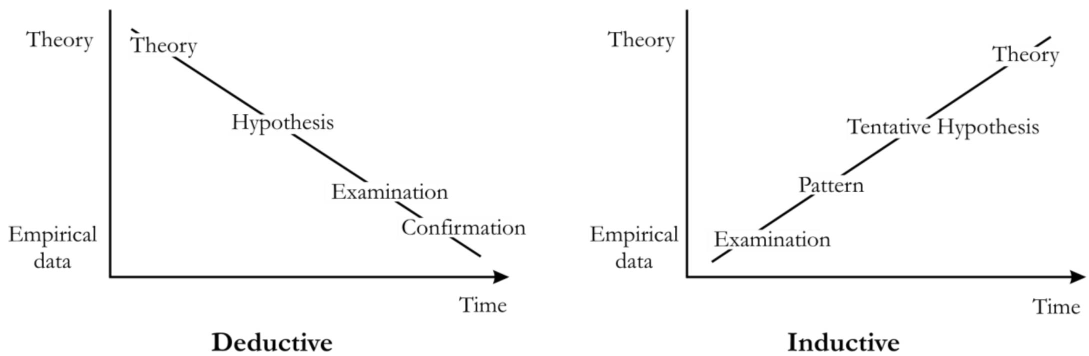


Figure 4-3: Deductive and inductive research

The research presented in this thesis constitutes an inductive approach. As such, empirical research was undertaken to examine the current situation in competitive bidding and identify the uncertainties influencing the pricing decision at the competitive bidding stage. The following section describes the methodology of the empirical research.

4.5 Empirical research

To identify and characterise the uncertainty influencing the pricing decision in competitive bidding, empirical research was undertaken. Different methods were considered suitable to investigate this area such as an observation study [Robson, 2011; Saunders et al., 2009]. An observation study offers the possibility to watch the decision makers in their usual working environment to obtain what they do, which usually includes recording of their actions. This offers the advantage of a direct analysis of the decision maker's actions without post rationalisation. However, due to the commercial sensitivity of this research, it was found to be very difficult to find industrial partners who would agree to have their process of compiling a competitive bid recorded and analysed. In addition, an observation study does not offer the possibility of investigating the decision maker's thought processes, i.e. the reasoning behind their actions.

Thus, to investigate the uncertainties influencing the pricing decision at the competitive bidding stage, the decision-making process was separated into three parts, namely the decision maker's interpretation of the cost estimate, the influence of competition and the further consideration of uncertainty (see also Figure 4-1). This allowed the conduction of three separate studies with specific focuses, each of which could be supported by research findings in the specific area. Table 4-1 depicts the focus of the three empirical studies and the theoretic research background in connection to the three parts of the decision-making process.

Table 4-1: Focus of three empirical studies

Step in decision-making process	Interpretation of cost estimate	Influence of competition	Consideration of uncertainty
Study focus	Approach to displaying uncertain costing information for further consideration of the uncertainty in the decision-making process.	Difference between the decision-making processes with and without the existence of competition and induction of decision maker's level of rationality.	Investigation of the main uncertain influences that are considered in the decision-making process and the amount of available information about them.
Theoretical background	Perception and interpretation of uncertain information in decision making.	Rationality in decision making under the existence of uncertainty.	Bidding for contracts

To investigate the decision maker's interpretation of the cost estimate, the first study focus was set on the influence of different approaches to displaying information on the decision maker's consideration of the connected uncertainty. The literature associated to this study concentrated on the perception and interpretation of uncertain information.

To explore the influence of the existence of competition on the decision outcome, the focus of the second study was on the decision-making process with and without the existence of competition. This was used to induce the decision maker's level of rationality at the competitive bidding stage, which could be used to predict the actions of decision makers for future bidding scenarios. Thus, this study was connected to literature in the area of rationality under uncertainty.

To examine the further consideration of uncertainty, the third study investigated the main uncertain influences which are typically considered in the decision-making process and the level of information available about these influences. Thus, the literature connected to this study focused on bidding for contracts, giving insights into typical decision contexts and conditions.

The following three sections describe the methods that were chosen to investigate the three steps of the decision-making process.

4.5.1 Experimental study 1 – Information display for decisions under uncertainty

The first experimental study aimed to achieve objective 2a "To identify the decision maker's interpretation of uncertain costing information". Presenting information in a graphical display can result in an improved understanding compared with using only textual or tabular information [Speier, 2006; Speier and Morris, 2003; Tufte, 2001; Dickson et al., 1986; Harvey, 2001]. In the light of these literature findings, the first experimental study focused on analysing people's propensity to consider uncertainty as a result of seeing different graphical displays. The study aimed at the identification of the most appropriate way of displaying the uncertainty involved in a forecasting problem. This included the identification of;

- The type of graphical display required to assist the decision maker in considering uncertainty.
- The amount of contextual information necessary to communicate uncertainty.

To investigate these points, the first experimental study was undertaken in the form of questionnaires which included a set of questions presented in a predetermined order [Saunders et al., 2009]. Questionnaires were utilised because they require a minimal level of interaction between the researcher and the participant. This minimises the influence of bias and preconception, offers the ability to determine the participants' attitudes and beliefs, and enables a comparison between the different attitudes and responses to gain insights into the importance of influences [Teddlie and Tashakkori, 2009; Saunders et al., 2009]. Questionnaires have been applied successfully to study the customer's perception of a product to obtain their level of satisfaction [Cardozo, 1965], to evaluate the effectiveness of the Delphi method for group decision making [Dalkey, 1969], to assess the influence of uncertainty on a person's commitment and trust of trading partners [Kollock, 1994], and to examine the influences on the response rate and quality of internet-based surveys [Deutskens et al., 2004].

Thus, an experimental study with questionnaires was used to investigate the influence of the approach to displaying uncertain costing information on the decision maker's perception of this uncertainty. The procedure of the first experimental study is described in more detail in Chapter 6.

4.5.2 Experimental study 2 – Competition in bidding

The second experimental study was aimed at achieving objective 2b "To identify the influence of the competitive environment on the pricing decision". This consisted of the following;

- The way the stated price bid changes with the existence of competition.
- The decision maker's perception of uncertainty connected to competition.
- An induction of the decision maker's rationality facing a competitive bidding situation.

The results of the first experimental study formed the basis, and were utilised in the construction of this study. The second experimental study was also undertaken with questionnaires for the same reasons as presented in Section 4.5.1. A detailed description of the experiment procedure of the second study is presented in Chapter 7.

4.5.3 Interview study - Information availability at bidding stage

The third empirical study encompasses objective 3 "To define the level of the identified uncertainties in the pricing decision process". This objective includes the evaluation of the following;

- To explore the availability of relevant information in the context of competitive bidding for a service contract on the supplier's side.
- To describe the subjective processes of the decision maker at the bidding stage.

As the answers may vary between companies and between service contracts, a solely qualitative method was applied (as opposed to the previous two empirical studies where the questionnaires were a mixture of both quantitative and qualitative data collection method) [Teddlie and Tashakkori, 2009]. Interviews were considered a suitable method to examine objective 3 as they offer not just a basis for discussion of particular aspects of the decision process but are also a flexible and adaptable way of revealing strategic information [Robson, 2002]. This includes the possibility that interviewees can ask for more information regarding a question. Interviews have been applied to assess the reasoning of decision makers in the areas of price stickiness during business cycles [Blinder, 1991], of authors of academic papers to adopt specific citations in their papers [Harwood, 2008], of professionals in the area of human-computer interaction concerning effective user modelling practice [Clemmensen, 2004], and of cancer patients' behaviour on seeking information in different stages of their illness [Leydon et al., 2000]. In summary, interview studies have been applied to research projects investigating decision makers' logical approaches to making their decision. Thus, it is a suitable method for the described aim of this empirical study.

A more detailed discussion of the method of the interview study can be found in Chapter 8. The next section summarises the empirical research.

4.5.4 Empirical research methodology

To fulfil the research aim, the influencing uncertainties on a pricing decision have to be identified and their importance in the decision-making process defined (objectives 2 and 3). To complete these objectives, the decision-making process (see Figure 4-1) was examined from different perspectives. This allowed examining the focus of this research, interpretation of the cost estimate, influence of the competitive environment and consideration of uncertainty, in more detail to answer objectives 2 and 3. Combined, they offer an integrated picture of the uncertainty in the researched context. The three empirical studies relate to objectives 2 and 3 as depicted in Figure 4-4. The applied method and procedure is discussed in Chapters 6-8.

Title		**Research objective**	
Information Display for Decisions under Uncertainty	**Phase 1**	**2: To identify the uncertainty influencing the pricing decision in competitive bidding**	a) To identify the decision maker's interpretation of uncertain costing information. - Type of graphical display required - Amount of contextual information necessary
Competition in Bidding	**Phase 2**		b) To identify the influence of the competitive environment on the pricing decision. - Change of the stated price bid - Induction of decision maker's perception of uncertainty - Induction of rationality of decision maker
Information availability at the bidding stage	**Phase 3**	**3: To define the level of the identified uncertainties in the pricing decision process.** a) To explore the availability of relevant information in the context of competitive bidding for a service contract on the supplier's side. b) To describe the subjective processes of the decision maker at the bidding stage.	

Figure 4-4: Three phases of empirical research

4.6 Research plan

Based on the research objectives and empirical research methodology described in this chapter, a research plan was established. Table 4-2 depicts the detailed objectives, adopted research method and the chapter where they are described in more detail.

Table 4-2: Research objectives and the methodology of addressing them

Research objective		Method	Chapter
1) To define a ***holistic*** approach to ***characterise*** and describe the ***uncertainty*** inherent in a situation as a basis for modelling.	a) To identify a classification of the general characteristics of uncertainty.	***Literature study*** of uncertainty research.	5
	b) To identify suitable modelling techniques for different uncertainty characteristics.	***Literature study*** of applications of uncertainty modelling techniques.	
2) To ***identify*** the ***uncertainty influencing*** the ***pricing decision*** in competitive bidding.	a) To identify the decision maker's interpretation of uncertain costing information.	***Study 1*** – Experimental survey of practitioners	6
	b) To identify the influence of the competitive environment on the pricing decision	***Study 2*** - Experimental survey of practitioners	7
3) To define the ***level*** of the ***identified uncertainties*** in the pricing decision process.	a) To explore the availability of relevant information in the context of competitive bidding for a service.	***Study 3*** – Interview study with practitioners	8
	b) To describe the subjective processes of the decision maker at the bidding stage.		
4) To define a ***framework*** of the uncertainties influencing a pricing decision.	a) To define the uncertainty characteristics influencing a pricing decision.	***Induction*** from objectives 1a, 2 and 3.	9
	b) To identify suitable techniques to model the uncertainties within the framework.	***Comparison*** of identified uncertainty characteristics (4a) to literature (1b).	
5) To create a ***decision matrix*** depicting the probability of winning the contract and the probability of making a profit for an exemplary case study.	a) To define the logical and mathematical relationships of the uncertainties to derive the probability of winning the contract and the probability of making a profit.	***Case study data*** in contract bidding and ***literature study*** of identified modelling techniques (4b).	10
	b) To validate the model of uncertainties and include the outcome in a decision matrix.	***Case study*** in contract bidding.	

Objective 1 was achieved by a literature study of current approaches in uncertainty research and applications of the uncertainty modelling techniques described in Chapter 3. Chapter 5 focuses on objective 1 and underpins the research presented in this thesis.

5 Characterisation of uncertainty

Research on uncertainty has been growing over the past decades and a vast number of publications can be found that describe different aspects of the topic in different domains and with varying scopes (see also Section 3.1). Furthermore, a large amount of techniques to model uncertainty have been developed; a selection of which was presented in Section 3.1.3. However, from literature, it is not clear, which modelling technique should be used when facing a particular uncertain situation or when a decision under uncertainty has to be made. The approaches described in the literature are typically presented for specific contexts and lack a clear method for their applicability to other situations. Fundamentally, the characteristics of uncertainty need to be described in order to identify the most suitable modelling technique to apply to a situation.

This chapter proposes a holistic approach to characterise the uncertainty inherent in a situation (objective 1 as described in Section 4.2). The method of inducing the holistic approach is presented, which formed the basis for the proposed classification of uncertainty characteristics. This classification is utilised throughout the research presented in this thesis.

5.1 Method

The presented classification is based on literature in the area of uncertainty research, particularly on uncertainty modelling across different domains such as engineering, design, metrology, economics and management. Analysing this literature offered insights into the similarities and differences between the approaches used within the field. The analysis resulted in the view that a holistic approach of characterising uncertainty required layers to offer a comprehensive and cross-sectorial classification. For example, the approaches found in literature differentiate between quantitative and qualitative uncertainty [Van der Sluijs et al., 2005], aleatory and epistemic uncertainty [Moeller and Beer, 2008], or exogenous and endogenous uncertainty [de Weck et al., 2007].

The concept of uncertainty layers was confirmed by the research approach presented by e.g. Walker et al. [2003] who describe the layers as the three dimensions of uncertainty. Their approach focuses on the model view of uncertainty and risk management for the support of strategic decisions such as company policies. It was based on the *precautionary principle* postulated by the European Environment Agency [Harremoës et al., 2001], which was aimed at the inclusion of uncertainty into the political agenda of the European Union particularly where decisions can potentially generate harm [Walker et al., 2003]. For example, the decision of British fisheries to fish herrings using trawls was found to harm other species [Harremoës et al., 2001].

The key points of the precautionary principle were the required level of certainty or uncertainty to make a decision of curtailing or banning potentially harmful activities and the organisation that should have the responsibility of proof and carrying the risk of a possible wrong decision. The approach presented by Walker et al. [2003] was aimed at offering a framework for the systematic support of these strategic decisions. Thus, the three dimensions described by the authors are the nature, level and location of uncertainty. In the approach described by Walker et al. [2003], the nature distinguishes the type of uncertainty, in other words if it is the inherent variability (aleatory uncertainty) or a general lack of knowledge (epistemic uncertainty). For example, the physical dimensions of a particular product may vary due to inaccuracies of the manufacturing process (aleatory) or because their values have not yet been specified in the product design (epistemic). The levels express the severity of the considered uncertainty, i.e. the amount of available information and the amount of missing information for a certain description of the situation [Courtney, 2001]. The location establishes where the uncertainty is revealed in the process, which can be used to establish whose responsibility the proof and the risk of a possible wrong decision is [Walker et al., 2003].

The advantages of this approach include that it established a generic terminology and typology for uncertainty research, which means that it can be used to characterise uncertainty. However it misses aspects that are important to characterising an uncertain situation holistically. The causes and the expression of uncertainty are important additional layers for identifying suitable modelling techniques, to prevent inappropriate decisions and insufficiently or excessively conservative analyses [Van der Sluijs et al., 2005; Helton et al., 2000, p. 159]. The causes define the source or reason of the uncertainty [García-Fernández and Garijo, 2010]. The expression classifies the way the uncertainty is communicated or articulated, either quantitatively or qualitatively [Van der Sluijs et al., 2005].

The approach presented by Walker et al. [2003] was enhanced into the holistic classification proposed in this chapter. The three dimensions of the nature, level and location of uncertainty are adapted; however, the used terminology was altered. The term of the *location* of uncertainty was changed into *manifestation* because the term used by Walker et al. [2003] indicates more of a physical meaning rather than the point within the process. In addition, two further layers describing the cause and expression of uncertainty are included. Following this identification method, a holistic approach for characterising uncertainty in five layers is adopted in this research: the nature, cause, level, manifestation and expression of uncertainty. These are explained in detail in the following section.

5.2 Uncertainty classification

This section introduces the approach, which describes the characteristics of uncertainty as layers, namely;

- Nature: whether the uncertainty is due to a lack of knowledge or inherent variability.
- Cause: the reason or source of the uncertainty.
- Level: the severity of the considered uncertainty.
- Manifestation: the location in a process where the uncertainty occurs.
- Expression: the way the uncertainty is communicated or articulated.

The following sections describe each of these five layers in detail and positions existing concepts and approaches from literature within them to illustrate the holistic approach.

5.2.1 Nature of uncertainty

Uncertainty can be classified according to its nature or type [Van der Sluijs et al., 2005; Thunnissen, 2003; Walker et al., 2003]. In general, two categories describing the nature of uncertainty can be distinguished: aleatory and epistemic. This classification has been described in most of the reviewed literature [Krzykacz-Hausmann, 2006; Oberkampf et al., 2002; Thunnissen, 2003]. Table 5-1 describes both categories with definitions and the sources of literature.

In this research, aleatory uncertainty describes physical systems or environments where the exact value varies by chance from unit to unit or time to time [Hazelrigg, 1996]. Epistemic uncertainty describes the fact that there may be a lack of knowledge about a system or the components of the process [Thunnissen, 2003; Vámos, 1990]. In this context, the term knowledge refers to an individual's understanding, assimilation and application of information [Nonaka and Takeuchi, 1995; Conway et al., 2007]. Information is a collection of measures or inferences of a certain quantity or quality, which can be communicated through different channels, such as speech, body language, reports, and drawings [Conway et al., 2007]. To create knowledge, the given information is combined with the existing one (such as experience) in order to use it effectively [Simon, 1954].

Table 5-1: Nature of Uncertainty

	Definitions	**Reference**
Aleatory	*"inherent randomness describes quantities that vary over time and space such as the flow of a river during a year or the weight of new-born infants in a specific area"*	Morgan and Henrion [1990, p. 63-64]
	Ontological uncertainty is "that which is uncertain by its nature (e.g. in quantum physics)"	Vámos [1990]
	"arises through natural variability in a system"	Bedford and Cooke [2001b]
	"fluctuations that are intrinsic to the problem being studied"	Wojtkiewicz et al. [2001]
	"inherent variation associated with the physical systems or the environment under consideration"	Oberkampf et al. [2002]
	"inherent variation associated with a physical system or environment under consideration"	Thunnissen [2003]
	"(or random variability) dimension describes the uncertainty about the precise value that the variable will take"	Pons and Raine [2004]
	"irreducible uncertainty (… is) a property of the system associated with fluctuations/variability"	Moeller and Beer [2008]
Epistemic	*"that which is uncertain because of our limited knowledge"*	Vámos [1990]
	"arises through lack of knowledge of a system"	Bedford and Cooke [2001b]
	"lack of information about some aspect of the problem being considered"	Wojtkiewicz et al. [2001]
	"lack of knowledge of the system or the environment".	Oberkampf et al. [2002]
	"lack of knowledge or information in any phase or activity of the modeling process"	Thunnissen [2003]
	"the degree to which the body of knowledge can adequately predict system behaviour from input variables"	Pons and Raine [2004]
	"reducible uncertainty (… is) a property of the analysts associated with a lack of knowledge"	Moeller and Beer [2008]

The following example characterises the difference between the two natures of uncertainty.

Example:

One person knows that there are red and black balls in an urn but has no information about the number of each. A second person knows there are three red and one black ball. In this example, the probability is 75-25 of picking the right ball; both persons face aleatory uncertainty. However, the first person perceives the probability to be 50-50. S/he faces additional epistemic uncertainty about the actual outcome, because of the lack of knowledge about the number of each ball.

Epistemic uncertainty has been described as reducible in its character [Bedford and Cooke, 2001b]. This means that in theory it is possible to obtain complete knowledge about a system or a process and, therefore, completely eliminate this type of uncertainty. In the urn example, the first person may just be told what the actual probabilities are. However, in practice, epistemic uncertainty may prove itself irreducible [Walker et al., 2003; Morgan and Henrion, 1990]. Even with the collection of further information to a theoretically "complete" knowledge about the system, some situations may still not be completely predictable.

The reason for this can be indeterminacy or the inability to define the cause-effect relationships exactly. This can exist in the form of radical or time indeterminacies [O'Connor, 1990; 1994]. Radical or ontological indeterminacy means that it is impossible, even in theory, to have a complete and correct description of the current state of the world [Faucheux and Froger, 1995]. One example is the butterfly effect, which states that a butterfly flapping its wings can cause a hurricane [Karkuszewski et al., 2002]. Time indeterminacy describes the unpredictability of the future [O'Connor 1994; Zotteri and Kalchschmidt 2007; Armstrong 2001]. For example, a company may have sufficient information about the past behaviour of a system; however, it remains uncertain whether this system will behave the same in the future.

5.2.2 Causes of uncertainty

The second layer of uncertainty is the cause [García-Fernández and Garijo, 2010]. In this research, the terms *cause*, *source* and *reason* are used interchangeably. Different causes can exist in parallel, in other words the uncertainty of a situation can happen due to more than one cause. This can add further complexity to the process; however, this is outside of the focus of this research. The reader is referred to other literature which discuss uncertainty in relation to complexity such as Earl et al. [2005], Dequech [2001] or Faucheux and Froger [1995].

The causes of uncertainty may be the most studied layer due to its importance in uncertainty research. References define the causes from three main viewpoints: lack of understanding [Thunnissen, 2003; Oberkampf et al., 1999; Brehmer, 1992], ambiguity [Ghirardato et al., 2008; Ellsberg, 2001; Dequech, 2000], and human behaviour [Morone and Morone, 2008; Bedford and Cooke, 2001b; Kotler, 1997]. The literature in each of the streams was analysed to derive the classification of the causes of uncertainty as presented in Figure 5-1.

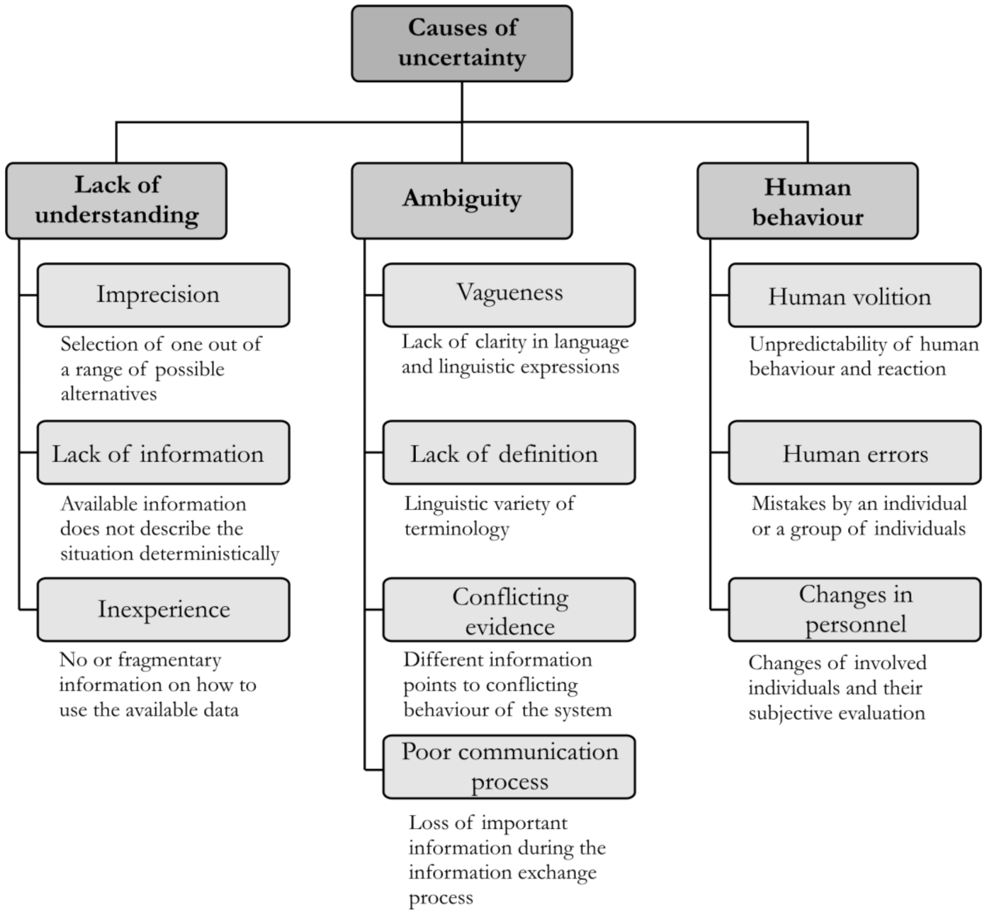


Figure 5-1: Classification of the causes of uncertainty in decision making

(1) Lack of understanding

One of the main causes of uncertainty has been described as the lack of understanding of a situation, process or phenomenon [Huyse and Walters, 2001; Yen and Tung, 1993; Booker, 2004; McMahon and Busby, 2005]. It may be due to the limited capability of the human mind to understand the complexity of systems such as the world even in a rudimentary way [Brehmer, 1992]. Many research papers apply the term *lack of knowledge* to both the cause for uncertainty and the epistemic nature of uncertainty and use the terms interchangeably [Farhangmehr and Tumer, 2009]. However, there is a difference between these two aspects. To distinguish this difference, the term *lack of understanding* is used to describe the cause and *lack of knowledge* refers to the epistemic nature of uncertainty. From the reviewed literature, three different reasons resulting in a lack of understanding were identified: imprecision, lack of information and inexperience.

Imprecision describes the situation before a decision about possible alternatives is made [Goh et al., 2010; Antonsson and Otto, 1995; Wood et al., 1990a]. Thus, there is a lack of understanding about which one of the alternatives will be implemented. This concept has also been discussed as decision uncertainty [Farhangmehr and Tumer, 2009] or design uncertainty

[Thunnissen, 2003]. It concerns for example specifications about the design of a new product [Pons and Raine, 2004; Lough et al., 2009]. It is known that the decision will have to be made in the process, but it has not yet been made.

A ***lack of information*** exists when the necessary information is not available for any reason [Zimmermann, 2000; Walley, 1991, p. 213; Galbraith, 1977]. This term includes both the possible absence of available information and the situation when the available information does not describe the decision problem deterministically [Earl et al., 2005]. For example, a decision maker may not have any information about the influences on the outcome of the decision [Abdellaoui and Hey, 2008].

Inexperience is referred to when the use or meaning of the available information is not evident or distinct given the knowledge state. It has also been described as e.g. lack of introspection [Walley, 1991, p.215]. It can be connected to organisational inexperience, for example, when a company aims at entering a new market segment [Podolny, 1994; Chen et al., 2005] or when a new product is launched or new technology introduced [Hihn and Habib-Agahi, 1991; Kota and Chakrabarti, 2009]. It can also be connected to personal inexperience, for example, when a decision maker does not know how to interpret specific costing information.

(2) Ambiguity

Uncertainty can also be caused by ambiguity [Stacey and Eckert, 2003]. This is connected to the situation when the available information or problem description does not give a consistent or coherent picture [Ellsberg, 2001; Schrader et al., 1993]. From literature, four different causes of ambiguity were identified: vagueness, lack of definition, conflicting evidence and poor communication process.

The ***vagueness*** describes the lack of clarity inherent in a language or in the use of linguistic expressions [Ellsberg, 2001; Klir and Folger, 1998; Lawrence and Lorsch, 1967]. The available information does not give a clear picture of the situation. For example, the requirements of a new product being specified by the customer may leave room for interpretation [Booker, 2004; Stacey and Eckert, 2003; Whiting et al., 1999]. If the customer says they want the product to be *red*, this can be interpreted in multiple different ways as a colour code. It is a typical aspect of expressing subjective likelihoods or impressions such as *"quite likely"* or *"highly improbable"* [Morgan and Henrion, 1990, pp. 60-62]. It can be connected to the state of the project in time when there is not yet enough information to clarify the alternatives.

The ***lack of definition*** can have a linguistic and a non-linguistic implication. It can describe the fact that certain linguistic expressions have entirely different meanings [Vámos, 1990]. It can be characterised by a one-to-many relationship of terminology, i.e. one term can be interpreted by two or more different meanings [Thunnissen, 2003]. For example, different researchers use definitions for terms whose intended meanings might not be familiar to everybody involved in the communication process. On the other hand, there may also be a non-linguistic lack of definition such as the product requirements at the "fuzzy front end", i.e. the period between the first consideration of a design opportunity and the readiness of this idea for development [Kim and Wilemon, 2002]. At this stage, the lack of definition of, for example, the physical product dimensions can cause uncertainty [Herstatt et al., 2004].

Ambiguity can also be caused by ***conflicting evidence***, which describes the fact that different sources of information can point to conflicting behaviour of a system [Thunnissen, 2003; Bomberger, 1996; Walley, 1991, p. 213]. It has also been discussed as confusion, contradictory assignments [Ayyub, 2004] or abundance of information [Zimmermann, 2000]. Conflicting evidence can appear especially in situations when the available information is subjective. Different experts may look at the same problem or scientific evidence from different viewpoints and, therefore, differ in their opinion or advice [Van der Sluijs et al., 2005]. A common approach to deal with this is to combine the opinions with different weightings or levels of importance [Morgan and Henrion, 1990, pp. 64-67]. However, this method can introduce new uncertainty to the model as a change of weighting may result in a different outcome and point toward a different course of action.

Communication has been reported as the key factor to the success of projects, with a good communication process having an impact on the success and a ***poor communication process*** on the failure of a project [Dyer, 2006]. A poor communication process can be characterised by the loss of important information, which leads to misunderstanding during the process of exchanging information [Farhangmehr and Tumer, 2009]. It can be connected e.g. to the use of inadequate representations, which means that the information does not get understood correctly [Stacey and Eckert, 2003].

(3) Human behaviour

Uncertainty caused by human behaviour is associated with the behaviour of an individual within the process, team or organisation [Thunnissen, 2003]. It has also been discussed as, for example, behavioural uncertainty [Weed and Mitchell, 1980; Kotler, 1997; Morone and Morone, 2008]. Particularly in the context of decision making, humans form an important uncertainty factor when modelling the decision process and predicting the decision outcome

[Simon, 1982; Sent, 2004]. It can be connected to human volition, human errors and changes in personnel.

Human volition causes uncertainty about decisions that can be made by individuals during different stages of the considered process [Bedford and Cooke, 2001a]. It arises from the fact that people's actions cannot entirely be predicted [Sent, 2004; Radner, 2000; Rubinstein, 1998]. Uncertainty caused by human volition can be connected to factors such as motivation [Eyring, 1966], the subjective perception of a situation [Collier et al., 2004], and the individual's personality [Bergman, 2000]. For example, the outcome of a forecasting process can depend on the judgement of the forecaster and his/her perception of the situation [Goodwin, 2002]. In this context, factors such as optimism [Seligman, 2006], regret [Connolly and Zeelenberg, 2002] or risk aversion [Agrawal and Seshadri, 2000] have been discussed.

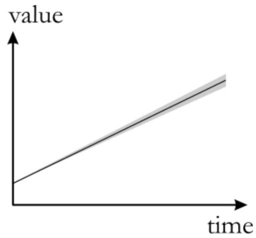
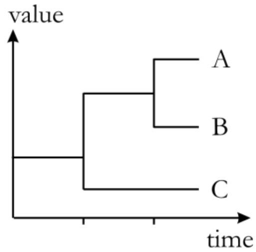
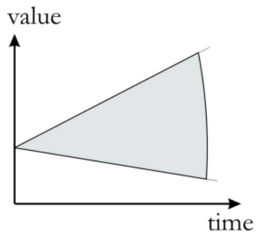
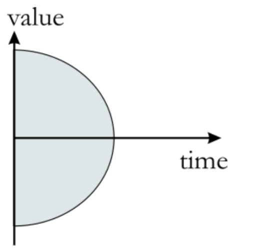
Human errors or individual's mistakes are another reason for uncertainty connected to human behaviour [Moeller and Beer, 2008; Nikolaidis et al., 2005, p. 8-10]. These usually occur unwittingly [Melchers, 1999, p. 41] but can be acknowledged or unacknowledged by the analyst [Oberkampf et al., 2002]. Human errors are a potential factor in any process where humans are involved. They are hard to predict but can be reduced with e.g. education, a reduction in task complexity or control measures such as inspections.

Changes in personnel describe possible modifications in the decision environment, for example, on the organisational or the individuals' level. The uncertainty can result from the changes of, for example, the belief in areas where only subjective judgement is possible [Farhangmehr and Tumer, 2009], a change in the level of trust given to a new team member [Costa, 2003; Hayes, 2010], or the loss of core knowledge or expertise in a specific business area [Aubert et al., 1998; Wüllenweber et al., 2008]. It is most important in parts of the process where the outcome is highly dependent on the individual(s) involved, such as the production of the cost forecast as input information for the decision process. It is a very important factor in the context of services as the perception of the final service quality also depends on the individual performing the service [Grönroos, 1983; 1984; Parasuraman et al., 1991; Bolton et al., 2006; Chuang, 2010].

5.2.3 Level of uncertainty

Uncertainty can exist with different levels of severity [Goh et al., 2007; Schlesinger, 1996]. For example, predicting the outcome of a throw of dice may contain less uncertainty than predicting the future costs of a product. Four different levels of uncertainty have been distinguished [Courtney, 2001]. Table 5-2 describes these four levels of uncertainty and depicts the outcome of a situation under the different levels over time in a graphical form as adapted from Courtney [2001]. The vertical axis labelled with *value* describes the possible outcomes of the factor under consideration in the future.

Table 5-2: Levels of uncertainty

Level	**Description**	**Interpretation**
Level 1 Deterministic	The future is sufficiently clear so that the outcome is predictable enough for a confident decision. This can usually be observed in information-rich and slow-moving environments such as stable and mature markets.	
Level 2 Set	A set of possible future outcomes can be distinguished, one of them will occur. The decision maker has a chance of being right. Further analysis cannot tell which outcome it is going to be and is dependent upon other factors.	
Level 3 Interval	A range of possible future outcomes may occur, i.e. the outcome can be bound between a maximum and a minimum value. It is, however, not possible to retrieve a point forecast, any point in the range is possible. This level of uncertainty is especially observable with new technologies or under unstable macroeconomic conditions [Courtney, 2001].	
Level 4 Ignorance	The highest level of uncertainty is characterised by total ignorance [Walker et al., 2003; Ayyub, 2004]. The future outcomes can be described as unknown and unknowable. This is usually the case for very long timeframes or situations in major economic or social discontinuity.	

The perception of the level of uncertainty is highly subjective, especially in a situation that is influenced by future developments [Mowrer, 2000]. The spectrum can range from ignorance, when there is nothing known about a situation, to deterministic where the outcome is known or predictable enough [Walker et al., 2003; Faucheux and Froger, 1995]. In level-1 uncertainty - deterministic, aleatory uncertainty can still be present as it is not reducible [Bedford and Cooke, 2001b; Oberkampf et al., 2002; Samson et al., 2009]. In other words, the collection of e.g. more information will not reduce the existence of statistical variation in the outcome of situations where aleatory uncertainty is present.

These levels of uncertainty are usually connected to the level of knowledge about the situation and its influences. The connection between the amount of knowledge and the level of uncertainty is depicted in the uncertainty cone in Figure 5-2.

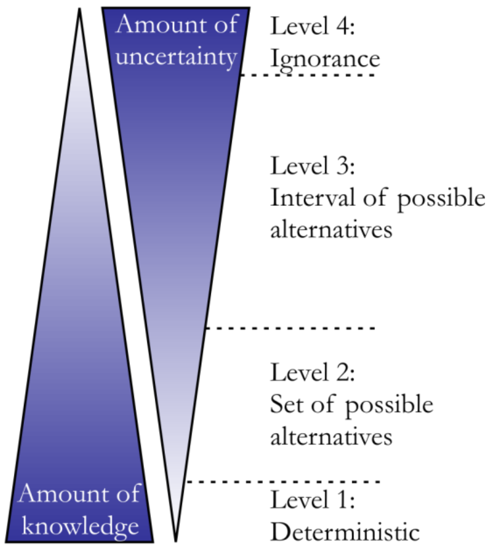


Figure 5-2: Knowledge and uncertainty cone

In general, it can be said that the less is known about a problem or a situation, the more uncertainty there is or in other words, the higher the level of existing uncertainty [Samson et al., 2009; Abdellaoui and Hey, 2008; Oberkampf et al., 2002; Faucheux and Froger, 1995]. For example, in the early design stages when the future product or service is not yet defined and only exist as an idea [Lindemann and Lorenz, 2008].

5.2.4 Manifestation of uncertainty

The manifestation of uncertainty, which was named by Walker et al. [2003] as location, describes where in the process the uncertainty occurs. In this classification the term *manifestation* was selected as *location* includes more of a physical meaning.

Literature describing the complete range of uncertainty manifestation is scarce. This issue has been mentioned in the domain of verification and validation (V&V) where the accuracy of simulations and models is assessed [Oberkampf and Trucano, 2002; Du and Chen, 2000; Isukapalli, 1999]. Verification means the correct solving of the (model) equations, while validation is the solving of the right equations [Goh, 2005, p. 2-19]. V&V is concerned with the full process including the different manifestations; however, the defined schemes are so demanding that only a few approaches would be able to fulfil them [Refsgaard and Henriksen, 2004]. Hence, literature is missing approaches that describe the full process, i.e. the connections between the different manifestations.

However, various approaches can be found that focus on the different steps of the process. These approaches describe the following manifestations: context, input information (or data), model and outcome. These points in the process are connected to context uncertainty, data uncertainty, model uncertainty and phenomenological uncertainty respectively as depicted in Figure 5-3.

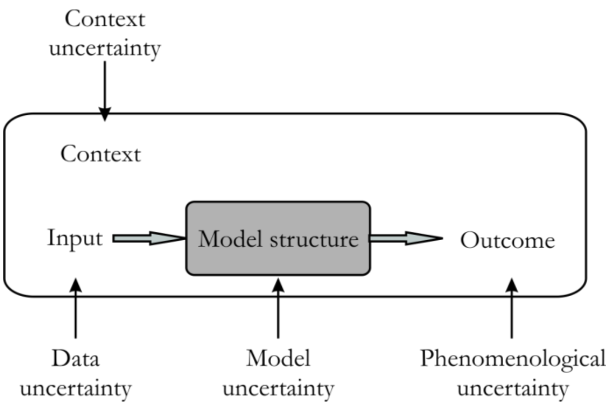


Figure 5-3: Manifestation of uncertainty

(1) Context uncertainty

The context of a situation can be defined as the circumstances that surround an event or a situation [Lough et al., 2009]. Context uncertainty can describe for example the level of instability of the situation context [Grebici et al., 2008; Eversheim et al., 1997]. Two types can be distinguished, namely endogenous (or internal) and exogenous (or external) uncertainty [de Weck et al., 2007]. Figure 5-4 illustrates this differentiation and names examples for each. This figure does not claim completeness in the description of each context; it rather names examples to explain the differences.

Endogenous uncertainties arise from "within" the system or product and are under the company's control [de Weck et al., 2007]. It typically arises from the product context (or service context, depending on the considered project) and the corporate context. The product related context has been discussed in literature e.g. under the light of quality management [Eckert et al., 2004; Phadke, 1989]. Authors such as Grönroos [1984] or Parasuraman et al. [1988] discuss quality management for the service related context (see Chapter 2). The corporate context describes the business environment, in which the product or service is designed [de Weck et al., 2007].

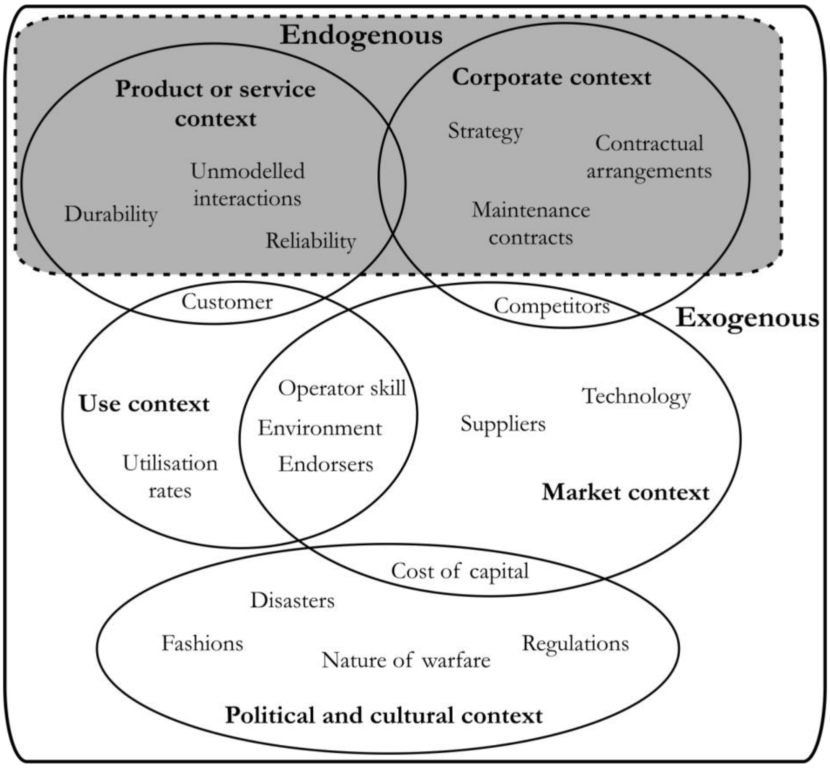


Figure 5-4: Classification of context uncertainty (adapted from de Weck et al. [2007])

Exogenous uncertainties lie outside a company's control or influence and typically arise from the use context of the product, the market context, and the political and cultural context [Chen et al., 2005; de Weck et al., 2007]. They can include for example the degree of change in the available technologies on the market [Moriarty and Kosnik, 1990] or the possible level of moisture in the environment of a metallic system [Lough et al., 2009].

(2) Data uncertainty

Data uncertainty is connected to the input into the system or model [Walker et al., 2003]. It has also been discussed as input uncertainty [Chick, 2001; Gittell, 2002] or design parameter uncertainty [Sun et al., 2003; Hills and Trucano, 1999; Frederiksen, 1998]. It can be divided into data incompleteness, data inexactness and data variation [Huijbregts et al., 2001].

The ***data incompleteness*** can be connected to gaps in the available data in comparison to the necessary data [Hastings and McManus, 2004]. It describes the fact that some of the data that is needed in the modelling process is not available. For example in engineering design, the problem specifications such as the requirements for a certain design may prove themselves insoluble or based on hidden goals and objectives [Eyring, 1966; Kärkkäinen et al., 2001].

Data inexactness can be connected to the inaccuracy of the available data [Huijbregts et al., 2001; Savchuk, 1995] or the trustworthiness/reliability of the information source [Hastings and McManus, 2004; Walker et al., 2003; Walley, 1991; Funtowicz and Ravetz, 1990]. Data inexactness has been discussed especially in the area of metrology which studies the measurement of the physical components of a product. Quantities can usually be only measured to a certain level of accuracy, which leaves uncertainty about the measurements at hand [JCGM, 2008b]. The standards published by the Joint Committee for Guides in Metrology (JCGM) [2008a; b] form important documents in this research area. In general, the trustworthiness of data is connected to the information source [Walley, 1991]. For example, it can be connected to the adequacy of a process to a specific task [Wagener and Gupta, 2005; Hakvoort and Van den Hof, 1997] or the level of expertise of a person in a specific area [Gordon, 1972; Martino, 2003].

Data variation means that different alternatives may be plausible as input values, which has also been described as input parameter uncertainty [Du and Chen, 2000]. In general, data variation can be controllable or uncontrollable (also noise). An example for controllable data variation is design variables such as changing requirements during the problem solving process. This phenomenon has been described for example in the areas of engineering design [Schrader et al., 1993; Eyring, 1966] or customer-supplier interaction [Bolton et al., 2006]. An example of uncontrollable data variation is the strength of a particular material due to e.g. inhomogeneity [Prinz et al., 2011] or the variation of the dimensions of a physical asset due to e.g. manufacturing capability [Swift et al., 2001].

The concepts of data and model uncertainty are closely related as data is typically used for the modelling purpose and a model is only as good as the data it uses [Kenneth, 1988; Alsop and Ferrer, 2006; Bierbaum et al., 2009]. However, it is important to differentiate between the two manifestations of uncertainty as their management may be different; as such the next section describes model uncertainty.

(3) Model uncertainty

Model uncertainty describes the inaccuracies of a model in comparison to reality [Nikolaidis et al., 2005, pp. 8-13; Nilsen and Aven, 2003; Melchers, 1999; Zhou et al., 1996]. It is connected to the use of simplified relationship(s) in models to represent real-world relationship(s) such as the assignment of quantities to qualitative values [Scott, 2007]. Model uncertainty means that model-based predictions may differ from reality [DeLaurentis, 1998]. It has also been described as internal uncertainty, particularly when it is discussed from a modeller's point of view [Du and Chen, 2000]. In the modelling process, these different categories of model uncertainty can be identified and reduced or managed. However, they will always be extant as the developed model is by default a simplification of the real world. For example, modelling the costs of a project including possible uncertainty usually generates a cost estimate with a possible confidence level of 95% [Tay and Wallis, 2000], allowing a difference due to the simplifications of the cost forecasting model. Model uncertainty can be further classified into conceptual, mathematical and computational model uncertainty [Zio and Apostolakis, 1996].

Conceptual model uncertainty describes the simplification and inaccuracies in the model assumptions for a system comprising different processes such as the possible physical behaviour of a particular material [Goh, 2005; Tucker and Ferson, 2003]. It has also been discussed as model parameter uncertainty [Isukapalli, 1999] or model structure uncertainty [Refsgaard et al., 2006]. The simplifications can result from undeliberate simplifications due to a lack of understanding [Nilsen and Aven, 2003], which can manifest itself as model structure uncertainty [Du and Chen, 2000], or by deliberate simplifications due to economic or convenience reasons, which has also been referred to as model parameter uncertainty [Du and Chen, 2000]. A model validation can offer a comparison between the conceptual model and the real world or other models to ensure that the right equations are solved [Robinson, 1997].

Mathematical model uncertainty describes additional approximation or simplification of the mathematical expressions to describe the qualitative model [Zio and Apostolakis, 1996; Farhangmehr and Tumer, 2009; Isukapalli, 1999; Tucker and Ferson, 2003]. These approximate relationships are typically called transfer functions when the conceptual model is developed into a mathematical model and are named performance functions when they relate to performance parameters [Goh, 2005].

Computational model uncertainty arises during the selection of the computational method or technique [Rieg and Koch, 2001] or the development of the computerised representation through programming and implementation [Oberkampf et al., 1999; Sargent, 1998; Hatton, 1997].

(4) Phenomenological uncertainty

Phenomenological uncertainty can be defined as the unpredictability of the future due to unknown events or influences [Abdellaoui and Hey, 2008; Mowrer, 2000; Kahneman and Tversky, 2000]. It can be measured with e.g. performance parameters [Gunasekaran et al., 2001]. For example, it can be connected to the inability of predicting the consequences of a decision in the future [Duncan, 1972; Chen et al., 2005] or the possible behaviour of a considered system [Melchers, 1999]. It is created by the fact that some relevant information may not be known at the point of formulation, sometimes even in principle [Thunnissen, 2003]. It has also been described as *unknown unknowns* and *Nature*, meaning that they cannot be foreseen or influenced [England et al., 2008; de Weck et al., 2007; Earl et al., 2005; Fargier and Sabbadin, 2005; Radner, 2000].

The aim of the description and management of phenomenological uncertainty is the reduction of avoidable surprises on the outcome of current decisions [Dewar, 2002]. This type of uncertainty can by definition not be known or modelled completely as there may always be the influence of an unexpected event. However, the aim of uncertainty management is to identify, describe and, therefore, be aware of important possible phenomenological uncertainties that may influence the outcome of an uncertain problem or situation.

The term of parameter uncertainty was mentioned in the sections of data and model uncertainty. This is due to the fact that it has been used in all these contexts, describing a system from the original state operands such as input data or design parameters, using simplifications such as model parameters and deriving the final state operands using e.g. performance parameters [Hubka and Eder, 1996; Isukapalli, 1999; DeLaurentis and Mavris, 2000]. Each of these concepts describes aspects of what is named as data, model or phenomenological uncertainty in this chapter. It is important to differentiate between these manifestations of uncertainty because they may cause differences in their management. However, some literature makes no distinctions between them [Kulkarni et al., 2006; Zouaoui and Wilson, 2003; Du and Chen, 2000].

5.2.5 Expression of uncertainty

The reviewed literature differentiates between two ways of articulating uncertainty: quantitative (or measurable) and qualitative (or unmeasurable) approaches [Van der Sluijs et al., 2005].

Quantitative uncertainty describes the uncertainties that can be measured in e.g. numbers. One example is technical inexactness, expressed in spreads such as ±, % or *"factor of"* [Van der Sluijs et al., 2005]. Quantitative uncertainty has been the topic of many research papers and approaches to model uncertainty over the decades [Pugsley, 1966; Zadeh, 1994; Emblemsvaring, 2003; Moens and Vandepitte, 2004].

Qualitative uncertainties are difficult to quantify and have, therefore, only received limited attention in past research [Van der Sluijs et al., 2005; Dubois et al., 2003]. They are mostly associated with the societal aspect such as the framing of the problem, model structures, system boundaries, and judgment [Amor et al., 2000]. However, qualitative uncertainty has to be expressed to be able to communicate, characterise and manage it. This section gives an overview of different ways to express both quantitative and qualitative uncertainties.

Uncertainty can be expressed with the help of numbers, symbols, or linguistic expressions [Zimmermann, 2000]. This is depicted in Figure 5-5. The expression with symbols can occur either in a quantitative or a qualitative way as is described later on in this section.

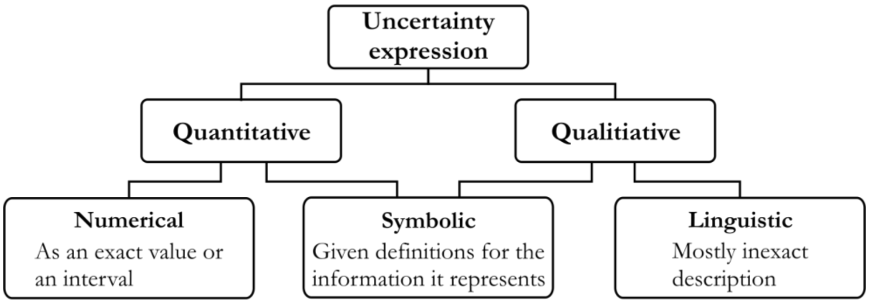


Figure 5-5: Expression of uncertain information

To articulate uncertainty numerically does not only require the information to be given in numbers but also the provision of a scale level which defines what is described by the numerical information [Zimmermann, 2000]. For example, a number can include a metric [Sneath and Sokal, 1973]. The expression with numbers can include a probability distribution with a mean value and a variance [Knight, 1921a; Dubois et al., 2003] or numerical intervals [Van der Sluijs et al., 2005; Moens and Vandepitte, 2004; Aquilonius et al., 2001; Fisher, 1906].

The representation of uncertainty in symbols can appear through numbers, letters, pictures or even words [Stacey and Eckert, 2003]. Symbols do not have a natural meaning; they gain their value through a definition. Thus, they can represent both quantitative and qualitative information as marked in Figure 5-5. For example, the quantitative expression of uncertainty in a symbol can be named as the ranking of the importance of uncertain factors on a particular project as e.g. the "top 10" [Pons and Raine, 2004]. Examples for the qualitative expression of uncertainty using symbols include the use of a "+" in order to describe the rise of a factor in the discussion of the development of this factor or the identification number of an athlete on his/her jersey [Pons and Raine, 2004]. The type of symbolic information processing should also be symbolic and not linguistic or numeric [Zimmermann, 2000; Berlyne, 1957].

Uncertainty can also be expressed in a linguistic way, especially in informal communication [Fargier and Sabbadin, 2005; Dubois et al., 2003; Amor et al., 2000; Bellman and Zadeh, 1970]. Characteristic for this type of information is the difference between the word as a label and the meaning of the word [Zimmermann, 2000]. Often, there is not a one-to-one relationship between these two sides of linguistic information (see also Section 5.2.2 b for lack of definition as a cause of uncertainty). For example, one person may interpret the sentence *"It is rather unlikely"* different from another. Furthermore, two different people may describe the uncertainty information about (the same) context in different ways. Mathematically speaking, there is an m-to-n relationship between a word or a sentence and its possible meanings. It is influenced by changes in the meaning of a word over time and the cultural and educational background of the person using it. The boundaries of linguistic information are not sharp or exact and there are generally no measures [Zimmermann, 2000].

5.2.6 The five layers of uncertainty

This chapter proposes a classification of uncertainty based on five layers that aims to provide a coherent and holistic understanding of the subject. These layers are the nature, cause, level, manifestation and expression of uncertainty as depicted in Figure 5-6. Characterising uncertainty in each of the layers offers a comprehensive description of the uncertainty existing in a situation. This characterisation has to be defined on each of the five levels. For example, aleatory uncertainty can occur in all four manifestations of uncertainty, i.e. context, data, model and phenomenological.

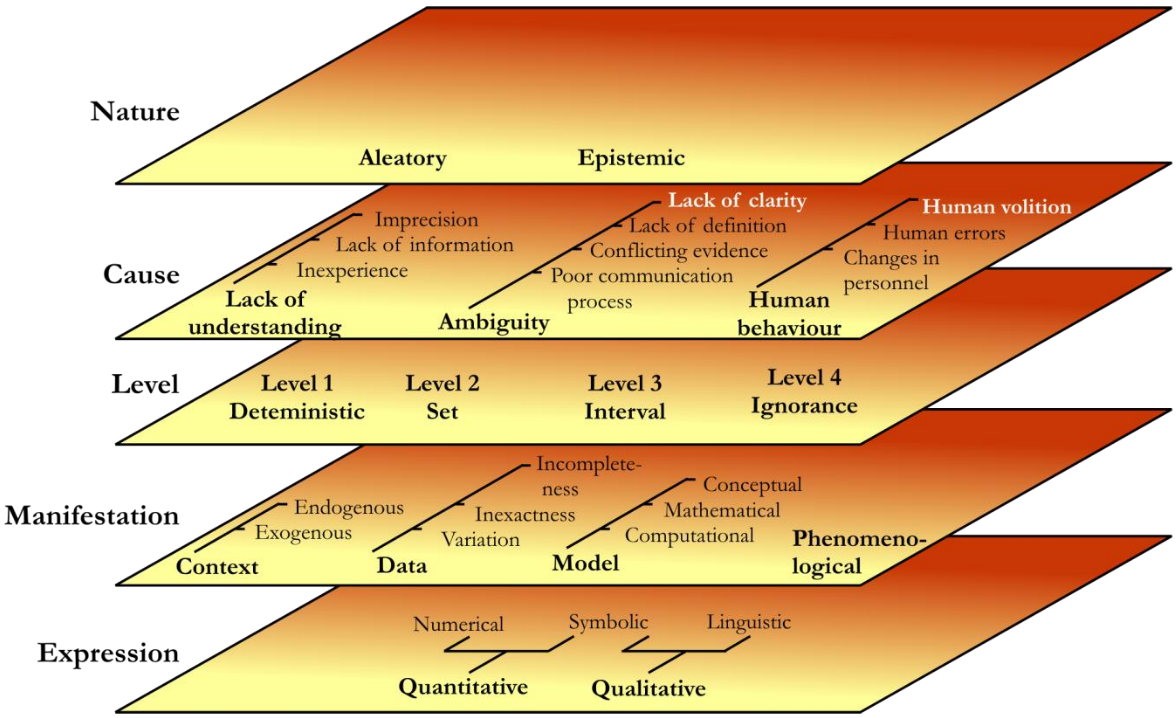


Figure 5-6: Five layer approach of characterising uncertainty

However, there are implications between the layers. For example, human behaviour is typically a cause of epistemic uncertainty [Thunnissen, 2003]. Likewise, lack of information (sub-category of lack of understanding) was discussed to be the main cause of aleatory uncertainty [Ben-Haim, 2001, p.12]. In addition, aleatory uncertainty has been characterised to be deterministic, i.e. exist only in level 1 [Oberkampf et al., 2002], while other approaches only exclude level 4 – ignorance from this nature of uncertainty [Walker et al., 2003].

There may be interdependencies within the layers. For example, a situation may consist of both aleatory and epistemic uncertainty (see also example in Section 5.2.1). The uncertainty may be caused by, for example, both a lack of understanding and ambiguity; it can manifest itself at different points in the process, or can be communicated using quantitative and qualitative expressions. In contrast, the uncertainty can by definition only exist in one of the described levels [Courtney, 2001], i.e. an uncertain situation may only be characterized by its deterministic, set, interval or ignorance.

This holistic approach to characterising uncertainty can be used to position existing uncertainty modelling techniques in their areas of application. The next section describes this application of the five-layer approach to the modelling techniques most frequently described in literature as introduced in Chapter 3.

5.3 Modelling uncertainty

The classification described in Section 5.2 can be used to classify and categorise existing applications of the different uncertainty modelling techniques described in Chapter 3. These are frequentist, subjective and imprecise probability theory, information gap theory, interval analysis, possibility theory, fuzzy set theory and evidence theory. The application of the uncertainty classification on these modelling techniques is depicted in Table 5-3. This is not an exhaustive list of the existing applications of each of the modelling techniques as found in literature, but it gives an example of typical areas and uncertainty characteristics they apply to.

Table 5-3: Classification of uncertainty modelling techniques with the five-layer approach

Technique	Nature	Cause	Level	Manifestation	Expression	References and research area
Probability theory - frequentist	Aleatory	Lack of understanding – lack of information	Deterministic	Context - exogenous	Quantitative	Kaishev and Dimitrova [2009]: Pricing of options. Detemple and Rindisbacher [2007]: Monte Carlo analysis for pricing of derivatives.
				Data variation	Quantitative	Jovanovic [1999]: Sensitivity analysis for investment decision making. Aquilonius et al. [2001]: Sensitivity analysis for cost factors of a fusion plant. Krzykacz-Hausmann [2006]: Sensitivity analysis for fluid depth in a tank. Helton et al. [2000]: Monte Carlo Analysis of input parameters for waste isolation. Karanki et al. [2009]: Modelling data variation in safety assessment for nuclear power plants.
			Deterministic	Phenomenological	Quantitative	Detemple and Rindisbacher [2007]: Modelling of the future price of derivatives.
			Set	Context - endogenous	Quantitative	Nikolaidis et al. [2004]: Catastrophic design failures.
			Interval	Context - endogenous	Quantitative	Asiedu and Gu [1998]: Monte Carlo analysis of the life cycle costs of products.
Probability theory - subjective	Epistemic	Lack of understanding – imprecision	Interval	Data inaxactness	Quantitative	Wood et al. [1990a]: Modelling imprecise input parameters in engineering design.

Table 5-3 (continued): Classification of uncertainty modelling techniques with the five-layer approach

Technique	Nature	Cause	Level	Manifestation	Expression	References and research area
Probability theory - subjective	Epistemic	Lack of understanding – Lack of information	Set	Context – exogenous	Quantitative	Ferreira et al. [2004]: Reasoning under uncertain conditions.
				Data incompleteness	Quantitative	Krzykacz-Hausmann [2006]: Possible failures resulting in varying fluid depths of "hold-up" tank.
				Mathematical model	Quantitative	Laskey [1996]: Mixture distribution over set of possible model structures.
				Phenomenological	Quantitative	García-Fernández and Garijo [2010]: Budget decisions for dynamic planning of projects using set of strategies.
					Qualitative	Elouedi et al. [2001]: Probabilistic decision trees with uncertain values. Smets and Kennes [1994]: Transferable Belief Model for future scenarios. Feather [1959]: Decision making under alternatives with subjective probabilities.
			Interval	Phenomenological	Qualitative	Faucheux and Froger [1995]: Decision making concerning environmental issues.
			Interval	Data variation, data incompleteness	Quantitative	Krzykacz-Hausmann [2006]: Theoretical validation of applicability of modeling technique for intervals. Helton et al. [2000]:Performance assessment of waste isolation plant.
		Ambiguity – conflicting evidence	Interval	Context – exogenous	Quantitative	Clemen and Winkler [1999]: Combination of subjective probabilities from experts.

Table 5-3 (continued): Classification of uncertainty modelling techniques with the five-layer approach

Technique	Nature	Cause	Level	Manifestation	Expression	References and research area
Probability theory – imprecise	Epistemic	Lack of understanding – lack of information	Interval	Data inexactness	Qualitative	Karanki et al. [2009]: Modelling inaccurate variables in safety assessment for nuclear power plants. Tucker and Ferson [2003]: Modelling iinaccurate parameter values with p-boxes.
				Conceptual model, Mathematical model	Qualitative	Tucker and Ferson [2003]:Modelling imprecise model structures , variable dependencies and imprecise probability distributions using p-boxes.
		Ambiguity – lack of clarity	Interval	Data inexactness	Qualitative	Moeller and Beer [2008]: Modelling of vague probabilities in engineering computation. Walley and de Cooman [2001]: Modelling uncertainty from vague information, e.g. 'high probability of rain'.
Information gap theory	Epistemic	Lack of understanding – lack of information	Interval	Context - exogenous	Qualitative	Hipel and Ben-Haim [1999]: Modelling uncertainty influencing the water resources management.
				Data incompleteness	Qualitative	Cheong and Berleant [2004]: Modelling competitors' influence on bidding strategy for generation companies. Duncan et al. [2008]: Modelling uncertainty for decision making in life cycle design.
				Phenomenological	Qualitative	McCarthy and Lindenmayer [2007]: Modelling forest value influenced by destruction through fire in Australia.

Table 5-3 (continued): Classification of uncertainty modelling techniques with the five-layer approach

Technique	**Nature**	**Cause**	**Level**	**Manifestation**	**Expression**	**References and research area**
Interval analysis	Epistemic	Lack of understanding – lack of information	Interval	Context – endogenous	Quantitative	Mohamed and McCowan [2001]: Modelling monetary gains of investment decisions.
				Context – exogenous	Quantitative	Shary [2002]: Modelling of systems which are influenced by external uncontrolled disturbances.
					Qualitative	Parsons and Fox [1991]: Modelling decisions in medical treatment of specific symptoms.
				Data variation	Quantitative	Rao and Berke [1997]: Analysis of structural systems in engineering design. Nakagiri and Suzuki [1999]: Modelling external loads on elastic flat plate subject. Moeller and Beer [2008]: modelling of interval input data in engineering computation.
				Mathematical model	Quantitative	Devooght [1998]: Bounding the inexactness of models within an interval.
Possibility theory	Aleatory	Lack of understanding – lack of information	Set	Context – endogenous	Quantitative	Nikolaidis et al. [2004]: Modelling Catastrophic design failure.
	Epistemic	Lack of understanding - imprecision	Interval	Context - endogenous	Quantitative	Dubois et al. [1996]: Problem solving with soft constraints and priorities.

Table 5-3 (continued): Classification of uncertainty modelling techniques with the five-layer approach

Technique	Nature	Cause	Level	Manifestation	Expression	References and research area
Possibility theory	Epistemic	Lack of understanding – lack of information	Set	Phenomenological	Quantitative	Yager [1979]: Decision making based on possibilistic evaluation.
					Qualitative	Dubois and Prade [1995]: Modelling possible outcomes of a decision.
			Interval	Context – endogenous	Qualitative	Mohamed and McCowan [2001]: Modelling non-monetary gain of investment decisions.
		Ambiguity – lack of clarity	Interval	Data inexactness	Qualitative	Walley and de Cooman [2001]: Modelling uncertainty arising from vague information, e.g. 'Mary is young'.
Fuzzy set theory	Epistemic	Lack of understanding – imprecision	Interval	Data inexactness	Quantitative	Wood and Antonsson [1989]: Modelling imprecise input parameters in engineering design.
		Lack of understanding – lack of information	Set	Phenomenological	Quantitative	Elouedi et al. [2001]: Belief decision trees with fuzzy values.
		Ambiguity – lack of clarity	Set	Data inexactness	Qualitative	Ghosh et al. [1998]: Modelling ambiguous information in telecommunication networks.
			Interval	Data inexactness	Quantitative	Bondia and Picó [2003]: Linear systems with ambiguous input parameters estimated by experts. Moeller and Beer [2008]: Modelling of uncertain input data in engineering computation.
					Qualitative	Shen and Leitch [1993]: Modelling vague information about physical systems.

Table 5-3 (continued): Classification of uncertainty modelling techniques with the five-layer approach

Technique	Nature	Cause	Level	Manifestation	Expression	References and research area
Evidence theory	Epistemic	Lack of understanding – imprecision	Set	Data incompleteness	Qualitative	Lalmas [1997]: Indexing and structuring documents for information retrieval.
				Data inexactness	Qualitative	Le Hegarat-Mascle et al. [1997]: Classification of incomplete images from different sensors. Kaftandjian et al. [2003]: Detection of weld defects by combining different incomplete scans of material.

The classification of existing modelling techniques in the five-layer approach as presented in Table 5-3 enables an analysis of typical areas of application. Some examples are discussed in this section.

The frequentist probability theory is suitable for modelling aleatory uncertainty if there is (or the possibility to obtain) enough information to derive a probability density function (PDF) (see also Section 3.1.3). Nikolaidis et al. [2004] compared the results of a frequentist probabilistic and possibilistic analysis of the catastrophic failure of a design and found that probability theory is more suitable for modelling this uncertainty. In other words, they found that under the existence of aleatory uncertainty, frequentist probability is the most suitable modelling technique.

However, the general principle of probability theory can also be applied to epistemic uncertainty with the help of e.g. subjective probability. Helton et al. [2000] and Krzykacz-Hausmann [2006] modelled the existence of both types of uncertainty in two loops using both the classic probability theory for the aleatory uncertainty and subjective probability for the epistemic uncertainty. Likewise, Karanki et al. [2009] modelled aleatory uncertainty using probability theory and epistemic uncertainty using imprecise probability, which results in a probability-box (p-box) describing the uncertain factors in the safety assessment of nuclear power plants. Thus, these three approaches are mentioned multiple times in Table 5-3 (frequentist, subjective and imprecise probability theory).

The applicability of probabilistic based techniques to model phenomenological uncertainty has been discussed and the shortcomings of these approaches have been highlighted by many authors [Ben-Haim, 2001; Davidson, 1991; Hicks, 1979; Keynes, 1937]. The main argument is that probability based techniques fail to identify or describe unexpected events, and thus, the application of probabilities and distributions from the past to the future is considered inappropriate. However, approaches have been described in literature, so they are listed in Table 5-3. Faucheux and Froger [1995] highlighted the applicability of subjective probabilities to situations with weak uncertainty where the future can be described with a reliable probabilistic function.

Moeller and Beer [2008] discussed three possible techniques for modelling uncertain input parameters in the area of engineering computation: interval analysis, fuzzy set theory and imprecise probabilities. They found that these techniques are applicable under varying conditions, namely if the input parameter can only be bound (interval analysis), can be described according to their degree of similarity (fuzzy set), or vague probabilistic information (imprecise probabilities).

Other combinations of modelling techniques can be found. Mohamed and McCowan [2001] combine interval analysis and possibility theory to model the monetary and the non-monetary gains of investment decisions. Walley and de Cooman [2001] compare the applications of possibility theory and imprecise probabilities to model the uncertainty arising from vague linguistic expressions.

5.4 Discussion

This chapter presented a holistic approach to characterising an uncertain situation or event by introducing a classification in five layers. This classification was then applied to approaches that utilise the uncertainty modelling techniques that were introduced in Chapter 3. In the reviewed literature, no techniques were found that model the uncertainty caused by human behaviour. This was unexpected as this cause of uncertainty has been highlighted by several researchers [Weed and Mitchell, 1980; Morone and Morone, 2008].

The presented classification was primarily derived from literature focusing on uncertainty, particularly in the areas of engineering, management and decision making. It is to be noted that at the current state of research, it is a proposed holistic approach to characterising uncertainty. It is the author's opinion that approaches and terms adopted by other researchers can be integrated in the proposed classification [Kreye et al., 2011a]. However, some approaches may offer further insights into specific areas to achieve a more detailed description of particular aspects of this classification. For example, deWeck et al.'s paper [2007] on context uncertainty describes the different categories within the classification of endogenous and exogenous uncertainty. This chapter does not focus on this level of detail.

Market developments such as servitisation may change specifications of the proposed classification. For example, the arrangement of Industrial Product Service Systems (IPS^2) [Rese et al., 2009] could indicate a change of the relationship between the supplier of the service and their customer in the future. In other words, the closer collaboration with the customer could extend the area of influence of the supplying company, which means that the customer would move from an exogenous uncertainty to an endogenous one (see Figure 5-4 for current state of literature).

5.5 Summary and conclusions

The contributions of this chapter can be summarised as follows;

- A holistic approach to characterise uncertainty and identify a suitable modelling technique was proposed due to the lack of current research to provide such an approach. The classification presented in this chapter aims at closing this gap. It also answers the first of the presented research objectives: "To define a holistic approach to characterise and describe the uncertainty inherent in a situation as a basis for its modelling and management" (as described in Section 4.2).

- A five-layer classification was proposed, which described the nature, cause, level, manifestation and expression of uncertainty. This answers objective 1a "To identify a classification of the general characteristics of uncertainty".
- Applications of the modelling techniques introduced in Chapter 3, i.e. frequentist, subjective and imprecise probability theory, information gap theory, interval analysis, possibility theory, fuzzy set theory and evidence theory, were categorised within the five-layer classification. This answers objective 1b "To identify suitable modelling techniques for different uncertainty characteristics".

The usefulness of the proposed classification of uncertainty is tested through its application to a pricing decision at the competitive bidding stage for service contracts. This is presented in Chapter 10. The focus was to validate the usefulness of this classification for characterising the uncertainty inherent in a situation and choosing a suitable modelling technique for this uncertainty. It is acknowledged that this does not offer a complete validation of the classification. Further research will have to be done in this area, which will be discussed in more detail in Chapter 12.

To identify the uncertainty influencing a pricing decision at the competitive bidding stage, empirical research was undertaken. The next chapter describes the first experimental study.

6 Information display for decisions under uncertainty

This chapter presents the first experimental study which focused on the decision maker's interpretation of the communicated cost estimate. This represents research objective 2a, namely "To identify the decision maker's interpretation of uncertain costing information". Figure 6-1 depicts the focus of this study within the decision-making process as presented in Section 4.1.

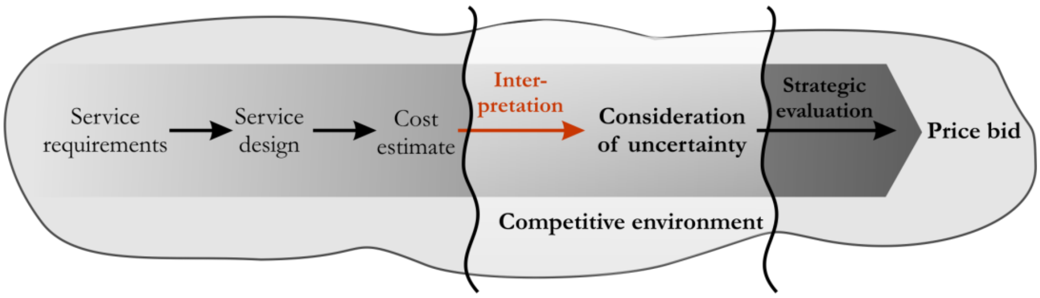


Figure 6-1: Focus of first experimental study in the decision process

The clear representation of input information is essential to support an informed decision [Speier, 2006; Speier and Morris, 2003; Greves and Schreiber, 1995]. It can therefore be assumed that an adequate representation of the uncertainty connected to the data enhances the consideration of uncertainty in decision making. Particularly, the presentation of information in a graphical display can result in an improved understanding in comparison to only using textual or tabular information [Speier, 2006; Speier and Morris, 2003; Tufte, 2001; Dickson et al., 1986; Harvey, 2001]. First, the state-of-the-art in the area of the perception and interpretation of uncertain information is described before the study itself and the results are introduced.

6.1 Perception and interpretation of uncertain information

Psychology research has investigated the way people experience the existence of uncertainty and their reaction. Two different reactions were identified: for some, the situation was overwhelming and they felt paralysed; for others, the situation encouraged them and they found new solutions and answers [Gerber, 2009]. The researchers concluded that the difference was created by the perception of "controlling" the uncertainty. When a situation offers a high level of control, individuals can feel more intrinsic motivation and show more initiative caused by the experience of psychological factors such as greater interest, less pressure, more creativity and a higher self-esteem [Seligman, 2006; Deci and Ryan, 1987]. If a situation offers a low level of control, these positive outcomes are less likely to occur [Taylor and Brown, 1988]. These reactions are very subjective and depend on the characteristics and experience of the specific person [Cialdini, 2007].

Decision makers tend to ignore uncertainty and in particular, they tend to avoid the possible negative impact of uncertainty [Dawes, 1988; Bell, 1985]. In this context, decision makers' reactions to the possibilities of regret and disappointment have been discussed [Loomes and Sugden, 1982; Bell, 1982; Connolly and Zeelenberg, 2002; Schwarz, 2000]. Other reactions that can be observed, particularly after the outcome of a decision problem has become reality, include the invention of a "higher rationale" to explain uncertain events and so treat them as if they involved the skills of the decision maker and, therefore, seem influenceable and controllable [Dawes, 1988; Langer, 1975a; b]. Experiments in this area have been described as the throwing of dice where the gamblers were observed to throw the dice with greater force in order to throw a higher number [Langer, 1975a], the prediction of coin tosses where students perceived themselves as "better-than-the-average" predictors of outcomes when they made correct predictions at the beginning of the experiment [Langer and Roth, 1975], and the winning of a lottery where the participants assigned higher confidence in having the winning lottery ticket when they had chosen the ticket themselves as opposed to receiving a randomly allocated one [Dawes, 1988, p. 257].

If decision makers do acknowledge the presence of uncertainty in the decision process, for example via a forecast range, they tend to underestimate it, in other words, they overestimate the probability that the range will include the true outcome [Lichtenstein et al., 1982; Pitz, 1974]. To indicate the percentage of true values out of a number of given estimates that fall outside the range expressed by the tested person, a surprise index was introduced. For example, for a 90% confidence interval this percentage should be 10%. If the observed percentage exceeds this value, the individual is overconfident. In contrast, if less than 10% of outcomes occur outside the interval, this would indicate that the person is underconfident (i.e. their interval is too wide). Many studies, which investigated the assessment of uncertain parameters, have found that forecasters tend to be overconfident [Lichtenstein et al., 1982; Alpert and Raiffa, 1982; Phadke, 1989; O'Connor and Lawrence, 1989; Giordani and Söderlind, 2003]. Even after the tested participants were confronted with their overconfidence and asked to give a new estimate, they improved but were still considerably overconfident [Alpert and Raiffa, 1982; Selvidge, 1980; Pickhardt and Wallace, 1974].

Different explanations for these phenomena have been found. However, the one that has received the most attention is the idea that decision makers use an "anchor-and-adjust" heuristic for estimating a range of possible values [Harvey, 2001; Tversky and Kahneman, 1974]. This means that they use their belief of the most likely value as an anchor and set the boundaries of the range or interval by adjusting away from that value. Within this procedure, they make too small an adjustment from the anchor and, hence, the range width is too small [Tversky and Kahneman, 1974; Lichtenstein et al., 1982; Lawrence and Makridakis, 1989; Harvey, 2001].

Nevertheless, some studies have found that, under some circumstances, uncertainty is overestimated [Bolger and Harvey, 1995; Diebold et al., 1997; Harvey, 2001; Lawrence et al., 2006]. For example, in a study by Bolger and Harvey [1995], decision makers were asked to estimate the probability of the future value in a time-series being below a given reference point and compared the answers to the true probabilities. The study found that the probabilities of less than 50% were overestimated and those of more than 50% were underestimated. Similarly, Diebold et al. [1997] found that forecasters overestimated the probability of the future value of inflation falling below a stated point forecast. Both research studies involved the estimation of uncertainty relative to a reference point, which suggests that uncertainty assessment is sensitive to the methods used to obtain the estimates.

This sensitivity suggests that well calibrated prediction intervals might be obtained by distributing the forecasting problem to two experts. One expert would be asked to give a range within which the future value is supposed to fall and the other would then be asked to estimate a probability value for this range [Harvey, 2001]. However, this is not an option when only one person is responsible for the decision.

In the case of overconfident decision makers, contradictory evidence has been found on the influence of additional information or knowledge on the estimation of uncertainty. Pickard and Wallace [1974] tested the influence of training on the overconfidence of the decision makers by giving them immediate feedback throughout five and six sessions of forecasting for the same problem. The results showed a moderate improvement (a 37.5% reduction of the surprise index for five sessions and a 47.8% reduction of the surprise index for six sessions) but there still remained a high level of overconfidence. O'Connor and Lawrence [1989] revealed that the provision of feedback to people on the accuracy of their forecasts improved the calibration of future confidence intervals considerably, especially when a confidence interval of 75% was requested. Other studies, on the other hand, show contradictory evidence. Brown [1973] studied the effect of additional information in the form of extensive historical data while Lichtenstein and Fischhoff [1980] studied the impact of calibration training on the surprise index of forecasters. Both results show no improvement in the estimation of uncertainty.

The uncertainty connected to an event or the outcome of a decision can be assessed through subjective probabilities, which typically represent degrees of belief [Elouedi et al., 2001]. This expresses the decision maker's (subjective) belief about the likelihood of an uncertain event happening or of an uncertain outcome of a process [Kahneman et al., 1982]. This belief can be expressed in a number of ways including the use of phrases such as *"It is likely that"* or *"highly improbable that"*, which may be ambiguous [Morgan and Henrion, 1990]. The belief function is affected by a number of influences such as the biases of the decision maker or his/her experience, which can lead to over or underestimation of the probability of the outcome. These subjective probabilities cannot usually be judged as right or wrong [Lichtenstein et al., 1982; Elouedi et al., 2001]; they can be judged, however, on their level of realism (e.g. see Lichtenstein et al. [1982]). In the experiment that is described in this chapter, the subjective beliefs in the likelihood of propositions are represented as confidence levels.

When the assessment of a forecasting problem is dependent on the judgement of the decision maker, it is subjective, which means that it is likely to be biased and inconsistent [Harvey, 2001]. Examples of biases include the underestimation of trends or the over-influence of recent events [Harvey and Bolger, 1996; Sanders, 1992]. Recent events can cause the probability of a forthcoming similar event to be either over or underestimated. Overestimation can result from the use of the availability heuristic [Cohen et al., 2008]. This was observed in the context of earthquake insurances in California after the earthquake in 1989, when the number of sold policies increased significantly [Kunreuther, 1996]. Underestimation can result from the gambler's fallacy which states the argumentation that if an event has occurred recently, it is less likely to occur again in the near future [Cohen et al., 2008].

The general ignorance of uncertainty in the decision process and the biases associated with this can lead to a misinterpretation of situations and wrong decisions [Bell, 1985; Courtney, 2001; Ullmann, 2009]. However, the consideration of uncertainty in cost estimation has not yet been addressed. One major aspect in the cost estimation process is the collection and interpretation of relevant information. Graphical displays of this information can be seen as an important communication channel to improve a decision maker's comprehension of the problem at hand [Speier, 2006; Speier and Morris, 2003; Harvey and Bolger, 1996]. However, different graphs displaying the same information point the viewer towards different aspects [Tufte, 2001]. Therefore, displaying uncertain forecasts in different ways is likely to change the decision maker's perception of the information and so influence, which aspects are included in the decision process. Section 6.2 introduces an experiment that was designed to test the relative effectiveness of different approaches to displaying cost forecasting information in terms of their ability to encourage decision makers to consider uncertainty in their decisions.

6.2 Method

The first experimental study investigated objective 2a, namely "To identify the decision maker's interpretation of uncertain costing information." In other words, the study aimed at the identification of the most appropriate way of displaying the uncertainty involved in a forecasting problem. This was divided into two aspects:

- To identify the type of graphical display required to assist the decision maker in considering uncertainty,
- To identify the amount of contextual information necessary to represent uncertainty in the decision-making process.

To investigate the decisions taken, it was necessary to identify the types of information typically available in a forecasting process. This includes time series information, labels and contextual information. Time series represent past information recorded at different points in time, such as the past development costs of a product. Labels are the representations of the variable that is being forecast, for example the vertical axis of a graph may be labelled as "monthly costs, $". Contextual information gives further background on the estimation problem. For example, it may contain details of special circumstances that may cause a trend in costs to be disturbed.

6.2.1 Study procedure

The experiment was carried out at a one day conference on "Cost Estimating for Defence Programmes" organised by the Society for Cost Analysis and Forecasting (SCAF), which was attended by costing experts from the aerospace and defence sectors [SCAF, 2011]. The experiment consisted of two questionnaires with questions, which were presented in a predetermined order [Saunders et al., 2009]. To reduce the likelihood of the participants remembering what they selected in questionnaire 1, questionnaire 2 was completed after a defined time difference. The first questionnaire was handed out and collected early in the morning and the second one in the afternoon.

In order to test different ways of displaying information, the participants were divided into three groups A, B and C. The affiliation to a certain group was allocated randomly. The participants stayed in their groups throughout the whole experiment so somebody who answered questionnaire 1 from group A would also answer questionnaire 2 for that group. For each of the groups, different graphical displays were used to represent the forecasts as shown in Figure 6-2.

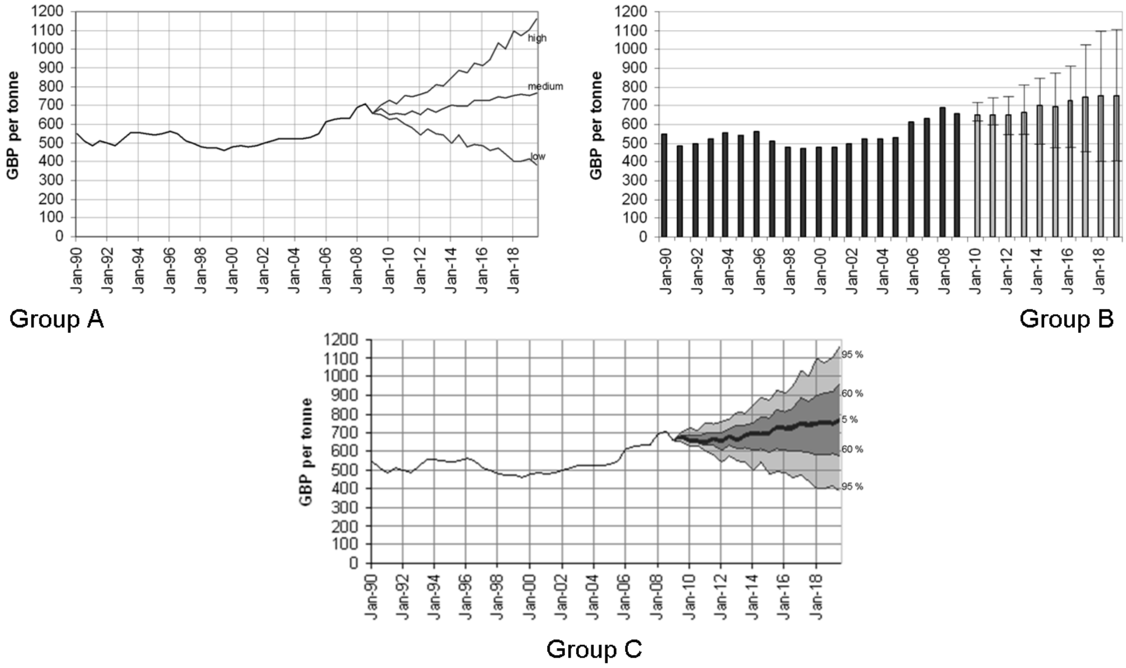


Figure 6-2: Graphical display of the forecasting problem

The graphical displays were as follows:

- A three point trend forecast for group A.
- A bar chart with minimum, medium and maximum estimates for group B.
- A fan diagram for group C.

Each of the graphs displayed past data on the monthly cost of a raw material from January 1990 to January 2009, together with the forecasts. They consisted of the same information and labels providing a forecast scenario with minimum, medium and maximum values. The cost data was artificially generated so that the observations were distributed randomly around a linear upward, flat or downward trend.

6.2.2 Questionnaire design

Both questionnaires comprised the same forecasting scenario and contained six questions.

- First, participants were asked to give an estimate of the future costs of the raw material for the year 2014 (January), based on the information given. The choice of giving a point or range estimate was left to the participants.

- Then, they were requested to give the reasons for their answer. This was phrased as an open question.

- Finally, they were asked to provide the confidence level for their estimate. Six discrete intervals were given between which the participants could choose. Those were 0-20%, 21-40%, 41-50%, 51-60%, 61-80%, and 81-100%. It should be noted that a statement of confidence in relation to a point forecast of a continuous variable is ambiguous since the theoretical probability that the forecast will equal the outcome is zero. However, this question gave an insight on the extent to which people were prepared to make such ambiguous statements when estimating future values of an uncertain variable.

The same questions were asked in order to obtain a cost estimate for 2018 in each of the questionnaires. The two questionnaires differed in the amount of information that was supplied:

- Questionnaire 1 gave general information on the forecasting problem and a graph with the historical and estimated future prices of the raw material.

- Questionnaire 2 included more detailed information relating to the forecast, e.g. what the different values meant and the assumptions that underpinned the forecasts. The additional information focused on the background of the graphical information. It was kept to a basic level as people are constrained in the amount of information they can consider and process in a decision making process [Sent, 2004; Radner, 2000; Rubinstein, 1998].

An exemplar of the questionnaires given to group A can be found in Appendix A.

6.2.3 Participants

The participants were cost engineers from industry part-taking in a cost estimation workshop. Forty-four experts (out of 52 attendees at the conference) participated in the experiment, of which 13 were assigned to group A, 15 to B, and 16 to C. Seventy-five per cent of participants stated that they had worked before with a diagram of the same type as that presented to them in the experiment and 40% said they had used it in cost estimation, albeit with differing frequencies. Of the people who had used that type of graph in their work, 13% stated that they used it once a week, 27% once a month, 20% once every other month, 20% once a year, and 20% used it only occasionally. Table 6-1 summarises the results per group in terms of familiarity with the diagram in the questionnaire and whether they had used the type of diagram in their work. The table shows both the absolute number of participants and the percentage. For groups A and C, these percentages do not add up to 100% because two participants in each group did not reply to these questions.

Table 6-1: Participants' experience with experiment diagram for the groups

Question	Group A			Group B			Group C		
	Yes	No	Y/N-Ratio	Yes	No	Y/N-Ratio	Yes	No	Y/N-Ratio
Have you seen a diagram like this before?	10* 76.9%	1* 7.7%	10.0	12 80.0 %	3 20.0 %	4	9* 56.3 %	5* 31.2 %	1.8
Do you use this type of diagram in your work?	7* 53.9 %	4* 30.8 %	1.75	5 33.3 %	10 66.7 %	0.5	4* 25.0 %	10* 62.5 %	0.4

* these figures do not sum to 100% because one participant failed to supply a forecast

The results show that the participants of group A (who were presented with the three point graph) had the highest level of familiarity with the graph they were given and also the highest level of experience of working with this type of graph. Those in group C (who were presented with a fan diagram) had the lowest levels of familiarity and experience with the graph they were given. The assignment of participants to the groups was as follows:

- Group A: 13 participants (10 experienced),
- Group B: 15 participants (12 experienced),
- Group C: 16 participants (9 experienced).

This categorisation of the participants was maintained throughout the analysis of the results.

6.3 Results

In this section, the results of the experiment are analysed and explained in terms of the chosen cost estimates, the confidence levels and the reasoning behind the given estimates. A chi-squared test (also χ^2-Test) was undertaken to assess the statistical significance of the results. The general process of this significance test is described in Appendix A, the test results are displayed in this section.

6.3.1 Cost estimates

A first indication of the participants' understanding of uncertainty can be found in the kind of estimate that was elicited from them. If a range of possible outcomes was given, it was assumed that the decision maker was aware of the uncertainty connected to the cost estimates. The following responses were interpreted as range estimates: i) a three point forecast, ii) a range between a minimum and a maximum value, and iii) uncertainty included in a narrative way, e.g. *"around £700"* or *"approximately £700"*. Table 6-2 shows the results for all the participants with those for the experienced subset of participants in brackets.

Table 6-2: Summary of type of cost estimate for groups and questionnaires

	Questionnaire	**1**		**2**	
	Year	**2014**	**2018**	**2014**	**2018**
Group A	**Range forecast quoted**	7.7% (10.0%)	7.7% (10.0%)	0 (0)	0 (0)
	Point forecast quoted	92.3% (90.0%)	92.3% (90.0%)	100% (100%)	100% (100%)
Group B	**Range forecast quoted**	20.0% (25.0%)	7.1% (8.3%)	7.1% (8.3%)	0 (0)
	Point forecast quoted	80.0% (75.0%)	92.9% (91.7%)	92.9% (91.7%)	100% (100%)
Group C	**Range forecast quoted**	25.0%* (33.3%)	12.5* (22.2%)	25.0% (33.3%)	25.0% (33.3%)
	Point forecast quoted	68.8%* (66.7%)	81.3%* (77.8%)	75.0% (66.7%)	75.0% (66.7%)

* these figures do not sum to 100% because one participant failed to supply a forecast

The results for the whole set of participants show no significant difference between the three groups ($p<0.05$). However, for the experienced participants, a difference can be observed for group C questionnaire 2. In this group, a range forecast was more usual than in the other two groups. This can be interpreted as the increased awareness of uncertainty that is caused by the fan diagram in combination with further contextual information.

For all three groups, some estimates stated as a range in 2014 were reduced to a point forecast in 2018. In general, an event further into the future will be subject to more uncertainty, which means that the range estimate for 2014 should change to a larger range in 2018. The difference between the theoretical explanation and the practical observation can be explained with the subjective perception that an event, which is a long way into, can be perceived as less uncertain because disturbances caused by short term incidents will not spread thus far.

The estimates produced by the participants were assigned to one of five categories ranging from low to high based on their position in the graphical display as depicted in Figure 6-3. If a range forecast was given, it was classified as either "low < medium" or "medium < high", depending on which side of the graph it was taken from. There was no significant difference between the estimates produced by those who were experienced in using the type of graph and those who were not experienced. Thus, Figure 6-3 displays the estimates for the whole set of participants.

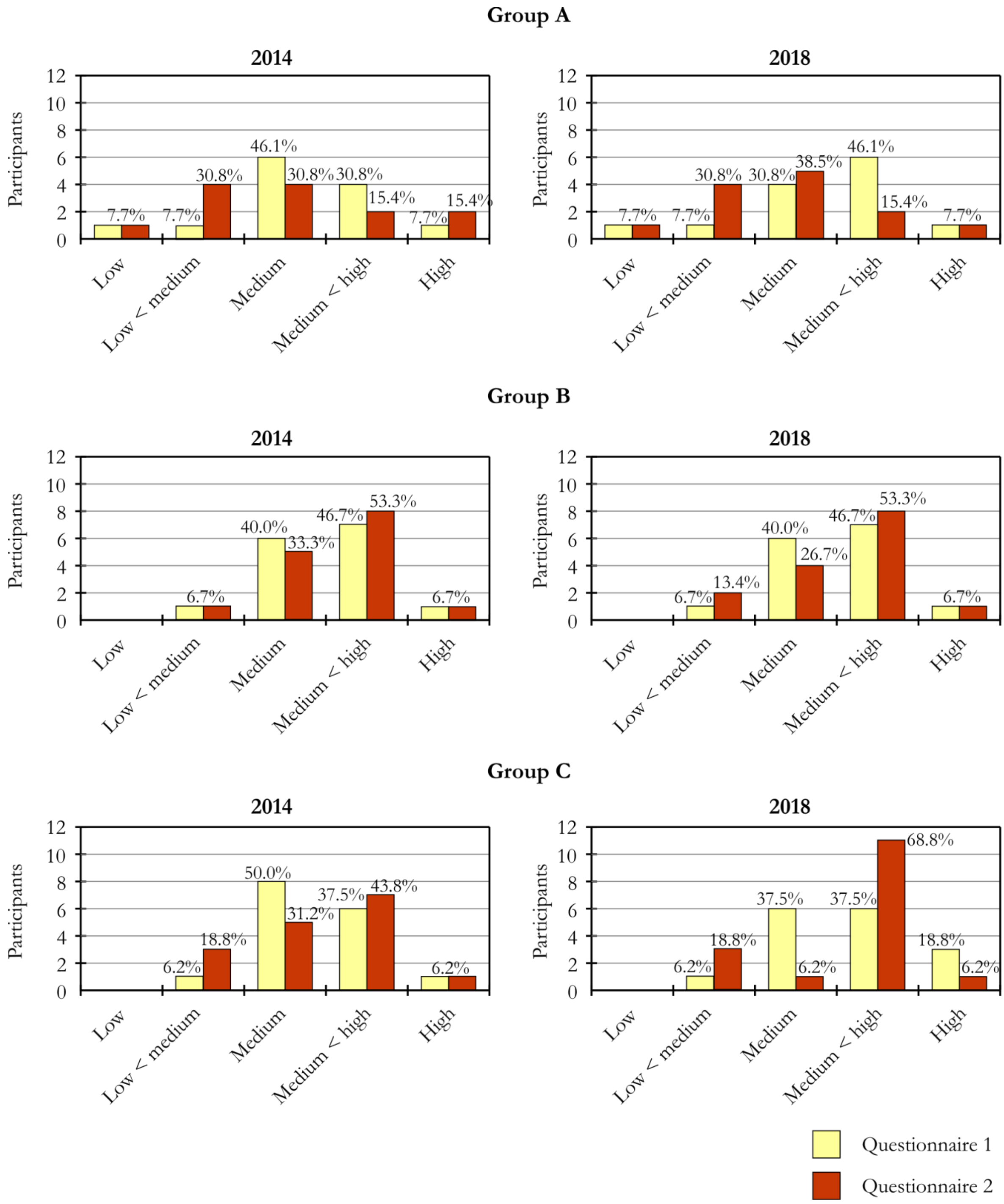


Figure 6-3: Forecasting values for each group in comparison

Table 6-3 shows the frequency of answers for all the participants and for the experienced subset in brackets.

Table 6-3: Forecasting values in comparison between whole set and experienced subset of participants

	Year	**2014**		**2018**	
	Questionnaire	**1**	**2**	**1**	**2**
Group A[3]	**Low**	7.7% (10.0%)	7.7% (10.0%)	7.7% (10.0%)	7.7% (10.0%)
	Low < medium	7.7% (10.0%)	30.8% (30.0%)	7.7% (10.0%)	30.8% (20.0%)
	Medium	46.1% (50.0%)	30.8% (30.0%)	30.8% (30.0%)	38.5% (40.0%)
	Medium < high	30.8% (20.0%)	15.4% (10.0%)	46.1% (40.0%)	15.4% (20.0%)
	High	7.7% (10.0%)	15.4% (20.0%)	7.7% (10.0%)	7.7% (10.0%)
Group B	**Low**	0 (0)	0 (0)	0 (0)	0 (0)
	Low < medium	6.7% (0)	6.7% (8.3%)	6.7% (0)	13.3% (16.7%)
	Medium	40.0% (41.7%)	33.3% (25.0%)	40.0% (41.7%)	26.7% (25.0%)
	Medium < high	46.7% (50.0%)	53.3% (58.3%)	46.7% (50.0%)	53.3% (50.0%)
	High	6.7% (8.3%)	6.7% (8.3%)	6.7% (8.3%)	6.7% (8.3%)
Group C[4]	**Low**	0 (0)	0 (0)	0 (0)	0 (0)
	Low < medium	6.2% (0)	18.8% (22.2%)	6.2% (0)	18.8% (11.1%)
	Medium	50.0% (55.5%)	31.2% (33.3%)	37.5% (33.3%)	6.2% (11.1%)
	Medium < high	37.5% (33.3%)	43.8% (44.4%)	37.5% (33.3%)	68.8% (77.8%)
	High	6.2% (11.1%)	6.2% (0)	18.8% (33.3%)	6.2% (0)

A comparison of the estimates between the three groups shows no significant difference in the chosen values (χ^2 values between 6.97 and 13.80, degrees of freedom=12 and p<0.05). However, comparing the values for the two questionnaires, the results for all the participants show that there is a significant difference for group A and C for the 2018 estimate. Participants of group A tended to lower their forecasts, those of group C to increase it. The

3 Significant difference between questionnaires 1 and 2 for group A, cost estimate for 2018, all participants, χ^2= 3.91, degree of freedom = 1, p<0.05.
4 Significant difference between questionnaires 1 and 2 for group C for all participants for 2018, χ^2=4.59; for experienced participants 2014 χ^2=7.04, for 2018 χ^2=6.60; degree of freedom=1, p<0.05.

reason for this difference in the reactions is explored in the following sections. No difference was found in the forecasts of 2014 and both estimates of group B. The results for the experienced participants show that there is a significant difference between the two questionnaires only for group C for both years. This indicates that for group A the difference of the stated estimates between the questionnaires was caused by the non-experienced participants.

6.3.2 Confidence levels

This section discusses the participants' reactions to the different types of graphical display in the context of their confidence level. Figure 6-4 shows the results for the three groups.

Again, no significant difference was found between the responses from the experienced participants and the others so there was no evidence that the experienced users of the graphs were more confident in their forecasts than the inexperienced users. In general, it would be expected that the participants would be less confident with their 2018 cost estimate than with their estimate for 2014. However, this expectation was not confirmed for either of the groups (χ^2 values between 0.19 and 5.18 for the whole set of participants and between 1.48 and 2.72 for the experienced participants, degrees of freedom = 1, $p < 0.05$).

The introduction of contextual information in questionnaire 2 resulted in a significant change only for group C; those participants became more confident. A possible reason can be seen in the fact that the most frequently stated confidence levels for group C in questionnaire 1 was 0-20% and thus were significantly lower than the ones of groups A and B. A more detailed analysis of the participants reasoning is discussed in Section 6.3.3.

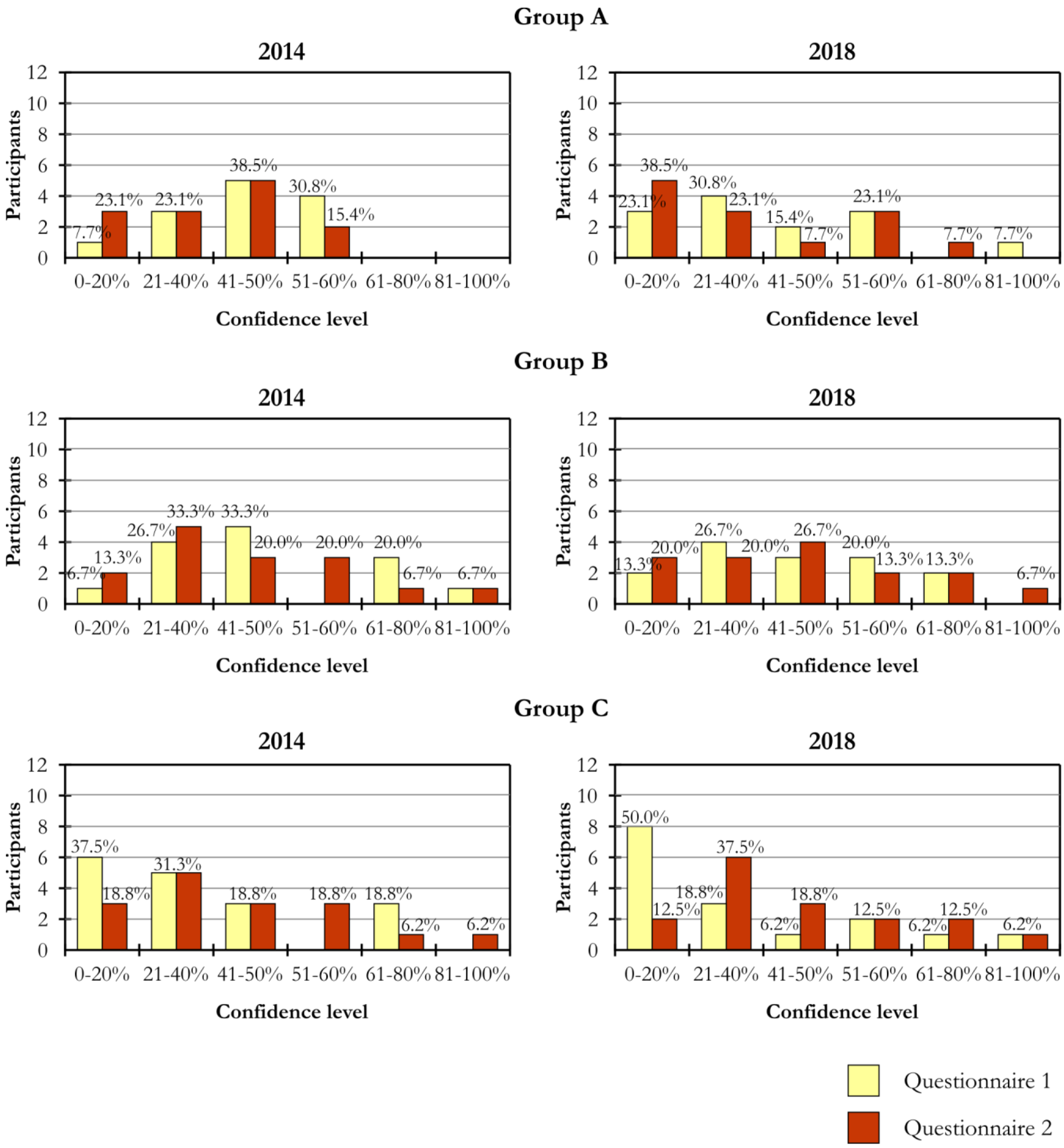


Figure 6-4: Confidence levels for each group in comparison

Table 6-4 depicts the given confidence levels in percentage for all the participants and for the experienced participants in brackets.

Table 6-4: Confidence levels by group for whole set and experienced subset of participants

	Year	**2014**		**2018**	
	Questionnaire	**1**	**2**	**1**	**2**
Group A	**0 - 20%**	7.7% (10.0%)	23.1% (30.0%)	23.1% (20.0%)	38.5% (20.0%)
	21 - 40%	23.1% (20.0%)	23.1% (30.0%)	30.8% (30.0%)	23.1% (10.0%)
	41 - 50%	38.5% (40.0%)	38.5% (20.0%)	15.4% (20.0%)	7.7% (10.0%)
	51 – 60%	30.8% (30.0%)	15.4% (20.0%)	23.1% (20.0%)	23.1% (20.0%)
	61 – 80%	0 (0)	0 (0)	0 (0)	7.7% (10.0%)
	81 – 100%	0 (0)	0 (0)	7.7% (10.0%)	0 (0)
Group B[5]	**0 - 20%**	6.7% (0)	13.3% (8.3%)	13.3% (8.3%)	20.0% (25.0%)
	21 - 40%	26.7% (33.3%)	33.3% (41.7%)	26.7% (33.3%)	20.0% (25.0%)
	41 - 50%	33.3% (33.3%)	20.0% (16.7%)	20.0% (25.0%)	26.7% (25.0%)
	51 – 60%	0 (0)	20.0% (16.7%)	20.0% (16.7%)	13.3% (16.7%)
	61 – 80%	20.0% (16.7%)	6.7% (8.3%)	13.3% (8.3%)	13.3% (0)
	81 – 100%	6.7% (8.3%)	6.7% (8.3%)	0 (0)	6.7% (8.3%)
Group C[6]	**0 - 20%**	31.3% (33.3%)	18.8% (22.2%)	50.0% (66.7%)	12.5% (11.1%)
	21 - 40%	31.3% (11.1%)	31.3% (22.2%)	18.8% (0)	37.5% (44.4%)
	41 - 50%	18.8% (22.2%)	18.8% (11.1%)	6.2% (0)	18.8% (11.1%)
	51 – 60%	0 (0)	18.8% (22.2%)	12.5% (11.1%)	12.5% (11.1%)
	61 – 80%	18.8% (33.3%)	6.2% (11.1%)	6.2% (11.1%)	12.5% (11.1%)
	81 – 100%	0 (0)	6.2% (11.1%)	6.2% (11.1%)	6.2% (11.1%)

5 Significant difference between questionnaires 1 and 2 for group B in 2014, for all participants $\chi^2 = 4.92$, experienced participants $\chi^2=4.08$, degree of freedom=1, $p<0.05$.

6 Significant difference between questionnaires 1 and 2 for group C, 2014: all participants $\chi^2=5.98$, experienced participants $\chi^2=4.87$; 2018: all participants $\chi^2=5.93$, experienced participants $\chi^2=8.57$, degree of freedom=1, $p<0.05$.

6.3.3 Reasoning for estimates

To understand the rationale used by the participants in providing their estimates, the narrative answers were examined. The reasons given for their estimates have been categorised as follows;

- ***More information:*** The participants stated the lack of information to enable a good estimate to be made.
- ***Medium:*** The medium point was judged as the most likely to occur.
- ***Conservative:*** A conservative answer was given, which includes the highest cost estimate or a point between medium and high.
- ***World economy:*** The given value was based on the subjective interpretations of the future development of the world economy.
- ***Uncertainty:*** The existence of uncertainty was explicitly mentioned.

Table 6-5 shows the values per category for all the participants with the answers of the experienced participants in brackets.

Table 6-5: Linguistic reasoning of groups

	Group A[7,8]		**Group B[9]**		**Group C[10,11]**	
Questionnaire	**1**	**2**	**1**	**2**	**1**	**2**
More information	15.4 % (20.0%)	0 (0)	20.0% (25.0%)	6.7% (10.0%)	12.5% (22.2%)	0 (0)
Medium	38.4% (30.0%)	38.4% (30.0%)	20.0% (0)	20.0% (0)	50.0% (33.3%)	6.2% (11.1%)
Conservative	15.4% (20.0%)	15.4% (20.0%)	33.3% (41.7%)	46.7% (58.3%)	12.5% (22.2%)	12.5% (22.2%)
World economy	15.4% (10.0%)	46.2% (50.0%)	13.3% (16.7%)	13.3% (16.7%)	18.8% (11.1%)	25.0% (11.1%)
Uncertainty	15.4% (20.0%)	0 (0)	13.3% (20.0%)	13.3% (16.7%)	6.3% (11.1%)	75.0% (55.6%)

7 Significant difference between questionnaires 1 and 2 for group A, $\chi^2=4.00$ for all participants and 6.67 for experienced participants, degree of freedom=1, $p<0.05$.
8 Significant difference between groups A and B for questionnaire 2, all participants and experienced participants $\chi^2=9.96$, degree of freedom=4, $p<0.05$.
9 Significant difference between groups B and C for questionnaire 2, all participants $\chi^2=9.88$, degree of freedom=4, $p<0.05$.
10 Significant difference between questionnaires 1 and 2 for group C, $\chi^2=7.59$ for all participants and 5.67 for experienced participants, degree of freedom=1, $p<0.05$.
11 Significant difference between groups A and C for questionnaire 2, all participants $\chi^2=11.88$, degree of freedom=4, $p<0.05$.

The additional contextual information in questionnaire 2 was found to influence the reasoning of the participants of groups A and C. Thus, for group B the graphical display had a higher influence on the chosen cost estimate than the additional contextual information. The same results were found for the experienced participants.

A comparison of the three groups shows a significant difference between the reasoning of the three groups for all participants only for questionnaire 2. This means that the combination of contextual information and different graphical displays triggered the decision maker to interpret the given information differently. In contrast, for the experienced participants, the only significant difference was found in the comparison of groups A and B, questionnaire 2. In other words, the knowledge of the experienced decision makers outweighed the influence of the display approach for group C.

Without the contextual information, the participants of groups A (three-point graph) and C (fan diagram) chose a medium value for their forecast and group B (bar chart) chose a conservative value. With the introduction of additional contextual information, participants of group A were more likely to state the influence of the world economy on their cost forecast, group B still chose a conservative forecast, and participants of group C stated uncertainty as an important reason for their cost estimate. Thus, the fan diagram can be identified as the graphical approach that is most likely to trigger the decision maker to recognise the uncertainty inherent in the cost estimate.

6.4 Discussion

The results of the first experimental study show the effect that different approaches to displaying uncertain forecasting information can have on its perception and interpretation. Participants in all groups were most likely to choose a cost forecast that was medium or between medium and high.

Participants of group A were more likely to have a confidence level around 50% and state the medium value as the reason for their decision. The additional contextual information caused these decision makers to lower their forecast and change their reasoning to the influence of the world economy. The confidence levels stayed unchanged. For the experienced participants of group A, these values were similar to that of the novices; however the additional contextual information had no influence on their answers.

Participants of group B were most likely to choose a confidence level around 40% and state a conservative value as the reason for their decision. The additional contextual information produced no change for this group. The level of experience had no influence on the participants of group B.

Participants of group C were most likely to have a confidence level around 20% and state the medium value as the reason for their decision. The additional contextual information triggered those participants to increase their confidence levels and to identify uncertainty as a main reason for their cost estimate. The experienced participants of this group had similar results; however, the additional contextual information triggered them to lower their cost estimate.

The identification of the world economy as a possible influence on the participants' decision (particularly of group A) can be classified as an uncertainty, which is outside of the decision maker's control or influence (also described as exogenous context uncertainty [de Weck et al., 2007], see also Chapter 5). Therefore, the three point trend forecast prompted the decision makers to include this particular type of exogenous uncertainty in their choice. Thus, it can be used as a display approach for cost forecasting scenarios, which are mainly influenced by this type of uncertainty.

Despite the uncertainty inherent in the given information, point estimates were common, even when the existence of uncertainty was identified. Most of the participants that stated range estimates were experienced in the field (the only exception was observed in group C where one inexperienced participant gave a range estimate). This indicates that decision makers tend to simplify their cost estimate when including the information in their decision, a finding, which is consistent with those of earlier studies, as described by e.g. Dawes [1988] and Simon [1982]. Decision makers tend to simplify the level of uncertainty from a possible range of future outcomes to a limited set. This is an important point especially in the context of inducing decision makers to consider uncertainty in their choices. A decision maker in reality is not only limited in the amount of information s/he can ascertain and its complexity but also on the level of uncertainty s/he is able to consider.

Particularly for group C, the additional contextual information triggered the participants to identify the uncertainty inherent in the cost estimate. However, drawing the conclusion that more contextual information would lead to an enhanced consideration of uncertainty is not applicable as human beings are bounded in the amount of information they can perceive and include in their decision process [Sent, 2004; Radner, 2000; Rubinstein, 1998]. Shanteau [1992] provides a review of experimental work that focuses on the use of given information in the decision process by both experts and non-experts. It was not the aim of this study to identify the optimal amount of information given to a decision maker nor was any such conclusion found in the literature. Further research needs to be carried out in this area.

The potential limitations of this experimental study are connected mainly to the decision making environment. Given the fact that the participants of the experiment were drawn out of their usual organisational and political environment and put into the artificial decision environment of the workshop, not all the impacts of possible influencing factors can be simulated [Goodwin and Wright, 1993]. Some of the motivations to produce a correct estimate may simply not be possible to include in the experiment situation. Those motivations can be rewards for an accurate forecast as well as those related to the organisational conditions the decision maker works in [Goodwin and Wright, 1993]. As the experiment was carried out in the professional environment of a workshop connected with the topic, those limitations can be accounted as only partly applicable. The participants were experts on the topic of cost forecasting and the interpretation of cost estimates belonged to their professional work.

6.5 Summary and conclusions

This chapter described the first experimental study and answered objective 2a, which was "To identify the decision maker's interpretation of uncertain costing information". The findings can be summarised as follows;

- The decision makers can be influenced in their recognition and consideration of the uncertainty connected to the cost estimate. In particular, the approach for displaying the uncertain cost information can influence this subjective decision process.
- The three tested approaches were interpreted differently by the participating decision makers. This includes differences in the stated reasoning behind their decisions, the confidence levels and interpretation of contextual information.
- The participants who were presented with the fan diagram were less confident in their estimates, were more likely to state a range forecast, and identified uncertainty as a major factor on the cost estimation outcome.
- The information describing the estimation context forms an important aspect to raise the decision maker's awareness of the uncertainty connected to the decision.

Out of the three displays tested, the fan diagram was the most effective in raising awareness of the associated uncertainty. Thus, the fan diagram was used in the following empirical research, in particular for the second experimental study, which is described in the next chapter.

7 Competition in bidding

This chapter presents the second experimental study, which focused on the influence of the competitive environment on the decision process. It investigated objective 2b, namely "To identify the influence of the competitive environment on the pricing decision". Figure 7-1 depicts the focus of this study within the decision process as presented in Section 4.1.

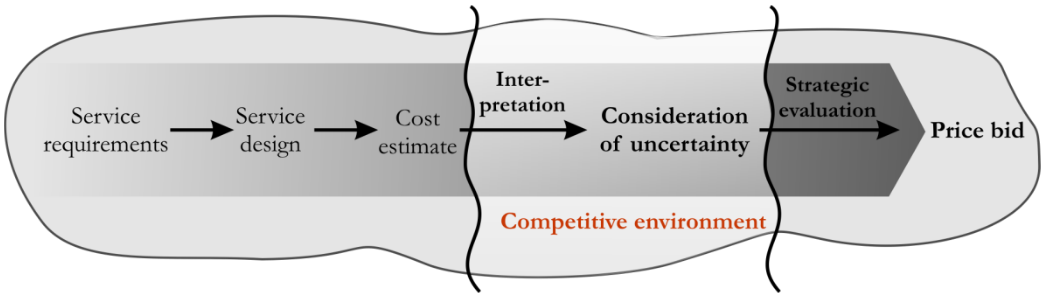


Figure 7-1: Focus of second experimental study within the decision process

The aim of the presented study was to describe and classify the influence that competition has on the pricing decision and the bidding strategy of the decision maker. An experiment is introduced, which investigated the decision makers' reaction to a bidding scenario with and without the existence of competition. Induced from the answers the participants gave in the different scenarios, the decision maker's rationality facing an uncertain situation caused by competition is analysed. First, the literature discussing the rationality of a decision maker is described.

7.1 Rationality under uncertainty

In literature, the rationality of a decision maker is typically described in the context of predicting the outcome of decision problems in e.g. Game Theory and utility theory [von Neumann and Morgenstern, 1944]. A decision maker has been described as instrumentally rational when s/he has priorities over the outcomes of his/her decision and selects actions that will best satisfy their preferences under the consideration of the information available for the specific decision problem. In theory, a rational decision maker who knows about the rationality of his/her competitors, can predict their likely actions in a bidding process [von Neumann and Morgenstern, 1944; Briceno and Mavris, 2006].

Under the existence of uncertainty, a decision maker cannot be described as instrumentally rational but as bounded rational [Sent, 2004; Radner, 2000]. The bounds on the decision maker's rationality have been described as e.g. the limited complexity of ascertainable information [Rubinstein, 1998] and the ability to learn [Radner, 2000]. Thus, the existence of uncertainty can influence the decision maker radically in his/her consideration of input information [Kreye et al., 2010], the belief of the occurrence of specific events in the future [Dickinson, 2009; Strat, 1990], or the decision made [Pomerol, 2001].

In this context, the decision maker's attitude towards uncertainty has been discussed[12] [Dickinson, 2009]. According to the literature in the field, a decision maker can be uncertainty averse, neutral or seeking. An uncertainty-averse decision maker would ask for a proportionately higher premium in exchange for higher uncertainty [Pratt, 1964]. This means that through the existence of competition, an uncertainty-averse decision maker would bid a higher price than without competition. An uncertainty-neutral decision maker is unaffected by the existence of uncertainty [Davies, 2006]; thus, s/he would not be affected through the existence of competition in a bidding process. An uncertainty-seeking decision maker looks for a negative uncertainty premium, i.e. prefers a situation of higher uncertainty in comparison to one of lower uncertainty [Davies et al., 2006]. The existence of competition would lead an uncertainty seeking decision maker to give a lower price bid.

This study does not focus on concluding the attitude of a decision maker when faced with a competitive bidding situation but on the deduction of their rationality. Thus, it is important to understand that all reactions - a raise, consistency and reduction of the stated price bid - are possible, explainable and compatible with existing theory. For this research, it forms the base for the assessment of the rationality of a decision maker in the described scenario.

For this research, a practical definition of a rational decision maker is adopted. In other words, for a decision problem under uncertainty, such as the discussed competitive bidding for service contracts, it is assumed that a rational decision maker exists. The rationality of the decision maker is observable in the stability of the strategy behind the choices and actions of the decision maker [Simon, 1982, p. 271]. This approach offers a practical application and differs from some literature such as the approaches used in decision theory [Abdellaoui and Hey, 2008; Harrington Jr., 2009]. However, this is not to be understood as a contradiction with the existing literature in this field but as an enhancement to practice. In this thesis, a rational decision maker is defined as an individual who chooses actions that best satisfy his/her preferences and apply it to a competitive bidding context. A definition for the

[12] This is typically discussed as risk attitude due to the different definitions of the terms uncertainty and risk in the domain of economics and decision making in comparison to the engineering domain. In economics, risk is usually understood as a decision situation when the probability of the outcome of events is known (see e.g. KAHNEMAN, D. & TVERSKY, A. (1979): *Prospect Theory: An Analysis of Decision under Risk*. In: Econometrica*,* 47(2), pp. 263-291.) This paper applies the definitions as described in the engineering domain. However, the decision maker's attitude towards uncertainty has only been discussed in the domain of economics, thus it is usually found under the terminology of "risk attitude" (see e.g. DICKINSON, D. L. (2009): *The Effects of Beliefs Versus Risk Attitude on Bargaining Outcomes*. In: Theory and Decision*,* 66(1), pp. 69-101.)

assessment of the rationality of the decision maker in the stated decision problem is given in Section 7.2.4.

7.2 Method

The main aim of the second experimental study was to assess and understand if and how a decision maker's bidding strategy changes when faced with competing companies for the same contract. Therefore, the objectives of the experiment were as follows;

- To understand the way the stated price bid changes in the presence of competition.
- To induce the decision maker's perception of uncertainty connected to competition.
- To induce the rationality of a decision maker facing a competitive bidding situation.

To test these objectives, a scenario of bidding for a service contract for a lathe machine was introduced. This scenario contained a qualitative description of the decision problem and a graphical display of the cost forecast for the service contract.

7.2.1 Study procedure

This experiment consisted of two questionnaires, which were handed out with a time difference to prevent the participant remembering their previous answers in detail. The aim of this time difference was to prevent the participants simply copying the answers from the first to the second questionnaire without carefully reading and processing the changes in the scenario. Furthermore, the experimental design aimed at keeping the participants in the same decision context for both questionnaires to reduce the influence of ulterior factors such as a change of emotions [Schwarz, 2000], stress levels [Cannon-Bowers, 1998], or the decision context [Adair, 1984; Robson, 2011]. In summary, the time difference between the questionnaires was chosen to be long enough for the participants to forget the details such as wording of their previous answers and short enough to not change the overall decision situation. Thus, the experiment was undertaken at an all-day conference on cost forecasting. The first questionnaire was handed out and collected early in the morning and the second one in the afternoon. In between the questionnaires the participants were engaged intensively in intellectual activities including presentations on costing practices in industry and informal discussions on current issues in the field. This approach is similar to the one used for the first experimental study presented in Chapter 6.

The general scenario was the same in both questionnaires: the participants were in the situation of bidding for a 5-year service contract for one of the company's lathes. The price was assumed to be a fixed yearly fee. The cost forecast information was given in a fan diagram as shown in Figure 7-2 because this graph was identified as raising the awareness and understanding of the participants with regards to the influence of uncertainty on the costing and decision outcome [Kreye et al., 2012].

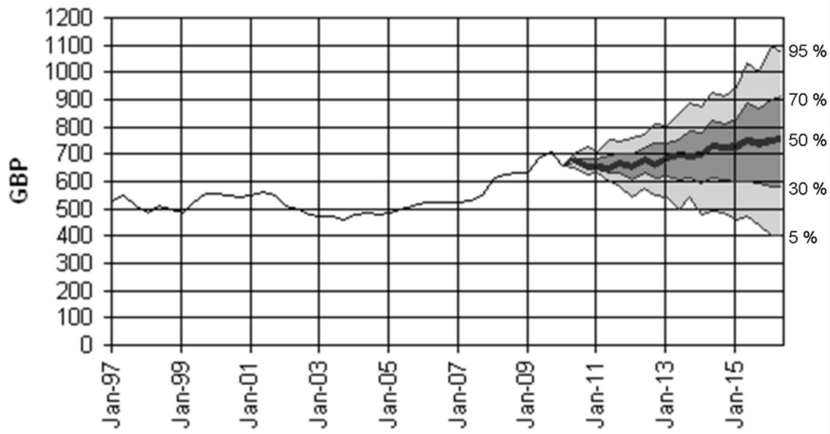


Figure 7-2: Graphical display of cost estimate in the questionnaires

In addition, a description of the general meaning of the graph was given as the following;

> *"The lower graph labelled 5% equals a 5%-confidence limit that the future costs will be these or lower. The equivalent explanation can be given for 30%, 50%, 70% and 95% confidence limits. The graph labeled 50% is the baseline estimate derived from typical service histories for CNC lathes. The lower graph shows the minimum costs expected to occur if only preventive actions i.e. planned maintenance occurs. The upper graph is based on the assumption that more than anticipated repairs are encountered in service."*

The cost data was artificially generated so that the observations were distributed randomly around a linear upward, flat, or downward trend.

7.2.2 Questionnaire design

The two questionnaires contained the following information:

- ***Questionnaire 1:*** The main scenario and bidding problem were introduced and described. The terminology "negotiate" and "tender" was used in order to not bias the participants. The existence of competition was neither mentioned nor excluded from the scenario. This assumption was left to the participant to answer. Other assumptions the participants had to make were about the bidding strategy of the customer, their budget limits, preferences or beliefs.

- ***Questionnaire 2:*** The general scenario and bidding problem were the same as explained in Questionnaire 1. The existence of competition was explicitly mentioned. It was assumed that the competitors had access to the same cost information as oneself and had sufficient knowledge about the processes of maintaining the lathe. Uncertainties influencing the decision were exemplified as the bidding strategy of the opponents, the price bids of the competitors and their overall service budget.

It can be assumed that each individual interprets the described information in a different way [Adair, 1984; Robson, 2011]. The graphical information the participants were given, was free of any recognisable past trends and time series to reduce the influence of interpretation. Furthermore, the participants were given the opportunity to use the terminology according to their own understanding and describe the meaning shortly.

Both questionnaires asked the following questions, all phrased as open questions:

1) What cost estimate would you choose?
2) Why did you select this?
3) What profit margin would you add?
4) What would your first tender be?
5) What is the minimum price you would bid?
6) In your opinion, what are the influencing factors on setting this minimum price?
7) What risks/uncertainties have an influence on your decision? How did they impact your decision?

Questionnaire 1 also asked for an explanation in case there was a difference between the *first tender* and *minimum bid* of the participant. The explanation given in this question can be expected to not change for the second questionnaire, hence the question was not asked a second time. However, Questionnaire 2 introduced a follow-up scenario to the described bidding scenario:

> *"In the negotiation process you reached your bidding limit, i.e. the lowest you can go to maintain your expected profit margins. However, the customer comes back to you asking for a price reduction, which could mean that at least one opponent has bid lower than you, or they have a lower budget. You have the choice of refusing that offer (and maybe affront the customer) or lower your bid (e.g. by reducing the profit margin or raising the risk to end up with a loss-generating contract)."*

The questions asked about this follow-up scenario were as follows;

1) Would you reduce your bid?
2) What would be the rationale/explanation for your reaction?

This additional scenario was aimed at the possibility of changing the bidding strategy of the decision maker when facing a more specified negotiation with the customer. The two questionnaires are presented in Appendix B.

7.2.3 Participants

The study was carried out at a conference of the Society for Cost Analysis and Forecasting (SCAF) and a conference of the Association of Cost Engineers (ACostE), which are the two main societies of industrial cost engineers in the UK [SCAF, 2011; ACostE, 2010]. The all-day conferences were attended by costing experts from the defense and aerospace sector, which have similar settings to the experimental study described in Chapter 6. The total number of returned questionnaires was 39 for questionnaire 1 and 32 for questionnaire 2, out of which 28 were traceable, i.e. the results of questionnaire 1 and 2 could be compared.

The participants were asked about their experience with a fan diagram as a graph to display uncertain forecasting information. These questions were "*Have you seen a diagram like this before?*" and *"How would you interpret the diagram?"* Out of the participants, 54% had seen a diagram like the one presented before, 43% had not and 3% did not give an answer. The question about the participants' interpretation of the fan diagram was formulated as an open question to encourage the use of their individual terminology and phrasing and to eliminate any bias. Although the exact wording was not the same, given answers showed a repetition of certain terms and ideas for some participants. The answers were therefore grouped into the following categories;

- ***Uncertainty/risk:*** The answers falling into this category mentioned either uncertainty or risk as a major feature of the fan diagram. Although the terms do not describe the same issue, they are grouped in the same category because the participants tended to use them interchangeably. What exactly each participant understood of risk and uncertainty was not part of the experiment.
- ***Probability:*** This group argued that the future occurrence of the service costs followed a distribution with certain probabilities shown in the diagram. This is not necessarily connected to the mathematical meaning of probability but also include the likelihood of the occurrence of an event in the future which can also be expressed in e.g. words [Zimmermann, 2000].

- ***Confidence over time:*** This group highlighted the importance of the cost estimator's/ decision maker's confidence in the cost forecast as one of the major factors of the diagram. At this point the meaning of "confidence" was not clarified.

- ***Other:*** These answers could not be included into any of the before mentioned categories. One participant highlighted the trend of the past service cost as a major character of the fan diagram, another stated the possible repair costs of the lathe as the major influencing factor.

Figure 7-3 shows frequency of interpretations of the fan diagram by the participants.

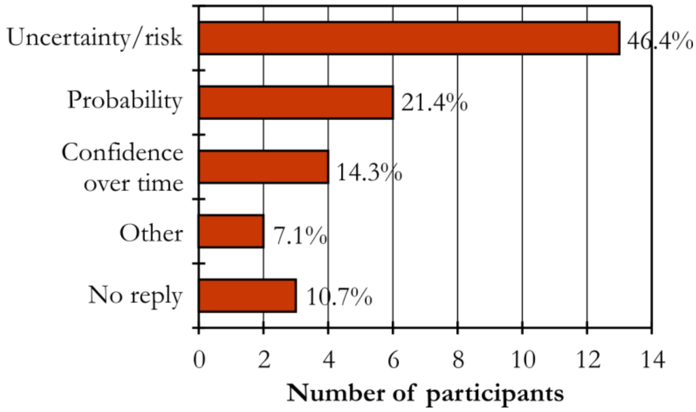


Figure 7-3: Participants' interpretation of the fan diagram

Figure 7-3 illustrates that 13 out of 28 participants (46.4%) explicitly mentioned uncertainty or risk as the major feature of the fan diagram. In addition, the definition of uncertainty as applied in this research is also connected to the understanding of probability values of a future event [Ben-Haim, 2004; Augustin, 2004] and different confidence levels over time [Giardini et al., 2008; Ellsberg, 2001, pp. 6-17]. Due to the open nature of this question, the terminology used by the participants could not be restricted. Hence, the explicit naming of uncertainty or risk (by 13 participants) as well as the descriptions of probability (six participants) and confidence (four participants) are indications of their understanding of uncertainty in its academic definition as applied in this research. Thus, it can be summarised, that 23 out of 28 participants understood the influence of uncertainty as the main aspect of the fan diagram. Based on this data, it can be assumed that the participants were able to understand and interpret the given information and fan diagram for their individual decision-making processes.

7.2.4 Rationality of a decision maker

In the context of bidding under uncertainty for a service contract, different decision makers perceive the situation differently and, hence, make different decisions. There is no absolute right decision that leads to a successful outcome mainly because of the influence of uncertainty [Hoffman and Yates, 2006]. The choices the participants had to make in the described scenario included:

1) The choice of a ***cost estimate***: This is the result of the decision maker's interpretation of the cost forecast. It gives a value to what the decision maker perceives as a likely outcome of the future cost value of the discussed contract.

2) The choice of a ***first price bid***: The decision maker then had to make a choice of what may be a good starting point for a possible negotiation with the customer. This gives a value to the optimal first price bid for covering the estimated costs, fulfilling the aspired profit margin and remaining in the negotiation/bidding process.

3) The choice of a ***minimum price bid***: This question assessed what the minimum acceptable price for the contract would be. In other words, it assessed the amount the decision maker was willing to reduce the profit margin to win the contract.

The entirety of these three choices is referred to as the ***bidding strategy***. The combination of first and minimum price bid is referred to as the ***pricing strategy.***

Based on these choices, the rationality of the decision maker was induced. Induction means that theoretical conclusions are drawn from empirical observations, as opposed to deduction where existing theory is applied to a particular practical situation. This research induces the decision makers' rationality based on their answers.

The following definitions of a rational, bounded-rational and irrational decision maker in the given decision problem are introduced at this point. The rationality of the participants is observable through their choices as follows:

Choice 1 - the cost estimate:

Perceiving the influencing factors correctly, a ***rational*** decision maker can be expected to choose a cost estimate that s/he thinks is most likely to occur in the future. Thus, a rational decision maker would not change this estimate when facing a competitive situation because the existence of opponents in the bidding stage does not have an influence on the costs of fulfilling the requirements of the contract.

A ***bounded rational*** decision maker may choose a more conservative cost estimate than what s/he thinks to be a realistic outcome. When facing a competitive situation, this estimate may then be "adjusted". Another reaction of a bounded rational decision maker may be to increase his/her own cost estimate as a result of a higher perception of the uncertainty involved in this situation. In this context a bounded rational decision maker is expected to change his/her cost estimate as a result to a change of the scenario.

In this context, an ***irrational*** decision maker does not exist as the influencing factors on that decision are various and the value, with which they are taken into account, cannot be categorised as *"absurd"* or *"delusive"* [Simon, 1982].

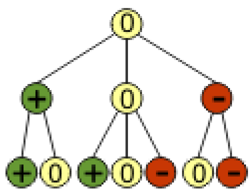
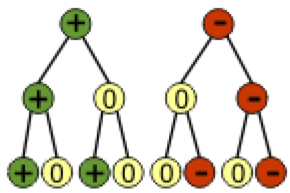
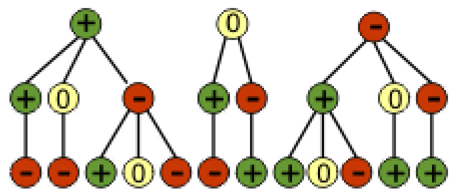
Choice 2+3 - the pricing strategy:

A ***rational*** decision maker can be expected to have a stable or semi-stable pricing strategy depending on the perception of the changed scenario. In this research, a stable pricing strategy is defined as both price bids are either changed in the same direction (so both price bids raised or reduced) or are both kept unchanged through the introduction of competition to the scenario [Afuah, 2009; Hall and Saias, 1980]. A semi-stable pricing strategy is defined as the change of one price bid while the other is kept unchanged. For example, the minimum price bid can be left unchanged when the first quoted minimum price already includes all perceived uncertainties and a minimum acceptable profit margin; or the first price bid was already chosen as the appropriate starting point for further negotiation.

An ***irrational*** decision maker can be expected to have a mixture of his/her bidding strategy, so s/he raises one of the values for first or minimum price bid while reducing the other.

Table 7-1 summarises the method of inducing the participants' rationality based on their observable bidding strategy. The raise of values through the influence of competition is marked with a "+", the reduction with a "-", and the consistency in value with a "0". These definitions are applied to the results of the empirical study.

Table 7-1: Characteristics of rational, bounded-rational, and irrational decision makers

Decision problem	Rational decision maker	Bounded rational decision maker	Irrational decision maker
1) cost estimate 2) first price bid 3) min. price bid			

7.3 Results

In this section the results of the experimental study are analysed in the order of the questions that were asked, explaining the differences between the first and second questionnaire of the experiment. First, the chosen cost estimates are described, then the preferred profit margins are introduced, before the first and minimum price bids are compared. Second, the uncertainties that the participants stated as influencing their choices are explained. Finally, the answers to the additional scenario in questionnaire 2, namely the customer's request for further reduction of the price bid, are illustrated. The results were tested regarding their statistical significance using a t-test due to the number of participants (in general, the t-test can be used when the tested sample is smaller than 30 [Lapin, 1987, p. 365]). The utilised equations are presented in Appendix B.

7.3.1 Cost estimates

Based on the information given in the fan diagram and the context of a bidding situation, the participants were asked to give a cost estimate. The results confirmed the author's expectation based on the first experimental study (see Chapter 6). Most participants (97%) chose a point estimate as opposed to a range forecast despite the uncertainty involved in the process. Figure 7-4 shows the point estimates stated by the participants for questionnaires 1 and 2. For reasons of clarity, the range estimates are not displayed; however, they are included in the percentage numbers in Figure 7-4. Hence, the percentages do not add up to 100%.

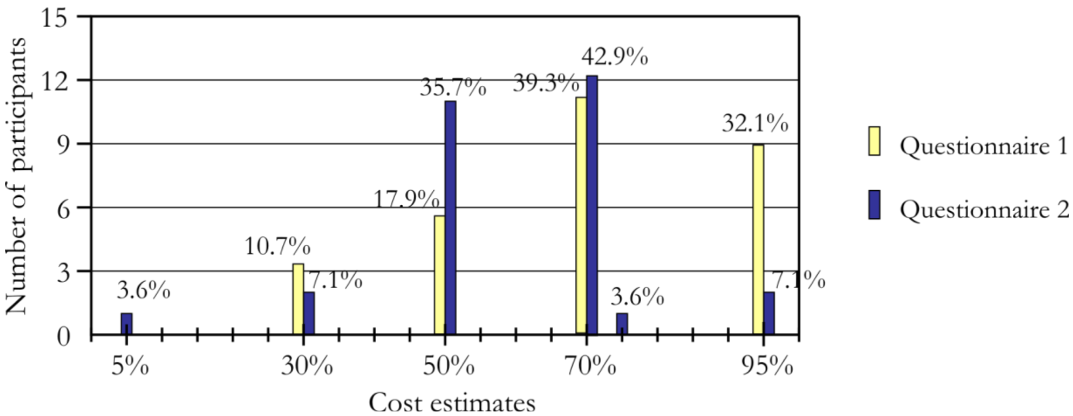


Figure 7-4: Cost estimates stated in questionnaires 1 and 2

In general, the stated cost estimates between both questionnaires are significantly different with a t-value of 3.131 (degrees of freedom = 27 and $p<0.05$; $t_0=1.703$). Comparing the answers of questionnaires 1 and 2, eleven participants (39.3%) reduced their cost estimate when competition was introduced to the scenario. This is an unexpected outcome as the costs are usually not lower due to competitors offering the same service. On the other hand, 16 participants (57.1%) did not change their cost estimate but chose the same (point) forecast.

To investigate, why the participants chose these cost estimates, they were asked to describe their reasoning (question 2). These reasons were classified into three categories: reduction due to competition, balance out the risk/uncertainty connected to the contract, and the expected costs over the contract period. Table 7-2 depicts these three categories including a more detailed description and the frequency, with which it was mentioned in the presented study.

Table 7-2: Participants' reasoning behind the chosen cost estimates

Category	**Description**	**Frequency**
Reduction due to competition	The presence of competition in the bidding scenario caused the decision makers to reduce their initial cost estimate to "*be competitive*" and *"stay in the negotiations"*[13].	10
Balanced risk/uncertainty	The decision makers explicitly mentioned risk or uncertainty as the reason for their cost estimate and balanced this in comparison to their expectations of the future costs.	7
Expected costs	The decision makers chose the cost estimate that best fitted their expectations of the future costs of the service contract. This could be a mean value over the contract period or a (imagined) trend line of the costs.	11

The results in Table 7-2 show that the majority of the participants (18 out of 28) did not change the reasoning behind their chosen cost estimate (even though they may have changed the cost estimate itself). However, it is possible that the participants stating *balanced risk/uncertainty* as a reason included the existence of competition in this statement. When the existence of competition was explicitly adopted in the decision makers' reasoning, they argued that they reduced the cost estimate to *"be competitive"* or to *"stay in the negotiations"*[13].

It is to be noted that the three reasoning categories were correlated with a particular reaction in the interpretation of the cost estimates. When the participants stated a "reduction due to competition" as their reason, they would also reduce their stated cost estimate value. Similarly, the reason of "balanced risk/uncertainty" was connected to a consistent interpretation of the cost estimate between both questionnaires. This indicates that for the participants of this category, the existence of competition did not raise or lower their perceived level of uncertainty influencing the decision outcome (with their individual definition of the term, the specifications of this definition was not investigated in this study). In contrast, the third

[13] Quotes from the participants' questionnaires.

category of reasoning with the "expected costs" was characterised by varying interpretations of the cost estimate, i.e. the values were raised, lowered or stayed level.

7.3.2 Profit margins

The second factor in calculating the price bid is the profit margin that should ideally be achieved with the contract. At this stage of bidding, the profit margin can only be estimated or planned but it should be as close as possible to the actual (in the future) achieved profit margin. Table 7-3 gives an overview of the results of this study. It is to be noted that for reasons of easier presentation, the column "most frequently stated profit values" includes the stated profit ranges. In other words, a participant who stated a profit margin of *"10-15%"* would be included in both values of 10% and 15%.

Table 7-3: Profit margins stated in questionnaires 1 and 2

	Range value of profit	**Point value of profit**	**No answer**	**Most frequently stated profit values**
Questionnaire 1	20.5%	69.2%	10.3%	10% (stated by 41.0%) 15% (stated by 38.5%) 8% (stated by 15.4%)
Questionnaire 2	15.6%	78.1%	6.3%	10% (stated by 50.0%) 15% (stated by 28.1%) 8% (stated by 15.6%)

The stated profit margins were in a range between 5% and 20%. The results show a significant difference between the two questionnaires, i.e. the introduction of competition caused a change of the profit margins (t-value of 1.731, $p<0.05$, degrees of freedom = 24 due to three participants not giving a profit margin in one of the questionnaires; $t_0=1.711$). Another difference between the questionnaires was the reduction of range margins to point margins. The participants went from stating a range of possible profit margins to stating their aimed profit margin for the first price bid. They chose a specific point from their range stated in questionnaire 1. It can be summarised that most of the participants stated 10% as their ideal profit margin for the described contract. The second most common selection for both questionnaires was a 15% margin.

7.3.3 Pricing strategy

In this experimental study the pricing strategy was simplified to the two values of first price bid and minimum bid. These values form the boundaries of the possible outcomes of the contract negotiations between the customer and the bidding decision maker. In practice, it can be expected that multiple factors have an influence on the final price bid due to the subjectivity of the decision process. However, the calculation of the different bid prices and the attributes taken into this calculation give a good indication of the subjective processes behind the bidding process. The pricing strategies described in this section are based on the 28 traceable questionnaires, out of which 25 stated all the values to define their pricing strategy as described in Section 7.2.4.

A comparison of the first price bids and the minimum price bids between the two questionnaires showed no significant difference (first price bid: t-value of 1.367, minimum price bid: t-value of 0.490, $p<0.05$, degree of freedom = 24, $t_0=1.714$). It is to be mentioned that the t-value for the first price bid shows a significant difference for $p<0.1$ ($t_0=1.321$), in other words the first price bid of a bidding decision maker is different (in this case significantly smaller) at 10% significance value. Furthermore, the changes of the first price bids between the two questionnaires show a high standard deviation (standard deviation of £137 around a mean of £33). This means that in the given cost range between £400 and £1100 (as depicted in Figure 7-2), the introduction of competition to the bidding scenario caused the decision makers to change their first price bid within a range of £411 (=3*£137). In other words, on average, the participants increased their first price bid by £33 but the actual change of each individual varied substantially. This indicates that with the introduction of competition, the price, from which the negotiations could start, can hardly be predicted, which introduces further uncertainty into the bidding process.

The stated price ranges, i.e. the difference between the first and minimum price bid, varied from £0 - £400. Figure 7-5 depicts the frequency, with which each range was picked by the participants.

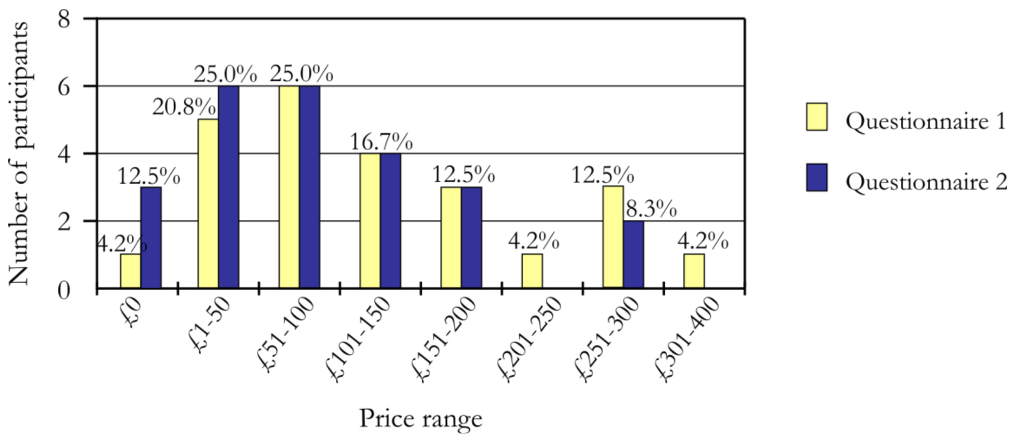


Figure 7-5: Price ranges in questionnaires 1 and 2

Of the 25 participants, 33.3% reduced their price range, 16.7% raised it and 50% remained indifferent with the introduction of competition. To interpret the implications, a closer look at the results has to be taken. Table 7-4 depicts the reaction of the participants to the introduction of competition to the scenario.

Table 7-4: Comparison of the pricing strategy between questionnaires 1 and 2

	Reduction	Raise	Level	Most stated values
First price bid	6	5	13	Questionnaire 1: £1000 (20.8%) £1200 (12.5%) £900 (12.5%) £700 (12.5%)
				Questionnaire 2: £800 (20.8%) £900 (16.7%) £1000 (16.7%)
Minimum price bid	5	5	14	Questionnaire 1: £800 (16.7%) £900 (12.5%) £700 (12.5%)
				Questionnaire 2: £800 (25.0%) £750 (16.7%) £700 (12.5%)

Comparing the price bids to the chosen cost estimates as described in Section 7.3.1, a difference can be noticed: 11 participants reduced their cost estimate; only six reduced their first price bid and five reduced their minimum price bid. On the other hand, only one participant raised their cost estimate, five participants raised their first price bid, and five raised their minimum price bid. This means that the participants pursued different strategies with the different scenarios.

The participants' pricing strategies in combination with their bidding strategies were used to induce their rationality (as described in Section 7.2.4). This is described in the following section.

7.3.4 Bidding strategy and rationality

The bidding strategy gives a holistic picture of the participants' decisions as it includes their chosen cost estimates and price bids. Comparing all three choices the participants were asked to make (1-cost estimate, 2-first price bid and 3-minimum price bid), the participants' level of rationality were induced. The results are summarised in Figure 7-6 which illustrates the classification of the participants' answers according to aspects of rationality as described in Section 7.2.4.

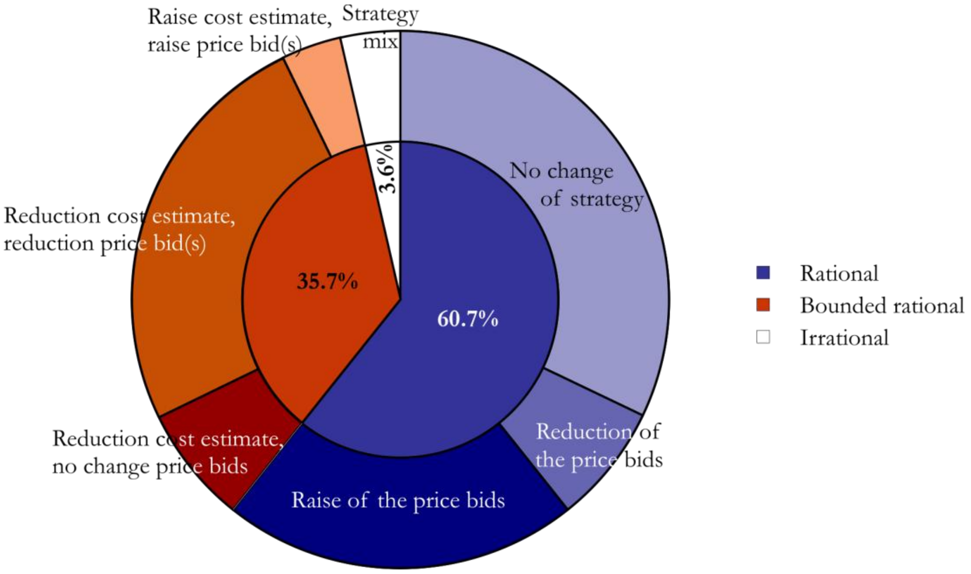


Figure 7-6: Rationality of the cost estimators

The induction of the participants' rationality resulted from their reaction to the changes made in the bidding scenario observable through their statements. It is not based on their intrinsic assumptions or the rationality of their aims as described by Simon [1982]. In general, stability in the participant's pricing strategy was observable: The participants either raised or reduced or did not change their price bids. Based on the introduction of competition in the second questionnaire, 32.1% did not change any of the three mentioned values. The other 67.9% made changes in one or more of these three choices. Only one participant (3.6%) chose a "mixture" of strategies: reducing the cost estimate with the introduction of competition but raising the price bids. This behaviour was classified as "irrational" in Section 7.2.4, which does not, however, mean, that this would not be justifiable. A possible explanation for this behaviour would focus on the increased profit margin that is applied to this contract, which can for example have positive impacts on the individual's evaluation in the company and therefore on the person's career development.

The majority of the participants (60.7%) chose a rational strategy as defined for a bidding decision under uncertainty (see Section 7.2.4). This means that they did not change their cost estimate between the two questionnaires and chose a stable (change of) pricing strategy. 35.7% of the participants' behaviour represented "bounded rationality", which means they chose to change their cost estimate as well as their price bid(s).

To understand the reasons for the choices and changes the participants made, it is important to see, which uncertainties they perceived as important influences on their decision. This is described in the next section.

7.3.5 Uncertainty at the contract bidding stage

The final question asked for the influencing uncertainty on the participants' decisions. This question is important as it offers information on the existence of uncertainty and possibility of reducing it. Hence, it is essential to include the perception of uncertainty in the decision making process. The answers to this question showed, that for the participants uncertainty was not an ungraspable concept that potentially threatens the outcome of the decision and the decision process. On the contrary, the decision makers were able to identify important uncertainties in the competitive bidding context and describe their influence. The uncertainties that were mentioned can be categorised as market uncertainties, uncertainties in cost estimation, product uncertainties, competition uncertainties and customer related uncertainties as listed in Table 7-5.

Table 7-5: Uncertainties at contract bidding stage

Uncertainty	Examples	Frequency
Market uncertainties	• Inflation • Future trends, economic changes • Technology development • Risk of cost increases in material costs and spare parts	34.2%
Uncertainties in cost estimation	• Inaccuracy of cost estimate • Uncertainty of bounding the estimate • Uncertainty in labour rates • Uncertainty in maintenance costs	36.8%
Product uncertainties	• Performance of the machine, ageing • Risk of failures • Level of repair	18.4%
Competition uncertainty	• Uncertainty in competitor • Risk of loss of contract • Experience with machine	26.3%
Customer related uncertainties	• Uncertainty of customer's utilisation rates of the machine • Uncertainty in future contracts and further orders	31.6%

The column entitled *"Frequency"* shows the percentage of the participants who mentioned these uncertainties in the presented study. These do not add up to 28 participants or 100%, as the question was phrased open-endedly and each participant could name as many uncertainties as s/he deemed were important. The percentages in Table 7-5 mark the amount that each of the categories was named out of every uncertainty entry.

The frequency of the different uncertainty categories show that the uncertainties connected to the cost estimate were valued as important by most of the participants. The least important uncertainty category of this experimental study was the product uncertainty; however, this category was still mentioned by 18.4% of participants. Thus, in an approach to model the uncertainty in a competitive bidding process, all of the described uncertainties have to be included and described.

7.3.6 Additional reduction of price bid

The additional scenario was to further reduce the price bid (beneath the previously named minimum price) when asked by the customer. The answers to this question showed the influence strategic mid and long term goals of the decision maker and the company have on the stated price bid. This gives an indication of the type of goals, which would have to be included in a model about the decision under uncertainty in a competitive bidding situation. Table 7-6 depicts the results of this additional scenario in this study.

Most of the participants (71.4%) refused a further price reduction in the described scenario. The stated reasons included the need to make profit, the unacceptably high risk of losses, the argumentation of the previous calculation being correct, and the inability to further reduce the uncertainty. The 28.6% of participants who stated they would accept a further reduction, argued that they could reduce the profit, remove further uncertainties, take the risk of making a loss, the need for the cash flow, and to adjust the costs (without an explanation of how this could be achieved). Table 7-6 shows the relative importance of these categories. The values do not add up to 100% because multiple answers were possible.

Table 7-6: Results of an additional reduction of the price bid

	Total frequency	Justification	
		Categories	Frequency
Refusal	71.4%	• ***Make profit***: The own company needed to make profit at reasonable risk with this contract. Further reductions would lower the profit and thus make the business less affordable.	35.0%
		• ***Risk of losses***: Further price reductions would enhance the risk of making losses.	25.0%
		• ***Correct calculation***: Some participants argued that their previously named minimum price bid was a result of correct calculation and thus already includes the possible risks that the company could take. Further reductions would not be possible.	20.0%
		• ***Uncertainty***: The uncertainty included in the forecast and their previous decisions cannot be reduced any further. Therefore, the previously stated minimum price already includes the minimum compensation for uncertainty which cannot be reduced either.	15.0%
		• ***Other***: Other reasons included the rejection of the price reduction was based on the negotiation style.	5.0%
Acceptance	28.6%	• ***Reduce profit***: further price reductions can be made affordable if the profit margin is reduced, e.g. by 25%.	12.5%
		• ***Remove uncertainty***: reduction of uncertainty involved in the scenario. Unfortunately, no examples or methods were given.	12.5%
		• ***Take risk***: take higher risk of making losses (without monetary compensation).	12.5%
		• ***Cash flow***: the importance of short term cash flows for a company.	25.0%
		• ***Adjust costs***: adjust the cost estimate to justify the further price reduction.	37.5%

7.4 Discussion

The aim of this experimental study was to assess and understand if and how a decision maker's bidding strategy changes when faced with competing companies for the same contract. The chosen method to investigate this aim was an experimental study consisting of two questionnaires, which offered the opportunity to study multiple decision makers in the same scenario. Additional influences such as knowledge and expectancy of the decision makers were taken into consideration throughout the preparation of the empirical research to limit their influence on the results.

In general, the simplified calculation of the price bid and the assumed decision process (introduced in Chapter 4, Figure 4-1) were proven applicable in the experimental study, i.e. a decision maker chose a cost estimate as an initial point of his/her decision and added a profit margin to achieve the price bid. The stated influencing information on the participants' pricing decisions was the cost estimate, the (aimed-for) profit margin and the uncertainty inherent in the process. In the choice of the bidding prices, the decision makers generally behaved in a rational or bounded rational manner, i.e. after the interpretation of the given information they followed a stable consideration in their bidding strategy. The final decision depended highly on the subjective interpretation of the situation and the uncertainty involved.

Other results of this experiment include the articulation of the participants' perception of influencing uncertainties in the bidding scenario. The answers to this question showed, that uncertainty is not an ungraspable concept but the decision makers were able to identify important uncertainties in the competitive bidding context and describe their influence. The possible impacts of uncertainty were understood and included in the decision process. The comprehension of the uncertainty in the decision process happened in different ways and to different levels, which was reflected in the price bids.

Findings and approaches described in literature were confirmed by this study. The existence of rational, bounded rational and irrational decision makers, as described by Simon [1982], Radner [2000] or Sent [2004], were found to be applicable to a competitive bidding situation. Moreover, the argumentation that the existence of competition results in low prices [Bajari et al., 2004, p. 1] was neither confirmed nor refuted with this study. In the participants' reasoning behind their chosen cost estimates, they stated that competition prompted them to reduce their cost estimates. However, in the investigation of the price bids, this general reduction could not be observed, the changes of the first price bids were connected to a high level of uncertainty.

The limitations of the presented study include the general criticism on closed studies, which means that the experiment was presented as a standalone decision problem. In practice this decision making problem may be embedded in a wider context, namely the general economic situation and other factors about the company's situation in the contract network [Robson, 2002].

7.5 Summary and conclusions

This chapter described the second experimental study, which investigated objective 2b "To identify the influence of the competitive environment on the pricing decision". The results of this study offer useful insights into the decision process under uncertainty in the competitive bidding situation. Testing two different bidding scenarios, one without and the other with competition, the following results can be summarised;

- The participants changed their decision when competition was introduced to the bidding scenario. In particular, their interpretation of the cost estimate and their chosen first price bid differed between the two scenarios. The stated minimum price bids were similar.
- The change of the first price bid showed a high standard deviation. Thus, the decision maker's perceivable reaction to the introduction of competition is uncertain.
- Based on these results, the rationality of the tested decision makers was induced. Most participants (60.7%) were judged to be rational in the sense that they did not change their cost estimate but adjusted their price bids in accordance with their evaluation of the uncertainty. Only 3.6% of the participants were judged to be irrational due to the fact that they mixed strategies.

This study showed that the existence of competition forms an important influencing factor on the pricing decision for service contracts. It poses a significant source of uncertainty, which is interpreted differently by different decision makers. However, this means that the existence of competition has to be included in a comprehensive description of a competitive bidding scenario in order to correctly model the influences of the different factors on the bidding strategy.

The two experimental studies presented in Chapters 6 and 7 investigated *what* uncertainties influence the decision maker at the bidding stage, i.e. objective 2. The findings show that particularly the cost estimate, the customer and competitors form important influences on the decision-making process. Based on these findings, the third empirical study investigated *why* or *how* this happens, which is presented in Chapter 8.

8 Information availability at bidding stage

This chapter describes the interview study focusing on objective 3 "To define the level of the identified uncertainties in the pricing decision process". Figure 8-1 shows the focus of this study within the bidding decision process as it was described in Section 4.1.

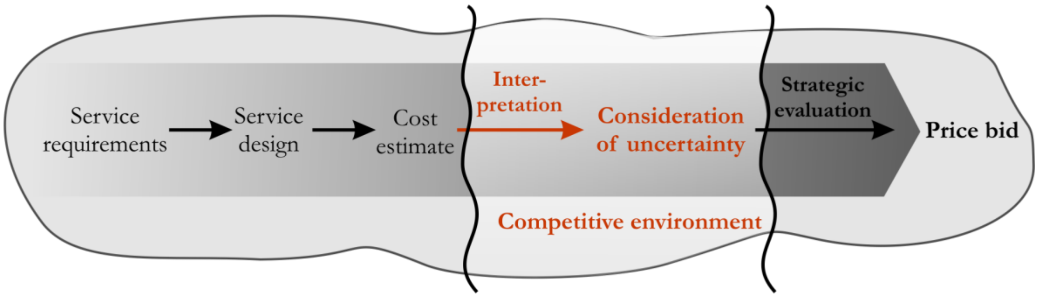


Figure 8-1: Focus of interview study within the decision process

This study investigated the pricing decision as a complete process to assess the reasoning, the availability, and the use of information at the competitive bidding stage. It shows the links between the two experimental studies and investigates the characteristics of the identified influencing factors on a pricing decision (described in Chapters 6 and 7), in particular the customer and competitors. The purpose of the interview study was to investigate the reasoning behind the decision and the levels of influence of these factors. First, the related literature in contract bidding including the bidding process, contract conditions and typical payment methods is described before the details of the study including procedure and participants are presented.

8.1 Bidding for contracts

Bidding for service contracts is typically based on conditions regarding the general bidding process, such as the level of negotiation between supplier and customer, and overall contract conditions, such as the contract length [Bajari et al., 2008]. These may differ between contracts but are typically applicable to all bidding parties for the same contract [Friedman, 1956; Bubshait and Almohawis, 1994; Shen et al., 2005; Sorrell, 2007]. These rules should limit the influence of favouritism or preferential treatment [Bajari et al., 2004] and ensure that the business proceeds for the "*mutual benefit of buyer and supplier*" [Nellore, 2001]. They also aid a successful completion of the bidding process itself and the development of a mutual understanding about the progression of the contract period [Bubshait and Almohawis, 1994] and, thus, frame the pricing decision process.

Specifications regarding the general bidding process include the permitted level of customer/supplier negotiation. In literature, different bidding processes for service contracts have been described, varying form auctions, where the competing bidders have one opportunity for the submission of a price bid, to negotiations, where the two parties (customer and supplier) can exchange important information prior to contract acquisition [Bajari et al., 2008]. Auctions are characterised by little interaction between the supplier and the customer [Klemperer, 2004; Milgrom, 2004]. It is a suitable method when many potential contractors exist and the service is of low complexity, i.e. only few independent tasks are necessary to fulfil the requirements [Bajari et al., 2008]. Examples for services of low complexity include cleaning services or domestic waste collection [Shostack, 1987; Skaggs and Youndt, 2004].

This research focuses on highly complex services (see Chapter 1); as such the processes of awarding service contracts with low complexity are not investigated. In contrast to auctions, negotiations can include the exchange of further information regarding the service and the contract agreement in bilateral form between supplier(s) and customer and are characterised by a long bidding process, starting from the call for bids and ending with the submission of the bids [Yee and Korba, 2003].

Specifications of the contract conditions typically concern the legal and financial aspect of the service contract and define the relationship between the parties during the contract period [Bubshait and Almohawis, 1994]. The legal aspects can include the terms and conditions of the contractual transaction and are often subject to standardisation [Bubshait and Almohawis, 1994]. These legal aspects represent an important part of the contract conditions and can influence the decision process during the bidding procedure.

The financial attribute includes the payment method for the service contract. Depending on varying specifications of the service itself, different payment methods have been described in literature [Tseng et al., 2009; Paul and Gutierrez, 2005];

- ***Fixed Payment (FP):*** The supplier receives a fixed payment irrespective of the actual occurred costs.
- ***Cost Plus (CP):*** The customer reimburses the supplier for the actual cost and an additional fee. This fee can either be fixed (Cost Plus Fixed Fee - CPFF) or variable (Cost Plus Percentage - CPP or Cost Plus Margin - CPM).
- ***Menu payment:*** This is an intermediate method between FP and CP payments, where the supplier receives a fixed price per unit of used material or work.

The first two methods have been described in various applications and can be seen as the standard approaches [Oliva and Kallenberg, 2003; Connor and Hopkins, 1997; Goldberg, 1976]. The third method, menu payment, was introduced by Paul and Gutierrez [2005] and was described as a possible payment method for Product-Service Systems (PSS), where the customer pays for the provision of an agreed result [Baines et al., 2007]. According to Bajari et al. [2008], who assessed the connection between these rules of contract bidding in the construction industry, fixed price contracts tend to be awarded through auctions and cost-plus priced contracts through negotiations.

Embedded in these rules regarding the bidding process and service contract conditions, the pricing decision has to be made, which is based on the cost estimate (see also Section 4.1). This can be influenced by various factors including the decision maker's interpretation of the cost estimate and the existence of competition as shown in the two experimental studies. However, the decision maker's approach or the reasoning behind the decision and the levels of influence of these factors has not yet been discussed. This is the purpose of the interview study presented in this chapter.

8.2 Method

The aim of this third study was the assessment of the level of the identified uncertainties in the pricing-decision process. To fulfil this objective, the following details were investigated;

- To explore the availability of relevant information in the context of competitive bidding for a service contract on the supplier's side.
- To describe the subjective processes of the decision maker at the bidding stage.

The following sections describe the applied method of this study in more detail. First, the interview procedure is described, then the design of the interview with the questions is explained, before the interviewees are characterised.

8.2.1 Interview procedure

A standardised open-ended interview was carried out, which means that the wording and sequence of questions was determined in advance. Thus, each interviewee was asked the same questions in the same order [Teddlie and Tashakkori, 2009] - unlike the use of semi-structured interviews, where the question order can be varied [Robson, 2011; Saunders et al., 2009; Blessing and Chakrabarti, 2009]. This ensured that all topics were covered in each interview allowing a comparison between the answers of the different interviewees [Patton, 2002]. The questions were open-ended, i.e. no predetermined answers were given (or suggested) and the interviewees were encouraged to describe the processes in their own words. The interview method was characterised by the following;

- A pre-determined set of questions that were covered in each interview in the same order. Even if the interviewee implied in a previous answer that a certain aspect may not be applicable to their specific company, the question was asked to offer further comments or a simple repetition of the previous statement. All interviewees received a list of the covered questions and areas prior to the interview.
- The wording of the questions was similar between each interviewee, however, not always exactly the same. The exact wording depended on previous answers such as the interviewees' own definition of the terms risk and uncertainty.
- The questions were open-ended, i.e. the interviewees were encouraged to talk freely and explain their specific context. In case of misunderstandings or misinterpretation of a question, this was corrected and the intention of the question clarified.
- The implementation of the interview was either face-to-face or via telephone. Most of the time, this was one-to-one. On two occasions it was one-to-two, i.e. there were two interviewees present. On the first occasion, the second person was merely an observer for reasons of confidentiality. On the second occasion, the two interviewees answered different questions of the interview according to their area of expertise, i.e. neither of them completed a full interview questionnaire on their own. Thus, both these occasions were treated as one interview respectively in the analysis.

The interviews were not recorded as most of the interviewees were from organisations in the defence sector or simply not comfortable with recording. The results are based on the notes the researcher took during the interview processes. However, to ensure the correctness and limit the misinterpretation of the given information, the responses were returned to the interviewees after the interview for confirmation as explained in Robinson et al. [2007].

8.2.2 Interview design

The questions covered the following four main areas:

- Uncertainty and risk.
- Bidding context.
- Input information for the pricing decision.
- Bidding strategy.

Questions included in the first main area established the meanings the practitioners applied to the terms uncertainty and risk and how these were considered and identified in the pricing process. This established a common ground for the terminology in comparison to the definitions applied in the presented research and formed the basis for later questions.

The second main area - bidding context - established background information that could potentially influence the bidding strategy. The issues investigated were the current contract situation of the company [Monroe, 2002; Chapman et al., 2000], the usual bidding process for service contracts [Lehman, 1986], and the typical payment method once the contract was awarded [Tseng et al., 2009].

The last two areas formed the main focus of the interviews. The area of the input information for the pricing decision examined the form and type of information normally used in the decision process and possible assumptions the decision maker may form [Goh et al., 2010; Bolton et al., 2006; Fargier and Sabbadin, 2005; Rubinstein, 1998; Loewenstein and Prelec, 1993; Lehman, 1986]. The questions in this area examined the following details;

- The form of the cost estimate.
- The uncertainties included in the cost estimate.
- Possible further uncertainties that the decision maker considers in the pricing process.
- The available information about the competitors and the customer.
- The amount of input information that is considered in the decision-making process.

The area of bidding strategy established the subjective processes of decision making in the competitive bidding situation as this may influence the outcome of the decision process [Kreye et al., 2012; Stecher, 2008; Yager, 1999; Lehman, 1986; Tulloch, 1980]. The questions explored the following;

- The selection criteria of the decision maker.
- The interpretation of the cost estimate.
- The calculation of the price bid.
- The calculation of the minimum price bid.
- The possibility of accepting contracts with a high risk of making a loss.

The complete questionnaire that was used in the interviews can be found in Appendix C.

8.2.3 Interviewees

The interviews were carried out over one year (March 2010 to March 2011) during a rebound period after the global economic recession of 2008-2009. Nine interviews were undertaken in the following sectors:

- Defence (1), aerospace (1) and both defence & aerospace (2).
- Engineering (2).
- Research (1).
- Information technology (1).
- Construction (1).

The group of interviewees focused on the suppliers of product-centred and highly-complex services as defined in Chapter 1. However, in order to characterise the applicability of the presented research to other domains, services of low complexity were included in this study. The contract complexity cannot be described by a distinct value or factor that defines the difference between the two complexity grades. Thus, the service contracts included in this interview study were separated as follows;

- ***Low complexity***: the number of independent tasks necessary to complete the service is low [Skaggs and Youndt, 2004; Shostack, 1987]. In other words, the requirements are clear to the involved parties [Bajari et al., 2008]. The interviewees of this study named these "*small contracts"* and characterised them using phrases such as *"less than £3 million"*, *"less than 150,000 €"* or *"simple requirements such as the need of three engineers to do some testing"*.
- ***High complexity***: the number of independent tasks necessary to complete the service is high [Skaggs and Youndt, 2004; Shostack, 1987]. In other words, at the point of the bid invitation, the service design may be hard to define in detail [Bajari et al., 2008]. The interviewees named these *"large contracts"* and distinguished them with phrases such as *"more than £3M"*, *"complex tasks such as 18 months contract"* or *"site management"*.

Table 8-1 shows the frequency of answers from the interviewees.

Table 8-1: Interviewees' positioning regarding the complexity of their service contracts

	Low complexity	High complexity
Contract focus	2	3
Contract portfolio	4	

Four of the nine interviewees said they hold a portfolio of different complexity contracts, two focused on contracts of low complexity and three interviewees concentrated on contracts of high complexity. This differentiation was used as a basis for the analysis of the results.

8.3 Results

This section analyses the results of the interview study and presents them in the four main interview areas, namely uncertainty and risk, bidding context, input information, and bidding strategy. The term bidding strategy refers to the pattern of activities, which has an impact on the achievement of bidding goals such as winning a profitable contract (see also Chapter 3).

8.3.1 Uncertainty and risk

The aim of the questions in this section was to clarify the terminology used by the industrialists and, thus, to guide further discussion of the topic. At this point, the interviewees' understanding of the terms is discussed; the complete list of definitions stated by the interviewees is listed in Appendix C.

Differences could be observed between the interviewees in general. Some had corporate-wide definitions for risk and uncertainty; others used examples to describe their individual understanding, two interviewees did not use the term uncertainty. However, comparing the meaning or interpretation of the definitions, similarities can be found. Out of nine interviewees, seven understood uncertainty as the variation of an aspect of the contract such as the cost estimate.

Discussing the term risk, the interviewees agreed that it is connected to an impact. Furthermore, seven interviewees stated that it was connected to a specific event, such as the risk of a red light during a car journey or the loss of a team member whose knowledge is central to the fulfilment of the service. Two interviewees described it as the impact on the project as a whole. The interviewees' definitions of the terms risk and uncertainty were utilised throughout the process of interviewing as a basis for clarity. However, for the purpose of this research, the described definition of uncertainty (see list of definitions) is applied in the further analysis of the interview results; the concept of risk is not discussed further.

The interviewees' sources of identification and management tools for uncertainty can be classified based on the level of subjectivity. To identify the uncertainty connected to a project, all interviewees identified experience as the main source, which was typically connected to the team that put the bid together (stated by six interviewees) or to the project manager (stated by three interviewees). In addition, more objective identification sources were used such as a formalised risk analysis process in the form of e.g. a risk management handbook or databases of previous projects. This category was mentioned by four interviewees. For the identification of uncertainties, the practitioners used either a subjective method on its own or in combination with an objective method.

To manage uncertainty, subjective approaches were of less importance than for the identification; only five interviewees named this approach. Four interviewees mentioned objective management methods, out of which three also mentioned objective identification methods. Table 8-2 depicts the connection between the classification of information sources and management tools for uncertainty. The frequencies highlight the amount of times each individual aspect was mentioned and thus do not add up with the combinatorial numbers in the remaining parts of Table 8-2.

Table 8-2: Interviewees' responses regarding sources of information and uncertainty management tools at bidding stage

				Management tools	
				Subjective	**Objective**
		Examples		Through project manager or team	Monte Carlo, Sensitivity Analysis
			Total	5*	4*
Sources of information	**Subjective**	Experience of the project manager or team	9*	5*	4*
	Objective	Database of previous projects	4	1*	3*

* these values do not sum up as combinations of subjective and objective methods were stated.

8.3.2 Bidding context

Describing the bidding process, the interviewees' answers were categorised as follows;

- ***One-bid process***: The competitors have one opportunity to submit their bid including the bid price and the specifications of the service and the contract. The customer then evaluates these bids and agrees to one of the offers. This includes the assumption that the customer has the ability to understand the technical and commercial details of the bids.

- ***Two bid process without negotiation***: The bidding process is split into two phases. In the first phase, a number of possible suppliers submit their bid, which usually includes their suitability for the service contract (this can be based on an invitation to bid or an open access). This number of competitors is reduced to the most suitable ones who are then invited to submit their full bid in the second phase. In this second phase, the competitors would typically know the identity of each other. None of the phases includes negotiation with the customer.

- ***Two bid process with negotiation***: The bidding process is split into two phases similar to the description above. However, the second phase is characterised by a negotiation between the supplier and the customer to clarify important issues and questions. The answers to these questions can be published to all competitors or stay confidential between the two negotiating parties.
- ***Negotiation***: A bidding process, which includes negotiation, is characterised by an exchange of large amounts of information concerning the service requirements, the customer's intention, technical scope or any other issues concerning the contract or bid.

The bidding process, which the interviewees typically faced in their decision process, depended on the level of complexity of the contract to be bid for. The definitions as described in Section 8.2.3 are used to describe the service complexity. Table 8-3 depicts the answer frequency of the usual bidding process connected to the level of service complexity. The values in Table 8-3 distinguish between usual and possible bidding processes as indicated by the interviewees. The numbers do not add up to nine as multiple answers were given by the interviewees managing a contract portfolio.

Table 8-3: Bidding process in dependence type of contract

		Level of information exchange (Auction → Negotiation)			
		One-bid process	**Two bid process without negotiation**	**Two bid process with negotiation**	**Negotiation**
Service contract	**Low complexity**	Possible: 4 Usual: 2	Possible: 1 Usual: 1	-	-
	High complexity	-	-	Usual: 3	Usual: 5

The results depicted in Table 8-3 indicate that low-complexity contracts with clear (enough) requirements were typically not negotiated, which can be constituted with the reason that negotiation is a time and cost consuming process [Bajari et al., 2008]. In contrast, contracts of high complexity were typically agreed after negotiation with varying levels of depth in this process. This suggests that the uncertainty that may arise from unclear requirements can usually be reduced by collecting further information from the customer. The parties were willing to commit additional time and costs to this process to ensure that the service outcome best fitted the needs of each party.

The interviewees' answers regarding the usual payment methods for service contracts were divided into three categories:

- ***Fixed prices***: Seven of the nine interviewees stated that (some of) their company's service contracts are paid with fixed prices, which can be based on milestones (mentioned by four) or over a set period of time (stated by three interviewees) such as a monthly payment.
- ***Cost based payment***: Three of the interviewees stated that the payment is based on the actually spent costs, which can be assessed through e.g. timesheets.
- ***Payment on completion***: The service supplier is paid upon completion of the project, which was mentioned by one interviewee. It is to be noted that this company offered research services, which usually only have deliverables at the end of the service period in the form of e.g. a research report.

Multiple answers were possible. Based on these results it can be summarised that fixed price payment seemed to be the standard method for service contracts.

8.3.3 Input information

The results of the interviewees' answers to the questions regarding the input information were analysed in three main sections: cost estimate and uncertainty, customer, and competitors. These are described in the following sections.

(1) Cost estimate and uncertainty

The way the cost estimate is communicated during the bidding process was found to be distinguishable into the following categories:

- ***Presented in a table***: The costing information included in a table was found to be in two different ways. Four interviewees used a detailed cost breakdown in the form of the necessary work steps, the time and expertise needed for each step, and the cost value assigned to the different steps. The other mentioned approach was to include a 3-point-estimate, which included pessimistic, most likely and optimistic assumptions represented in a tabular form.
- ***Presented in a graph***: The approach that was used most frequently to include cost estimating information in a graph was a 3-point estimate. Another approach mentioned

was a s-curve, which displayed the cumulative costs over time and adopted the form of the letter S (see e.g. [Cioffi, 2005]).

The specification of the available costing information in practice was found to be influenced by the way uncertainty was included in the estimate. The levels of uncertainty included in the cost estimate were reported as follows;

- ***None***: Four interviewees stated that they included no uncertainties in their cost estimate.
- ***Variation in the input data***: The available information of the cost estimate can vary. For example, to fulfil a specific task, a particular engineer may have taken 4 to 5 hours depending on other variables.
- ***Quantification of qualitative uncertainty***: This category included the assessment of the question of *"what can go wrong"* and connecting a value to this assessment. This occurred subjectively through the experience of the decision maker.

Furthermore, the interpretation of the cost estimate was found to be dependent on the way uncertainty was included. Thus, it is discussed in this section (this question was asked in connection to the bidding strategy). The answers were grouped as follows;

- ***None***: In this category, the cost estimate was not interpreted but taken as it was. All four interviewees who stated that no uncertainty was included in their estimate also said that the cost estimate they received was not interpreted. However, two of those stated that the possibility of reducing this estimate was kept in mind due to the fact that it was based on conservative values. For example, if the historic data would show that a specific task took between 4 and 5 hours, the cost estimate would be based on the 5-hour estimate. If the final cost estimate would be considered too high, these cost values would be adjusted in a second iteration of the process.
- ***As point estimate***: The costing information with the related uncertainty was stated to be interpreted as a point estimate, based on e.g. the 50% or 80% line in the graph. One interviewee stated that this was only held up when the uncertainty connected to the contract was low, otherwise a cost range was kept.
- ***As range estimate***: The communicated costing information was carried forward in the pricing process as a range estimate, either with its original spread or as a reduced spread. One interviewee stated that the full range was utilised when there was high uncertainty connected to the contract in the form of a high variation in the input data.

Table 8-4 shows the comparison of the way the cost estimates were presented and interpreted against the included uncertainty.

Table 8-4: Appearance of cost estimate in dependence of included uncertainty

				Included uncertainty		
				None	**Variation in input data**	**Quantification of uncertainty**
			Total	4	3	4
Presentation of cost estimate	**Table**	**Cost breakdown**	4	4	-	-
		3-point estimate	1	-	-	1
	Graph	**3-point estimate**	4	-	3	2
		s-curve	1	-	-	1
Interpretation of cost estimate	**None**		4	4	-	-
	As point estimate		4	-	3	1
	As range estimate		2	-	1	1

In Table 8-4, the total values do not add up to nine because two interviewees stated the use of multiple methods to communicate their cost estimates; one used both types of graphical displays, the other one stated the use of tables to present the cost breakdown and graphs to present the overall costs. However, the total values give an indication of how often each type of presentation was mentioned and how uncertainty was included.

The companies that presented the cost estimate as a breakdown in a table did not include any uncertainty; rather, it was based on specific assumptions. These assumptions included the choice of a conservative value when the input data varied, e.g. when a task was recorded to take between 4 and 5 hours, the estimate would be based on 5 hours. Furthermore, when uncertainty was included, the cost estimate was more likely to be presented in graphical form. All interviewees who stated that they used a graphical approach to display their costing information included uncertainty in it.

The interviews also assessed, which further uncertainties could influence the pricing decision. Two out of the three interviewees who stated that their cost estimate did not contain any uncertainties, also stated there were no further uncertainties influencing the pricing decision.

Both of them, however, stated that they would reduce the cost estimate if the originally derived price bid would be considered as too high. Hence, it can be concluded that they were aware of the influence of uncertainty on the pricing decision, but their method of dealing with this uncertainty was reactive as opposed to an active management approach.

The answers of the remaining interviewees regarding further uncertainties influencing the pricing decision were categorised as follows;

- ***Customer-related uncertainties***: These included the customer's previous choices of bidders for similar projects to recognise observable patterns. For example the customer might always go for the price bid that is 5% below their stated budget limit. Other factors were mentioned as the assessment of questions such as the possible consequences if the customer found a mistake in the bid, the location of the customer to evaluate the possible travel costs, and assumptions about the usage of the serviced product or machine. In addition, the level of experience of the customer's personnel involved in the usage of the product or machine was named as a further uncertainty. Further aspects related to the customer are analysed later in this section.
- ***Competitor-related uncertainties***: These assessed the identification of the competitors for the particular service contract and an evaluation of their most likely bid. Furthermore, the contract might be let to multiple suppliers who would either focus on different aspects of the service or would have to be able to share the project. Further aspects related to the competitors are analysed at a later point in this section.
- ***Cost-estimation uncertainties***: As discussed, the cost estimate was stated to either include different uncertainties in the form of a spread or was based on assumptions that may not prove true. Further uncertainties included the possibility of cost reductions through e.g. a reduction of the overhead costs.
- ***Economic uncertainties***: These included factors, which may influence the commercial activities, such as legal changes, gains that can be achieved with the contract, and the situation of the overall economy, the market place and the specific sector.
- ***Others***: Other mentioned uncertainties included the bidding company's contract situation and the uncertainty arising from the technical requirements.

Most interviewees mentioned more than one of the presented sources of uncertainty with a clear emphasis on one important factor, usually concerning an example from the recent past. For this reason, there is no quantitative analysis of the relative importance of each of the mentioned categories.

(2) Customer

The available information concerning the customer considered the areas of their bidding strategy, the past relationships, their future needs and whether these aspects influence the decision maker of the bidding company. For these interviews, the customer's bidding strategy was addressed through the aspect of their budget and their evaluation criteria regarding the bids. The interviewees' answers indicated two different categories: either these strategic aspects were communicated with the service requirements or they could be assessed through a *"getting-to-know-the-client"* process, in which usually a commercial team was involved. Of the nine interviewees, four stated that the customer's bidding strategy was communicated, two said it could be assessed, and three that it varies between these two categories depending on the kind of customer (resulting from aspects such as if they had worked with them before and the preferred bidding process of the customer).

The past relationship between the bidding company and the customer was described by all interviewees as an important source of information. An ideal bidding situation would involve a long relationship where trust had been built up and the parties would already know each other. When this was not the case, the bidding company may still have previous experience with the customer to build up knowledge about them. In cases where there was no previous experience, the bidding company had to rely on the information communicated by the customer themselves or published in e.g. the press.

The assessment of the customer's possible future needs caused different reactions with the interviewees. One part (seven of nine interviewees) stated that this was one aspect that they assessed during the process of compiling the bid and included it if appropriate. These interviewees stated the importance of possible follow-up work, future relations and the length of the service contract to demonstrate their suitability for e.g. the next five years. The other two interviewees highlighted that the bid only covered the service requirements, that a consideration of the customer's possible future needs was highly speculative and, thus, not included in the bid-compiling process. Therefore, for a specific competitive bidding situation, the customer's future needs may play an important role in the bidding process and need to be included in a conceptual framework of the influencing uncertainties at the bidding stage.

Regarding the consideration of the available information about the customer, all interviewees stated that it was of importance for the decision maker and the compilation of the bid. Five interviewees stated that all the available information was considered, two described the customer and their bidding strategy as the most important influence on the bid, and two stated that there were other more important aspects such as the contract costs. This means that the customer can constitute a central factor in a bidding decision, however, its relative importance depends on the particular service contract.

(3) Competitors

The interviewees were asked questions, which aimed at determining the following information regarding their competitors: their identity, their cost estimates, their available technology or knowledge, and the consideration of these aspects in the pricing decision.

As indicated in Section 8.3.2, the identity of the competitors may be known depending on the bidding process. If this is not the case, the bidding company may either have a *"pretty good"* idea regarding their competitors, due to their experience about who is capable of dealing with the requirements, or not be able to identify them at all, particularly when trying to bid in new market segments where their experience is limited. For the purpose of this analysis, the three possibilities are named as the competitors' identity is known, knowable or not known.

The competitors' cost estimates are not usually known to the bidding company, which was confirmed by all interviewees. However, there are different levels of speculation. Based on previous experiences, a "ballpark" or top level deduction may be known, which could be formulated as an absolute value or assessed in relation to the bidding company's costs. Another possibility was the knowledge of cost details such as salaries based on information obtained from previous employees of the competitor. In other cases, particularly when dealing with new or unknown competitors, the cost estimates may be neither known nor deducible.

The third investigated aspect concerned the competitors' available technology or level of knowledge, which may give them a competitive advantage. The answers varied between three categories. A common answer (by six out of nine interviewees) was that it was known as the competitors advertise themselves on e.g. the internet or have other publicity in e.g. newspapers. Two interviewees stated that this aspect of the competitors is knowable due to the decision maker's experience in the area. In other cases, particularly when the company bids in a new market segment, this aspect was stated to be neither known nor knowable (stated by two interviewees).

Table 8-5 shows the frequency of the interviewees' answers for their knowledge of the competitors' cost estimates and their available technology or knowledge plotted against the competitors' identity. The numbers do not sum up to nine due to the fact that four interviewees stated multiple answers regarding the competitors' identity, which can be dependent on the particular service contract. Hence their answers varied also for the other points.

Table 8-5: Available information about the competitors at the bidding stage

			Identity of competitors		
			Known	**Knowable**	**Not known**
		Total	7	7	2
Value of competitors' cost estimates	**Top level costs**	**6**	6	6	-
	Cost details	**2**	2	2	-
	No	**2**	1	2	2
Competitors' availability of technology and/or knowledge	**Known**	**6**	6	4	-
	Knowable	**3**	2	3	-
	Not known	**2**	-	-	2

The results shown in Table 8-5 give an indication of the availability of information about the competitors and thus the level of uncertainty connected to them. In cases where the competitors' identity was known or determinable, the bidding company also had a reasonable level of knowledge about the other aspects. In other words, the bidding company is not normally ignorant about their competitors and their possible bidding strategies unless it is bidding in a new market sector.

Investigating the interviewees' consideration of these aspects during the decision process, six replied that they used all the information that was available to them and two stated that they considered the available information but that there are other more important factors such as the customer. One interviewee said that the information regarding the competitors was not considered in the pricing-decision process. This confirms the results of the second empirical study, namely that competition is one of the influences on a pricing decision. Furthermore, most of the interviewed companies (seven out of nine) stated that it was one of the most important factors.

Similarly, the availability of the original service and contract requirements was assessed with the interview as they would have been communicated by the customer at the beginning of the bidding process. They were stated by all interviewees to be available and included in the decision process. The following section describes the interviewees' answers regarding their bidding strategy.

8.3.4 Bidding strategy

The interviewees' answers to the questions concerning the bidding strategy were analysed in three main sections: the choice of the decision maker, the method to obtain the price bid and the acceptance of a contract with a high risk of making a loss. These are described in this section.

(1) Choice of the decision maker

As the bidding strategy can be very subjective, the interview assessed the reasoning behind the choice of the decision maker. Most of the interviewees (seven out of nine) highlighted that the decision was made by a team; two stated that a team was involved in the bid compilation process and the final decision was made by the team manager. The team decision was connected to contracts of both low and high complexity; four of the seven interviewees managed contract portfolios, one dealt with contracts of low complexity and two focused on ones of high complexity. Thus, it can be derived that the assignment of a team to the decision process is not correlated with level of contract complexity. This means that team dynamics may influence the decision outcome and that the uncertainty caused by human behaviour, which is connected to one individual decision maker (as discussed in Chapter 5), is of minor importance in this context. The decision makers were chosen based on the following criteria;

- ***Experience***: The decision maker(s) would be chosen based on their experience with bidding in general, bidding for similar contracts, or in managing (similar) service contracts.
- ***Delegation***: The decision maker(s) had to have a certain level of authority to make the bidding decision.
- ***Courses***: The decision maker would be chosen based on the completion of courses that were offered in the companies on e.g. writing proposals or negotiating.

Multiple replies were possible. The most important criterion for choosing a decision maker was named as their experience, which was mentioned by six of nine interviewees. Of similar importance (mentioned by five interviewees) and connected to experience is the category of delegation in the company. The completion of courses was mentioned by two interviewees; however, both highlighted that this was only a supportive aspect; the decision maker(s) would not be chosen based solely on the courses they had completed.

(2) Obtaining the price bid

The calculation of the price bid, in other words the assessment of the monetary values to be included in the bid, was categorised into two approaches;

- ***Cost-based approach:*** This approach can be simplified to *cost + profit margin=price* and was utilised by most of the interviewees (seven out of nine). To the interpretation of the cost estimate, a profit margin is added, which can include a contingency, an administration margin and the consideration of inflation.

- ***Price-focused approach***: Two of the interviewees stated that their process was focused on the price and the costs were not considered separate from that. This means that the price is considered in different steps within the bidding company regarding to either its suitability to the customer's stated budget (one of the interviewees) or to strategic evaluation of the market situation and the customer needs (the other interviewee).

Following this question was the assessment of the minimum price bid, underneath which the bidder would not accept the contract. The interviewees agreed that there was not a usual process to calculate this price before the tendering or negotiation process. However, the interviewees' approaches to evaluate the minimum price was categorised as follows;

- ***Cost + minimum profit***: Six of the nine interviewees stated that they were prepared to reduce their profit. This included the situation of no profit but excluded a deliberate loss. One of the interviewees stated that the price bid communicated to the customer would be the minimum acceptable price.

- ***Available alternatives***: Two of the interviewees said that the minimum price varied according to the available alternatives in the economic situation at the time of bidding. This comparison could include not achieving an agreement.

- ***Potential of follow-on work***: The minimum price was dependent on strategic aims such as the possibility of receiving future contracts from this customer. Two of the interviewees belonged to this category, one of which stated it in addition to the best available alternative.

(3) Acceptance of a contract with a high risk of making a loss

To assess other strategic aspects that may influence the bidding decision, the interviewees were asked if they had agreed to contracts which deliberately made a loss. This question corresponds to a similar question asked in the second experimental study (discussed in Section 7.3.6). Of the nine interviewees five stated that they would not accept such a contract, whilst four said they had done. The answers to the question were categorised as depicted in Table 8-6.

Table 8-6: Interviewees' responses to follow-up scenario

Reply	Reasoning	Number of interviewees
Refusal	***No deliberate loss:*** depending on the company policy and the situation in the market sector, the company would not consider to deliberately making a loss. The price would be reduced in a realistically achievable process; further reductions of the price were not possible.	5
Acceptance	***Long term gains:*** One strategic consideration was mentioned as the possibility of long term gains through the acceptance of a contract with a high probability of making a loss. Such future gains can include follow-on work and further contracts with the client.	3
	Eliminate competition: Another aim with a contract including a loss could be to eliminate the competition for this market sector or this particular customer.	2
	High profile customer: If a particular customer was a major client of the bidding company, this customer could be given 'special prices'. This aspect was mentioned in connection to the two other strategic aims of accepting a contract with a high probability of making a loss.	1

Table 8-6 shows that there was just one reason mentioned by the interviewees regarding the refusal of a contract with a high probability of making a loss, which was typically connected to company policy or the usual conduct in the market sector. However, for the acceptance, the answers could be divided into three categories, namely the bidding company's long term gains, the possibility of eliminating competition, and the profile of the customer as a client. The interviewees, who stated that they would accept such a contract, usually mentioned multiple aims in these categories.

8.4 Discussion

The pricing process used by most of the interviewees was cost based, which confirms the assumptions made for this research (as described in Chapter 4) and the results of previous studies as described by e.g. Avlonitis and Indounas [2005]. Furthermore, a connection was observed between the complexity of the contract and the bidding process, i.e. the level of negotiation between customer and possible supplier. It was found that the more complex a service contract, the closer the two parties worked together during the bidding process. This confirms the research of Bajari et al. [2008]. However, a connection between the payment method and the bidding process as described by Bajari et al. [2008] was not confirmed in this study.

The cost estimate usually considered uncertainty in the form of a cost range. In cases where the cost estimate did not include uncertainty, it was usually based on specific assumptions, which would be reassessed during the following pricing process. The uncertainty influencing the pricing decision was usually considered in the process, either explicitly throughout the process or through reassessing the assumptions after a conservative estimate was compiled. Where possible this uncertainty was reduced, for example if the service requirements were not clear or vague, the bidding company usually had the opportunity to receive further information from the customer through negotiation.

Focusing on certain sources of uncertainty such as the competitors and the customer, the bidding company was usually not ignorant about these factors and their possible influence on the decision outcome. The identity of the competitors was usually known to the bidding company or could be assessed during the process of compiling the bid. This means that the competitors' profile and available resources can be taken into account in the decision process. Similarly, the customer's bidding strategy was either known or assessable. This means that the customer's evaluation of the service price and quality as well as other criteria is or can be known at least vaguely. Particularly customers, that the bidding company had had a previous connection with to build up trust [Johnson and Grayson, 2005], form an important source of information and reduce the level of uncertainty.

The presented interview study found that the pricing decision under uncertainty was based on the subjective evaluation of the decision maker(s) regarding the consideration of different uncertainties. As indicated by literature in uncertainty research [Samson et al., 2009; Thunnissen, 2003], the terms uncertainty and risk are hard to define and distinguish comprehensively. This was confirmed by the interview study. Some interviewees used examples to overcome this difficulty. For the identification of uncertainties that may influence the considered service contracts, subjective methods were prominent, while for their management, subjective methods were used in combination with objective methods. This suggests that there is a need for models to support the decision process in practice. Another aspect to overcome the uncertainty arising from individual assessment was the involvement of a decision team.

Limitations of this empirical study include the small set of participants and the lack of consideration of the interviewees' phrasings of the answers. However, the results are to be understood as indicative as opposed to a comprehensive characterisation of the current bidding situation for service contracts. With this purpose, they identify common patterns of approaching the decision problem, aspects, and opportunities for further improvement, as well as possibilities for offering support to the decision maker.

8.5 Summary and conclusions

This chapter presented the interview study, which investigated objective 3 "To define the level of the identified uncertainties in the pricing decision process". Based on the interview results, the following conclusions can be drawn;

- The bidding process is dependent on the level of complexity of the service contract. Services of low complexity are usually awarded without any negotiation process; ones of high complexity are typically allocated based on negotiation between customer and potential supplier.
- The level of uncertainty connected to the different influences on the pricing decision at the bidding stage can be bound. Typically the identified factors would not exist under ignorance; in other words, each of the identified factors can be characterised and bound to an interval or even a set of possibilities. This indicates that the uncertainty connected to the influences on a pricing decision can be modelled and managed during the process.
- The decision is typically made by a decision team. This eliminates the uncertainty connected to human behaviour, which would cause a high level of uncertainty for a decision, made by one decision maker. However, this introduces further questions regarding the interactions between the team members (see also Chapter 2). Future research will have to determine if the team composition could cause uncertainty regarding the decision outcome, for further discussion see Chapter 12.

Chapters 6–8 combined allow a description and characterisation of the uncertainty influencing the pricing decision at the competitive bidding stage. These can be summarised in a conceptual framework that includes the different influences as identified in the three empirical studies presented in Chapters 6-8. The characteristics and specifications of the influencing uncertainties are based on the findings of the interview study presented in this chapter. Chapter 10 describes the uncertainty framework.

9 Uncertainty framework for competitive bidding

This chapter describes a conceptual framework of uncertainties influencing the pricing decision at the competitive bidding stage for service contracts. It focuses on objective 4, "To define a framework of the uncertainties influencing a pricing decision". The framework was derived from the three empirical studies described in Chapters 6-8 and literature. First, the method of inducting the framework is presented, before each of the uncertain factors is introduced and described. Finally, the use of the uncertainty framework for obtaining a decision matrix depicting the probability of winning the contract and the probability of making a profit is presented.

9.1 Method

The uncertainty framework is based on both literature and the three empirical studies presented in Chapters 6-8. This section describes how these two resources were combined in the proposed framework.

9.1.1 Framework basis

The basis for the conceptual framework proposed in this chapter was taken from literature. In literature, approaches can be found that support a company's business strategy, in other words, these are frameworks that support the formulation of a company's long-term vision and performance. In particular, one approach has received a high level of acceptance and recognition: the Balanced Scorecard [Afuah, 2009; Haimes, 2009; Rainey, 2003; Adler, 2001; Bontis et al., 1999; Neely, 1999]. The Balanced Scorecard was introduced by Kaplan and Norton [1992; 1996] and depicts the organisational performance of a company or business which is viewed from the following four perspectives;

- ***Financial:*** This perspective describes the link between the objectives and targets of the different business units to the financial aims of the company as a whole [Kaplan and Norton, 1996]. Approaches such as risk management, cost reduction, productivity improvement, or investment strategy have been described in this context [Duintjer Tebbens et al., 2006].
- ***Customer:*** This perspective identifies potential customers and market segments the company operates in [Kaplan and Norton, 1996]. In other words, this perspective delivers the resources for the achievement of the company's financial goals. In general,

the marketing department deals with this perspective in problems such as market segmentation, customer satisfaction or company image.

- ***Internal business:*** This perspective deals with the company's capabilities and limitations in the context of the market, identifying the critical processes for achieving the goals. Ideally, it offers a complete internal process value chain from the innovation process, the operations process, to the offering of post-sale services [Afuah, 2009; Kaplan and Norton, 1996].
- ***Learning and growth:*** This perspective describes the future objectives and targets of the company and its ability to change and improve to achieve its goals within the market. It provides the basis for achieving ambitious objectives that were identified in the previous three perspectives.

The Balanced Scorecard can be depicted as a framework with its four perspectives influencing the company's vision and business strategy as depicted in Figure 9-1. It shows the four perspectives on a company's business strategy from the approach presented by Kaplan and Norton [1992; 1996].

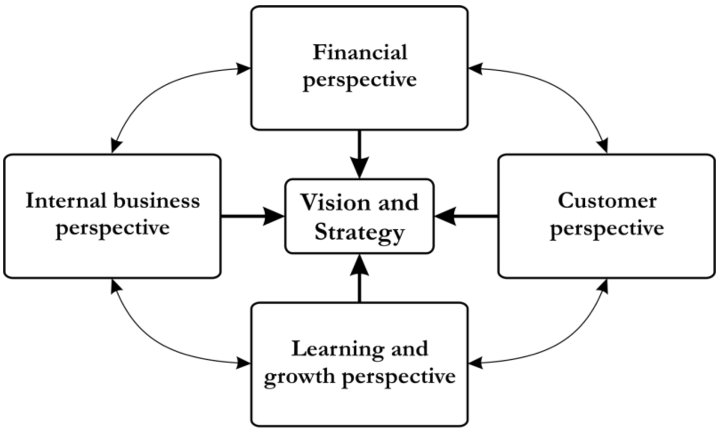


Figure 9-1: Framework of Balanced Scorecard with four blank perspectives (adapted from Kaplan and Norton [1996])

The structure of this framework was used as the basis for the proposed uncertainty framework of the bidding strategy. The four perspectives were left blank and filled with the results and conclusions from the three empirical studies described in Chapters 6-8. The next section describes the process of filling the blank framework to induce the conceptual uncertainty framework for the bidding strategy.

9.1.2 Framework construction

To induce the uncertainty framework, the results and conclusions from the empirical studies were included in the blank framework. These results were categorised into four groups as follows:

- ***Customer:*** This group focused on uncertainties that were related to the customer of the service contract.
- ***Competitors:*** Uncertainty can arise from the competitors for the service contract and their possible actions.
- ***Others:*** Other factors, that could not be included in either of the above mentioned groups, were categorised into uncertainties that would be ***controllable*** or ***uncontrollable*** by the bidding company. This differentiated between factors that could be changed and/or influenced (controllable) and factors that would have to be accepted and managed (uncontrollable) by the bidding company during the bidding process.

These four categories were used to induce the conceptual framework and then filled with the results from the empirical studies. Figure 9-2 shows a flowchart of inducing the conceptual framework proposed in this chapter by including the results from the three empirical studies.

The first study – information display for decisions under uncertainty (Chapter 6) - focused on the uncertainty from the cost estimate and the decision maker's interpretation of it. It was found that the uncertainty connected to the cost estimate forms an important influence on the pricing decision at the competitive bidding stage. Thus, from the first experimental study, the cost estimate was added to the empty framework.

In the second study – competition in bidding (Chapter 7) – further uncertainties were identified to influence the pricing decision. These included the service requirements, the product specifications and performance (see "Product uncertainties" in Section 7.3.5), and the uncertainties connected to the specific market and the economy in general (see "Market uncertainties" in Section 7.3.5). Furthermore, it was found that the pricing decision can be influenced by the contract portfolio of the bidding company, i.e. other possibilities to secure profit (see justification for additional reduction of price bid in Section 7.3.6 named as "Cash flow"). Another important influence was named as the customer's budget constraints and the possibility of future contracts with the customer. Further uncertainties include the identities of the competitors for the specific service contract and their experience with similar services (see "Competition uncertainty" in Section 7.3.5).

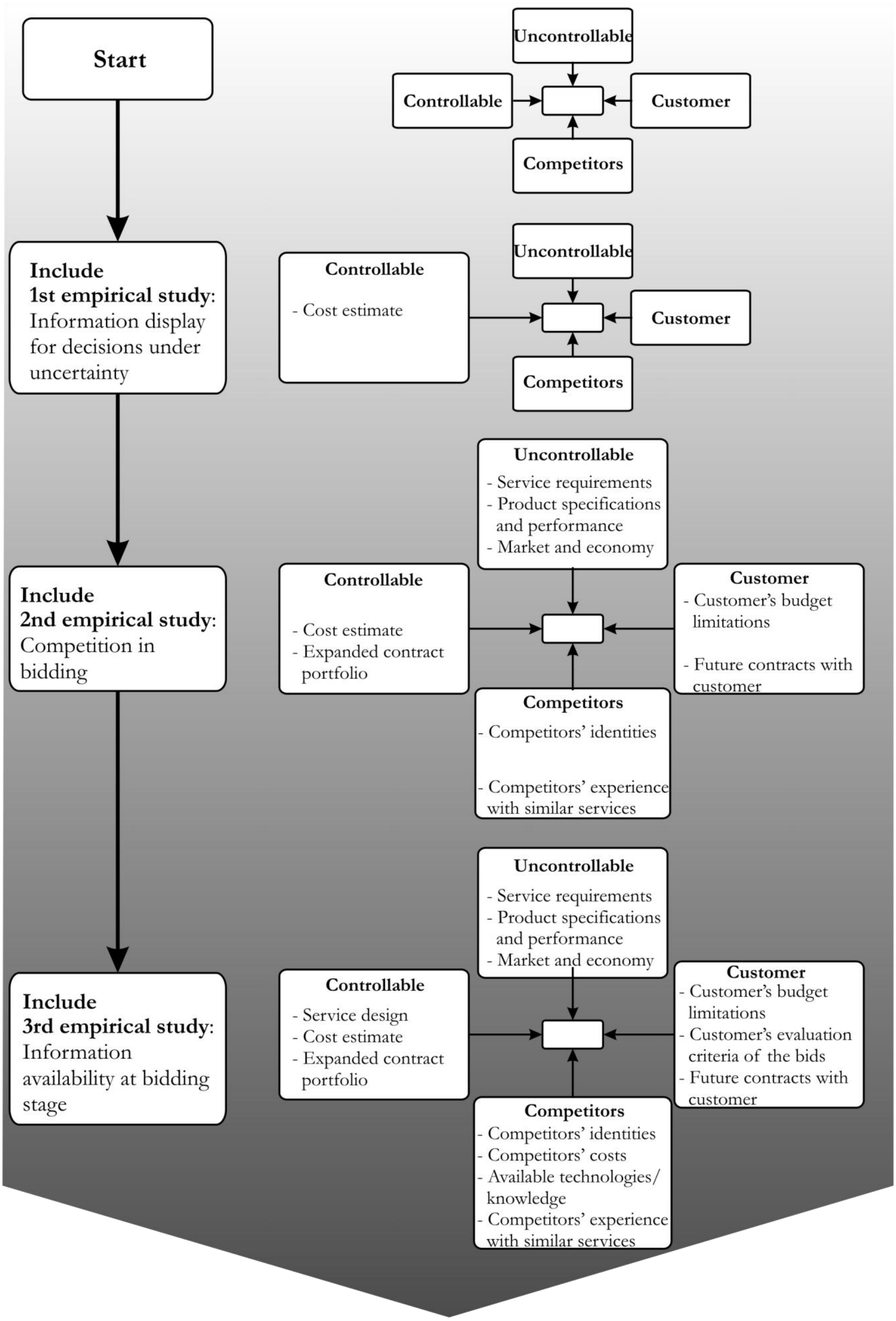


Figure 9-2: Flowchart of constructing the uncertainty framework

This was complimented with the results of the third empirical study, i.e. the interviews with industry – information availability at the bidding stage (Chapter 8). The influences mentioned by the interview participants confirmed some of the uncertainties identified by the first and second experimental studies. Further uncertainties include the service design (see "High complexity contracts" in Section 8.2.3). In addition, the competitors' cost estimate (or the bidding company's assessment of them) and the competitors' available technology or knowledge form important uncertain influences on the pricing decision (see Section 8.3.3). Furthermore, the customer's criteria for evaluating the competitive bids were named as an influencing uncertainty (see "Customer-related uncertainties" in Section 8.3.3).

The uncertainties identified through the empirical studies can be grouped into four influencing factors. The following section describes the process of inducing the uncertainty framework from the four groups depicted in Figure 9-2.

9.1.3 Factors influencing the bidding strategy

To identify the suitable terminology for these factors, further literature in the field was consulted. This also ensured that the framework would be consistent with literature in the field and the terms used do not contradict existing terminology. In particular, the terminology for the controllable and uncontrollable uncertainties was substantiated through the literature.

A review of the relevant literature in competitive bidding for contracts was presented in Chapter 8. The uncertainties mentioned in the group *uncontrollable*, namely service requirements, product specifications and performance, and market and economy, are typically referred to as *service contract conditions* [Bajari et al., 2008; Sorrell, 2007]. Thus, this terminology is adapted for the uncertainty framework.

Similarly, the uncertainties listed in the group *controllable*, namely service design, cost estimate and expanded contract portfolio, are processes that are internal to the bidding company [BSI, 1994; Goldstein et al., 2002; Newnes et al., 2008]. As presented in Chapter 2, the bidding company creates a service design and cost estimate for the requirements communicated by the customer. Thus, this factor is named *internal company processes* in the uncertainty framework.

Thus, for the conceptual framework depicting the uncertainties influencing a bidding strategy, four factors can be identified: the service contract conditions, the internal company processes, the customer and the competitors.

The ***service contract conditions*** form the context of the bidding situation including the contract and the service requirements. The contract requirements are defined by the contract type with the negotiation style, the payment method, and the contract scope. The negotiation style of a contract describes, for example, if there is a first round where only the lowest price bids will be accepted for further negotiation [Lehman, 1986]. The payment method defines what sort of price bid is required: a fixed contract price or a cost-plus payment [Tseng et al., 2009; Paul and Gutierrez, 2005]. These two characteristics can be expected to be set by the customer in advance and be influenced by industry standards and customs. The contract scope describes what is included in the contract, in other words what decision rights and organisational activities are transferred to the supplier [Sorrell, 2007]. The service requirements include the problem description, for which the customer is seeking a solution with the service contract. They define the specific service to be bid for.

The ***internal company processes*** consider the capabilities and limitations of the bidding company such as their ability to deal with a contract of the required complexity. If it cannot fulfil a contract of the quality or quantity asked for, the process may result in the decision not to bid [de Boer et al., 2001]. Values and issues raised can influence essential points of the bidding process. The central aspect of this factor is the creation of a service design and the cost forecast for the service contract being bid for (see also Chapter 2).

Similar to the potential suppliers, the ***customer*** can be expected to have a bidding strategy [Tulloch, 1980; Harrington Jr., 2009]. This includes the customer's budget limits, their long-term business goals, short-term contract goals and the customer's evaluation of the service quality. The bidding company may be able to base its decision on the past relationship with the customer and the possibility of a future relationship.

On the single contract level, the existence of ***competitors*** is not abstract and anonymous as it is on the level of business strategy. For a specific contract, the number and identity of the competing companies may be known or knowable (see Chapter 8). Furthermore, the portfolio of supplied products and services is usually marketed by a company which means that it is known to competing companies. Given this level of knowledge, the bidding company may evaluate its competitive advantage for the specific service contract.

The uncertainty arising from the four factors influencing the bidding strategy, service contract conditions, internal company processes, customer and competitors can be summarised in a conceptual framework which is depicted in Figure 9-3. It indicates that the factors can be interlinked. For example, if the bidding company is uncertain about the service requirements (service contract conditions), the service design and cost forecast (internal company processes) may be more uncertain. The framework highlights the most important uncertainties as identified during the three empirical studies. The following section describes how the uncertainty in each of the four factors can be characterised.

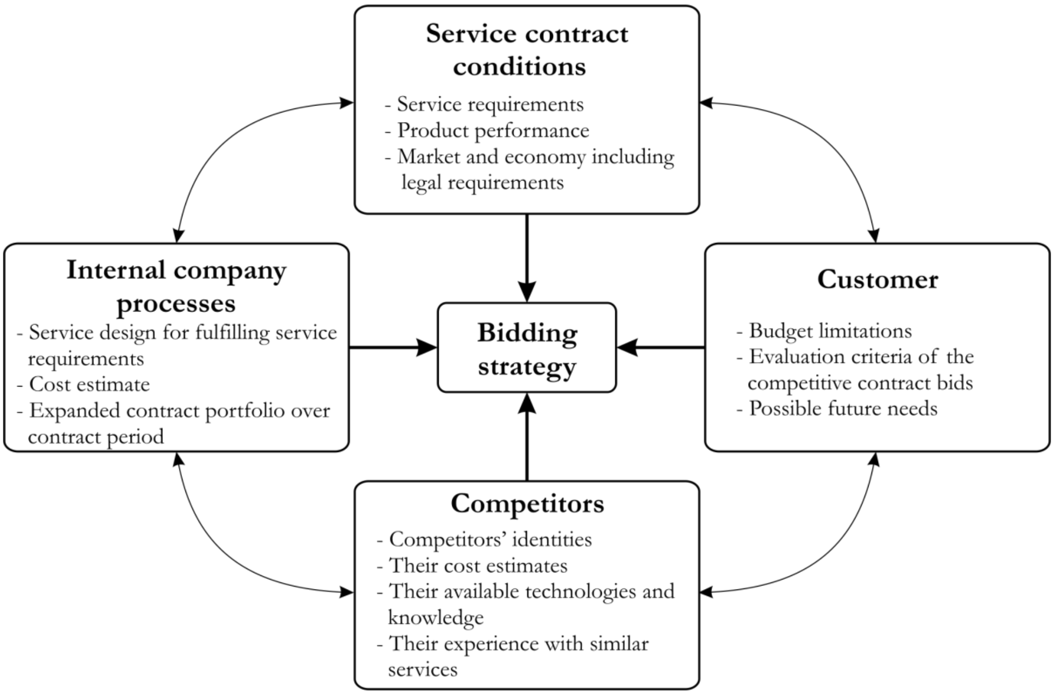


Figure 9-3: Uncertainty framework for pricing decisions

9.2 Characterising the uncertainty influencing the pricing decision

To characterise the uncertainties influencing the pricing decision at the competitive bidding stage, the uncertainty classification introduced in Chapter 5 is applied to the conceptual framework. To remind the reader of the five-layer approach, it is repeated in Figure 9-4. To identify the characteristics, the results of the interview study (Chapter 8) were used to indicate the typical availability of information at the bidding stage.

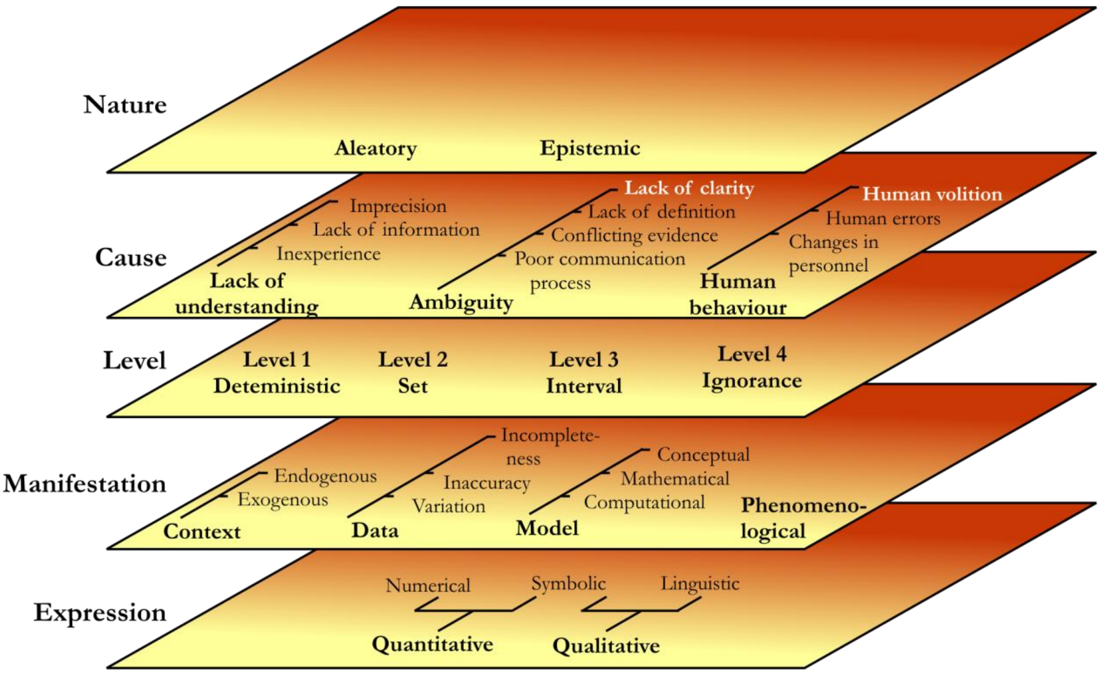


Figure 9-4: Five layer approach of characterising uncertainty

9.2.1 Service contract conditions

The service contract conditions define aspects such as the general bidding process, payment method, and the contract scope which can cause uncertainty in the bidding process. As indicated by the interview study (see Chapter 8), these are either subject to conduct of the market segment, the particular customer, or they are defined prior to the bidding procedure.

Further aspects of the service contract conditions are the service requirements which may be subject to uncertainty particularly when the customer is not able to define or even indicate them precisely. However, as discussed in Section 8.3.2, this uncertainty is usually accounted for with the bidding process. In cases where the service requirements are clear (enough) to the point that the customer knows the aims of the service and can communicate them precisely, there is little uncertainty connected to them. In cases where the service requirements may be unclear, e.g. the customer can only define the service aims vaguely or the way of communication leaves the bidding supplier uncertain, the bidding process usually includes some form of negotiation. This means that this uncertainty can be reduced through further communication and discussion with the customer.

Further uncertainty connected to the service contract conditions is the product performance which includes, for example, the utilisation rate of the serviced product or the service history such as previous repairs. In cases where the bidding process includes negotiation, the bidding company may obtain information regarding these influences. In other cases, the contract may include specifications such as maximum utilisation rates which limit the uncertainty. However, due to the phenomenological character of this influence, the uncertainty cannot be reduced completely. For example, the customer may not be able to forecast with complete certainty how much they will use or need to use the product in 5 years. Thus, there is uncertainty regarding the product performance at the bidding stage, the level of this uncertainty may vary due to contractual commitments.

In addition, market and economic uncertainties can influence the service contract conditions over the contract period. These uncertainties can include possible legal changes, the economic situation in general, and the specific market segment as discussed in Section 7.3.5. Assuming that these uncertainties are assessed over the period of the service contract, they can usually be bound to an interval of possible future values; however, it is also possible that the bidding company has to act under ignorance concerning these aspects. Table 9-1 depicts the characteristics of the uncertainties arising from the service contract conditions.

In general both parties, the customer and the bidding supplier, have an incentive to reduce the uncertainties of the service contract conditions to establish a service that fulfils their needs best [Goldberg, 1977; Yee and Korba, 2003; Tung and Lin, 2005; Bajari et al., 2008]. Thus, it can be summarised that this factor is of less importance regarding its influence on a competitive advantage of the bidding company. For this reason, this factor is not included in the discussion about the uncertainty model at the competitive bidding stage.

Table 9-1: Uncertainties arising from the service contract conditions

	Nature	Cause	Level	Manifestation	Expression
Service requirements	Epistemic	Lack of understanding – imprecision	Deterministic	Data inexactness or data incompleteness	Qualitative
Product specifications and performance	Epistemic	Lack of understanding – lack of information	Deterministic Set Interval	Phenomenological	Qualitative
Market and economy	Epistemic	Lack of understanding – lack of information	Interval Ignorance	Phenomenological	Qualitative

9.2.2 Internal company processes

The uncertainties within the factor of the internal company processes can be connected to the service design, the cost estimate and the company's contract situation as mentioned in the interview study (Chapter 8).

The bidding company may be uncertain about the service design, in other words the activities to fulfil the service requirements. The service design forms a basis for the cost estimate and the pricing decision process (see also Chapter 4). Thus, the uncertainties connected to these two aspects of the internal company perspective are interlinked. Important assumptions, that had to be made, include, for example, the customer's utilisation rates of the serviced machine, the frequency of necessary repairs, and the duration of maintenance activities. The connected uncertainty to the service design may vary depending on the available information about the service activities. However, it is unlikely that a company would be included in the bidding process if it had no experience in the area, in other words if it was ignorant of the service design.

In cost-based pricing, the cost estimate is an important influence on the price bid as it forms the basis of the estimation of the profit and price connected to the service contract to be bid for. The uncertainty connected to the cost estimate may be depicted explicitly in the form of a range or is included implicitly through assumptions that may not prove true (for a more detailed discussion of the implicit uncertainty in the cost estimate see Chapter 8). For a pricing decision, the uncertainty connected to the cost estimate arises from the decision maker's interpretation of the modelled results [Kreye et al., 2012; Wang et al., 2007]. Thus, it is typically of an epistemic nature and caused by a lack of information about the future.

The uncertainty connected to the company's contract portfolio can be influenced by the bidding company and forms the context of current and future decisions. For example, a company can influence what percentage of its contract portfolio it would earn through short-term consultancy agreements or through long-term capability contracts. Through the empirical studies, the contract portfolio was identified to be of less importance in the decision process than the uncertainty arising from the cost estimate. However, it can influence the strategic evaluation of the price bid particularly in the formulation of the minimum bid. The contract situation is only examined for the implementation period of the service contract to be bid for. Depending on the usual contract length, the level of the uncertainty is either deterministic (level 1), if the company holds many long-term contracts, or it can only be bound as an interval (level 3), if the company maintains a majority of short-term contracts. If the bidding company holds a portfolio of contracts, the uncertainty level can also be described as a set (level 2).

Table 9-2 depicts the characteristics of the main uncertainties within the internal company processes.

Table 9-2: Uncertainties arising within the internal company processes

	Nature	Cause	Level	Manifestation	Expression
Service design	Epistemic	Lack of understanding – lack of information	Set Interval	Phenomenological	Qualitative
Cost estimate	Epistemic	Lack of understanding – lack of information	Interval	Phenomenological	Quantitative
Company's contract portfolio	Epistemic	Lack of understanding – lack of information	Deterministic Set Interval	Context - endogenous	Qualitative

9.2.3 Customer

The uncertainty connected to the customer can arise from their budget constraints, their evaluation criteria for the submitted bids and possible future needs. As discussed in Section 8.3.3, the uncertainty arising from these aspects depends on the bidding process and the information communicated between the parties.

If the customer's budget limit is communicated, it may still cause the bidding company to be uncertain regarding its enforcement [Leopoulos and Kirytopoulos, 2004]. For example, a customer may award their service contracts typically 5% lower than the stated budget or may be willing to pay more if the benefits are considered worth it (see also Chapter 8). This means that, where the budget is communicated, there is still a low level of uncertainty connected to it. If the customer's budget limit is not communicated, the bidding company may still be able to put boundaries to it using experience. The experience may be based on analysis of the customer's previous bidders selection for similar projects in order to recognise observable patterns. If this experience is not available (for example when entering a new market sector), the bidding company is ignorant towards the customer's budget limit and cannot model this uncertainty to include it in their decision process.

A similar pattern can be followed for the uncertainty arising from the customer's evaluation criteria. These may be communicated in different levels of detail. In some cases, they may be communicated in a quantitative way stating clearly the importance each aspect of the bid would receive. In this case, there is a small level of uncertainty connected to the customer's evaluation criteria. In other cases, the criteria may only be communicated in a qualitative way, for example stating the mandatory and optional service requirements. In this case, the uncertainty connected to the customer's evaluation criteria can be characterised as level 2 – set. The bidding company has information about the mandatory service criteria; however, it is still uncertain about the relative importance of the different requirements in relation to each other. Particularly regarding the optional characteristics, the bidding company may remain uncertain as to which options would give them a competitive advantage. If the criteria are not communicated but the bidding company has experience with this customer, they may be able to bound the relative importance of the different service characteristics in an interval. The spread of the interval then depends on the amount of experience. If the bidding company does not have any previous experience with the customer and the criteria are not communicated, it may be ignorant about them.

In addition, uncertainty may arise from the customer's future needs regarding other related services. Being awarded a particular service contract may open further opportunities with this customer. Including possible future benefits into the proposed bid, may raise its perceived quality by the customer and, thus, give the bidding company a competitive advantage. In general, all four levels of uncertainty are possible depending on the particular market segment and time horizon under consideration. The market sector may be rich in information and slow-moving which means that the future development of the customer can be predicted (level 1 – deterministic). In other cases, the customer may plan to explore new market segments which would increase the uncertainty (level 2 – set). The bidding company may be able to bound this uncertainty (level 3– interval). However, the bidding company may include the customer's future needs when they expect to gain a competitive advantage. The uncertainties would then consist of set (level 2) or interval (level 3).

Table 9-3 summarises the characteristics of the uncertainties connected to the customer.

Table 9-3: Uncertainties arising from customer

<table>
<tr><th></th><th>Nature</th><th>Cause</th><th>Level</th><th>Manifestation</th><th>Expression</th></tr>
<tr><td rowspan="3">Customer's budget limit</td><td rowspan="3">Epistemic</td><td>Lack of understanding – lack of information</td><td>Deterministic</td><td>Data variation</td><td rowspan="3">Quantitative</td></tr>
<tr><td>Lack of understanding – lack of information</td><td>Interval</td><td rowspan="2">Data incompleteness</td></tr>
<tr><td>Lack of understanding – lack of information and experience</td><td>Ignorance</td></tr>
<tr><td rowspan="4">Customer's evaluation criteria</td><td rowspan="4">Epistemic</td><td rowspan="2">Lack of understanding - imprecision</td><td>Deterministic</td><td rowspan="2">Data inexactness</td><td rowspan="4">Quantitative</td></tr>
<tr><td>Set</td></tr>
<tr><td>Lack of understanding – lack of information</td><td>Interval</td><td rowspan="2">Data incompleteness</td></tr>
<tr><td>Lack of understanding – lack of information and experience</td><td>Ignorance</td></tr>
<tr><td rowspan="4">Customer's future needs</td><td rowspan="4">Epistemic</td><td rowspan="4">Lack of understanding – lack of information</td><td>Deterministic</td><td rowspan="4">Phenomenological</td><td rowspan="4">Qualitative</td></tr>
<tr><td>Set</td></tr>
<tr><td>Interval</td></tr>
<tr><td>Ignorance</td></tr>
</table>

9.2.4 Competitors

The uncertainty arising from the competitors is typically connected to the identification of the competitors for the particular service contract and an evaluation of their most likely bid. In some cases, the competitors' identity is communicated during the bidding process which means that there is a low level of uncertainty connected to this aspect as they might decide not to bid. If this is not the case, the bidding company has to assess their identity based on its experience in the market segment. In this case, the level of uncertainty connected to the competitors' identity may be either set (company has experience in the area but no specific information regarding the competitors' identity) or ignorance (company has no experience in the area).

If the identity of the competitors is not known or knowable, no further knowledge about their possible behaviour is available (see also Chapter 8). In this case, all further assumptions about the competitors have to be made under ignorance, which means that the uncertainty cannot be modelled with existing techniques (see Chapter 5).

If the identity of the competitors is or can be known, a top-level guess of their estimated costs may be used. This means that the level of uncertainty arising from the competitors' cost estimates may be bound in an interval (level 3). This leads to a high level of uncertainty connected to the competitors' cost estimates which is connected to the fact that the bidding company knows less about the competitors' cost estimates than about their own. However, the information or experience that is available can be used to guide the competitiveness of one's own price bid.

The availability of certain technology or knowledge to a competitor may give them a competitive advantage in that they may be able to offer a better service quality or a cheaper price (or both). The competitors usually advertise these aspects in the public domain on e.g. their homepage or the newspaper which means that the availability of the competitors' technologies or knowledge is assessable for the bidding company (see Section 8.3.3). This suggests that, when the competitors' identity is known, the uncertainty connected to their available technology and/or knowledge is low (level 1- deterministic).

The competitors' experience with similar services can be an important influence on their suitability for the service contract. The uncertainty connected to this can either be described as level 4 – ignorance if the bidding company does not have any experience in the market sector and hence does not know the competitors background, or as level 3 – interval if the company does have experience but lacks detailed information about their competitors' experience. Table 9-4 summarises the uncertainty within the influencing factor of the competitors.

Table 9-4: Uncertainties arising from competitors

	Nature	Cause	Level	Manifestation	Expression
Competitors' identity	Epistemic	Lack of understanding – lack of information	Deterministic	Context - exogenous	Qualitative
		Lack of understanding – lack of information	Set		
		Lack of understanding – lack of information and experience	Ignorance		
Competitors' cost estimates	Epistemic	Lack of understanding – lack of information	Interval	Context - exogenous	Quantitative
		Lack of understanding – lack of information and experience	Ignorance		
Competitors' technology	Epistemic	Lack of understanding – lack of information	Deterministic	Context - exogenous	Qualitative
		Lack of understanding – lack of information and experience	Ignorance		
Competitors' experience with similar service	Epistemic	Lack of understanding – lack of information	Interval	Data inexactness	Qualitative
		Lack of understanding – lack of information and experience	Ignorance		

In addition to the categories mentioned in Table 9-4, the contract might be let to multiple suppliers who would either focus on different aspects of the service or would have to be able to share the project. This may influence the supplier's bidding strategy and the pricing decision. However, it may result in further uncertainty connected to the service design and thus be considered in the factor "internal company processes" and not in the factor "competitors". However, for this research, the uncertainty arising from multiple suppliers or supply chains for a service contract is not considered. Further research will have to be done to investigate this uncertainty and its characteristics. Thus, it is not included in the discussion and Table 9-4 but it is described in Chapter 12.

Based on the characterisation of the uncertainty in each influencing factor, suitable modelling techniques can be identified to enable these uncertainties to be included in the pricing decision. This is described in the following section.

9.3 Uncertainty modelling in competitive bidding

To identify suitable modelling techniques for the uncertainty influencing the pricing decision at the competitive bidding stage, the uncertainty characteristics described in Section 9.2 can be compared to the classification of modelling techniques with the five-layer approach presented in Table 5-3 in Chapter 5. The focus of this research is on the influencing factors of the customer and competitors. This is based on the following two reasons:

- The customer and competitor were identified as the most important influences on the bidding strategy through the three empirical studies. Furthermore, in literature the importance of competitors [Cheong and Berleant, 2004; Chapman et al., 2000; Afuah, 2009] and the customer [Cohen et al., 2006; Skaggs and Youndt, 2004; Keaveney, 1995] as influencing factors on a bidding strategy was highlighted.
- Both the customer and competitors also assist the bidding company in identifying its competitive advantage. For example, the derived price bid may be higher than the expected bid of a competitor, however, it may be expected to better satisfy the customer's requirements or future needs.

This section describes the process of choosing suitable modelling techniques for the two influencing factors of the customer and the competitors on a company's bidding strategy.

9.3.1 Modelling the uncertainty connected to customer

To identify suitable techniques to model the uncertainty connected to the customer, the uncertainty characteristics identified in Section 9.2.3 and depicted in Table 9-3 were compared to the classification of applications of existing modelling techniques, presented in Chapter 5. Existing modelling techniques have not been applied to cases of ignorance as discussed in Chapter 5. This concerns situations such as when the bidding company does not have any information or experience about the customer. These situations are special cases and do not constitute a regular bidding situation as described in the interview study (Chapter 8). Hence, these uncertainties are not considered in this section.

Table 9-5 shows the suitable modelling techniques for the different uncertainty characteristics connected to the customer as identified in Section 9.2.3. Table 9-5 names the suitable modelling techniques from the choices introduced in Chapter 3 and the applications classified in Chapter 5. Other techniques might also be suitable; however, the focus of this research is to validate the usefulness of the five-layer classification of uncertainty to identify suitable modelling techniques.

Table 9-5: Identification of suitable modelling techniques for uncertainty connected to customer

Nature	**Cause**	**Level**	**Manifest-ation**	**Expression**	**Suitable modelling technique**
Epistemic	Lack of understanding – lack of information	Deterministic	Data variation	Quantitative	***Subjective probability*** [Helton et al., 2000; Krzykacz-Hausmann, 2006]
	Lack of understanding - imprecision	Set	Data inexactness	Quantitative	***Subjective probability*** [Wood et al., 1990b] ***Fuzzy set theory*** [Wood and Antonsson, 1989]
	Lack of understanding – lack of information	Deterministic	Phenome-nological	Qualitative	***Subjective probability*** [Faucheux and Froger, 1995] ***Information gap theory*** [McCarthy and Lindenmayer, 2007] ***Possibility theory*** [Dubois and Prade, 1995]
		Set			***Subjective probability*** [Elouedi et al., 2001; Smets and Kennes, 1994; Feather, 1959] ***Possibility theory*** [Dubois and Prade, 1995]
		Interval			***Subjective probability*** [Faucheux and Froger, 1995] ***Information gap theory*** [McCarthy and Lindenmayer, 2007]
	Lack of understanding – lack of information	Interval	Data incompleten ess	Quantitative	***Subjective probability*** [Krzykacz-Hausmann, 2006]

The identified modelling techniques in the second row of Table 9-5 were applied to a higher level of uncertainty, namely level 3 – interval [Wood et al., 1990b; Wood and Antonsson, 1989]. The characteristics of the remaining four layers were the same as the ones named in Table 9-5. The techniques were identified as suitable to lower-level uncertainty due to two reasons;

- If a modelling technique has been successfully applied to model with a higher level of uncertainty, it should be valid for a lower level of uncertainty and thus to an increased level of information [Sargent, 1998; Walker et al., 2003; Duncan et al., 2008].
- Both modelling techniques have been applied to level-2 uncertainty (set) with different combinations of characteristics in the remaining four layers [García-Fernández and Garijo, 2010; Krzykacz-Hausmann, 2006; Ferreira et al., 2004].

These two reasons were also applied to the third row of Table 9-5. All three named approaches, subjective probability, possibility theory and information gap theory, are applicable to the combination of uncertainty characteristics.

Table 9-5 shows various techniques that were identified as suitable to model the different characteristics of the uncertainty connected to the customer. Only one approach is named in each of the rows, namely subjective probability theory. The other approaches can also be used; however, to achieve a holistic view of the uncertainty connected to the customer, the model outputs would have to be combined. The combination of the outputs of different uncertainty modelling techniques may cause a loss of important information, in other words cause an inconsistency in the conditions [Nikolaidis et al., 2004; Moens and Vandepitte, 2004]. A technique for modelling the uncertainty of a situation should be able to accurately represent the available information [Zimmermann, 2000]. The application of subjective probability theory offers this consistency in modelling the different uncertainties connected to the customer.

9.3.2 Modelling the uncertainty connected to competitors

A similar argumentation was applied to identify a suitable technique to model the uncertainty connected to the competitors. Again, cases of ignorance were eliminated from the discussion based on the lack of representation in uncertainty modelling literature. This means that the presented approach is not applicable to situations where the bidding company has no experience in the market and is thus ignorant towards their competitors.

Table 9-6 shows the suitable modelling techniques that were identified through the comparison of the uncertainty characteristics for the competitors with the applications of modelling techniques listed in Chapter 5. This table focuses on the modelling techniques introduced in Chapter 3. It is to be mentioned, that the modelling techniques named in the first row of Table 9-6 have been applied to a higher level of uncertainty, namely level 3 – interval [Hipel and Ben-Haim, 1999; Parsons and Fox, 1991]. Following the same reasoning as presented in Section 9.3.1, these techniques were identified as suitable for this lower level of uncertainty. The reasons are that these techniques have been applied to a higher level of uncertainty with the same combination of characteristics in the remaining four layers and have also been previously applied to a deterministic level of uncertainty with other characteristics in the remaining four layers.

Table 9-6: Identification of suitable modelling techniques for uncertainty connected to competitors

Nature	**Cause**	**Level**	**Manifest-ation**	**Expression**	**Suitable modelling technique**
Epistemic	Lack of understanding – lack of information	Deterministic	Context - exogenous	Qualitative	***Information gap theory*** [Hipel and Ben-Haim, 1999] ***Interval Analysis*** [Parsons and Fox, 1991]
		Interval	Context - exogenous	Quantitative	***Interval Analysis*** [Shary, 2002]
		Interval	Data inexactness	Qualitative	***Imprecise probability*** [Karanki et al., 2009; Tucker and Ferson, 2003]

In contrast to the customer, none of the identified techniques is able to model all uncertainty characteristics connected to the competitors. This means that different modelling techniques have to be combined to achieve a holistic understanding of the uncertainty connected to the competitors. To minimise the effort of combining modelling techniques and, thus, the difficulties connected to it, only two of the three identified modelling techniques will be used: interval analysis and imprecise probability theory. The first row of Table 9-6 indicates that information gap theory could also be used to model that combination of uncertainty characteristics (specifically the uncertainty connected to the competitors' identities and their available technology or knowledge). However, using this third modelling technique would mean another process of combining the modelling outcomes.

Furthermore, in imprecise probability theory, the probability distributions are defined with upper and lower probability bounds, i.e. with intervals [Walley, 1991]. In other words, it shares mathematical similarities with Interval analysis. This might limit the difficulties connected to the combinations of the model outcomes such as loss of information and an inconsistency in the conditions.

9.4 Discussion

This chapter presented a conceptual framework of the factors which can influence the pricing decision at the bidding stage for service contracts. Based on the empirical studies described in Chapters 6-8, four factors were identified and the uncertainties within these four factors were described and characterised with the five-layer approach described in Chapter 5. This characterisation enables the identification of suitable modelling techniques for uncertainty.

The framework was related to theory in the area of business strategy. Particularly, the Balanced Scorecard framework described by Kaplan and Norton [1996] was used as a basis for the uncertainty framework introduced in this chapter. The main criticism of the Balanced Scorecard is its static projection of a company's business strategy [Norreklit, 2000; Mooraj et al., 1999]. In other words, it offers a momentary representation of the company's objectives, targets and performance measures without giving a history or indication of future development. Similarly, the uncertainty framework introduced in this chapter offers a static, momentary picture of the uncertainties influencing the pricing decision. However, the aim of this framework is to offer a conceptual basis to support the decision process at the bidding stage. In other words, it represents the uncertainty at the moment of making the pricing decision.

The described uncertainty framework is applicable to product-centred services that are highly complex, long-lived, delivered from business to business (B2B) and allocated in a competitive environment (see also Chapter 1). Nonetheless, the interview study indicated that this framework may also be applicable to services of low complexity (see Chapter 8). However, to test and validate this broader applicability, further research has to be done (see also Chapter 12).

9.5 Summary and conclusions

The contributions of this chapter can be summarised as follows;

- This chapter presented a conceptual framework which depicts and characterises the uncertainties influencing the pricing decision at the competitive bidding stage. This framework consists of four factors; the service contract conditions, the internal company processes, the customer and competitors. It answers research objective 4, namely "To define a conceptual framework of the uncertainties influencing a pricing decision" as introduced in Chapter 4.

- The uncertainty within these four factors was described and characterised by applying the five-layer approach as introduced in Chapter 5. To do this, the information typically available at the bidding stage as identified in the interview study (Chapter 8) was used.
- To model the uncertainty at the competitive bidding stage, the five-layer approach described in Chapter 5 was used to identify suitable modelling techniques. In particular, the two influencing factors of the customer and competitors were the main focus in this research. For their modelling, subjective probability is used for the uncertainty connected to the customer and a combination of interval analysis and imprecise probability for the uncertainty connected to the competitors.

To validate the uncertainty framework, it was applied to a case study. Applying the framework to a specific service contract and modelling the uncertainty in all four factors gives a holistic picture of the uncertainties and their influences on the pricing decision and bidding strategy. However, it was discussed that the two factors *customer* and *competitors* offer the largest potential impact for identifying the bidding company's competitive advantage. Thus, these two factors are the main focus for modelling the probability of winning the contract. In addition, the uncertainty connected to the cost estimate is used to derive the probability of making a profit. This is described in the next chapter as an exemplar case study.

10 Designing a decision matrix – A case study

To demonstrate the application of the framework and the design a decision matrix, this chapter introduces a case study of competitive bidding for a service contract. This encompasses objective 5 of this research "To create a decision matrix depicting the probability of winning the contract and the probability of making a profit" (see also Section 4.2). To obtain the decision matrix, the uncertainty modelling techniques identified in Chapter 9 are used, namely;

- Subjective probability to model the uncertainty connected to the customer.
- A combination of interval analysis and imprecise probability to model the uncertainty connected to the competitors.

This chapter presents the application of these techniques to a case study. The contract details of this case study are confidential, thus, the system description was changed. The following scenario focuses on the delivery of the capability to rescue trapped miners from underground. Due to confidentiality reasons, the description of the case study is kept anonymous. This means that neither companies nor the point in time of the bids are named throughout the chapter. However, their properties will be described in Section 10.1 to give an idea of the bidding situation. First, the background of the case study is introduced before the method of collecting the case study data is described. The outcome of this case study is the decision matrix depicting the probability of winning the contract and the probability of making a profit.

10.1 Case study background

The case study focused on the delivery of the capability to rescue trapped miners from underground worldwide. To achieve this, a Product-Service System (PSS) had to be created. This section describes the process of delivering the PSS, i.e. the emergency capability, before introducing the case study company. Then, the service contract conditions are described. Finally, the service design and cost estimate are presented.

10.1.1 Delivering emergency capability

To deliver emergency capability for trapped miners worldwide, the complete system had to be mobile to be transported to the emergency location and operated locally. Hence, there was a constraint in the system size and mobility. The rescue system consisted of the following two sub-systems;

- ***Investigation system:*** Its task was to locate the trapped miners, establish communications, and find dangers in their environment such as poisonous gases, flooded tunnels, explosive vapours, unstable walls and roofs. To achieve this, a mine rescue robot, which was remotely controlled, was to be utilised.
- ***Rescue system:*** This included the necessary equipment to drill a connection to the trapped miners, deliver emergency supplies and transfer them to the surface.

These Investigation and Rescue systems could be mobilised independently from each other. Figure 10-1 depicts the general situation of rescuing trapped miners (this sketch is not drawn to scale).

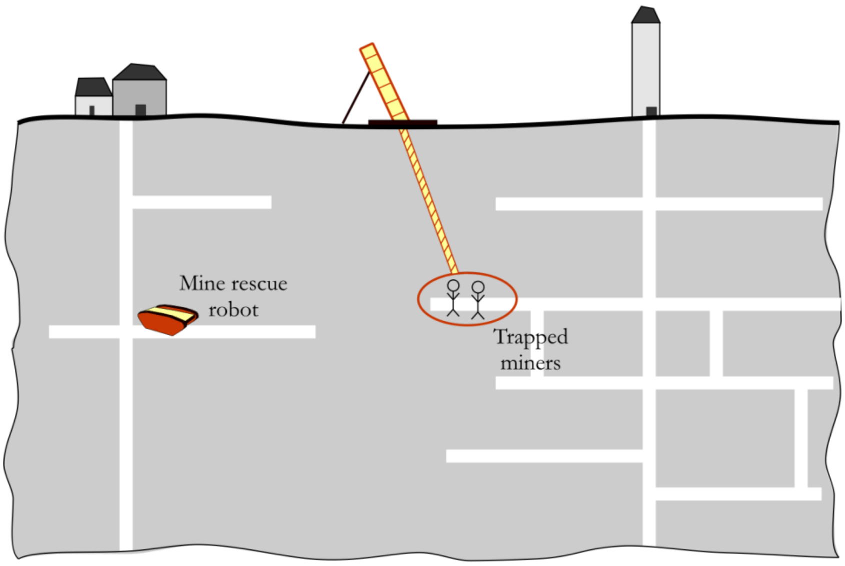


Figure 10-1: Sketch of the systems to rescue trapped miners

Both systems were stored at a base station. When the alert message is received, the Investigation system is transported to the site, where a rescue robot is lowered into the mine to ensure the security of the site. In the meantime, the Rescue system with the necessary equipment and personnel is mobilised, which means that it is transported to the site. The equipment includes a drilling tower, rescue chamber and mobile hospital.

10.1.2 Case study company

The company that provided the case study is a large, global company with substantial experience in the business area. For the presented bidding situation of delivering emergency capability for trapped miners, the case study company evaluated their own strengths and weaknesses as a supplier of such a system at the time of bidding. These are presented in Table 10-1. Due to confidentiality reasons, the case study company is named Bidding Company throughout this chapter.

Table 10-1: Self-appraisal of case study company - strengths and weaknesses

Strengths	Weaknesses
• Major current customer contractor. • Good long term customer relationships. • Good in-depth project knowledge. • Early dedicated team for planning and teaming. • Probably further ahead than others in planning for bid.	• Internal resources only offer knowledge, project management and integration services. • Not particularly good record of delivery to customer. • Perceived as being expensive and not well organised. • No major component or operations partner yet.

10.1.3 Service contract

The contract was being bid for before the economic recession in 2008, in other words during a period that can be characterised economically by a steady growth (average growth rate of 2.68% in the UK between 1997 and 2008)[14]. Table 10-2 lists the service contract conditions of the presented case study. This includes the contract period, service requirements (presenting a selection of the 295 requirements from the original bid), payment method, and bidding process.

The contract was allocated for a period of ten years, divided into a design and manufacture period starting at the point of contract award, followed by a seven year operating period. The design and manufacturing period ended in the delivery of the physical products necessary for the emergency capability, such as the mine rescue robot and the drilling system to reach the trapped miners.

The competing suppliers were given a list of 295 service and product requirements that were divided into mandatory and optional requirements. These were connected particularly to the design and manufacturing period. Minimum values for technological details such as the operation time of the mine rescue robot were given to the competing companies (mandatory requirements). The competing suppliers were given the option of exceeding these minimum technological details if they considered this to be valuable (optional requirements). The operation period was characterised by the delivery of the emergency capability. Further details were left deliberately vague, to be interpreted by the competing suppliers.

Depending on the contract period, the payment method was defined. The payment throughout the design and manufacturing period was based on milestones linked to specific

[14] For further details see National Statistics Report 605 "Economic Trends", April 2004, available under: http://www.statistics.gov.uk/downloads/theme_economy/ET605.pdf.

technological details. There were not more than 4 milestones per year for the design and manufacturing period. During the operation period, the payments occurred quarterly.

Table 10-2: Service contract conditions of the case study

Aspects	**Characteristics for this case study**
Contract period	10 years, divided into a design and manufacturing period and 7 year operation period.
Service requirements	***Design and manufacturing period***: Design and build the Investigation and Rescue systems including the mine rescue robot. These had to be capable of the following; • It had to be able to transport trapped miners to the earth's surface. • It had to be mobile, i.e. easily transportable with established transport systems such as trucks. ***Operation period:*** The requirements of the operation period were as follows; • Delivery of the emergency capability at all times for 7 years. This included the operation of the base where the rescue system was to be stored. Further details were left deliberately for interpretation by the bidding suppliers.
Payment method	Milestone payment during design and manufacturing phase, level periodic payments (quarterly) during operation period according to performance indicators.
Bidding process	Multi-stage: • Expressions of interest by possible suppliers. Out of these, five bidders were short-listed for the next stage. • Submission of a competitive bid against the service requirements. • Assessment period: Presentation of the bid to the customer and answering of clarification questions. • Best and Final Offer: Provision of revised offer. • Final negotiation process with preferred bidder and customer.

The bidding process was multi-stage, initiated by a bid invitation from the customer to which companies could express their interest. At this stage, the possible suppliers had to convince the customer of their ability to fulfil the contract by suggesting solutions. Based on this list of submitted interested companies, the customer short-listed five bidding companies for the next stage, i.e. for submitting a competitive bid. The case study data investigated in this chapter focuses on the bidding period at the stage of submitting a competitive bid against the stated service requirements after the competitors were short-listed for the contract. This means that the Bidding Company knew the identity of their competitors for this particular service contract. This also implies that the customer considered each of these competitors as a suitable supplier of the required service. Figure 10-2 shows the different companies involved in the bidding process at the stage before submitting the competitive bids.

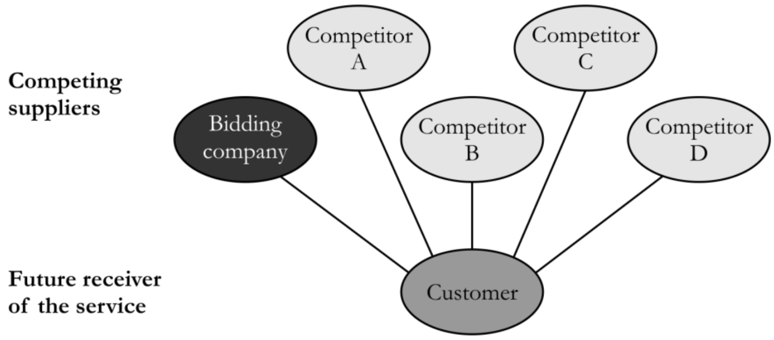


Figure 10-2: Companies involved in the bidding process of the case study

The uncertainty model based on this case study could also be used at the earlier stage of expressing an interest in the contract, which is discussed further in Section 10.5.

10.1.4 Service design and cost estimate

Based on these criteria, the Bidding Company designed different service options including different optional requirements and other suggestions. For these options, cost estimates were compiled based on a bottom-up approach. The estimates were presented in a table format as a cost breakdown depicting cost factors such as labour, sub-contracts with 2nd-tier suppliers of e.g. material, and a risk allowance. Table 10-3 depicts the total cost breakdown for two design options. These cost estimates did not include any uncertainty in the form of a minimum-maximum cost range; however, the risk allowance was treated as a monetary security which the Bidding Company did not expect to spend during the contract period.

Table 10-3: Costs estimates for two options of emergency capability contract

	Option 1 [£]	**Option 2 [£]**
Labour	2,906,680	2,834,190
Subcontract	35,010,681	34,600,627
Training & Simulation	373,611	373,611
General & Administration	1,262,951	1,231,218
Risk allowance	1,400,000	2,101,388
Total costs	40,953,921	41,141,032

Both options refer to fulfilling only the mandatory contract requirements as described in Section 10.1.3. Option 1 includes more risk mitigation which refers to the inclusion of the risk allowance in the base costs. This means that the values for the "risk allowance" in the cost estimate is smaller for this option. The annual breakdowns of these two options are described in Appendix D. Comparing these total cost values to the customer's stated budget limitations of £40M, the Bidding Company concluded that only the mandatory requirements would be included in their service design to *"make the contract affordable"*[15]. Of the two options listed in Table 10-3, the Bidding Company focused on option 1 for their further assessment of the contract. Hence, option 1 forms the basis of the further discussion in this chapter.

Based on the case study background, further data was collected that was necessary for the design of the decision matrix depicting the probability of winning the contract and the probability of making a profit. The following section describes the method of data collection.

10.2 Method

Before describing the details of the uncertainty model used to derive the decision matrix, the method that was applied to collect the necessary data to derive the probability of winning the contract and the probability of making a profit is explained. In particular, the data collection process and the method to elicit subjective information are presented, before the collected information is summarised.

10.2.1 Data collection process

The data was collected during eight main phases including three meetings with the Bidding Company. This is depicted in Table 10-4 which also highlights the outcome of each of the eight data collection phases.

These data collection phases, particularly the meetings, served as a basis for discussing the applicability of the presented research to the Bidding Company, in order to develop trust between the researcher and the company, and to identify the information and necessary level of detail for the presented uncertainty model. All meetings took place at the Bidding Company's site.

During the second meeting (phase 5), the subjective information was collected through interviewing the decision maker of the original bid. The following section describes how this subjective information was elicited.

[15] This statement used by the Bidding Company to describe the affordability to the supplier, not the customer. This included that the supplier wanted to make profit with this contract.

Table 10-4: Case study data collection process

Data collection phase	Description	Outcome
1) Establish contact with Bidding Company	Initial discussion with case study contact to explain context and aims of research.	Expression of interest from the Bidding Company to participate in the presented research.
2) Initial meeting with Bidding Company	Presentation and discussion of the uncertainty framework (see Chapter 9). Further discussion to verbally explain the type of required information.	Confirmation of suitability of the framework to the company's processes. Identification of a suitable case study for this research.
3) Collection of context information	Collection of the information regarding the case study context by the Bidding Company.	Transfer of context information regarding the case study from Bidding Company.
4) Analysis of bidding context by researcher	Analysis of the received information. Identification of areas where further clarification was required. Identification of questions regarding the subjective evaluation of the bidding situation.	Transfer of a list containing areas of further clarification to the Bidding Company.
5) Meeting with Bidding Company	Interview with the decision maker of the original bid compilation process and other members of the Bidding Company to acquire the necessary data for the uncertainty model. Detailed discussion of the bidding situation, available data for researcher and necessary information for the uncertainty model. Obtain answers to the questions regarding the subjective evaluation of the bidding situation (method see Section 10.2.2).	Detailed description of the bidding scenario. Subjective information for uncertainty model including confidence levels. List of further information necessary for uncertainty model.
6) Collection of detailed information	Collection of detailed information necessary for the uncertainty model by the Bidding Company. Anonymisation of the collected information by the Bidding Company.	Transfer of detailed, anonymised information from Bidding Company.
7) Further clarifications	Obtaining further clarification of the bidding information in cases of vague or ambiguous descriptions between researcher and case study contact via email and telephone.	Information for uncertainty model
8) Feedback to Bidding Company	Meeting with Bidding Company to present and discuss the uncertainty model.	Uncertainty model Areas of future research

10.2.2 Eliciting subjective information

Eliciting subjective information can cause difficulties due to the nature of this information. Experts tend to be overconfident in their judgements and underestimate the uncertainty connected to the decision, as described in Chapter 6. Furthermore, the expression of probabilistic information can vary between experts: the statement of numerical values such as *"with a confidence value of 95%, the customer's budget limit was expected to be around £40 million"* gives a clearer basis for interpretation (and thus less ambiguity) than a qualitative statement such as *"the customer's budget limit was very likely to be around £40 million"*. However, experts have been found to be more comfortable expressing probabilistic information as a qualitative statement rather than a quantitative one [van der Gaag et al., 1999; Wallsten et al., 1993].

Due to the constraint that only one expert was accessible for the data collection of this case study, a two-step approach was applied as depicted in Table 10-5.

Table 10-5: Two-step approach to elicit subjective information

Steps	**Questions**
1) Elicit an ***interval statement***	• In your opinion, does the customer have any lowest budget limit under which they will not consider accepting the offer for different reasons? • What, do you think, will be the customer's maximum budget, including possible royalties for additional capability?
2) Elicit ***confidence level*** of the interval statement from first step.	• How confident are you that the customer's budget limits are within these boundaries? This question referred back to the interval derived in step 1. To ensure an unambiguous interpretation of this confidence level, a probability scale was used depicting both quantitative and qualitative probability statements as depicted in Figure 10-3.

In the first step, the expert was asked for a lower and upper bound to eliminate overconfidence of the expert judgement [Cagno et al., 2001]. For example, in the bidding process, the customer's budget limits were indicated to be *"in the region of £40 million"* (statement by the Bidding Company). To assess the decision maker's judgement of the customer's budget limit, the following questions were asked:

- In your opinion, does the customer have any lowest budget limit under which they will not consider accepting the offer for different reasons?
- What, do you think, will be the customer's maximum budget, including possible royalties for additional capability?

In the second step, the expert was given the interval determined in step 1 and was asked to give a confidence level connected to this interval. To elicit this probabilistic information, the expert was shown a scale displaying different probabilistic values, both in qualitative (or verbal) and in quantitative (or numerical) form as depicted in Figure 10-3.

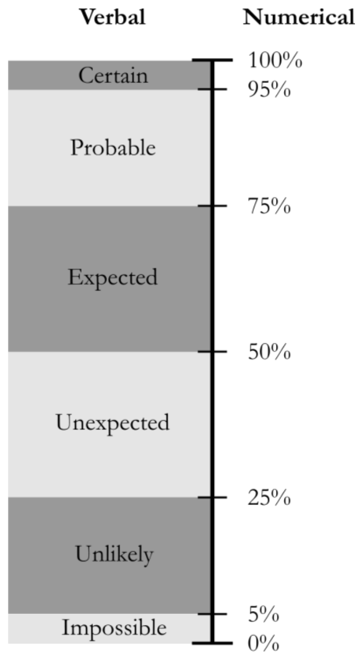


Figure 10-3: Probability scale to elicit subjective probabilities

The probability scale is based on literature, in particular on the research findings from van der Gaag et al. [1999] who developed it based on multiple studies [Renooij and Witteman, 1999] and extensively tested it in the area of cancer treatment and diagnosis. In these areas it was described as a helpful tool to support the decision makers in quantifying their subjective assessment of the situation. Its suitability to non-medical contexts such as competitive bidding was tested with this case study and is evaluated in Section 10.4.

The scale offers multiple anchor points to guide the expert while avoiding biasing them in their choice of a confidence level. Due to the ambiguous nature of the qualitative statements in comparison to quantitative ones, the information given in this way was interpreted as a confidence range. For example, if the expert stated that he was *"certain"* about a statement, a confidence range of 95-100% was used in the further uncertainty modelling process. This was verbally explained to the expert before and during the data collection.

10.2.3 Collected information

Following the data collection process (Section 10.2.1) and the method for eliciting subjective information (Section 10.2.2), the necessary information for obtaining the decision matrix was accumulated. Table 10-6 summarises what information was collected and where it was used.

The subjective information from the bidding decision maker and the detailed information from the bidding scenario as recorded by the Bidding Company during the original bid compilation process were used in the uncertainty model to derive the decision matrix. The following section describes this uncertainty model.

Table 10-6: Summary of collected case-study information

Type of information	Included details	Use in this chapter
Bidding context	• General process of delivering emergency capability including the stages to rescue the trapped miners. • Service contract conditions including contract period, service requirements, bidding process, and payment method. • Service design and cost estimate.	Section 10.1: Case study background
Detailed information of bidding scenario	• Bidding company's approach to bid compilation. • Assessment of the strengths and weaknesses of the competitors. • Relative weighing of assessment of the competitors and of the customer in their importance for the pricing decision.	Section 10.3: Uncertainty model
Subjective evaluation by bidding decision maker	• Customer's budget limitations with confidence level. • Competitors' cost estimates with confidence levels.	Section 10.3: Uncertainty model

10.3 Uncertainty model

Based on the collected information, an uncertainty model was created to derive the decision matrix. This section describes the modelling approach before the model to obtain the probability of winning the contract and the probability of making a profit is presented.

10.3.1 Modelling approach

To create the uncertainty model, the framework described in Chapter 9 was used as a basis. Figure 10-4 shows the four factors from this framework where the uncertainties that were included in the presented model are highlighted.

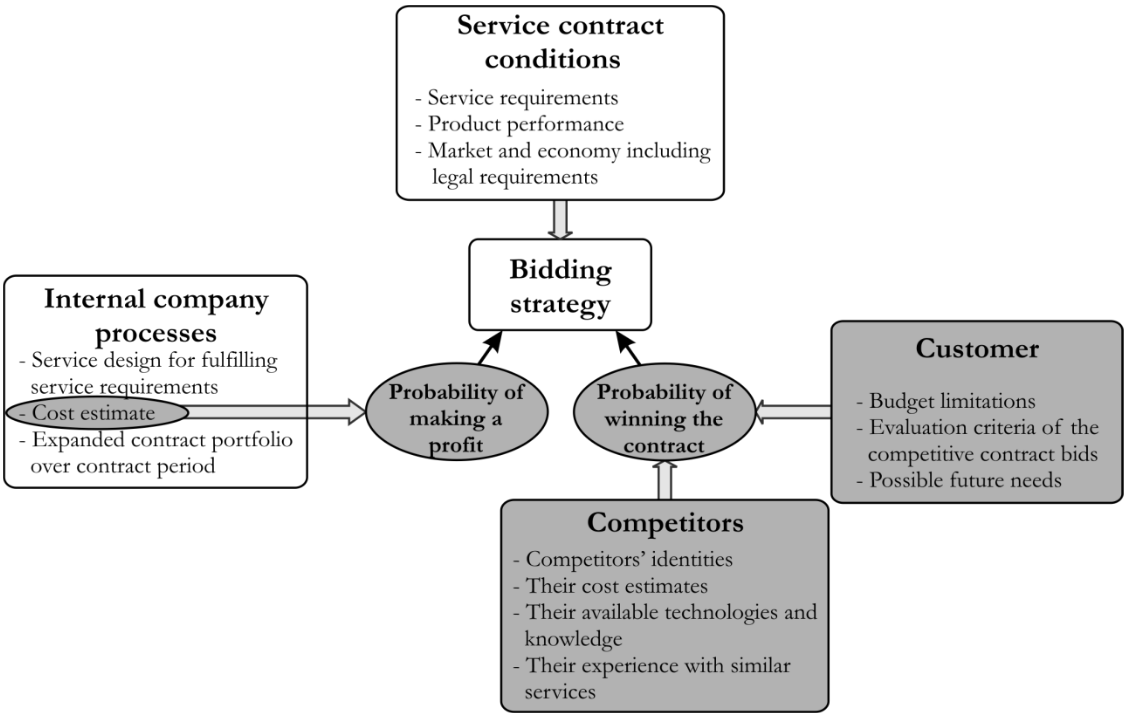


Figure 10-4: Uncertainty model for obtaining the probability of winning the contract and the probability of making a profit

10.3.2 Modelling the probability of winning the contract

To model the probability of winning the contract, the uncertainty connected to the customer and competitors were used as depicted in Figure 10-5.

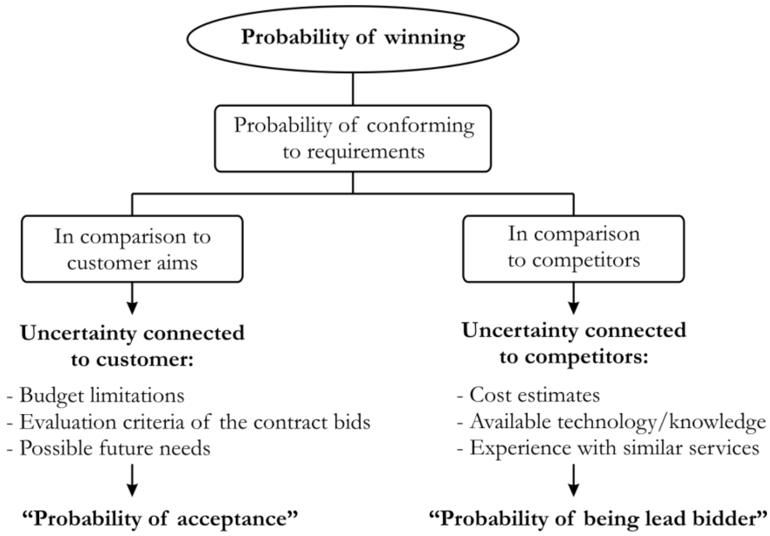


Figure 10-5: Model to obtain the probability of winning the contract.

The probability of winning the contract can be interpreted as the probability of conforming to requirements – both in comparison to the aims of the customer with the service contract and in comparison to the competitors' bids. For the purpose of this research, the uncertainty connected to the customer is understood as the probability of acceptance and the uncertainty connected to the competitors is interpreted as the probability of being the lead bidder.

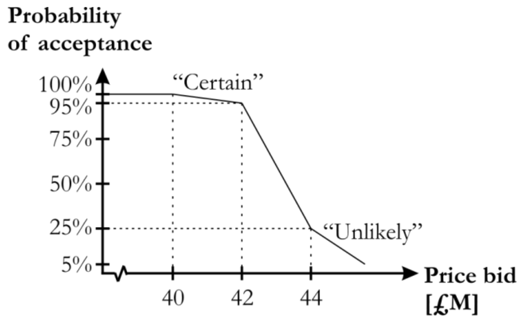
The following sections describe how the uncertainty connected to the customer and the competitors was modelled before being integrated to depict the Bidding Company's probability of winning the contract.

(1) Uncertainty connected to the customer

The uncertainty connected to the customer included the budget limitations, their evaluation criteria and possible future needs. After estimating the contract costs and comparing these to the stated budget limitations, the Bidding Company decided that they would only include the mandatory service requirements as described in Section 10.1.4. Thus, the uncertainty connected to the customer's evaluation criteria and future needs are not included in the presented model for obtaining the probability of winning the contract. However, the Bidding Company included different additional options to their competitive bid that could be chosen by the customer. These were priced including the estimated costs and the target profit value.

The uncertainties connected to the customer are depicted in Table 10-7, which shows a comparison of the information that was communicated by the customer during the bidding process and the subjective assessment by the decision maker.

Table 10-7: Evaluation of the uncertainty connected to the customer

Uncertainty connected to customer	**Uncertainty information**	
	Communicated values from customer	Evaluation from bidding decision maker
Budget limitations	£ 40M	
Evaluation criteria	***Mandatory*** and ***optional criteria*** for the design and manufacturing period and the operation period	***Mandatory criteria:*** Focus on fulfilling mandatory criteria for both phases due to costs (see Section 10.1.4). ***Optional criteria:*** Solutions for the optional criteria were developed and included in the bid as additional options that were not included in the price bid.
Future needs	None	None

For the purpose of this research, the uncertainty connected to the customer is expressed as the *probability of acceptance*, in other words, it describes the probability of conforming to requirements in comparison to the customer's aims with the contract. In a non-competitive bidding process, the probability of acceptance would correlate with the probability of winning the contract. In competitive bidding, the probability of acceptance only constitutes one part of the probability of winning the contract (as depicted in Figure 10-5).

The customer's budget limitations were communicated to be at £40M. However, Table 10-7 shows that the subjective assessment by the Bidding Company did not expect this to be a definite value. The Bidding Company evaluated the customer's budget to have no minimum limit under which the customer would not accept the bid under the condition that the competing supplier could justify that all the technical and service quality included in the competitive bid could be achieved within the stated price. Hence, a price bid up to a value of £40M would be accepted with 100% confidence.

The Bidding Company furthermore was *"certain"*[16] that a price bid up to £42M would be accepted which was interpreted as a probability interval of 100-95% (using the probability scale presented in Figure 10-3). Any value between £42M and £44M would be accepted with a probability between the 95% and 25% as depicted in Table 10-7. Moreover, a price bid of £44M or over was *"unlikely"*[17] to be accepted which refers to a probability of acceptance of 25-5% (according to the probability scale). For the purpose of the uncertainty model, the probability of acceptance is assumed to follow a downward trend until the value of £48M where it reaches the value of 5%. This means that the uncertainty connected to the customer can be used to obtain the probability of acceptance as presented in equation (1). This equation represents the graph depicted in Table 10-7.

$$P_{acceptance} = \begin{cases} 1 & for\ p \le 40 \\ 2 - 0.025 \cdot p & for\ 40 < p \le 42 \\ 15.65 - 0.35 \cdot p & for\ 42 < p \le 44 \\ 2.45 - 0.05 \cdot p & for\ 44 < p \le 48 \end{cases} \qquad (1)$$

$P_{acceptance}$ – probability of acceptance,

p – price bid [£M].

This equation only represents one aspect of the probability of winning. The other side includes the uncertainty connected to the competitors as described in the next section.

[16] Statement by the Bidding Company

(2) Uncertainty connected to the competitors

Due to the complexity of the service contract, the Bidding Company assessed that the successful bidder would have to collaborate with other companies to cover the full width of the service requirements and, hence, they would need to form a supplier network. It is acknowledged that this may cause uncertainties in itself [Mason-Jones and Towill, 1998; Bowersox et al., 2002; Harland et al., 2003]. This is outside of the scope of this research but offers opportunities for future research as discussed in Chapter 12.

The 2nd-tier supplier network constituted part of the bid offer by the competing companies as depicted in Figure 10-6.

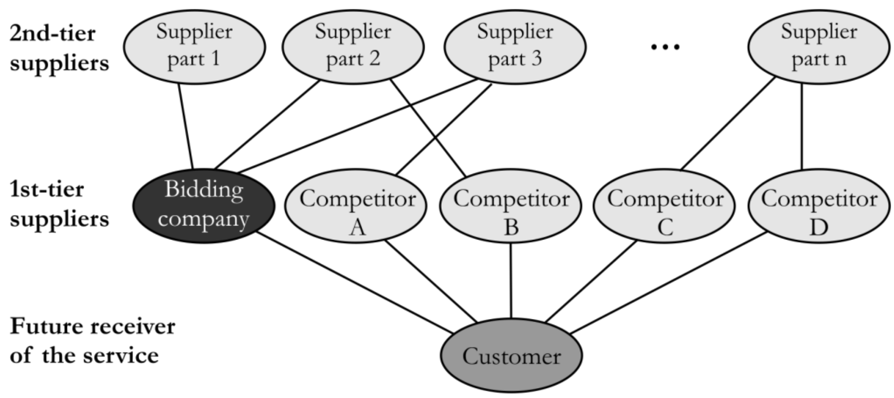


Figure 10-6: Possible supplier network for delivering capability

To ensure the competitiveness of their bid, the Bidding Company adopted the following approach;

1) Identification of companies with key capabilities in the area of mine emergency systems that might become 2nd-tier suppliers for one of the five competing bidders.
2) Identification of the possible 2nd-tier suppliers that have key capabilities in the areas that were missing from the Bidding Company's portfolio. The Bidding Company then approached these companies and invited them to commit to them as the exclusive supplier for the capability contract. In other words, the identified 2nd-tier suppliers who were contacted by the Bidding Company and accepted their offer gave up their right to negotiate with other suppliers that were the competitors for the service contract.
3) If the suppliers accepted to become exclusive suppliers to the Bidding Company, this would reduce the links of the key 2nd-tier suppliers to the other competitors shown in Figure 10-6. The Bidding Company could then exclude the capability of these key 2nd-tier suppliers from the offers of the four competitors for the emergency capability contract.

In addition to this process, the Bidding Company assessed their competitors with their strengths and weaknesses for the presented contract in a qualitative way. Table 10-8 presents these strengths and weaknesses for each of the four competitors. Based on this qualitative assessment, the Bidding Company was able to evaluate their competitors quantitatively by assessing their likely costs for fulfilling the contract in relation to itself.

It is highlighted that the information presented in Table 10-8 is a subjective assessment of the competing companies made by the Bidding Company at the time of bidding. Hence, the comments listed in Table 10-8 formed a one-sided assessment; they were not confirmed (or disconfirmed) by objective sources.

To obtain the probability of being the lead bidder, only the quantitative information could be included. This means, that for the presented case study, only the competitors' cost estimates were included and the uncertainty connected to their available technology/knowledge and their experience with similar services is not represented in the uncertainty model. The purpose of the presented case study was to validate the uncertainty framework and its use to obtain a decision matrix depicting the probability of winning the contract and the probability of making a profit. Due to limitations in the available information, this focuses on the competitors' cost estimates. This is discussed further in Section 10.4.

Competitor A consisted of a consortium of companies, which had complimentary areas of expertise and participated as "one" competitor. The Bidding Company estimated that Competitor A's solution for the technological issue of the emergency system (for the design and manufacturing period) would be cheaper because they had already invested in the development. However, overall, Competitor A was considered to be probably (with a confidence of 50%) £1-2M more expensive than the Bidding Company due to higher overhead costs. Competitors B and C were considered to have similar costs for providing the emergency capability as the Bidding Company. In other words, their costs were likely to be within an interval of ± £1M of the Bidding Company's costs with a confidence level of 40-50%.

For the considered service contract of delivering emergency capability for trapped miners, the Bidding Company considered Competitor D as the most dangerous competitor. This was due to two main reasons: Competitor D was the supplier of the previous rescue system to the customer (which was not a capability contract) so they had previous experience in the development and technological side of the case study contract. This meant that they were probably (with a confidence of 50-70%) able to supply the emergency capability contract for less costs than the Bidding Company (£0-2M).

Table 10-8: Assessment and evaluation of four competitors for emergency capability contract

Strengths	Weaknesses	Evaluation
Competitor A		
• Recent involvement in concept study. • Significant existing facilities and resource. • Recent close relationship with customer. • Competitor subsidiaries have involvement in related projects. • Have the only specifically valid, but as yet undelivered capability. • Product solution likely to be cheaper because development is already funded. • Have demonstrated strong commitment by early teaming. • Their solution would inevitably be compatible for other markets.	• Customer was not entirely happy with the quality and late delivery of the concept study. • If the customer followed the lead of related projects – it would negate most of the concept study work done to date. • Reliant totally on existing solution. • No practical project experience. • Key components will be made overseas. • Competitor has reported poor results for last year.	Costs: £1-2M > Bidding Company. Confidence level: 50%.
Competitor B		
• Major existing support contractor to customer. • Strong UK Base and engineering support. • Have demonstrated serious commitment by recently taking on staff from current project. • Bullish and confident approach by Project Manager– appears to have good rapport with customer. • Good international partner – we think they will design and build the key components. • Best pre-qualification questionnaire. • Teamed with one other significant supplier.	• No previous relevant involvement to date. • Not rated for thinking ability (subjective). • No suitable geographic base.	Costs: Bidding Company ± £1M. Confidence level: 40-50%.
Competitor C		
• Strong and knowledgeable project manager. • Incumbent contractor. • Have most technically and operationally knowledgeable team capable of designing key components. • Very good track record in relevant projects. • Have existing geographic base and local knowledge.	• Very limited personnel to put together a major bid. • Not had experience of major customer project of this magnitude. • Very daunted by bid costs and effort required.	Costs: Bidding Company ± £1M. Confidence level: 40-50%.

Table 10-8 (continued): Assessment and evaluation of four competitors for emergency capability contract

Strengths	Weaknesses	Evaluation
Competitor D		
• Current supplier to customer. • Offer good in-house key component knowledge. • Key component experience and capability. • Have spoken early to most potential sub-contractors. • Considered a "rank outsider" by most primes.	• Not highly rated historically by the customer. • No project knowledge or experience. • No sensible geographical base.	Costs: £0-2M < Bidding Company. Confidence level: 50-70%.

Based on this assessment of the uncertainty connected to the competitors, the probability of being the lead bidder for the emergency capability contract can be obtained. It represents the probability that the Bidding Company is the lead bidder depending on the price bid. The assessment of the competitors' cost values was done in relation to the Bidding Company's own costs. Hence the cost value of fulfilling the mandatory requirements as presented in Section 10.1.4 (option 1), i.e. £40.95M, is used as a reference point to assess the probability of being the lead bidder. This was then translated into likely price bids for each competitor with the given confidence value.

Table 10-9 shows the steps of obtaining the probability of being a lower bidder than Competitors A-D based on the presented information. Competitors B and C were summarised in one column because the Bidding Company evaluated them as having the same costs in relation to the Bidding Company. The notation "[*a, b*]" refers to an interval with the minimum value "*a*" and the maximum value "*b*".

The starting point was the Bidding Company's evaluation of the competitors' costs in relation to their own cost estimate. For Competitor A, this starting point was the evaluation of their costs to be £1-2M over the costs of the Bidding Company (with 50% confidence). Using the cost value of the Bidding Company (£40.95M), the costs of Competitor A are likely to be between £41.95M and £42.95M. Adding a profit of 12.31%[17], the price values for Competitor A are likely to be between £47.11M and £48.24M with a confidence of 50%. The same process was followed to obtain the likely price values for Competitors B, C and D; a detailed description of this is given in Appendix D.2.

[17] This was the profit the Bidding Company evaluated for their target value, see also Appendix D. It is assumed that the competitors have similar cost and profit structure as the Bidding Company.

Table 10-9: Obtaining the likely price bids and probability of being a lower bidder for four competitors

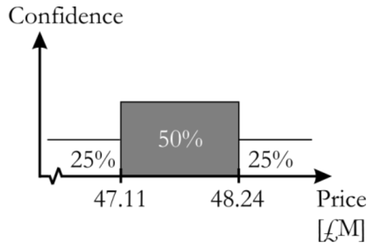
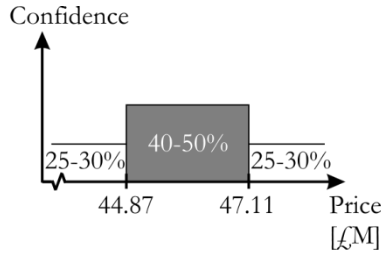
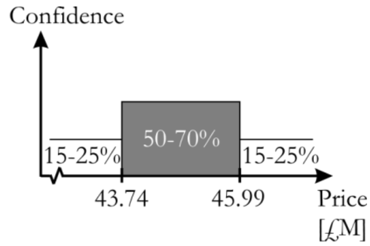
Competitor A	**Competitor B/C**	**Competitor D**
Cost values:		
c_A=£40.95M + £[1, 2]M =£[41.95, 42.95]M	$c_{B/C}$=£40.95M ± £1M =£[39.95, 41.95]M	c_D=£40.95M - £[0, 2]M =£[38.95, 40.95]M
Profit (12.31% of costs):		
£[5.16, 5.29]M	£[4.92, 5.16]M	£[4.79, 5.04]M
Price values:		
£[47.11, 48.24]M	£[44.87, 47.11]M	£[43.74, 45.99]M
Confidence:		
50%	40-50%	50-70%
Visual interpretation:		
		
Probability of competitor's price bid:		
$P(p_A < 47.11) = [0, 0.25]$ $P(47.11 \le p_A < 48.24) = 0.5$ $P(p_A \ge 48.24) = [0, 0.25]$	$P(p_{B/C} < 44.87) = [0, 0.25/0.30]$ $P(44.87 \le p_{B/C} < 47.11) = [0.4, 0.5]$ $P(p_{B/C} \ge 47.11) = [0, 0.25/0.30]$	$P(p_D < 43.74) = [0, 0.15/0.25]$ $P(43.74 \le p_D < 45.99) = [0.5, 0.7]$ $P(p_D \ge 45.99) = [0, 0.15/0.25]$
Probability of having a lower price bid than competitor *n* $P(p < p_n)$:		
$= \begin{cases} [0.75, 1] & for\ p \le 47.11 \\ [0.25, 0.75] & for\ 47.11 < p \le 48.24 \\ [0, 0.25] & for\ p > 48.24, \end{cases}$	$= \begin{cases} [0.7, 1] & for\ p \le 44.87 \\ [0.25, 0.75] & for\ 44.87 < p \le 47.11 \\ [0, 0.3] & for\ p > 47.11 \end{cases}$	$= \begin{cases} [0.75, 1] & for\ p \le 43.74 \\ [0.15, 0.85] & for\ 43.74 < p \le 45.99 \\ [0, 0.25] & for\ p > 45.99 \end{cases}$

Table 10-9 depicts how each of the probability values for being a lower bidder than the four competitors was obtained. For Competitor A, the probability of their price bid can be framed between the two values £47.11M and £48.24M with a probability of 0.5. This means that with a joint probability of 0.5 Competitor A's price bid can fall outside of this interval. Due to the lack of any further information, it is assumed that both sides outside of the stated interval are equally likely to occur. In addition, it can be assumed that the further away the price bid gets from the named interval, the less likely it is for Competitor A to bid this price. Thus, the probability that Competitor A bids a value over £48.24M (or under £47.11M) can be expressed as an interval between 0 and 0.25. The same process was applied to the information regarding Competitors B, C and D to obtain the probability of having a lower price bid than them.

The price values were then used to obtain the likelihood of being the lead bidder, which can be expressed as the probability of having a higher value bid than any of the competitors. In this case study, the probability of being the lead bidder consists of the probability of having a lower price bid than any of the competitors for fulfilling the mandatory service criteria. This can be expressed as follows;

$$P_{lead} = P(p < p_A) \cap P(p < p_B) \cap P(p < p_C) \cap P(p < p_D)$$

$$P_{lead} = P(p < p_A) \cdot P(p < p_B) \cdot P(p < p_C) \cdot P(p < p_D) \qquad (2)$$

P_{lead} - Probability of being the lead bidder,

p - Price bid of Bidding Company, in £M,

$P(p < p_n)$ - Probability of the Bidding Company's price bid being lower than competitor n's bid, n=A … D.

The probability functions depicted in Table 10-9 were multiplied according to equation (2) to obtain the probability of being the lead bidder the emergency capability contract as presented in equation (3).

$$P_{lead} = \begin{cases} [0.28,1] & for\ p < 43.74 \\ [0.06;0.85] & for\ 43.74 \le p < 44.87 \\ [0.01;0.48] & for\ 44.87 \le p < 45.99 \\ [0,0.14] & for\ 45.99 \le p < 47.11 \\ [0,0.02] & for\ 47.11 \le p < 48.24 \\ [0,0.01] & for\ p \ge 48.24 \end{cases} \qquad (3)$$

Figure 10-7 depicts this function. The x-axis showing the price values in £M is not drawn to scale; the purpose of this figure is to visualise the probability of being the lead bidder for the presented case study.

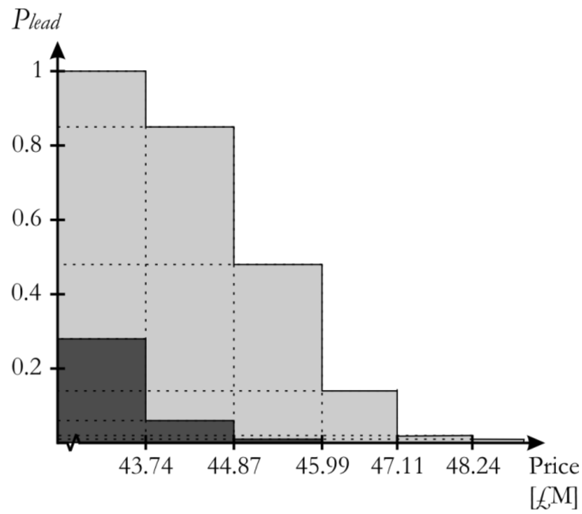


Figure 10-7: Probability of being lead bidder for case study

The assessment of the competitors for this emergency capability contract was combined with the assessment of the customer to obtain the probability of winning the contract. The following section describes the model including both uncertainty factors.

(3) Combining uncertainty from customer and competitors

This section describes the model used to combine the uncertainty connected to the customer and the one connected to the competitors to obtain the probability of winning the contract. It is acknowledged that the uncertainties can have a different importance in the decision process. Hence, weightings are introduced that allow a scaling of the two probability equations as presented in equation (4).

$$P_{winning} = x \cdot P_{acceptance} + y \cdot P_{lead} \tag{4}$$

x Importance of customer,

y Importance of competitors,

$x+y=1$.

The Bidding Company weighted the uncertainty connected to the customer with 0.8, the uncertainty connected to the competitors 0.2. Hence, the probability of winning the contract can be calculated as follows;

$$P_{winning} = 0.8 \cdot P_{acceptance} + 0.2 \cdot P_{lead} \tag{5}$$

Substituting the according equations for the probability of acceptance (equation 1) and for the probability of being the lead bidder (equation 3) into the equation for obtaining the probability of winning (equation 5), the following probability of winning can be derived (equation 6).

$$P_{winning} = \begin{cases} [0.86, 1] & for\ p \le 40 \\ [1.66 - 0.02p, 1.8 - 0.02p] & for\ 40 < p \le 42 \\ [12.58 - 0.28p, 12.72 - 0.28p] & for\ 42 < p < 43.74 \\ [12.53 - 0.28p, 12.69 - 0.28p] & for\ 43.74 \le p \le 44 \\ [1.97 - 0.04p, 2.13 - 0.04p] & for\ 44 < p < 44.87 \\ [1.96 - 0.04p, 2.06 - 0.04p] & for\ 44.87 \le p < 45.99 \\ [1.96 - 0.04p, 1.99 - 0.04p] & for\ 45.99 < p \le 47.11 \\ 1.96 - 0.04p & for\ 47.11 \le p \le 48 \end{cases} \quad (6)$$

This equation is depicted in Figure 10-8.

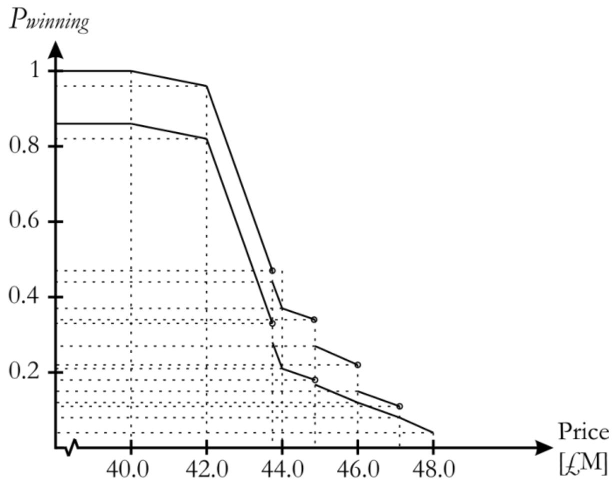


Figure 10-8: Probability of winning for providing emergency capability for trapped miners

The function has multiple jumps, which are marked with a circle. At these points, the probability of winning suddenly drops at the point of the defined values due to a sudden drop in the probability of being the lead bidder and a continuous function for the probability of acceptance. If the assessment of the uncertainty connected to the customer and the competitors had been more detailed, this function would have less jumps and steps. This is discussed further in Section 10.4. This function was used in the decision matrix as described in Section 10.3.4.

10.3.3 Modelling the probability of making a profit

The probability of making a profit can be interpreted as the probability that the actual costs are lower than the price bid. This can be transcribed as follows;

$$P_{profit} = P(p > c_a) \quad (7)$$

P_{profit}	Probability of making a profit,
p	price bid,
c_a	actual costs, [£M].

At the point of bidding, the actual costs could not be observed yet. However, for the presented bidding example, a cost estimate was compiled (see Section 10.1.4) which was connected to a specific confidence level. The Bidding Company's confidence connected to this cost estimate was 70%. Thus, the probability profile of the actual costs, as expected at the time of bidding, can be represented as follows;

$$P(c_a) = \begin{cases} [0, 0.15] & \text{for } c_a < 40.95 \\ 0.7 & \text{for } c_a = 40.95 \\ [0, 0.15] & \text{for } c_a > 40.95 \end{cases} \quad (8)$$

In addition, the profit margin consisted of a risk allowance, which the Bidding Company added to the costs as a "security value". The Bidding Company did not expect to spend the risk allowance but it was taken as a standard value for possible uncertainties in the estimated costs. The risk allowance for the potential profit was given as £1M (see Appendix D). This value was added to the estimated costs to obtain the probability of making a profit as follows;

$$P_{profit} = \begin{cases} [0, 0.15] & \text{for } p < 40.95 \\ [0.15] & \text{for } p = 40.95 \\ [0.15, 0.85] & \text{for } 40.95 < p \leq 41.95 \\ [0.85, 1] & \text{for } p > 41.95 \end{cases} \quad (9)$$

The probability of winning the contract as presented in Section 10.3.2 and the probability of making a profit as presented in Section 10.3.3 were integrated to obtain the decision matrix. This is described in the following section.

10.3.4 Decision matrix

Table 10-10 shows the decision matrix for delivering emergency capability and depicts the probability of winning the contract and the probability of making a profit. The probability values are dependent on the price bid. The decision matrix shows the probability values for price bids between £40M (which was the value of the estimated costs, see Section 10.1.4) and £48M (which was the maximum value of the definition of the function describing the probability of winning).

Table 10-10: Decision matrix for emergency capability contract

Price bids [£M]	**40**	**41**	**42**	**43**	**44**	**45**	**46**	**47**	**48**
$P_{winning}$	86-100%	84-98%	82-96%	54-68%	21-37%	16-26%	12-15%	8-11%	4%
P_{profit}	0%	15-85%	85-100%	85-100%	85-100%	85-100%	85-100%	85-100%	85-100%

The two probability functions may be defined beyond these two values, as presented in Sections 10.3.2 and 10.3.3. However, for the decision matrix, these bounds were chosen as the most useful possible price bids to support the decision process.

Based on the decision matrix depicted in Table 10-10, the decision maker could have made a more informed decision about the trade-offs between the two probability functions. For example, the difference of the probability of winning between a price bid of £40M and £42M is relatively small, however, the probability of making a profit changed from 0% to 85-100%. The following section presents feedback from the Bidding Company regarding the usefulness of the uncertainty model and the decision matrix.

10.3.5 Feedback from the Bidding Company

Based on a presentation of the uncertainty model and the decision matrix, the Bidding Company gave feedback regarding their usefulness. The general comment was that it is a useful tool to support the decision process at the competitive bidding stage. It provides the decision maker with the ability to include the existence of uncertainty in the assessment and evaluate the trade-offs between the different influences. In particular, the Bidding Company appreciated the possibility to collect and record the subjective evaluation of the uncertain influences.

At the point of collecting the case study information, the Bidding Company did not have a tool to collect the subjective information influencing the pricing decision at the competitive bidding stage. This means that a retrospective evaluation of the assumptions made in the decision-making process was not possible. With the presented uncertainty model to derive the decision matrix, such an evaluation would be possible and the lessons learnt from a specific service contract could be included in future decisions.

10.4 Discussion

This chapter described the application of the conceptual framework introduced in Chapter 9 to a case study to obtain a decision matrix for a bidding example. Information regarding the customer and the competitors was included in the selection of the probability of winning the contract; furthermore it was shown how the cost estimate can be used to obtain the probability of making a profit. The model described in Section 10.3 can be applied to competitive bidding situations for service contracts with the characteristics introduced in Chapter 1 as evidenced by this chapter (i.e. service which are product-centred, highly complex, long-lived, business-to-business, and bid under competition). The process of applying this model was described in this chapter.

This model could also be applicable to other competitive bidding situations. For example, the presented method could be used to support decision making at the earlier stages in the bidding process, such as when the suppliers expressed their interest in bidding for the described contract. The model-based approach described in Section 10.3.1 could be used to assess the competitive situation at this stage of the bidding process. Other possible applications could include competitive bidding for the supply of a product such as that defined in the design and manufacturing period of the presented case study. This application would be similar to the one presented in this chapter, particularly regarding the assessment of the customer, the competitors, and the Bidding Company's cost estimate. However, the assessment of the bidding context might differ. This offers opportunities for future research in the area of competitive bidding, which are discussed in Chapter 12.

Through the described process, subjective information can be elicited using the probability scale depicted in Figure 10-3. During data collection for this case study it was found that the probability scale was a helpful tool to support the decision maker in quantifying his subjective assessment of the situation. This confirms the findings of van der Gaag et al. [1999] and Renooij and Witteman [1999] and suggests that the presented scale is applicable to the engineering domain. It should, however, be noted that the probability scale was used as a support tool to develop a shared understanding of terminology between the Bidding Company and the researcher. It did not replace the decision maker's evaluation process. Thus, the decision maker chose to use the scale when they were unsure how to communicate their subjective assessment of the bidding situation.

The assessment of the competitors' likely price bid was based on the assumption that their cost and profit structure is similar to the one used by the Bidding Company. This was an assumption made by the Bidding Company and was based on their expertise and experience in the described market sector. This assumption was adopted in the presented uncertainty model because of the nature of the bidding context and the market sector. The case study concerned a contract in the defence sector, where the customer is usually a part of a country's government. As such, rules regarding contract prices such as maximum values for risk allowances to be included in a cost estimate and a profit margin are enforced. These rules applied to all competitors. Thus, the assumption of similar cost and profit structures seems reasonable in the presented bidding context, although the actual structure of a particular competitor may vary within the enforced rules. Additional uncertainty analysis may offer further insights into the actual adopted cost and profit structures; however, this was outside the scope of this case study. In addition, other sectors may feature higher uncertainty connected to the competitors' cost and pricing strategy due to less stringent rules, which leaves opportunities for future research.

The case study demonstrated that the necessary information for the uncertainty model was available in the Bidding Company. This may be a special case as the bidding process included cooperation between the suppliers, which means that the Bidding Company had specific information regarding their competitors. It was shown that this information was collected and recorded in a qualitative way. Due to the time difference between the original bidding situation and the data collection for the presented case study (more than seven years), it was unfeasible to transform all of this qualitative information into quantitative values that could be processed in the uncertainty model. The process of eliciting the required quantitative information was continued in accordance with the confidence of the Bidding Company and the decision makers. The process was stopped when the Bidding Company was not confident in giving the quantitative information and, thus, any further values would have resulted in a high level of speculation. However, the approach presented in this thesis showed, that the uncertainty model could be constructed with the available quantitative information.

The availability of more detailed information concerning e.g. a quantitative interpretation of the competitors' strengths and weaknesses would have resulted in "smoother" function for the probability of winning the contract. The equations presented in this chapter include jumps and steps (see Figure 10-8). If more detailed information could be incorporated in the uncertainty model, the functions would have less of these jumps and steps and become smoother.

Due to the limits of evaluating past information, the uncertainty model presented in this chapter does not consider each of the uncertainties described in Chapter 9. The presented decision matrix does not include the uncertainty around e.g. the customer's evaluation criteria due to costs of fulfilling the mandatory requirements (see Section 10.1.4). Further uncertainties that are not included in the decision matrix concern the assessment of the competitors' experience, which was only recorded qualitatively by the Bidding Company. At the time of the bid compilation, this information was interpreted subjectively by the bidding decision makers which included a quantitative assessment of the service quality that the competitors were likely to offer.

To assess the level of importance of the listed qualitative information about the competitors and the quantitative assessment of their relative cost values, the Bidding Company was asked to rank the different criteria. For this the strengths and weaknesses listed in Table 10-8 were grouped into 13 categories such as *"capability in key areas of the project"*, *"experience and relationship* *with customer"*, and the price bid. These were given to a bidding decision maker in the Bidding Company to rank them according to their importance. The full list of the 13 categories and their ranking is presented in Appendix D.3. This ranking showed that the price bid is the most important influence on the bidding decision. This investigation does not replace a more rigorous assessment of the different characteristics, but it suggests that the presented uncertainty model includes the central part of the influencing uncertainty connected to the competitors, which were their price bids in relation to the Bidding Company's price bid.

However, in a study where the time difference between bidding situation and the uncertainty modelling is smaller than for the presented case, it may be possible to connect the qualitative assessment to quantitative values. Particularly, if the model is used to support the decision process in real time, i.e. during the period when the bid is compiled, the necessary information could be elicited quantitatively. This was confirmed as appropriate and manageable by the Bidding Company. Their process of compiling the final bid includes multiple meetings between a board of decision makers where they discuss the qualitative information and evaluate their influence on the bid. This information would not usually be recorded but forms an important input to the final bidding decision. Eliciting this information with the presented method would enable a record of the subjective evaluation and a more complex model than the one presented in this study to be developed. This would need to be included in future research as discussed in Chapter 12.

The function used to derive the probability of making a profit was based on the confidence connected to a single value cost estimate. It enables only limited insights in the influence of the price bid on the probability of making a profit. The use of a three-point diagram with confidence levels or a fan diagram to represent the uncertainty of the cost estimate would result in a more detailed model of the probability of making a profit. It may be possible, that at the time of compiling the bid, the Bidding Company's decision makers were able to attach further probability values to the single-value cost estimate. For example, the decision makers could have been able to give a subjective interval of possible maximum and minimum costs around the estimated cost value. However, none of this information was recorded by the Bidding Company, which means that it was not assessable for this case study. Again, the support of a real-time bidding process could enable the elicitation of such information with the described method.

10.5 Summary and conclusions

This chapter described a case study used to give an exemplar application of the uncertainty framework induced in this research (Chapter 9). This addressed objective 5 "To create a decision matrix depicting the probability of winning the contract and the probability of making profit" (see also Section 4.2). The findings from this case study can be summarised as follows;

- The necessary information to derive the probability of winning the contract and the probability of making a profit can be assessed, particularly in the case of service contracts with the characteristics defined in this thesis (i.e. services which are product-centred, high-complex, long-lived, business-to-business, and bid under competition, see also Chapter 1).
- The presented method for eliciting subjective information can be used to store this type of information for future evaluation of the accuracy of the decision makers' assessment of the bidding situation and lessons learnt.
- The two probability functions can be obtained depending on the level of detail of the available information. The more detailed information the Bidding Company collects about their potential customer and competitors, the more useful results are yielded by the uncertainty model and the decision matrix.

With the design of an exemplar decision matrix, the aim of this research "To support the pricing decision by defining a process for modelling the influencing uncertainties and including them in a decision matrix depicting the trade-off between the probability of winning the contract and the probability of making a profit" was fulfilled. The next chapter offers a concluding discussion of the research described in this thesis.

11 Discussion

This chapter presents the concluding discussion of the research. In particular, issues that were encountered throughout the project are highlighted. The discussions are reflective and link back to the research assumptions, state-of-the art in uncertainty and competitive bidding. Then, the main research contributions are discussed, which are the proposed holistic approach for characterising uncertainty and the uncertainty framework for competitive bidding. Finally the scope and limitations of this research are presented.

11.1 Research assumptions

The primary assumption used for this research was that the pricing decision process was based on an existing service design and cost estimate for the service contract (see Chapter 4). In other words, it was assumed that the bidding company knew the necessary steps and the associated costs for providing the service. The decision-making process investigated in this research focused on the decision maker's interpretation of this cost estimate and the consideration of further uncertainties within the competitive environment.

The applicability of this assumed decision-making process was confirmed through the three empirical studies, which investigated the interpretation of the cost estimate, the influence of the competitive environment and the information availability at the bidding stage (Chapters 6-8). Particularly during the interview study (see Chapter 8), this decision process was verified. This also validates the statement found in literature that the cost-based pricing approach is the one most frequently used in practice [Avlonitis and Indounas, 2005; Hytönen, 2005]. Thus, it can be concluded that the assumption made in this research is applicable to the researched context.

11.2 State-of-the art in uncertainty and competitive bidding

A literature review in the areas of uncertainty and competitive bidding (see Chapter 3) showed that current approaches fail to offer the following;

- A clear process to assist in the selection of suitable techniques to model the uncertainty inherent in the bidding process.
- A framework for characterising the uncertainties that influence the decision maker at the bidding stage.

- A structured approach for assessing and including the uncertainties, which have an influence on the pricing decision at the bidding stage, to enable the bidding company to identify an appropriate price bid.

From analysis of the state-of-the art it was concluded that a holistic approach to characterise uncertainty would have to be identified before a framework of the influencing uncertainties at the contract bidding stage could be defined. The holistic approach and the uncertainty framework are discussed in the following sections.

11.3 Holistic approach for characterising uncertainty

The holistic approach for characterising uncertainty was an important research objective due to the lack of literature providing such an approach. Uncertainty literature in different areas such as engineering and management was found to offer varying, sometimes contradicting, viewpoints on the subject. In particular, it was not clear what modelling technique should be used for a specific uncertain situation and which areas a modelling technique could be applied to.

The holistic approach defined in Chapter 5 was realised through the assessment and analysis of the research on uncertainty from various academic domains such as engineering and management. Based on the analysis it was ascertained that the different viewpoints could be defined using five layers [Kreye et al., 2011b]. This section discusses the advantages of using the five-layer approach as well as the perceived limitations.

11.3.1 Advantages

The method of inducing the approach from literature in various domains offers the advantage of a broadly founded classification. Thus, it includes the approaches from current literature and depicts their understanding of the field in relation to each other (see Chapter 5). Further approaches, particularly in the area of engineering design can also be included in the five layers [Kreye et al., 2011a].

Moreover, the five-layer approach was used to classify applications of existing modelling techniques such as frequentist probability theory and possibility theory. This offered a "database", which can be used to identify a suitable modelling technique for a specific uncertain situation. This process offers a robust and theory-based support in choosing an applicable modelling technique. In addition, the "database" can be used as a roadmap to identify further application areas for existing modelling techniques (see Chapter 12).

11.3.2 Limitations

The five-layer classification offers a theoretically founded approach that could be applied to different uncertain situations. For this research, it was applied to the uncertainty at the competitive bidding stage for service contracts. Hence, the presented research forms an initial validation of the usefulness of the five-layer approach. The applicability to other uncertain situations will be included in future research (see Chapter 12).

In addition, the "database" presented in Chapter 5 is based on a limited amount of modelling techniques, namely on probability theory (frequentist, subjective and imprecise), information gap theory, interval analysis, possibility theory, fuzzy set theory and evidence theory. The reason for this is that these techniques are most frequently mentioned in literature. Expanding the "database" to other techniques and further applications will be part of future research. However, although the approach does not include all the possible modelling techniques, it does include the approaches that are commonly used within the fields of uncertainty modelling, which are core to this research. Utilising this knowledge and understanding, the holistic approach for characterising uncertainty provided the foundation for defining a framework of the influencing uncertainties on a pricing decision at the competitive bidding stage.

11.4 Uncertainty framework for competitive bidding

The uncertainty framework for competitive bidding shows the different influences on the pricing decision and the decision maker. It can be applied to different competitive bidding situations, which may emphasise differing weightings to the identified factors. For distinguishing a competitive advantage, the uncertainty connected to the customer and competitors were identified as most important for this research.

The framework was induced based on the results and conclusions from empirical work in combination with literature in strategy research. This offers the advantage that the framework is relevant from a practical point of view, whilst maintaining a strong connection to existing theory. Three empirical studies were undertaken with different focuses in the pricing decision process - interpretation of the cost estimate, the influence of the competitive environment and the information availability at the bidding stage. The majority of the participants were from the aerospace and defence sector in the UK. However, other domains that fulfilled the research focus of product-centred, highly-complex and long-lived services that are supplied from business to business (B2B) and bid under competition were also included. This reflects that the research results are applicable to industrial sectors conforming to the named service characteristics.

11.4.1 Advantages

The uncertainty framework offers multiple advantages. Firstly, by applying the framework to industrial decision-making processes in competitive bidding, a company can eliminate contracts from further consideration in their portfolio and identify contracts that deserve further attention in the bid compilation process.

Secondly, the uncertainty model supports the decision makers at the bidding stage by depicting the uncertainties that influence the decision outcome, allowing a more informed decision to be made. In this research, this was demonstrated by modelling the probability of winning the contract and the probability of making a profit. These probabilities were then represented in the form of a decision matrix to illustrate the trade-off, which can be used in the further strategic evaluation of the price bid.

Finally, the framework can be utilised by researchers investigating the different uncertainties that may influence the pricing decision under competitive bidding. The identified uncertainties can form the basis for choosing the most applicable ones for a specific competitive bidding situation and modelling their influence on the pricing decision. In other words, for a specific situation only some of the named uncertainties in a framework may be applicable and important.

11.4.2 Limitations

The application of the framework has been in the field of competitive bidding for contracts of product-centred, highly complex, long-life and B2B services. Although the interview study (see Chapter 8) offered the conclusion that the framework may also be applicable to low-complexity services; it is outside the scope of this research. Further research is proposed to confirm this finding (see Chapter 12).

The case study exemplified the application of the uncertainty framework, particularly for the two influencing factors *customer* and *competitors*. The uncertainty connected to these two factors can be included in a model to derive the probability of winning the contract. The uncertainty connected to the *internal company processes* was included in the uncertainty model by utilising the cost estimate to derive the probability of making a profit. The other uncertainties within this influencing factor and within the *service contract conditions* were not included in the case study.

A further limitation to the applicability of the uncertainty framework and the model is the availability of the relevant information. In situations, where the bidding company is ignorant about, for example, their competitors for the service contract, the uncertainty connected to the competitors cannot be modelled. However, due to the subjective nature of the input information, modelling results can be obtained with vague linguistic expressions (see Chapter 10). These can be used to model and represent the uncertainty, albeit this may results in a function containing jumps and steps.

11.5 Summary of research scope and limitations

The scope and limitations of the presented research can be summarised as follows;

- The defined holistic approach for characterising uncertainty is based on a broad review of literature in uncertainty research and may, thus, be applicable to various uncertain situations. In the scope of this research, the approach was applied to characterise the uncertainty influencing the pricing decision at the bidding stage for service contracts and its usefulness was validated in this context.
- The presented research focused on the industrial domain facing servitisation, i.e. the transformation of market structures into the direction of offering services as opposed to products such as the aerospace and defence sector.
- The defined uncertainty framework depicts the factors influencing the decision-making process based on the service requirements, service design and cost estimate. It facilitates the consideration of uncertainty influencing the pricing decision at the bidding stage for this strategic evaluation.
- The decision matrix depicting the probability of winning the contract and the probability of making a profit is aimed at supporting the decision process at the bidding stage. It validates the defined framework by focusing on two of the four identified influencing factors and including them in the probability of winning the contract. These two factors are the *customer* and the *competitors* and were chosen as key to identifying the competitive advantage of the bidding company. In addition, the uncertainty connected to the cost estimate (internal company processes) was modelled to obtain the probability of making a profit. A further validation of the remaining factors of the framework, namely *service contract conditions* and the *internal company processes*, will be the focus of future research.

Based on the results summarised in this chapter, conclusions can be drawn. Moreover, the limitations that were presented in this chapter point towards future research opportunities, particularly in the further validation of the presented findings. The next chapter describes both the conclusions from this research and the opportunities for future research.

12 Conclusions and future research

This chapter highlights the conclusions that can be drawn from the research presented in this thesis. First, a summary of the research is described by reflecting on the research aim and objectives. Then, the research implications are presented, before highlighting the contribution to knowledge. Finally, the opportunities for future research are described.

12.1 Summary and reflection

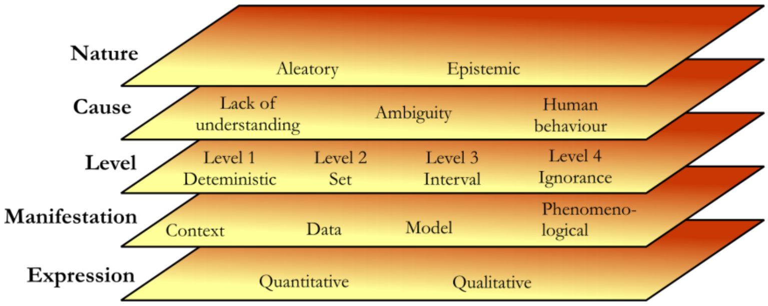
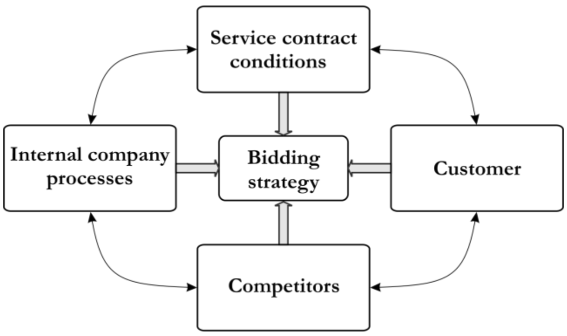
The aim of this research was to support the pricing decision by defining a process for modelling the influencing uncertainties and including them in a decision matrix depicting the trade-off between the probability of winning the contract and the probability of making a profit. To achieve this, the following five objectives were identified;

1) To define a holistic approach to characterise and describe the uncertainty inherent in a situation as a basis for modelling.
2) To identify the uncertainty influencing the pricing decision in competitive bidding.
3) To define the level of the identified uncertainties in the pricing decision process.
4) To define a framework of the uncertainties influencing a pricing decision.
5) To create a decision matrix depicting the probability of winning the contract and the probability of making a profit for an exemplary case study.

Table 12-1 presents a reflection on the achievement of these objectives by listing the applied method and main findings.

Through answering the five objectives, the research aim was achieved. A process was defined for the modelling of the influencing uncertainties on a pricing decision and including these in a decision matrix. The findings showed how the uncertainties connected to the influencing factors on a pricing decision can be modelled with established techniques. The outcome of this process was a decision matrix showing the probability of winning the contract and the probability of making a profit.

Table 12-1: Summary of the research objectives, method and result

<table>
<tr><th>Method</th><th>Main findings</th><th>Chapter</th></tr>
<tr><td colspan="3">Objective 1: To define a holistic approach to characterise and describe the uncertainty inherent in a situation as a basis for modelling.</td></tr>
<tr><td>Literature study of uncertainty research.</td><td>Uncertainty classification in five layers:

</td><td>5</td></tr>
<tr><td colspan="3">Objective 2: To identify the uncertainty influencing the pricing decision in competitive bidding.</td></tr>
<tr><td>Two experimental studies with 83 practitioners</td><td>The main influences on a pricing decision can be summarised as the cost estimate, the customer and competitors.</td><td>6 +7</td></tr>
<tr><td colspan="3">Objective 3: To define the level of the identified uncertainties in the pricing decision process.</td></tr>
<tr><td>Interview study with 11 practitioners</td><td>The bidding company is not ignorant towards the influencing uncertainties in the competitive bidding process. In particular, the following conclusions can be drawn:
• The bidding company does usually have some information about their possible competitors for the specific contract or initiate efforts to acquire this information.
• The decision is typically made by a decision team.
• The bidding companies usually apply the cost-plus pricing approach.</td><td>8</td></tr>
<tr><td colspan="3">Objective 4: To define a framework of the uncertainties influencing a pricing decision.</td></tr>
<tr><td>Induction from three empirical studies, literature and characterisation with five-layer approach (objective 1).</td><td>Four influencing factors on a pricing decision at the bidding stage:

</td><td>9</td></tr>
<tr><td colspan="3">Objective 5: To create a decision matrix depicting the probability of winning the contract and the probability of making a profit.</td></tr>
<tr><td>Case study in contract bidding</td><td>The influence of the uncertainty connected to the customer and competitors was modelled as the probability of winning the contract and the uncertainty from the cost estimate as the probability of making a profit. These were included in a decision matrix.</td><td>10</td></tr>
</table>

12.2 Implications

In this section, the conclusions are summarised into two main areas. Firstly, the implications for research are discussed and secondly the implications for industry are presented.

12.2.1 Implications for research

The conclusions that can be drawn from this research from an academic perspective can be summarised as follows;

- Previously, research in the area of competitive bidding utilised various approaches to model the uncertainties influencing the pricing decision. These approaches tended to prioritise different aspects of the bidding process depending on the area of application. Literature lacked an approach which could be used to depict an overview of the uncertainties influencing the pricing decision and which would be applicable to different competitive bidding situations for service contracts. The framework presented in this thesis fills this gap.

- Previous research did not offer a process for the identification of the characteristics of the uncertainty inherent in a bidding situation. In addition, the selection of a suitable modelling technique for this uncertainty, despite the multiplicity of research papers in the area, was challenging. This research proposed a holistic approach for characterising uncertainty, identifying a suitable modelling technique and applying it to the area of competitive bidding for service contracts.

- The methodology applied within this research to identify the influencing uncertainty on the pricing decision included three empirical studies which investigated different aspects of the decision-making process from different viewpoint. This methodology could be used for other situations where uncertainty is the main research focus. In particular, the interview study (presented in Chapter 8) can be repeated to investigate the applicability of the identified uncertainty framework in other competitive bidding contexts.

- The use of the existing modelling techniques and presenting the outcome in a decision matrix depicting the probability of winning the contract and the probability of making a profit can be applied to other competitive bidding scenarios where the bidding object is a service contract. The utilised modelling techniques - subjective probability, interval analysis and imprecise probability – had not been applied to the context of competitive bidding before. Hence, the research presented in this thesis broadened the applicability of these modelling techniques.

In addition to these conclusions for research, implications for industry can be formulated and are presented in the following section.

12.2.2 Implications for industry

Based on the research presented in this thesis, the implications for industry can be summarised as follows;

- The framework shows the uncertainties influencing the pricing decision (Chapter 9) and can be applied by industry to different service contracts, which are allocated through competitive bidding. Through this framework, industrial decision makers can eliminate contracts from further consideration in their portfolio and identify contracts that deserve further attention in the bid compilation process.
- The decision matrix supports the decision maker at the bidding stage by depicting the uncertainties that influence the decision outcome, allowing a more informed decision to be made. In particular, it enables the decision maker to appraise the trade-off between the probability of winning the contract and the probability of making a profit based on different price bids. This can form the basis for strategic evaluation of the price bid.
- The holistic approach to characterising uncertainty can be used to support industry in their uncertainty (and risk) management. By offering a process that can be applied to identify the uncertainty characteristics and suitable modelling techniques, industry may be able to adopt more effective uncertainty management to be included in their project-management processes. However, it is to be noted that this holistic approach to characterising uncertainty is not completely validated - offering opportunities for further research (see Section 12.4).

Based on these conclusions, the next section summarises the main contributions the research presented in this thesis makes to knowledge.

12.3 Contribution to knowledge

The main contribution to knowledge made by this thesis is the identification of the uncertainties influencing a pricing decision and their depiction in a conceptual framework. This framework can be applied by industry to support their decision process at the competitive bidding stage and by researchers as a basis for developing further understanding of the uncertainties in competitive bidding in general. Furthermore, the methodology for identifying the uncertainty in the decision process can be applied to other situations where uncertainty is the main focus of the research.

Another contribution of this research is the method that was used to develop the decision matrix. The model showed how the probability of winning the contract can be obtained from the uncertainty connected to the customer and competitors and how the probability of making a profit was attained from the uncertainty connected to the cost estimate. The uncertainty model can be applied to other competitive bidding situations to support the decision-making process.

A third contribution of this research is the holistic approach to characterising uncertainty inherent in a situation and the process to assist in the selection of suitable techniques to model this uncertainty. The usefulness of this approach was initially validated in this thesis by its application to the presented research in the area of decision making in a competitive bidding context for service contracts.

12.4 Future research

As indicated throughout this chapter (and Chapter 11), the findings from this research provides several opportunities for future work in various areas. In particular, the areas of decision making in competitive bidding, uncertainty research and services are highlighted.

12.4.1 Future research in decision making and competitive bidding

Future research is needed to further validate the defined framework of the uncertainties influencing the pricing decision at the bidding stage in different contexts. First, the framework can be tested in its applicability to other industrial sectors. This validation is now in progress for the supply of services of electronic systems and aims to be completed in 2013. Another area to further validate the framework is in the support of "real-life" bidding decisions, in other words to use a real-time case study to support the decision process as the information is generated. This could make the process of collecting the necessary information easier.

In addition, the method for designing a decision matrix might be applicable to other factors in the framework such as the internal company processes and including this as the expected value of the profit. This will offer a broader support of the decision process for competitive bidding.

The framework can be further validated by utilising it in other types of service contracts such as the provision of low-complexity services such as management consultancy or medical counselling contracts. This would broaden the applicability and understanding of the competitive bidding processes in the wider context.

Another opportunity for future activities in the area of decision making in competitive bidding is the application of the methodology to the decision process made by the customer. In other words, this concerns the identification of the uncertainties influencing the decision of accepting a bid and including these in a conceptual framework. The framework from the supplier's and customer's sides would then offer a holistic understanding of the uncertainties at the competitive bidding stage.

This increased understanding could then be used to model the competitive bidding process through an application of e.g. Game theory (as introduced by von Neumann and Morgenstern [1944] and further discussed by e.g. Nash [1950] or Chinchuluun [2008]). With the help of this theory, an (theoretical) equilibrium outcome of the decision problem can be calculated which would suggest the optimal decision to be enforced by the different parties. To do so, the rationality of the decision makers at the bidding stage as presented in Chapter 7 could be used as a basis for predicting the actions and decisions of the competitors. This would not only enhance the decision process by enabling a more informed decision to be made but guide the process by advising an optimal or most suitable decision for the specific service contract and bidding context.

Although the studies in the research have focused on service contracts the applicability of the uncertainty framework to competitive bidding for products would provide a range of research challenges. Specific uncertainties such as the requirements or the uncertainty connected to the service design may differ from the application in the service context; however, the strategic assessment of the customer and the competitors could be based on the approach presented in Chapter 10. Future research would have to ensure the applicability of the uncertainty framework to the competitive bidding for products.

12.4.2 Future research in uncertainty

The most important implication of this thesis for future research in the area of uncertainty is the further validation of the holistic approach for characterising uncertainty and the process of identifying a suitable technique for modelling this uncertainty. This means that the approach will have to be applied to various other uncertain situations to characterise these and identify how they can be modelled, and subsequently included in the decision process.

In addition, specific research opportunities within the holistic approach to characterising uncertainty can be identified;

- It may be possible to classify phenomenological uncertainty, in other words the uncertainty connected to the future. The importance of e.g. *"black swans"* [Taleb, 2010] has been highlighted, i.e. the influence of highly improbable or unexpected events, but no classification or discussion of the different aspects of phenomenological uncertainty can be found in the literature. Future research may close this gap and make phenomenological uncertainty more graspable and manageable.

- Within current uncertainty modelling techniques, no approach was found that could handle level-4 uncertainty, i.e. ignorance. This may be due to the fact that under this level of uncertainty, the decision maker does not have any information that enables him/her to bound the possible outcomes of his/her decision. However, future research may find ways of managing this level of uncertainty.
- To show areas of applications of existing uncertainty modelling techniques, a "database" was presented in Chapter 5 which was based on techniques are most frequently mentioned in literature - probability theory (frequentist, subjective and imprecise), information gap theory, interval analysis, possibility theory, fuzzy set theory and evidence theory. Expanding the "database" to other techniques and further applications will be part of future research.

These are three examples of specific implications of the holistic approach to characterise uncertainty for future research. Further implications may be identified (see also Chapter 5).

12.4.3 Future research in services

Implications of the presented research for future research in the area of servitisation may include the validation of the bidding framework for industrial domains that are established in the provision of service contracts. Examples include the construction industry or information technology (IT) sector. These domains have had a longer history in competitive bidding for service contracts, which indicates that their decision makers have more experience in the area. Hence, the process of the strategic evaluation of the influencing uncertainties at the bidding stage may indicate differences. The application of the presented framework to these areas could ensure the long-term usability of the presented framework for manufacturing companies in the future and ensure their sustainability and profitability.

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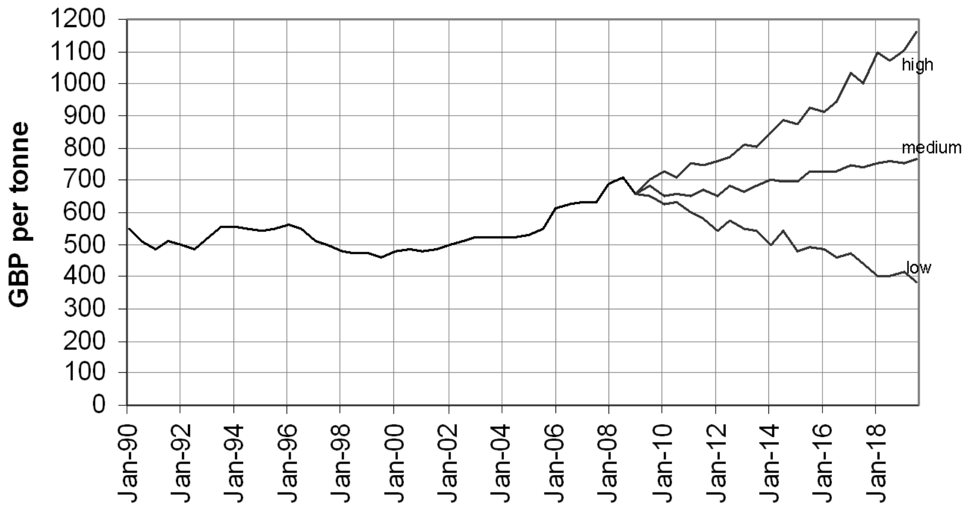
Appendix A – Experimental study 1

A.1 Questionnaires

Questionnaire 1, group A

You are a manager at a company which is going to introduce a new product. The cost of producing the product is highly dependent on the price of raw material A. The graph below shows the historical and forecasted price of raw material A.



1. You have been asked to estimate the price of raw material A for the year 2014 based on the given forecast. What would your forecast be?

___

2. Why did you choose this answer?

___

___

___

___

3. In your opinion, what is the chance that your estimate is within a range of ±25 GBP/tonne of the actual future price?

0-20 %	21-40 %	41-50 %	51-60 %	61-80 %	81-100 %

4. You have been asked to estimate the price of raw material A for the year 2018 based on the given forecast. What would your forecast be?

____

5. Why did you choose this answer?

____

____

____

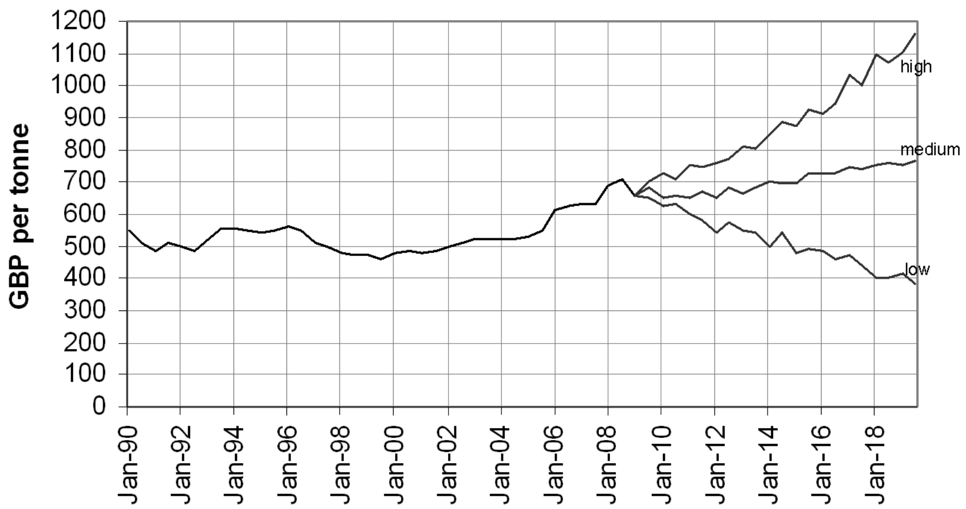
____

6. In your opinion, what is the chance that your estimate is within a range of ±50 GBP/tonne of the actual future price?

0-20 %	21-40 %	41-50 %	51-60 %	61-80 %	81-100 %

Questionnaire 2, group A

You are a manager at a company which is going to introduce a new product. The cost of producing the product is highly dependent on the price of raw material A. The graph below shows the historical and forecasted price of raw material A. The uncertainty associated with the forecast is represented by the different slopes. The graph specified as "high" is based on an optimistic forecast, including a positive growth of the world's economy and a growing market for raw material A. The "medium" graph results of a moderate forecast of future economic values. The graph "low" contains pessimistic forecasts, including the development of a replacement material which decreases the market demand of the raw material used in our product and therefore its price. It is assumed that your product will still be produced with the original raw material.



1. You have been asked to estimate the price of raw material A for the year 2014 based on the given forecast. What would your forecast be?

____

2. Why did you choose this answer?

____

____

____

____

3. In your opinion, what is the chance that your estimate is within a range of ±25 GBP/tonne of the actual future price?

0-20 %	21-40 %	41-50 %	51-60 %	61-80 %	81-100 %

4. You have been asked to estimate the price of raw material A for the year 2018 based on the given forecast. What would your forecast be?

---

5. Why did you choose this answer?

---

6. In your opinion, what is the chance that your estimate is within a range of ±50 GBP/tonne of the actual future price?

0-20 %	21-40 %	41-50 %	51-60 %	61-80 %	81-100 %

7. Have you seen a diagram like this before?

☐ Yes

☐ No

8. Do you use this type of diagram in your work?

☐ Yes

☐ No

If you answered YES, how regularly do you do so?

every day	**once a week**	**once a month**	**every other month**	**once a year**	**occasionally**

If you answered NO, do you know what the diagram represents?

☐ Yes

☐ No

9. How would you interpret the diagram?

A.2 Statistical significance tests:

To test the significance of the results of the experimental study 1, a χ^2-test (also Chi-squared test) was used. The general procedure of the significance test is described with an example. The general results of the significance tests were highlighted in Chapter 6. The described example tests the significance of the different frequencies of a stated range or point forecast for a comparison of group A and B, questionnaire 1, year 2014. The procedure is as follows.

1. Observed values F_0:

	Group A	**Group B**	**Total**
Range forecast (% of participants)	1	3	4
Point forecast (% of participants)	12	12	24
Total	13	15	28

   The degree of freedom for this comparison = (number of rows – 1) * (number of columns – 1)) = 1.

2. Expected values F_e (these values describe what should have been observed if there is no difference between the results of groups A and B, i.e. the results are not statistically significantly different):

	Group A	**Group B**	**Total**
Range forecast (% of participants)	1.8572	2.1428	4
Point forecast (% of participants)	11.1428	12.8572	24
Total	13	15	28

3. Difference between observed and expected values $\frac{(F_e - F_o)^2}{F_e}$:

	Group A	**Group B**	**Total**
Range forecast (% of participants)	0.3956	0.3429	0.7385
Point forecast (% of participants)	0.0659	0.0571	0.1230
Sum (χ^2_{obs})			***0.8615***

   The observed χ^2-value = 0.8615.

4. This observed χ^2-value is compared to the expected value. To obtain the expected value, the degree of freedom and p-value of the comparison is needed. For multiple comparisons such as the comparison of the results of the two questionnaires between

the groups, a ***Bonferroni correction*** has to be applied. This correction ensures that the combined p-value responds to the individual p-value ($p < 0.05$) and does not over or underestimate it. To derive the combined p-value, the following procedure is applied;

a. Calculate p_{FWD}:

$$p_{FWD} = (1-(1-p))^n$$

$$p_{FWD} = (1-(1-0.05))^3 = 0.1426$$

b. Calculate combined p-value: $p_{comb} = \frac{p_{FWD}}{n} = 0.0475 \approx 0.05$

In the case of this empirical study, the combined p-value equals the individual p-value and is 0.05.

The expected χ^2-value for the identified degree of freedom = 1 and $p < 0.05$ is 3.84. The comparison of the observed and expected χ^2-values is;

$$\chi_o^2 = 2.2248 < 3.84 = \chi_e^2$$

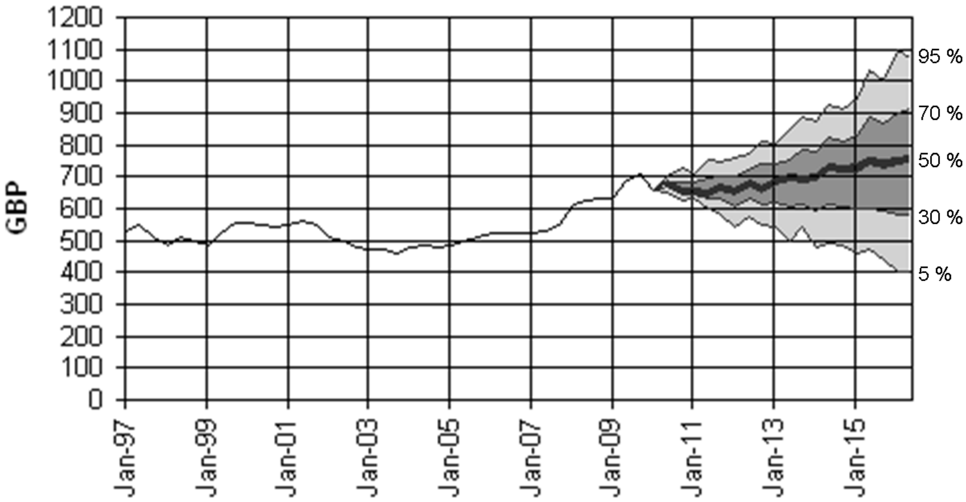
The observed value is smaller than the expected value, thus, the results are not significantly different, or in other words the observed difference is due to chance and variation.

Appendix B – Experimental study 2

B.1 Questionnaires

Questionnaire 1

You are a manager in a company producing CNC lathes working in the contract department. The company is about to negotiate a service contract with a customer for one of the company's lathes. The graph below shows the costs that might occur every year during the 5 year service period of Machine A. Uncertainty arises for example from variability in labour rates, material price, utilisation of the machine and spares storage costs.



The lower graph labelled 5% equals a 5%-confidence limit that the future costs will be these or lower. The equivalent explanation can be given for 30%, 50%, 70% and 95% confidence limits. The medium graph is the baseline estimate derived from typical service histories for CNC lathes. The lower graph shows the minimum costs expected to occur if only preventive actions i.e. planned maintenance occurs. The upper graph is based on the assumption that more repairs are encountered in service.

You are asked to participate in the negotiation process with the customer for a service contract for Machine A. You are negotiating a yearly fee for the 5 year service contract. You do not have any information on the budget limits of the customer.

1. What cost estimate would you choose?

---

2. Why did you select this?

---

3. What profit margin would you add?

4. What would your first tender be?

5. What is the minimum price you would accept for the service contract?

6. In your opinion, what are the influencing factors on setting this minimum price?

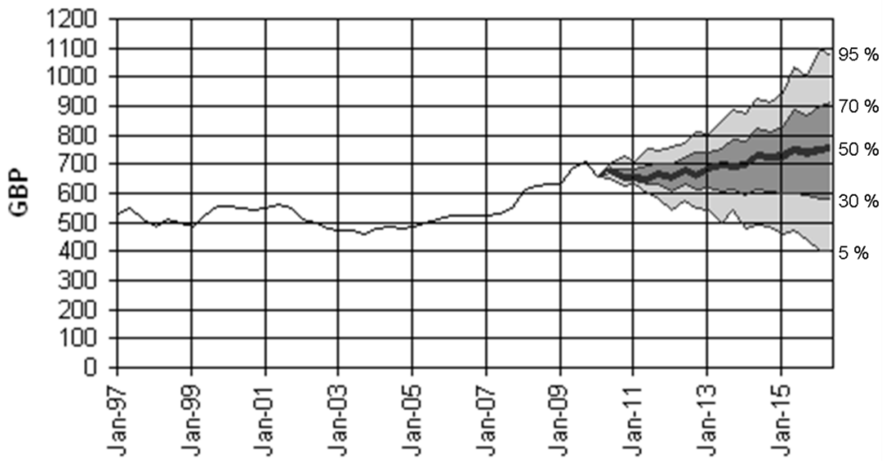
If there is a difference between your first tender and the minimum price:

7. Please state why?

8. What risks/uncertainties have an influence on your decision? How did they impact your decision?

Questionnaire 2

You are a manager in a company producing CNC lathes working in the contract department. The company is about to negotiate a service contract with a customer for one of the company's lathes. The graph below shows the costs that might occur every year during the 5 year service period of Machine A. Uncertainty arises for example from variability in labour rates, material price, utilisation of the machine and spares storage costs.



The lower graph labelled 5% equals a 5%-confidence limit that the future costs will be these or lower. The equivalent explanation can be given for 30%, 50%, 70% and 95% confidence limits. The medium graph is the baseline estimate derived from typical service histories for CNC lathes. The lower graph shows the minimum costs expected to occur if only preventive actions i.e. planned maintenance occurs. The upper graph is based on the assumption that more repairs are encountered in service.

You are asked to participate in the bidding process with the customer for a service contract for Machine A. You are negotiating a yearly fee for the 5 year service contract. You do not have any information on the budget limits of the customer. The customer is in negotiation with other contractors for the same contract. It is assumed that the competitors have sufficient knowledge in maintaining Machine A without the need to contact your company. Your opponents have access to the same cost information as you.

Uncertainties connected to the opponents are:

- their bidding strategy,
- their budget limits or price bids,
- their overall service budget (including other contracts they have).

1. What cost estimate would you choose?

2. Why did you select this?

3. What profit margin would you add?

4. What would your first bid be?

5. What is the minimum price you would bid?

6. In your opinion, what are the influencing factors on setting this minimum price?

7. What risks/uncertainties have an influence on your decision? How did they impact your decision?

Addition

In the negotiation process you reached your bidding limit, ie the lowest you can go to maintain your expected profit margins. However, the customer comes back to you asking for a price reduction which could mean that at least one opponent has bid lower than you, or they have a lower budget.

You have the choice of refusing that offer (and maybe affront the customer) or lower your bid (e.g. by reducing the profit margin or raising the risk to end up with a loss-generating contract).

1. Would you reduce your bid?

____

2. What would be the rationale/explanation for your reaction?

____

____

____

____

1. Have you seen a diagram like this before?

   ☐ Yes

   ☐ No

2. Do you use this type of diagram in your work?

   ☐ Yes

   ☐ No

   If you answered YES, how regularly do you do so?

every day	once a week	once a month	every other month	once a year	occasionally

   If you answered NO, do you know what the diagram represents?

   ☐ Yes

   ☐ No

3. How would you interpret the diagram?

B.2 Statistical significance tests

To test the significance of the results of the experimental study 2, a t-test was used. The general procedure of the significance test is described with an example. The general results of the significance tests were highlighted in Chapter 7. The described example tests the significance of the stated first price bid between both questionnaires (Q1 and Q2). In general, the following values are necessary; the two compared first price bids of Q1 and Q2 for each of the participants, the difference d between these two values for each participant, and the squared difference d^2. These are depicted in Table B-1. The answers of four of the participants cannot be compared due to missing values for either of the questionnaires (participant 7, 8, 11, and 17) which means that they were ignored for the purpose of this particular significance test. This influences the degree of freedom which is derived from the number of tested participants minus one, i.e. 23.

Table B-1: Input data for t-test of stated first price bids between questionnaires 1 and 2

i	First price bid Q1 [GBP/year]	First price bid Q2 [GBP/year]	Difference d_i	d_i^2
1	850	900	-50	2500
2	880	990	-110	12100
3	700	900	-200	40000
4	700	700	0	0
5	990	990	0	0
6	1000	1000	0	0
7	-	460	-	-
8	600	-	-	-
9	750	750	0	0
10	650	720	-70	4900
11	-	650	-	-
12	1200	800	400	160000
13	800	800	0	0
14	1000	800	200	40000
15	900	800	100	10000
16	1200	1200	0	0
17	-	-	-	-
18	1000	1000	0	0
19	1000	1000	0	0
20	1200	850	350	122500
21	1100	1000	100	10000
22	900	900	0	0
23	700	700	0	0
24	900	900	0	0
25	880	880	0	0
26	750	800	-50	2500
27	1150	1150	0	0
28	1000	750	250	62500
∑			920	467000

Furthermore, the following values are required: d_{mean} which is the average difference between Q1 and Q2 and s_d which is the sample standard deviation. These are calculated as follows;

$$d_{mean} = \frac{\sum d}{n} = \frac{920}{24} = 38$$

$$s_d = \sqrt{\frac{\sum d_i^2 - n \cdot d_{mean}^2}{n-1}} = \sqrt{\frac{467000 - 24 \cdot 38^2}{23}} = 137.007.$$

The t-value of the observed sample is then calculated as follows;

$$t_{obs} = \frac{d_{mean}}{s_d / \sqrt{n}} = \frac{38}{137.007 / \sqrt{24}} = 1.3707.$$

This observed t-value is compared to the expected value which is defined by the degree of freedom and p-value of the comparison. For a degree of freedom of 23 and $p<0.05$, the t_0-value is 1.714, for $p<0.1$ it is 1.321. The comparison between the observed t-value and t_0 is;

$$t_{obs} = 1.3707 \ < \ 1.714 = t_0(p < 0.05),$$
$$t_{obs} = 1.3707 \ > \ 1.321 = t_0(p < 0.1).$$

It is shown that for a p-value of 0.05, the observed t-value is smaller than the expected one, hence the test results are not significantly different. However, for a p-value of 0.1, the results are different.

Following the presented steps, the statistical significance of the stated cost estimates, profit margins and minimum price bids was determined. The obtained values are presented in Table B-2.

Table B-2: Input data for t-test of stated cost estimates between questionnaires 1 and 2

	Cost estimates	**Profit margins**	**Minimum price bids**
d_{mean}	11	1.16	8
s_d	18.412	3.350	82.882
Degrees of freedom	27	24	25
t_{obs}	3.131	1.731	0.490
t_0 $(p<0.05)$	1.703	1.711	1.708
t_0 $(p<0.1)$	1.134	1.319	1.316

Appendix C – Interview study

C.1 Questionnaire

Uncertainty and risk:

1. Do you differentiate between risk and uncertainty?
2. What is uncertainty for you?
3. What is risk?
4. What triggers you to identify something as a risk/uncertainty?
5. What are the sources of information for uncertainty/risk?

Context:

6. How would you characterise the contract situation in your company?
7. What is a usual bidding process for service contracts?
8. What is the usual payment method for service contracts in your company?

Input information for the bidding decision:

9. How does the cost forecast for a particular contract usually look?
10. How do you currently manage and consider uncertainty?
11. What uncertainties are included in the cost forecast?
12. What uncertainties/risks influence the decision making process in the contract bidding stage?
13. What information do you have about your competitors?
14. What information do you have about customers?
15. What information do you need/have available about the product of the service contract?

Bidding strategy:

16. How is the decision maker selected?
17. After you receive the cost forecast, how do you interpret it?
18. How do you calculate the price bid, what factors do you consider when calculating the price bid?
19. How do you calculate the minimum price bid/ the price bid beyond which you would not accept the contract?
20. Would you agree on a contract that has a high risk of making loss? If so what are the influencing factors (why would they do so or not, aims etc.)

C.2 Results

Table C- 1: Industrialists' definitions of the terms uncertainty and risk

	Uncertainty	Risk
1	Uncertainty is the potential variability inherent in all estimates. It is something that will happen but the exact parameters are not known yet.	Risk is a discrete event that may or may not happen. The estimator will determine the potential impact and probability of occurrence.
2	Uncertainty exists within the estimate; it describes the range of the estimates. It exists about something that is going to happen.	Risk is something that may or may not happen; it is something that is out of the range of the estimate. It can also be positive, for example someone who is able to do it in less time.
3	The starting point is the unknown, i.e. what points are uncertain or not known. On each of these a decision is made whether to cover them or not. Then, there are assumptions about these unknown points such as "about 6 weeks" to remove the uncertainty. The problem is bound by assumptions. Each of the unknown points is treated separately.	Risk is taken into account at the commercial step with "How wrong can we be?" A contingency number and price for the risk is allocated for the problem as a whole.
4	No different definition or treatment.	Risk is more generic at the project level and is considered in one pot as its total effect on the bid (Monte Carlo). There is subjectivity in assessing the outcome of the risk analysis.
5	On example of a car journey: It exists about e.g. the average speed on the journey.	On example of a car journey: A risk is the possible red light during the journey.
6	Uncertainty is the variation around estimates.	Risk is connected to specific events that may or may not happen. They have a probability distribution connected to them.
7	Uncertainty is how much time, money and resources are necessary to do a certain set of activities. For example, a certain task should take 2 hours but it could take 2.5 hours so we would schedule in a higher value to allow this contingency. So uncertainty is when we don't know the exact value to a specific task with a variation.	Risk exists outside of the specific research tasks which could add to time or costs. An example is the loss of a key researcher for a project or the unavailability of certain data.
8	No definition	***Project risks*** are general risks connected to the project. For example when a project makes it necessary to dig a hole, we could find a medieval graveyard preventing us from continuing the project. ***Program risks*** are the risks around the time and delay of the project or the fact that the client may change their mind or cannot afford the project anymore. For both risks, we try to find out what the possible impact is and what price we can connect to that.
9	Uncertainty in the technical scope of the service and the basis of estimate/pricing	Discrete event-based risk that could impact delivery in terms of schedule and/or cost

Appendix D – Case study

D.1 Cost estimate

Table D-1 shows the annual cost breakdown of option 1, Table D-2 for option 2. The contract period of 10 years was divided into two periods: design and manufacturing period and operation period. The scheduled start of the contract (and, thus the design and manufacturing period) was in the middle of Year 1. After three years, the operation period was scheduled to start which was in the middle of Year 4. Thus, both tables show the cost values for eleven calendar years, however, the contract period was only ten years.

The tables also show a breakdown of the potential profit that was added to the costs. This consisted of the following points;

- A standard profit for a risk-bearing project as the one presented as a case study. The listed values were given by the Bidding Company and were the results of a set percentage of the declared process of the project.
- A standard charge for labour, subcontract and Training & Simulation.
- A risk allowance that was not expected to be spend as costs and thus to be retained as potential profit.

Table D-1: Annual cost values for option 1

		Design and manufacturing period			Operation period							
	Total	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**
Labour	2,906,680	437,473	558,004	686,900	202,841	161,336	155,269	156,669	161,487	167,947	174,664	44,090
Subcontract	35,010,681	2,075,225	7,928,435	10,635,095	2,027,049	1,984,299	1,859,026	1,726,131	2,258,190	2,074,276	1,963,475	479,480
Training & Simulation	373,610	57,924	77,388	78,564	34,735	20,000	20,000	20,000	20,000	20,000	20,000	5,000
General & Administrative	1,262,950	82,535	288,079	383,728	72,162	70,150	65,766	61,115	79,737	73,300	69,422	16,957
Risk allowance	1,400,000	272,727	363,636	363,636	45,000	60,000	58,333	56,111	55,556	55,556	55,556	13,889
Total costs	40,953,921	2,925,885	9,215,542	12,147,923	2,381,787	2,295,785	2,158,394	2,020,026	2,574,969	2,391,078	2,283,116	559,416
Standard profit for project	3,342,864	131,490	384,894	503,190	261,575	331,910	312,383	292,623	370,218	344,473	329,359	80,749
Labour, subcontract, Training & Si[illegible]	700,000	225,000	225,000	250,000								
Risk Allowance	1,000,000	136,364	181,818	181,818	56,250	75,000	72,917	70,139	69,444	69,444	69,444	17,361
Total potential Profit (% of costs)	5,042,865 (12.31%)	492,854 (9.16%)	791,713 (8.00%)	935,008 (9.83%)	317,825 (6.91%)	406,910 (15.06%)	385,300 (15.20%)	362,762 (15.17%)	439,662 (14.59%)	413,918 (14.76%)	398,803 (14.92%)	98,110 (14.67%)
Price	45,996,786											

Table D- 2: Annual cost values for option 2

		Design and manufacturing period			Operation period							
	Total	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**	**Year 11**
Labour	2,834,190	392,778	541,769	676,451	201,730	161,336	155,269	156,669	161,487	167,947	174,664	44,090
Subcontract	34,600,627	1,883,315	7,489,269	10,906,050	2,013,326	1,979,264	1,851,721	1,722,120	2,241,801	2,075,401	1,948,271	473,700
Training & Simulation	373,611	57,924	77,388	78,564	34,735	20,000	20,000	20,000	20,000	20,000	20,000	5,000
General & Administrative	1,231,218	81,068	277,958	369,844	71,241	69,364	64,639	60,256	78,514	72,402	68,124	16,585
Risk allowance	2,101,388	768,750	425,000	475,000	128,750	80,000	56,250	37,083	33,333	33,333	33,333	8,333
Total costs	41,141,032	3,183,835	8,811,384	12,505,908	2,449,780	2,309,964	2,147,879	1,996,128	2,535,136	2,369,083	2,244,393	547,709
Standard profit for project	3,668,758	170,442	479,319	621,914	303,937	367,881	335,325	292,207	361,658	337,256	320,484	78,335
Labour, subcontract, Training & Simulation	700,000	225,000	225,000	250,000								
Risk Allowance	1,920,833		550,000	550,000	257,500	160,000	112,500	74,167	66,667	66,667	66,667	16,667
Potential Profit (% of costs)	6,289,592 (13.27%)	395,442 (6.72%)	1,254,319 (12.47%)	1,421,914 (14.45%)	561,437 (11.70%)	527,881 (18.60%)	447,825 (17.31%)	366,374 (15.45%)	428,324 (14.46%)	403,923 (14.57%)	387,151 (14.76%)	95,002 (14.52%)
Price	47,441,962											

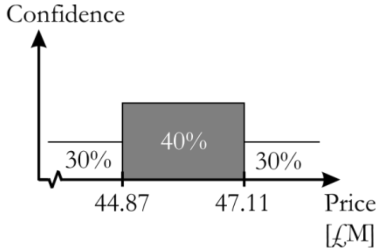
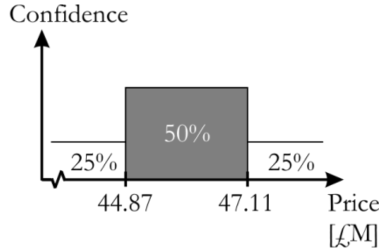
D.2 Modelling the probability of having a lower bid

Table 10-8 in Chapter 10 depicts how the probabilities of having a lower bid than each of the competitors were obtained. This was exemplified with Competitor A where the confidence level was given as a single probabilistic value. For the other three competitors, this confidence level was given as an imprecise probabilistic value which makes the process of deriving the probability of having a lower bid than these competitors more complex. This process is exemplified in this appendix for Competitor B. The probability function regarding Competitor B's price bid was obtained as the following;

$$\begin{aligned} &P(p_B < 44.87) = [0, 0.25/0.30] \\ &P(44.87 \le p_B < 47.11) = [0.4, 0.5] \\ &P(p_B \ge 47.11) = [0, 0.25/0.30] \end{aligned} \tag{D1}$$

This can be divided into two scenarios: one where the probability of the price bid interval [44.87, 47.11] is 0.4 and the other where this probability is 0.5. This is depicted in Table D- 3.

Table D- 3: Deriving probability of having lower price bid than Competitor B for lower and upper probability bounds

<table>
<tr><th>Scenario 1: Probability of 0.4</th><th>Scenario 2: Probability of 0.5</th></tr>
<tr><td colspan="2">Visual interpretation</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td colspan="2">Probability of competitor's price bid</td></tr>
<tr><td>$P(p_B < 44.87) = [0, 0.30]$
$P(44.87 \le p_B < 47.11) = 0.4$
$P(p_B \ge 47.11) = [0, 0.30]$</td><td>$P(p_B < 44.87) = [0, 0.30]$
$P(44.87 \le p_B < 47.11) = 0.5$
$P(p_B \ge 47.11) = [0, 0.30]$</td></tr>
<tr><td colspan="2">Probability of having a lower price bid than Competitor B</td></tr>
<tr><td>$= \begin{cases} [0.7, 1] & for\ p \le 44.87 \\ [0.3, 0.7] & for\ 44.87 < p \le 47.11 \\ [0, 0.3] & for\ p > 47.11 \end{cases}$</td><td>$= \begin{cases} [0.75, 1] & for\ p \le 44.87 \\ [0.25, 0.75] & for\ 44.87 < p \le 47.11 \\ [0, 0.25] & for\ p > 47.11 \end{cases}$</td></tr>
</table>

These two scenarios were then integrated to obtain the probability of having a lower bid than Competitor B as depicted in Table 10-8 in Chapter 10. Thus, the interval values for Competitors B, C and D overlap due to the imprecise nature of the confidence intervals.

D.3 Importance of qualitative information in competitive bidding

To assess the importance of the qualitative information presented in Table 10-5, an investigation was undertaken with the bidding company. In this investigation, a bidding decision maker of the bidding company was interviewed. This person was not the same person as the bidding decision maker on whose subjective evaluation the uncertainty model presented in Chapter 10 was based, but the company's Head of Knowledge Management which means that s/he has an overview of the company's projects.

D.3.1 Method

The decision maker was presented the 13 categories of competitor characteristics and was asked to do the following;

- A pair's analysis where s/he compared two of the 13 categories and ranked them according to their relative importance to each other. The relative importance was rated on a scale of one to three with the following meanings;
    - 1 – slightly more important,
    - 2 – moderately more important,
    - 3 – much more important.
- A ranking of the 13 categories in a subjective way in the order of importance as s/he thought most appropriate.

The main purpose of this investigation was to assess the relative importance of the 13 factors using the pair's analysis; however, the results from the subjective ranking are listed to assess the consistency of the expert's evaluation.

D.3.2 Results

Table D- 4 shows the results of both the pair's analysis and the subjective ranking. The results of the pairwise comparison are presented in the main body, the listed letter names the preferred option, the number refers to the relative level of importance according to the scale from 1-3. If two letters are named, the options have the same importance. To obtain the ranks of importance of the 13 categories, the points of 1-3 were added up, if two options were as important as each other, 0 points were given. The categories were then ranked based on the amount of points they achieved.

Table D- 4 shows that the price bid was considered the most important competitive characteristic. This rank was confirmed by the subjective assessment of the decision maker (without the pairwise ranking). The following characteristics according to their importance were the company's *"capabilities in key areas of the project"* and *"partnerships with key suppliers in the field"*. The importance of these two characteristics was reversed in the subjective ranking.

Table D- 4: Comparison of pairwise and subjective ranking of competitor characteristics

		B	C	D	E	F	G	H	I	J	K	L	M	Total	Pairwise ranking	Subjective ranking
A	Experience +relationship with customer	B2	C2	D2	E3	F1	A2	H1	I3	A/J	K2	A/L	M3	2	**10=**	10
B	Experience with similar services		B/C	B2	B/E	F1	B2	B2	I2	B2	B/K	B2	M3	12	**4**	4
C	Personnel capability to fulfil the contract			C/D	E2	F1	C2	C/H	I2	J1	K1	C1	M3	5	**8=**	11
D	Outsourcing of key operations				E2	F1	D1	H1	I1	J1	K1	D2	M3	5	**8=**	9
E	Partnerships with key suppliers in the field					E2	E3	E2	E/I	E2	K1	E2	M2	18	**3**	2
F	Economic situation of supplier						F3	F1	F1	F/J	F/K	F2	M2	11	**5=**	5
G	Existence and availability of physical facilities							H3	I3	J3	K2	L1	M1	0	**13**	13
H	Personal characteristics of project manager								I2	J2	K2	H/L	M3	2	**10=**	8
I	Capability in key areas of the project									I2	I2	I2	M1	19	**2**	3
J	Company reputation of the possible supplier										J/K	J1	M2	8	**7**	6
K	Demonstration of project commitment											K2	M2	11	**5=**	7
L	Reusability of solution for other contracts												M3	1	**12**	12
M	Price of the contract													28	**1**	1

D.3.3 Discussion

The presented investigation assessed the importance of the competitive characteristics that were given qualitatively by the case study company in relation to the price bid that was included in the uncertainty model in Chapter 10. It was shown that the price bid was the most important characteristic of the competitive bid.

It is acknowledged that these results were not based on a comprehensive study of multiple decision makers of the bidding company. However, the results give an indication of the relative importance and the representation of the model results in comparison to the actual bidding situation at the time. The model included only a quantitative evaluation of the competitors that resulted in the assessment of their likely price bids. As shown in this investigation, this gives a realistic picture of the actual bidding situation and represents the most important competitive characteristic. However, further research will have to investigate the relative importance of the characteristics more rigorously to enable an uncertainty model that incorporates a more realistic picture of the bidding situation.