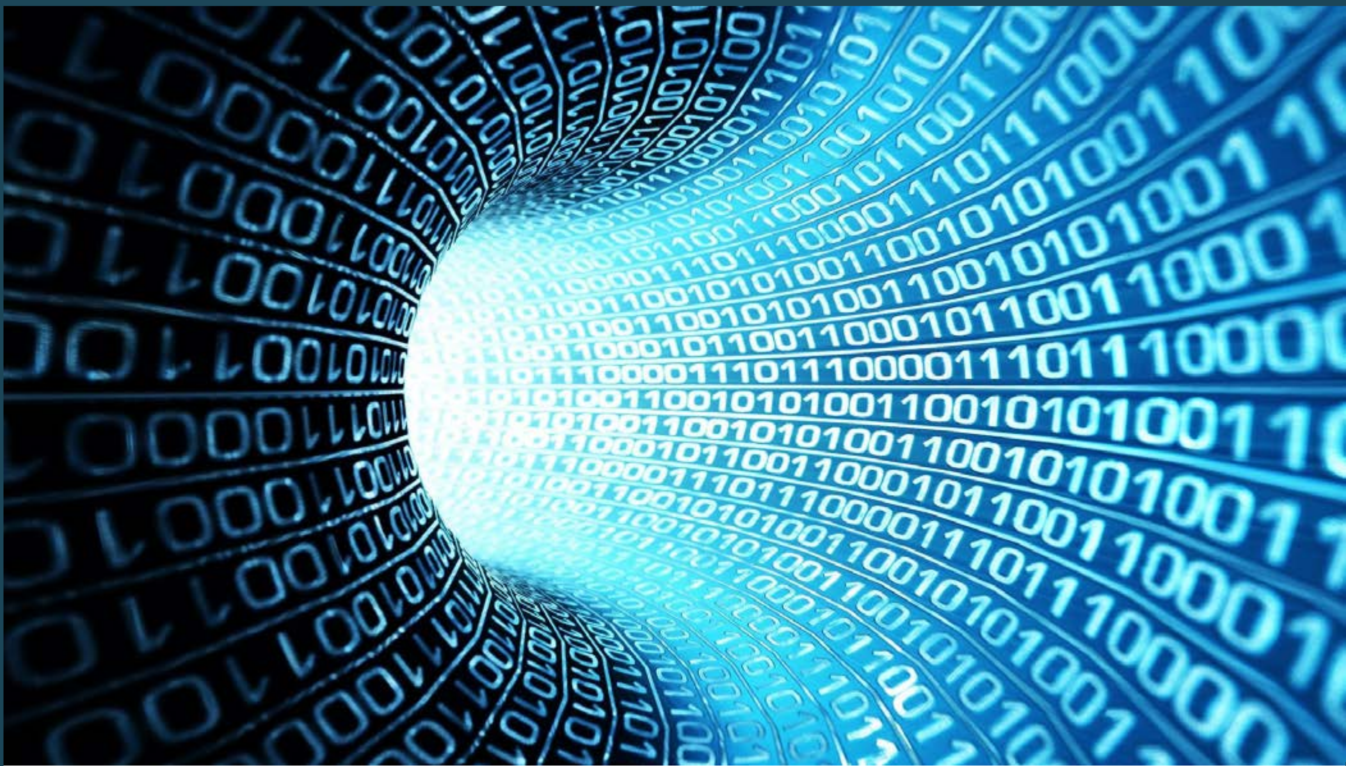
PROBABILISTIC ESTIMATING OF ENGINEERING COSTS

MSc. Thesis Construction Management and Engineering



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Colophon

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Summary

Approximately 10 to 20 percent of the total cost of a project in the Energy and Chemical Industry consists of costs for home office services such as engineering, procurement and project management, from here on called cost of services. The cost of services consist of the sum of the amount of man-hours and the corresponding wage rates (hourly rate) of the various individuals that work on a project. This is complemented with costs for payroll burdens, overhead, other office and field expenses, non billable costs, cost of cash, possible business travel or assignment costs, escalation and contingency.

Engineering contractors estimate the cost of services to determine their bidding price for tenders. On the one hand the cost estimates must be as accurate as possible but on the other hand there is a limitation to the amount of effort to conduct the estimate. Proposal activities are usually not financially compensated by clients. This means that these are a direct burden to the overhead of the engineering contractor. Accuracy and the effort to conduct the estimate are both important criteria that determine the quality of services cost estimates. The accuracy of a cost estimate is measured by its precision and its trueness. Other criteria that are important are the reliability, available time and reproducibility. Currently it is not yet clear whether the most appropriate cost estimating methods are used to deal with these criteria. This leads to the main research question for this research.

What are the most appropriate cost estimating methods that can be used in the current practice of estimating the costs for engineering and construction management services in the Energy and Chemical Industry?

In literature, there are three deterministic estimating methods which are in potential appropriate for the estimation of the cost of services: comparative estimating, parametric estimating and detailed estimating. Each estimating method is different in the possible accuracy it can reach. The result of a deterministic estimate is a single value while in reality the estimate is a range of possible values, which can be visualized by a probability distribution. Therefore, probabilistic estimating is also analyzed; this method uses probability distributions to model the uncertainties in the cost estimate. These probability distributions can be simulated with a Monte Carlo simulation resulting in a probability function of the cost estimate. The main benefits of the probabilistic estimating method are that it is possible to choose the reliability of the estimate and that the probability of cost overruns is known. Furthermore, the probabilistic estimate provides insight in the accuracy of the estimate and the impact of uncertainties and risks.

The estimating practice of the services costs can be influenced by several factors. Based on a literature study and an analysis of the industry seven groups of factors influencing cost estimating practice are established: project information, contractual arrangements, location factors, project team requirements, market conditions, project complexity and project duration. Each category consists of one or more factors, e.g. project information consists of the scope and scale of the construction, the project phase, the extent of completion of the pre-contract design and the quality of information. These factors that influence the cost estimating practice have to be taken into consideration during the estimation of services costs.

The current estimating practice of services costs of the engineering contractor Fluor is analyzed by interviews with representatives from several international offices. Furthermore, the estimated and

actual costs of several projects in the Front-End Engineering Design phase (FEED) are analyzed. The man-hours are the most dominant factor in the services cost estimate, because the man-hours are multiplied with the total rate, which includes the wage rates and all burdens, overhead etc. The second most dominant factor is the wage rate according to the sensitivity analysis that is performed. All other cost components in the estimate have an impact less than one percent on the total cost of services, if their initial value is changed with ten percent.

The most used estimating method to determine the wage rates of a project team in Fluor is by finding the specific wage rates of the key positions in the project team. The other project team positions are divided over certain labor grades to determine their rates. This approach requires quite a lot of effort to perform. The most used method to estimate the man-hours is to ask a few key disciplines to make a detailed man-hour estimate. The man-hours of the other disciplines are determined based on benchmarks of previous projects. All other cost components required for estimating the services costs are either fixed per year or are estimated for each project specifically. The total of all cost components, the total services cost, is estimated completely deterministic.

The analysis of the FEED-projects showed that there are large differences between the estimated services costs and the actual outcomes. Causes of this are scope changes, poorly defined scope before estimating, client influences, decisions from management during execution and work shift between offices. Such circumstances occur on each project and are very difficult to predict.

A probabilistic cost model is developed to potentially improve the current estimating practice. This model runs on the software @Risk, which can perform Monte Carlo simulations. Probability distributions are established for the wage rates of each of Fluor's project disciplines, and for the possible increase in engineering and project support man-hours. The man-hours can also be simulated by inputting the most likely, pessimistic and optimistic amount of man-hours for each discipline (three-point estimate). The model creates a triangular probability distribution based on the three point estimates.

The model is verified by checking all formulas, the cost build up, the internal links and the probability distributions on errors. The limitation that occurred during the verification is that the probability distribution for the engineering and project support man-hours can only be used for comparative man-hour estimates in the FEED-phase. This distribution uses over- and under runs of the man-hour analysis of FEED-projects. The model is further validated by using a new FEED-project as a test case. Three options are analyzed:

1. Only probability distributions for the wage rates
2. Only probability distributions for the man-hours
3. Probability distributions for both wage rates and man-hours

The options are validated with respect to the criteria that determine the quality of the cost estimating process, which are accuracy, effort to conduct the estimate, reliability, timeliness and reproducibility. The results are that the timeliness and the reproducibility of the estimate remained the same but the outcomes of the criteria accuracy, effort to conduct the estimate and reliability are improved. The validation of the accuracy is shown in Table 1, where it can be seen that the precision of the cost estimate in the probabilistic estimates is known as opposed to the deterministic estimate. Also, the trueness of the probabilistic estimate is improved with respect to the deterministic cost estimate.

Table 1: Validation of accuracy of different options

Estimate:	Precision	Trueness
Initial deterministic cost estimate	N/A	22%
Option 1	7%	1%
Option 2	32%	2%
Option 3	34%	-1%

This shows that probabilistic estimating can be an appropriate estimating method for the estimation of services costs in the Energy and Chemical Industry. A framework is developed to support the answering of the main research question, see Figure 1.

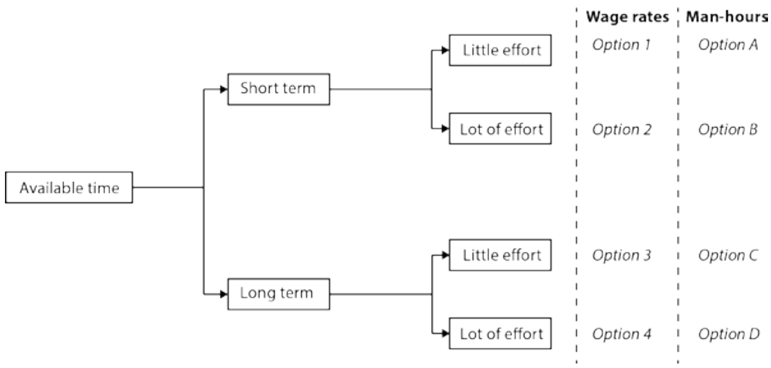


Figure 1: Framework for deciding most appropriate estimating method

The available time is used as fixed basis in the framework and is divided in short term (1-4 weeks) and long term (+1 month). This separation is important because some estimating methods may not be appropriate due to time constraints. The second criterion in the framework is the amount of effort that is put into the estimate. This separation is important because all estimating effort is usually not reimbursed and therefore a direct burden to the overhead. The choice for the amount of effort is dependent on the required accuracy and several other factors influencing cost estimating practice, from which the type of contract is the most important. The framework results in four options for estimating the wage rates (option 1-4) and four options for estimating the man-hours (option A-D), see Table 2.

Table 2: Appropriate estimating method for different wage rates and man-hour options

Wage rates	Man-hours
Option 1: Use the probabilistic cost model to quickly simulate the possible wage rates of all disciplines.	**Option A**: Use the amount of man-hours of comparable projects that are previously performed and adjust based on the factors influencing the cost estimating practice. The probability distribution for engineering and project support man-hours can be used if the project is in the FEED-phase.
Option 2: Use the probabilistic cost model, but increase/decrease the average distributions by consulting the disciplines. Take also into consideration the estimating factors that could influence the estimating practice.	**Option B**: Ask a few key disciplines to make a detailed man-hour estimate and determine the amount of man-hours of the other disciplines based on parameters regarding the number of equipment pieces and number of services. All disciplines should be confronted and asked for a three point estimate to create probability distributions that can be simulated with the probabilistic cost model.
Option 3: Use the probabilistic cost model, but increase/decrease the average distributions by the factors influencing the cost estimating practice and experience.	**Option C**: Use the same approach as in option B, except that not all disciplines have to be asked for the three-point estimate. Only the key disciplines, which make the detailed estimate, create a three-point estimate.
Option 4: Find out the exact mix of project team members and price them out individually. The probabilistic model can be used as a benchmark.	**Option D**: Ask all disciplines for a detailed man-hour estimate and let them incorporate probabilistic information on the lowest level of detail. This means that for each activity for which man-hours are assigned there should be a three-point estimate.

The main benefit of simulating probabilistic wage rates is that it requires less effort to use compared to the current practice. Furthermore, both the accuracy and the reliability of the cost estimate are insightful and can be comprehended. The benefit of simulating probabilistic man-hours is that it improves the accuracy of the estimate by correcting it for its trueness.

The main recommendation is to start implementing the probabilistic estimating tool. The wage rates should be probabilistically estimated on all new projects, first to get familiar and experienced with the method and over time the current estimating method can be replaced. Probabilistic estimating of the man-hours should be performed on a pilot project first to show the additional benefits. Furthermore, probabilistic estimating has to be implemented in the tools that are used to make detailed man-hour estimates to get more accurate estimates. The probabilistic cost model should further be improved by including information of multiple offices and by analyzing and using more projects as basis for the probability distributions.

The research has gone some way towards implementing probabilistic estimating in the current practice of the engineering contractor Fluor. The methods used to develop the probabilistic estimating model may be useful for other engineering organizations as well.

Samenvatting

Ongeveer 10 tot 20 procent van de totale kosten van een project uit de Energie en Chemische Industrie bestaat uit kosten voor ingenieurs-, aanbestedings- en projectmanagementdiensten, vanaf hier genaamd ingenieurskosten. De ingenieurskosten bestaat uit de som van het aantal manuren en de bijbehorende uurtarieven van de verschillende individuen die op een project werken. Dit wordt aangevuld met kosten voor loonlasten, overhead, andere kantoor- of bouwplaatskosten, niet-declareerbare kosten, financieringskosten, mogelijke zakenreizen of detachering op locatie, escalatie en onvoorziene kosten.

Ingenieursbureaus maken ramingen voor ingenieurskosten om de biedprijs te bepalen voor hun aanbestedingen. Aan de ene kant moeten de kostenramingen zo nauwkeurig mogelijk gemaakt worden terwijl er aan de andere kant een limitatie bestaat omtrent de hoeveelheid inspanning die er gedaan wordt om de kostenraming te maken. Aanbestedingskosten worden normaal gesproken niet vergoed door opdrachtgevers. Dit betekent dat deze kosten een directe last zijn op de overhead van het ingenieursbureau. Nauwkeurigheid en de inspanning om de kostenraming te maken zijn belangrijke criteria die de kwaliteit van het kostenramingsprocess bepalen. De nauwkeurigheid wordt gemeten met de precisie en de juistheid. Andere criteria die van belang zijn, zijn betrouwbaarheid, beschikbare tijd en de herproduceerbaarheid van de kostenraming. Momenteel is het niet duidelijk of de meest geschikte kostenramingsmethoden gebruikt worden om met deze criteria om te gaan. Dit leidt tot de volgende onderzoeksvraag voor dit onderzoek:

Wat zijn de meest geschikte kostenramingsmethoden die gebruikt kunnen worden in de huidige praktijk van het ramen van ingenieurskosten in de Energie en Chemische Industrie?

In de literatuur worden drie deterministische kostenramingsmethoden beschreven die potentieel geschikt zijn om de kosten van ingenieurskosten te ramen: vergelijkend kostenramen, parametrisch kostenramen en gedetaileerd kostenramen. Iedere methoden is verschillend in de nauwkeurigheid die bereikt kan worden. Het resultaat van een deterministische kostenraming is een enkele waarde, terwijl de raming in werkelijkheid een reeks van mogelijke waarden is; dit kan worden gevisualiseerd met een kansdistributie. Daarom wordt probabilistisch kostenramen ook geanalyseerd, deze methode gebruikt kansdistributies om de onzekerheden in een kostenraming te simuleren. De kansdistributies kunnen met een Monte Carlo simulatie worden gesimuleerd wat resulteert in een kansdistributie van de kostenraming. De voordelen van de probabilistische methode zijn dat er de mogelijkelijkheid is om de betrouwbaardheid van de raming te kiezen en dat de kans op kostenoverschrijdingen bekend is. Verder biedt de probabilistisch methode ook inzicht in de nauwkeurigheid van de kostenraming en de impact die onzekerheden en risico’s kunnen hebben.

De kostenramingspraktijk van ingenieurskosten kan worden beïnvloed door meerdere factoren. Gebaseerd op een literatuurstudie en een analyse van de industrie zijn zeven groepen van <u>factoren die invloed hebben op de kostenramingspraktijk</u> samengesteld: project informatie, contractuele condities, locatiefactoren, eisen aan het projectteam, marktcondities, complexiteit van het project en duur van het project. Iedere categorie bestaat weer uit een of meerdere factoren, project informatie bijvoorbeeld bestaat uit de scope en omvang van de constructie, de projectfase, de mate van voltooiing van het pre-contractuele ontwerp en de kwaliteit van de informatie. Met deze

factoren die de kostenramingspraktijk beïnvloeden moet rekening gehouden worden tijdens het ramen van ingenieurskosten.

De huidige ramingspraktijk van ingenieurskosten van het ingenieursbureau Fluor is geanalyseerd met behulp van interviews met vertegenwoordigers uit verschillende internationale Fluor kantoren. Verder zijn de geraamde kosten en daadwerkelijke ingenieurskosten van een aantal basis ontwerpprojecten geanalyseerd. Het aantal manuren is de meest kritische factor in de ingenieurskostenberekening, omdat de manuren vermenigvuldigd worden met het totale tarief, bestaande uit het uurtarief, alle loonlasten, overhead etc. De op een na meest kritische factor is het uurtarief volgens de gevoeligheidsanalyse die is uitgevoerd. Alle andere kostencomponenten in de raming hebben minder dan een procent invloed op de totale ingenieurskosten, wanneer hun initiele waarde met 10 procent wordt veranderd.

De meest gebruikte methode om de uurtarieven te bepalen in Fluor is door van een aantal belangrijke personen in het projectteam hun uurtarief te vinden. De rest van het projectteam wordt over bepaalde salarisschalen verdeeld om daarmee hun tarieven te bepalen. Deze aanpak kost redelijk wat inspanning om uit te voeren. De meest gebruikte methode om de manuren te bepalen is door een aantal disciplines te vragen om een gedetailleerde urenschatting te maken. De manuren van de overige disciplines worden dan weer bepaald met behulp van maatstaven gebaseerd op eerdere projecten. Alle overige kostencomponenten die vereist zijn om de kostenraming te maken zijn per jaar gefixeerd of moeten per project specifiek geschat worden. Het totaal van alle kostencomponenten, de totale ingenieurskosten, worden volledig deterministisch berekend.

De analyse van de basisontwerpprojecten liet grote verschillen zien tussen de geraamde en daadwerkelijke kosten. Oorzaken hiervan zijn scope veranderingen, slecht gedefinieerde scope, invloeden van de opdrachtgever, beslissingen van het management tijdens de uitvoering, en werkverplaatsing tussen verschillende kantoren. Zulke omstandigheden gebeuren op ieder project en zijn lastig te voorspellen.

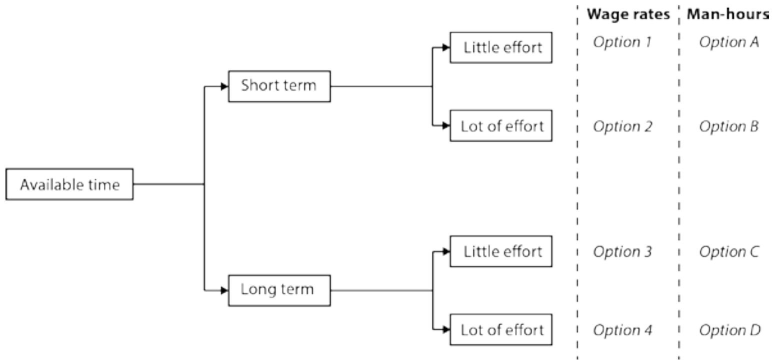
Er is een probabilistisch kostenramingsmodel ontwikkeld om de huidige kostenramingspraktijk potentieel te verbeteren. Dit model draait op de software @Risk, wat Monte Carlo simulaties kan uitvoeren. Voor iedere discipline van Fluor is een kansdistributie opgesteld voor de uurtarieven en voor de mogelijke over/onderschrijding van de manuren van de ingenieurs en projectondersteunende disciplines. De manuren kunnen ook gesimuleerd worden met behulp van een meest waarschijnlijke, pessimistische en optimistische schatting van het aantal manuren voor iedere discipline (driepuntsschatting). Het model creëert dan driehoeksdistributies op basis van de driepuntsschatting.

Het model is geverifieerd door alle formules, kostenopbouw, interne links en kansdistributies te controleren op fouten. De limitatie die hier optrad is dat de kansdistributie voor de manuren van de ingenieurs- en projectondersteunende disciplines alleen toegepast kunnen worden als de manuren op een hoog niveau geraamd zijn en het een project betreft in de basisontwerpfase. De distributie gebruikt de over- en onderschattingen van de manuren gebaseerd op de analyse van de basisontwerpprojecten. Het model is verder nog gevalideerd door middel van een test met een nieuw recentelijk uitgevoerd basisontwerpproject. De volgende drie opties zijn geanalyseerd:

1. Alleen kansdistributies voor de uurtarieven
2. Alleen kansdistributies voor de manuren
3. Kansdistributies voor zowel de uurtarieven als de manuren

Tabel 1: Validatie van de nauwkeurigheid van verschillende opties

Kostenraming:	Precisie	Juistheid
Initiele deterministische kostenraming	n.v.t.	22%
Optie 1	7%	1%
Optie 2	32%	2%
Optie 3	35%	-1%



Figuur 1: Raamwerk om de meest geschikte kostenramingsmethode te bepalen

De opties zijn gevalideerd met de criteria nauwkeurigheid, inspanning om de kostenraming te maken, betrouwbaarheid, tijdigheid en herproduceerbaarheid. De validatie liet zien dat de criteria tijdigheid en herproduceerbaarheid hetzelfde bleven maar de criteria nauwkeurigheid, inspanning om de kostenraming te maken en de betrouwbaarheid verbeterden. De resultaten van de validatie van de nauwkeurigheid staan in Tabel 1, waarin gezien kan worden dat de precisie van de probabilistisch kostenramingen wel bekend is in tegenstelling tot die van de deterministische kostenraming. Daarnaast verbeteert de juistheid van de probabilistische kostenramingen vergeleken met de deterministische raming. Dit laat zien dat probabilistisch ramen een geschikte methode kan zijn om ingenieurskosten te schatten in de Energy en Chemische Industry.

Om de onderzoeksvraag te kunnen beantwoorden is een raamwerk opgesteld, zie Figuur 1. De beschikbare tijd is de basis van dit raamwerk en wordt verder onderverdeeld in korte termijn (1-4 weken) en lange termijn (meer dan een maand). Dit onderscheid is van belang, omdat een aantal ramingsmethoden wellicht niet geschikt zijn vanwege tijdsbeperkingen. Het tweede criteria in het raamwerk is de hoeveelheid inspanning die in het kostenramen gestopt kan worden. Dit onderscheid is weer van belang, omdat de inspanning normaal niet wordt vergoed en dus een directe last is op de overhead. De hoeveelheid inspanning die in het ramen gestopt moet worden is afhankelijk van de gewenste nauwkeurigheid en de andere factoren die invloed hebben op de kostenramingspraktijk, van welke het contract type het belangrijkst is. Het raamwerk resulteert in vier mogelijke opties om de uurtarieven te ramen (opties 1 tot 4) en vier opties om de manuren te ramen (opties A tot D), zie Tabel 2.

Tabel 2: Geschikte ramingsmethoden voor verschillende opties van uurtarieven en manuren

Uurtarieven	Manuren
Optie 1: Gebruik het probabilistische kostenmodel om in korte tijd de mogelijke uurtarieven van alle disciplines te simuleren.	**Optie A**: Gebruik de hoeveelheid manuren van vergelijkbare projecten die recentelijk uitgevoerd zijn en pas dit aan op basis van de factoren die de kostenramingspraktijk kunnen beïnvloeden. De kansdistributie voor de ingenieurs- en projectondersteunende disciplines voor de manuren kan gebruikt worden als het om een project in de basisontwerpfase gaat.
Optie 2: Gebruik het probabilistische kostenmodel, maar verhoog/verlaag de gemiddelde distributies door de disciplines te raadplegen. Houd ook rekening met de factoren die de kostenramingspraktijk kunnen beïnvloeden.	**Optie B**: Vraag een aantal grote projectdisciplines om een gedetaileerde manurenraming te maken en bepaal de hoeveelheid uren van andere disciplines op basis van het aantal apparaten en diensten in het project. De disciplines kunnen met deze maatstaf geconfronteerd worden en gevraagd worden om een driepuntsschatting te maken, waarmee kansdistributies gemaakt kunnen worden die dan weer gesimuleerd kunnen worden in het probabilistische kostenmodel.
Optie 3: Gebruik het probabilistische kostenramingsmodel, maar verhoog/ verlaag de gemiddelde distributies met de factoren die de kostenramingspraktijk kunnen beïnvloeden.	**Optie C**: Gebruik een vergelijkbare aanpak als in optie B maar vraag niet alle disciplines om een driepuntsschatting. Alleen de disciplines die de gedetailleerde manurenraming maken creeeren ook een driepuntsschatting.
Optie 4: Vind de exacte mix van projectleden en prijs ze individueel uit. Het probabilistische kostenmodel kan gebruikt worden als een maatstaf.	**Optie D**: Vraag alle disciplines om een gedetailleerde manurenschatting en laat ze probabilistische informatie op het laagste detail niveau implementeren. Dit betekent dat voor iedere activiteit waarvoor manuren geraamd worden er een driepuntsschatting gemaakt moet worden.

Het grootste voordeel van het probabilistisch simuleren van de uurtarieven is dat het minder inspanning kost vergeleken met de huidige praktijk. Verder zijn zowel de nauwkeurigheid en de betrouwbaarheid van de kostenraming inzichtelijk en te begrijpen. Het voordeel van het probabilistisch simuleren van de manuren is dat het de nauwkeurigheid van de raming verbeterd door het te corrigeren voor de juistheid.

De belangrijkste aanbeveling is om te starten met het implementeren van het probabilistische kostenramingsmodel op alle nieuwe projecten. Eerst om meer bekend te raken en ervaring te krijgen met de methode en op termijn kan het model de huidige methode vervangen. Het probabilistisch kostenramen van de manuren zou eerst nog op een nieuw testproject moeten worden uitgevoerd om de aanvullende voordelen te laten zien. Verder zou probabilistisch ramen geïmplenteerd kunnen worden in de applicaties die momenteel gebruikt worden om de gedetaileerde manurenramingen te maken met als doel om een hogere nauwkeurigheid te behalen. Het probabilistische kostenramingsmodel zou verder verbeterd kunnen worden door er informatie van meerdere kantoren in te zetten en door meer projecten te gebruiken als basis voor de kansdistributies.

Dit onderzoek zet een eerste stap naar de implementatie van probabilistisch kostenramen in de huidige praktijk van het ingenieursbureau Fluor. De methodes die gebruikt worden om het probabilistische kostenmodel te ontwikkelen kunnen ook voor andere ingenieursbureaus erg waardevol zijn.

Preface

This thesis is the end-result of 8 months research in the field of services cost estimating, with a focus on the implementation of probabilistic cost estimating. It is the result of my graduation internship at Fluor and it concludes my six years of study at the Delft University of Technology for the master program Construction Management and Engineering. Thereby, my last days as a student have come to an end. I have enjoyed my student time, first during my bachelor in Civil Engineering and now as a student in the master program CME. The CME master is a great combination of legal, financial and management aspects, which really interested me.

Cost estimating has been a specific area of interest for me, so I wanted to learn more about this. I had the pleasure to carry out this research in the field of probabilistic cost estimating at Fluor. This has been a great experience, where I had the possibility to use the large experience and knowledge that is available and to meet experts in the field of cost estimating. In Fluor I had the freedom, opportunity and support to bring this research to a success. I would like to thank my supervisor Martijn Koster for making this research possible and all the opportunities and advice you provided throughout the research process. Also, I would like to thank my supervisor Rob van Lohuizen for sharing your experience in the field of services cost estimating and your overall support. Furthermore, I am grateful for all colleagues from Fluor Haarlem for making me feel welcome and for contributing to this research. Next to that l like to thank the interviewees from the other offices of Fluor for providing me their time and patience to perform the interviews.

In addition to this, I want to thank my supervisors from the Delft University of Technology. Thanks to Pieter van Gelder for sharing your expert knowledge in the field of probabilistic estimating; Jan Anne Annema for your input, enthusiasm and encouragements in all meetings; and Jules Verlaan for supporting me during the entire research process and helping me to accurately define my research approach.

Last but not least, I would like to thank my family and friends for all their support, their encouragements and all the great moments in the past years.

Jascha Zwaving, April 2014

1. Introduction

This graduation project focuses on finding the most appropriate cost estimating methodology to estimate the costs of services for engineering contractors in the Energy and Chemical Industry. The costs of services in this research is defined as: 'the costs that are required to carry out design, engineering, procurement and project management services for construction projects'. Engineering contractors working in the Energy and Chemical Industry regularly have to estimate the costs of services in order to acquire new projects. Providing services and professional advice to their clients is the main business of engineering contractors and estimating the costs of these services is an essential part of their business continuity. The construction projects in the Energy and Chemical Industry are often very large and complex by nature and can go up to several billion Euros. The costs of home office services (services executed from the home office location) are 10 to 20% of the total costs of these projects, which is a significant part. Therefore, it is important that the most appropriate estimating methodology is used to estimate these costs. This research is performed in close cooperation with the engineering contractor Fluor.

Accuracy is an essential aspect of cost estimating (Trost & Oberlender, 2003) and inaccurate cost estimates can lead to large financial risks (Flyvbjerg et al., 2003). On the other hand, it is just as important that costs can be estimated within a certain timeframe. An accurate estimate is of little use if it is not finished when required. Furthermore, if too much effort is put in the preparation of the cost estimate it may become a burden to the overhead and profit of the business.

The tradeoff between the required effort to conduct the estimate and the accuracy of the estimate is an interesting area to research. If an estimate has to be made in a compressed timeframe, the accuracy of the estimate may be hampered (Government Accountability Office, 2009). Basically this influences the choice for the most appropriate estimating method. The more accurate estimating require an increase in detail resulting in a higher cost of preparation (Ostwald & McLaren, 2004).

Kuiper and Vrijling (2005) define the accuracy of a cost estimate by the range of outcomes and its corresponding statistical reliability. The reliability of an estimate is also important to know in addition to the accuracy and required effort. Managers and decision makers want to know the reliability of the cost estimate in order to make informed decisions whether or not to bid on a specific project. Deterministic cost estimating methods deliver a single value and do not provide understanding of the range of outcomes. Therefore, it is also interesting to consider using probabilistic estimating methods. These methods consider the amount of uncertainty in the cost estimate and provide a range of outcomes.

The context in which this research is performed will be further explained in chapter 2 of this report. In chapter 3 a literature study is performed in order to find the potentially most appropriate estimating methods for services and to find other recommended practices for the estimating process. In chapter 4 the current estimating practice of an engineering contractor working in the Energy and Chemical industry is analyzed as well as specific market characteristics that could have an impact on the choice of the most appropriate estimating method. Chapter 5 consists of the analysis of multiple projects, performed to find causes for changes between the estimated and actual costs of services. In chapter 6 a methodology is developed that could be a potential improvement of the current practice. This improvement is verified and validated in chapter 7. The research is concluded with the conclusions, recommendations and opportunities for further research in chapter 8.

2. Research context

The main objective of this chapter is to provide an understanding of the research problem, its context, the research objectives, the research question and the sub questions that are necessary to answer the research question. In addition, the scope and limitations, the research methodology, the contribution to scientific knowledge and the contribution to society are explained.

In chapter 2.1 the problem background and the relevance of the research is described in detail, concluding with the problem formulation that is used during the research. Chapters 2.2 and 2.3 provide the research objective and the research question and relevant sub questions respectively. The scope and limitations of the research are explained in chapter 2.4. Furthermore, the methodology that is used during the research is visualized and explained in chapter 0. Chapter 2.6 is the last section of chapter 2 and contains the research its contribution to scientific knowledge and the contribution to society.

2.1. Relevance

In the introduction it is addressed that it is currently not known if the most appropriate cost estimating methodology is used by engineering contractors to estimate the costs of services. This research is performed in close collaboration with the engineering contractor Fluor. The field of work of this engineering contractor will first be explained.

Engineering contractor

An engineering contractor, such as Fluor, is a company involved in the design and construction of (petro)chemical plants, oil refineries, power plants, and all sorts of installations for the process, the oil and gas and the off-shore industry (Van Rooij & Homburg, 2002). The general term for these industries that will be used during this research is the Energy and Chemical Industry. Engineering contractors (often called Engineering Procurement and Construction (EPC) contractors) perform various services for their clients varying from feasibility studies to the complete engineering, procurement and construction management of construction projects. The projects that are performed in this sector in which engineering contractors work, are often very complex and heterogenic. Up to eighteen engineering and project support disciplines have to cooperate in order to realize the projects. There are often lots of interfaces between the disciplines which have to be managed closely to ensure the project stays within budget and planning. The amount of unique equipment pieces in a project in the Energy and Chemical Industry may reach up to 1600 indicating the complexity in the management in these projects but also in the cost estimating.

Cost estimating

This section emphasizes the importance of cost estimating in general and the importance of services costs estimating subsequently.

Cost estimating is one of the most important aspects in project management for engineering contractors. The cost estimate establishes a baseline for financial control of the project at different stages of development (Lester, 2013). The cost estimate is the overall assumed cost to execute a project including all facilities and services as required by the contract. Estimates can be made both for the costs of projects and the costs of services (Mustapa, 2010). The estimation of the costs of services, which will be the focus of this research, can be defined as: ‘the development of an approximation of the costs to provide the required services to realize the client’s demands’.

It is important to accurately estimate the costs of services, because the main business of engineering contractors is to provide their services to potential clients. It is on these services, that they make most of their revenue and profit. Inaccurate estimates of the services costs can therefore result in large financial losses on projects.

Services costs

It is important to understand the structure and cost components that exist in the services costs. Simply stated, the estimation of the services costs is based on the expected amount of labor required (man-hours), multiplied by the corresponding wage rate (hourly salary an employee receives). In practice, estimators first have to prepare an estimate for the amount of hours that is required to realize the services described in the scope of the project. Subsequently, they have to find out the duration of the project, the persons that are expected to work on the project and define the amount of work each person is expected to perform. Lastly, they add the wage rates for the persons and correct the resulting costs with several cost components such as payroll burdens, overhead, office expenses, cost of cash and other risk or uncertainty related factors. The quantity of these factors are not easy to measure, but they are necessary in order to estimate the costs of services (Bashir & Thomson, 2000).

Payroll burdens are additional costs that employers are required to pay for taxes, insurances, retirement and other benefits. Overhead consists of costs related to the ongoing expense of business; office expenses are direct project related costs that are related to the use of office services and supplies; cost of cash are costs to compensate for the pre-financing of the project; and escalation and contingency costs can be used for risk or uncertainty related factors. The total rate, where all these cost components are incorporated, is called the costs of services and eventually an amount of profit for the engineering company will be added to this.

Services cost estimating is a little researched area and there is not a lot of literature available regarding this topic. This may be explained by the fact that companies do not want to share information of their cost estimating methodology. This information could give their competition and clients insight in the way they estimate their internal costs and on their eventual bidding price for a project. Therefore, this subject may be bound by sensitive information and confidentiality reasons not to publish such information.

Cost estimating methodology

There are several strategies and methodologies that can be used to estimate costs, however finding the most appropriate methodology considering the project specific information and constraints is not that simple. Uman (1990) noticed that it is difficult to develop a standard process from which to develop a cost estimating system for engineering and construction of projects. This was blamed on the diversity in building methods, suppliers, contractors and workforce. For the cost estimation for projects in the construction industry in general several other authors attempted to create a standard, guide or manual regarding the estimating process. These authors and their standards are addressed in more extensive in chapter 3. In the construction industry companies currently use a variety of cost estimation techniques to estimate the cost of services (Brook, 2004; Burke, 2003). Ostwald and McLaren (2004) assert that more accurate estimating methods have an increase in cost of preparation. During a project’s lifecycle the quality of cost estimates improves since more information comes available and the actual costs that have incurred can be processed in the estimate (Burke, 2003; Lester, 2013).

Project cost estimating can be defined as: 'The process of developing an approximation of the cost of the resources needed to complete project activities' (Project Management Institute, 2004). In which resources can be a combination of skilled human resources, services, supplies, equipment, materiel, commodities, budgets or funds (Project Management Institute, 2004). Cost engineers are specialists in this field and are responsible for the budgeting, planning and monitoring of investments in which an optimal balance between cost, quality and time is sought (Dutch Association of Cost Engineers, 2013).

In the Netherlands, Rijkswaterstaat and Prorail emphasized the importance of having a standard systematic approach in order to estimate the costs. This resulted in the 'SSK' a standard methodology for cost estimations in the building industry (CROW, 2010) and in the Guidebook for cost estimating that focuses on maintenance and development of the Dutch rail track (Prorail, 2011). In this systematic approach risks and uncertainties are considered in a probabilistic manner.

Quality of the cost estimate

Accuracy is the most important factor when considering the quality of a (services) cost estimate. The accuracy of the estimate is dependent on several factors such as the quality of the information that is available and the definition of the scope (NASA, 2008). The accuracy of the estimate is defined by the range of the outcomes and the corresponding statistical reliability (Kuiper & Vrijling, 2005). The accuracy can be measured by two factors: the precision and the trueness or bias. The precision is defined by the 'closeness of agreement between the independent test results obtained under stipulated conditions' (ISO, 1994). The trueness is defined by the ISO (1994) as: 'the closeness of agreement between the average value obtained from a large set of test results and an accepted reference value'. To illustrate these terms, they are visualized in Figure 2.

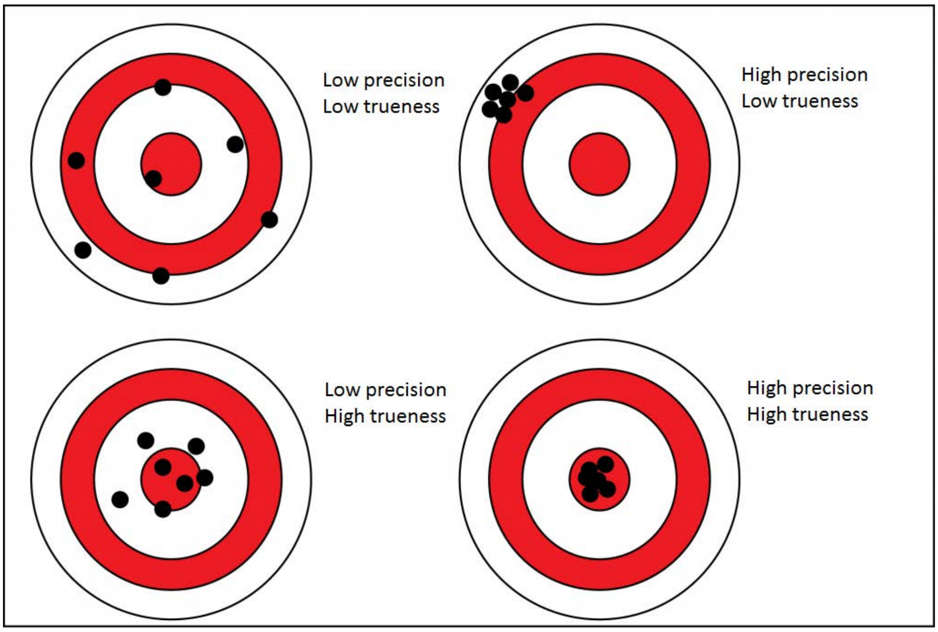


Figure 2: Accuracy defined by precision and trueness

The quality of the cost estimate is not measured by accuracy alone, there are more factors important. Government Accountability Office (2009) states that the timeliness (occurring at the appropriate time) of the estimate is just as important as the accuracy of the estimate. It is argued that an estimate is of little use if it is not finished when required. On the other hand, they argue that the accuracy of the estimate is hampered if the time to develop it is compressed. The data, which is the key driver for the accuracy of an estimate may require some time to collect and verify (Government Accountability Office, 2009).

Problem formulation

The focus of this graduation project is on the engineering contractor Fluor, which is active in the Energy and Chemical Industry. The estimating of the cost of services in this sector is especially interesting, because the engineering, construction and management activities are usually executed in a parallel approach. In the parallel approach activities are performed in parallel in contrast with the sequential approach that uses a more phased approach. This approach realizes the project in a shorter time and with fewer large iteration loops (Herder, 1999), which results in changes in the estimation of the cost of services.

There is always a trade-off between the intended accuracy of a cost estimate and its costs of preparation. The preparation costs normally result from the increases in detail and the additional estimating time required. For this reason, it is important that before conducting a cost estimate the scope and planning of the estimate itself are clear. In general this means that the expected accuracy has to be clear as well as the required time to perform the estimating process. This will influence the decision of the most appropriate estimating method.

Analyzing this playing field between accuracy, required time and different estimating methods with regard to the estimation of the cost of services has not yet been done in literature. With this research it is attempted to provide more insight in the way services costs can be estimated and how to deal with quality and time constraints. The following problem formulation is formulated for this research:

It is not yet clear whether the appropriate cost estimating methods are used in the cost estimation of engineering and construction management services for engineering contractors. Furthermore it is not yet clear if the most appropriate estimating methods are used to their full extent in this sector.

One of the considerations that has been made during the process of this research is to include probabilistic cost estimating. This estimating method is also included in the title of this report which is 'Probabilistic estimating of Engineering Costs'. During the process of this research this estimating method proved to be a possible and additional cost estimating method that is currently not used in services costs estimating of Fluor. The theoretical background of this estimating method is sketched in Text box 1 on the next page.

Text box 1: Probabilistic Cost Estimating

Probabilistic cost estimating

Akintoye and Fitzgerald (2000) stated that developments in cost estimating techniques that consider risks and uncertainties such as probabilistic cost estimating are not adopted in the cost estimating process of contractors in the UK and conventional techniques are still used to estimate the costs. The outcome of conventional techniques is often a single value estimate (deterministic), while it is more sensible to use probabilistic range estimation due to the fact that actual outcomes vary from the estimate (Elkjaer, 2000). The single value estimate, whose value is uncertain, is a single value in the range of possible values of the estimate (Garvey, 2000a). This reflects the fact that cost estimates are not static or deterministic; they are forecasts that have a range of possible outcomes. The main disadvantages of using a single value estimate is that this does not provide an understanding of the range of outcomes.

The probabilistic estimating method uses probability distributions for quantities, prices and risks often based on historical data or experience. The risks can be quantified if the probability and the consequence of occurrence are known. If the uncertainties in the costs and quantities are also quantified and a cost model is established, then a Monte Carlo Simulation can be used to determine the probabilistic range of values (Touran & Wiser, 1992). A Monte Carlo Simulation is a tool which runs a preset number of simulations with predetermined probability ranges resulting in a probability density distribution. The benefits of this simulation are a more substantiated accuracy of the estimate and more insight in the impact of risks and uncertainties. The results of the Monte Carlo Simulation can be used to answer questions such as: 'What is the chance of exceeding a particular cost in the range of possible costs?', 'How much could the cost overrun?' and 'What are the uncertainties and how do they drive the total cost?'

In order to use the probabilistic estimating method, there should be sufficient knowledge about the distribution of the cost parameter of interest. This often requires historical data as input for the verification of a certain probability distribution, or it can be determined based on experience of the estimator. The application of these methods are explained by Garvey (2000a) in his book Probability Methods for Cost Uncertainty Analysis.

2.2. Research objective

The problem context and theoretical background explained in the previous section provides the opportunity to analyze potential quality improvements in the estimation of the cost of services. This results in the main objective for this research which is to:

Provide recommendations to improve the quality of the cost estimates of engineering and construction management services while taking into account the effort that is required to conduct the estimate.

This research objective is used during this research and will be achieved by:

- Reviewing literature regarding cost estimating methods and the cost estimating process;
- Analyzing the current estimating practice of an engineering contractor;
- Comparing the estimated costs and the actual costs of several projects;
- Developing appropriate cost estimating methods that can be used in practice.

Furthermore, it is important that the quality of a cost estimate is properly defined. The factors that are important for the quality of the estimate are:

- Accuracy
- Required effort to conduct the estimate
- Timeliness (ability to prepare the estimate on time)
- Reliability
- Reproducibility

The accuracy of an estimate is measured by the precision and the trueness (or often called bias). The precision can be measured by the standard deviation of the cost estimate. The precision and trueness are visualized by the probability density function of a cost estimate in Figure 3.

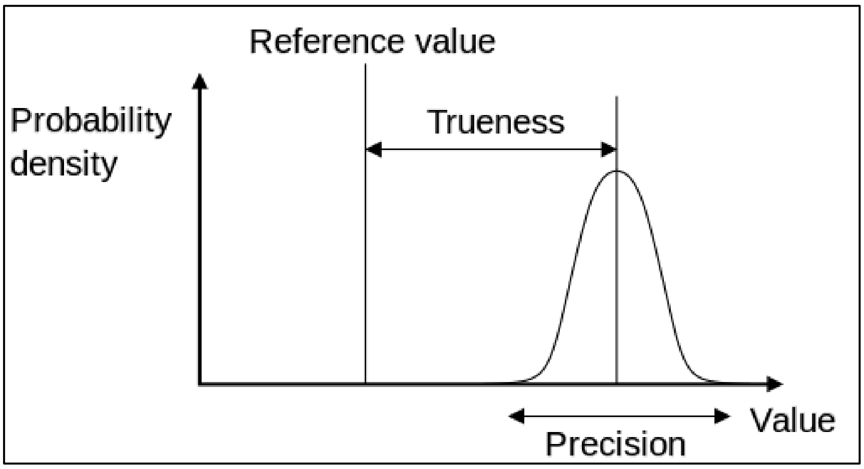


Figure 3: Accuracy of an estimate

The required effort cannot be measured on a quantitative basis such as the accuracy. Therefore, this will be done on a qualitative basis, where different cost estimating methods are assessed on the required time that is necessary to use the method relative to another method. The required effort has some overlap with timeliness. Other estimating methods will be appropriate if the estimate must be made in short time but with relative high accuracy. Furthermore, it is important to know the reliability of the estimate. The reliability can be measured by the confidence interval that indicates the probability of remaining within the estimated costs. The confidence interval is usually indicated by a percentage e.g. there is a 95% confidence level that the costs do not exceed our confidence interval of 2 million Euros. The confidence level can also be two-sided e.g. that there is a 90% confidence level that the costs are in the confidence interval of 1.8 and 2.2 million euro. The confidence level and interval therefore indicate the reliability of a cost estimate.

The last factor that is used to define the quality of a cost estimate is reproducibility. Reproducibility means that all assumptions and data sources are documented with sufficient information so that anyone can reproduce the estimate. In other words the estimate must be consistent and transparent. The reproducibility of an estimate cannot be measured quantitatively and will therefore be assessed on a qualitative basis.

2.3. Research question

The problem background of the topic provided in the relevance as well as the problem formulation and the research objective result in the following research question:

What are the most appropriate cost estimating methods that can be used in the current practice of estimating the costs for engineering and constructions management services in the Energy and Chemical Industry?

In order to answer the research question, the following sub questions have been identified:

1. Which cost estimating methods are described in literature and that are appropriate for estimating the cost of services and how should they be applied?
2. What are the recommended practices in literature with regard to the cost estimating process?
3. What is the current practice of the engineering contractor Fluor with regard to estimating the cost of services and which cost components are used in their estimates?
4. What are the factors in the market for engineering contractors in the Energy and Chemical Industry and in literature that could potentially impact the cost estimating practice?
5. What are the causes of changes between the estimated costs and the actual costs of services?
6. Could the cost estimating methodology in the current practice be improved by using an alternative estimating method?
7. Is the new developed estimating method an improvement with respect to the current practice of engineering contractors in terms of quality and required effort to conduct the estimate?

The reasons for establishing these sub questions are further explained in the research methodology.

2.4. Scope and limitations

Industries

The industries in which the cost estimation will be analyzed circumvent the engineering and construction branch of the Process, Oil and Gas Industry (from here on called the Energy and Chemical Industry). Services as defined for this research are studies, design, engineering, procurement and project management. These activities are required for new or renovation of upstream and downstream (petro) chemical projects, as well as new energy plants and chemical process installations. Therefore, it is chosen to generalize the estimation approach in order to be useful for all of these industries.

Estimating methods

An initial exploration of the estimation techniques that are used for estimating the cost of services provides the following:

- Parametric estimating
- Detailed cost estimating
- Comparative estimating
- Probabilistic estimating

The first three methods are calculated deterministic and can be described as deterministic estimating methods. The last method, probabilistic estimating, considers risks and uncertainties by probability density functions. This results in a range of possible values as has been explained in Text box 1.

Estimating factors

With regard to factors that exist in the engineering contractor environment that potentially influence the cost estimating practice, an infinite amount of characteristics can be considered. It is not feasible and necessary to map all these factors; instead it is more feasible to look at the most occurring and most dominant factors that impact the cost estimating approach and that are relevant for the Energy and Chemical Industry, which is in the scope of this research.

Management decision making

The focus in this research will be on the estimation of the cost of services. The management of an engineering contractor always faces a pricing dilemma during the bidding phase. This is the trade-off between reducing their profit, and improving their chance of winning the contract. In this research, decisions of management on the revenues are not incorporated. The focus is on the cost-side, which is one of the inputs for management to decide the price to bid. Management can decide to reduce the eventual bidding price or give specific price reductions to acquire the project. However these decisions do not affect the estimate of the costs and therefore the scope of this research is purely on the cost-side. It might occur that specific client's wishes regarding the revenue have an effect on the cost-side as well. In that case these occurrences will be taken into account as an external factor.

Project phases

The cost of services is estimated to be used as the bidding price for a project. This is during the proposal phase of a project, which is the project phase in which the services costs estimate is prepare. Later in the lifecycle of a project, after the project award, other estimates might be made for the cost of services. The cost estimation then becomes more and more accurate because 'actual' working hours already occurred. It is important that project controllers 'measure' the actual deployment of staff against the estimated deployment. Large differences may result in large financial risks.

2.5. Research Methodology

The methodology used during this research is based on finding the answer of the main research question from chapter 2.3. This research question focuses on finding the most appropriate cost estimating methodology for the costs of services. The following two sub questions are established in order to find the most appropriate cost estimating methods and general recommendations with regard to the process of cost estimating.

1. Which cost estimating methods are appropriate for estimating the cost of services and how should they be applied?
2. What are the recommended practices with regard to the cost estimating process?

These two research questions will be answered in chapter 3 of this report, where a literature study is performed. The first part of the literature study focuses on the cost estimating methods and their application in general. An initial study of potential cost estimating methods that are appropriate for the cost estimating of services provided four broad categories of cost estimating methods: Probabilistic estimating, Parametric estimating, Detailed estimating and Comparative estimating. The cost estimating methods purposes and applications are explained in chapter 3.1-3.3. The second part of the literature study (chapter 3.4) focuses on the recommended practices in literature with regard to the entire estimating process. A few of the recommended practices are selected after an initial literature study and these practices are explained in more detail.

The second part of the main research question concerns the sector on which this research is focused. This is the Energy and Chemical Industry, and a sub question is established to find out the current estimating practice of engineering contractors. This is necessary in order to verify if the most appropriate cost estimating methods are currently used. Another sub question is established to analyze the factors in the Energy and Chemical Industry that have an impact of the cost estimating practice of engineering contractors.

3. What is the current practice of an engineering contractor with regard to estimating the cost of services and which cost components are used in the estimates?
4. What are the factors in the market for engineering contractors in the Energy and Chemical Industry and in literature that could potentially impact the cost estimating practice?

Both these sub questions are answered in chapter 4 of this report. In order to answer the first sub question a study is performed at Fluor, one of the leading engineering contractors in the Energy and Chemical Industry. The current cost estimating process for services and the related cost components of an engineering contractor (Fluor) are in chapter 4. The information that was required for this was retrieved by interviews with relevant services cost estimators of several offices of Fluor. The interview group was international in nature, which provided the opportunity to retrieve information for the cost estimating of services on an international scale. In addition, the software tools that are used to estimate the costs of services in the different offices of Fluor are analyzed.

This study by Fluor also provided the opportunity to investigate the current market of an engineering contractor. Based on literature and experience that was available, the most important Industry characteristics in the sector are described that could potentially impact the estimating methodology of Fluor.

The second part of this research focuses on developing a framework that establishes the most appropriate cost estimating method in various situations. The current practice is analyzed in sub question 3 in a descriptive way, but verifying the quality of the cost estimates that are made by Fluor is not yet done. Therefore, the fifth sub question focuses on potential differences between estimated costs and actual costs of services.

5. What causes differences between the estimated costs and the actual costs of services?

In order to find the answer to this sub question a quantitative analysis of several projects is performed. The estimated costs at the proposal stage of the project are compared with the actual occurred costs. As explained in the scope, the focus of this research is on finding the most dominant factors in the services cost estimating. This has been done with a sensitivity analysis of a typical engineering project. The most dominant factors are further analyzed and insight is provided in the current estimating practice and causes of changes between estimated and actual costs. The results of these analyses are gathered in chapter 5.

The main research question focuses on finding the most appropriate cost estimating methods that can be used in the current practice. This includes taking along the cost estimating methods that are not currently used in the current practice. Therefore a sub question is established that focuses on finding other cost estimating methods that are not currently used.

6. Could the cost estimating methodology in the current practice be improved by using another estimating method?

The current estimating practice has at this point of the research already been analyzed elaborately. A new cost estimating model will be developed for the cost estimating method that is part of this research scope and which is currently not used in the estimating practice. This will be done with the software that is available in the estimating department of Fluor. The information about this cost estimating model is described in chapter 6.

Obviously, this cost estimating models has to be verified and validated in order to assess if it indeed is an appropriate cost estimating method that can be used. For this testing a sub question has been established.

7. Is the new developed estimating method an improvement with respect to the current practice of the engineering contractor Fluor in terms of quality and required effort to conduct the estimate?

The new developed estimating method will be verified and validated on an engineering project that is currently performed by Fluor and is not analyzed as part of answering sub question 5. In chapter 7 it will be assessed whether this developed cost estimating model is an appropriate estimating method and can be used to estimate the services costs.

The combination of the seven sub questions should provide sufficient information to provide a substantiated answer to the main research question. The conclusions and recommendations of this research are combined in chapter 8 of this report. The methodology that is described is also visualized in Figure 4.

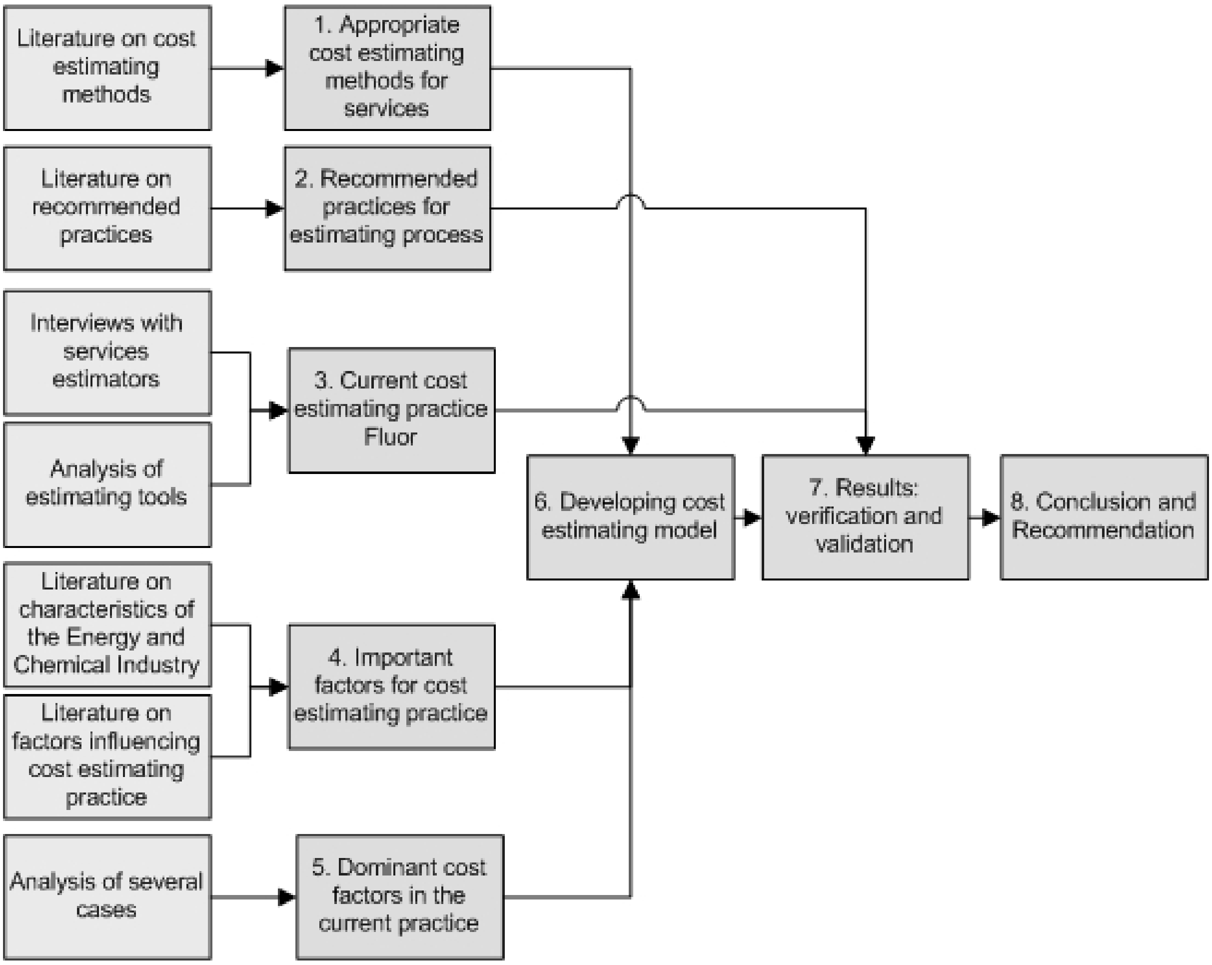


Figure 4: Methodology of the research

The left column of the figure provides the information sources which are used to answer the sub questions. The sub questions are numbered, question 1 and 2 are answered in chapter 3, questions 3 and 4 in chapter 4, and the other questions are answered in the chapter corresponding with the sub question number.

Figure 5, shows a more simplified visualization of the methodology used for this research.

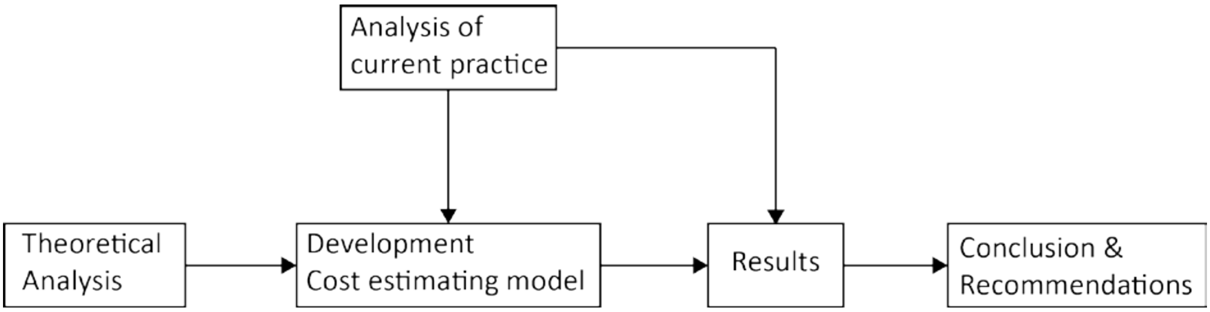


Figure 5: Simplified methodology of the research

2.6. Contribution to knowledge

The relevance of this research can be divided in the contribution to the current scientific knowledge and to the society.

2.6.1. Scientific relevance

This research will contribute to the scientific knowledge on cost estimating of services with a specific focus on projects executed by engineering contractors working in the Energy and Chemical Industry, by:

- Providing an overview of the cost estimating methods that are useful and appropriate for the estimation of the costs of services.
- Exploring and gathering the specific knowledge about the estimating practice of the cost of services in the Energy and Chemical Industry.
- Explaining the impacts that project and market characteristics have on the cost estimating methodology and strategy.
- Analyzing and explaining the potential differences between the estimated costs and the actual costs occurred of several projects performed.
- Providing methodologies that could improve the current estimating practice of the cost of services in the Energy and Chemical industry.

2.6.2. Societal relevance

In addition to the scientific relevance this research will contribute to the society by the following points:

- The estimating methods provided can also act as a basis for the cost of services estimating in other industries. For the offshore industry, consultancy industry and the construction industry the content of this research may be used as a guideline to improve the cost of services estimating practices.
- The reduction in estimating effort that may be realized by the introduced methodologies in this research will result in cost savings for clients, contractors and engineering companies and reduced likelihood of financial losses.
- Improvements in the estimating process of the cost of services will result in a more transparent and consistent approach and more substantiated decision making.

3. Theoretical Analysis

In Chapter 2 the problem and the context of this research is explained. Also several research questions are mentioned that are important for answering the main research question. In this chapter a literature study is performed to find the answers to the first and second research question:

1. Which cost estimating methods are appropriate for estimating the cost of services and how should they be applied?
2. What are the recommended practices with regard to the cost estimating process?

In chapter 3.1 the most important cost estimating methods are described. Based on an initial literature review, four main estimating methods are selected. Herein, the separation is made between deterministic and probabilistic estimating methods. First, the deterministic methods parametric, detailed and comparative estimating are explained in chapter 3.2. Second, the probabilistic estimating method is described in chapter 3.3. For each of these methods the principle behind the method and the application is provided.

Furthermore, in chapter 3.4 the recommended practices for the cost estimating process are described as well as the entities that are relevant in the field of cost estimation. Lastly, the chapter's conclusions and the answers to research questions 1 and 2 are provided in chapter 3.5.

3.1. Cost estimation methods

In literature a lot of information is available regarding the various estimating methods that are available to estimate construction costs. Literature in the more specific estimates for cost of engineering services is more limited, but many of the methods used in construction cost estimating can also be applied on the estimation of services. From an initial literature review it was possible to identify two broad categories of estimating methods: deterministic estimating and probabilistic estimating. Deterministic estimating can be further divided in parametric, detailed, and comparative estimating. These methods are deterministic, meaning that the result is a single point estimate.

The probabilistic estimating method is probabilistic meaning that the use of distributions for one or more of the parameters is possible. The estimating methods can be combined in any way to realize the final cost estimate. The estimating methods are explained in more detail in the following sections of this chapter. The basis for the categorization in deterministic and probabilistic is an initial literature review. The sources for the information of the cost estimating methods are summarized in Table 3.

Table 3: Literature sources per estimating method

Source	Estimating method			
	Deterministic			*Probabilistic*
	Parametric	*Detailed*	*Comparative*	
Brook (2004)	x	x		
Rolstadås (2004)	x	x		
Burke (2003)	x		x	
Lester (2013)	x	x	x	
NASA (2008)	x	x	x	x
Garvey (2000a)				x
Ostwald and McLaren (2004)	x		x	x
Government Accountability Office (2009)	x	x	x	x
Chou et al. (2009)	x	x	x	x
Elkjaer (2000)				x
Sonmez (2008)	x			x
ISPA (2008b)	x	x		x

The table shows several sources for estimating methods and which of the defined four estimating methods are described by which author. The estimating methods are now described in more detail.

3.2. Deterministic Cost Estimating

3.2.1. Parametric Cost Estimating

Definition

Parametric estimating, or sometimes referred to as top-down estimating, uses consequential projects and project's deliverables in order to estimate the use of resources required to perform a new project (ISPA, 2008a). It is often based on computerized cost models that, if properly designed and used, can improve the accuracy of project estimates. The model is a mathematical representation of Cost Estimating Relationships (CERs) that provide a logical and predictable correlation between the physical or functional characteristics of a project and its resultant cost (Dysert, 2008).

Benefits that are attributed to parametric estimating are reduced likelihood of serious overruns of budget and schedule, reduced cost of preparing project proposals and the enabling for project management to consider more decision options (ISPA, 2008a). In addition, such parametric cost models can be used to serve as advice for uncertainties and risks. Parametric estimating can also be combined with probabilistic estimating (also called range estimating) combining the benefits of both methods (Sonmez, 2008).

On the other hand it is not always easy to describe and document the development of the CERs in a way that is understandable to others. Furthermore, it is difficult to collect the appropriate data that is required for statistically correct cost predictors and outside the data range the CERs are of little use due to the loss in credibility.

Application

The essence of the parametric estimating approach is that historical data is related to represent future cost by Cost Estimating Relationships (CERs). CERs can be verified with a number of statistical regression analyses to see whether the CER is strong enough to be used as cost indicator. The tested parametric CERs can be used to estimate a new project's costs by entering its specific characteristics into the parametric model (Government Accountability Office, 2009). The estimator has to be aware that serious estimating errors can occur when the CER is improperly used. Therefore, the assumptions made early in the project's lifecycle have to be continually checked to ensure they still apply.

The parametric estimating process consists of three major components: database development, model development and model use. The development of the cost estimating model that is required for parametric cost estimating is shown in Figure 6. The most important starting point for the cost estimating model is the historical data that is available. The historical data should be captured in a database, which can in turn be used for the cost estimating model. The database has to be maintained and update once new projects are performed or when other relevant information becomes available. The data in the database should be completely reproducible so that later on the information can be used and the costs can be corrected for inflation.

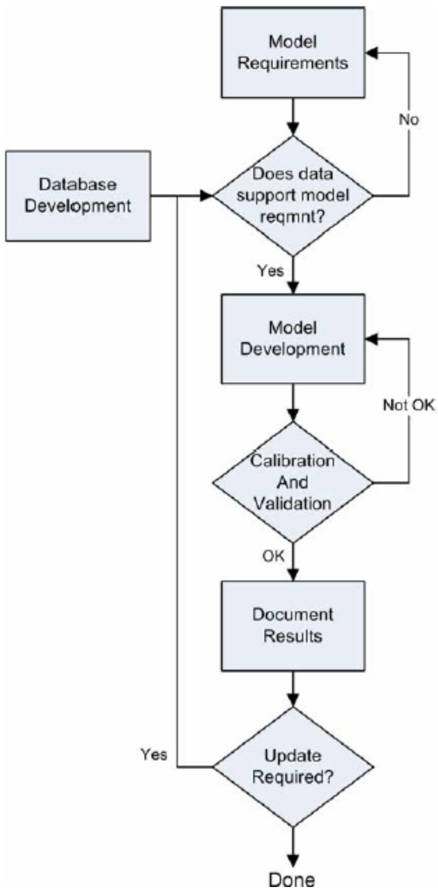


Figure 6: Flowchart for developing parametric cost estimating model (ISPA, 2008b)

Once the database is in place, the cost estimating model can be developed. The Cost Estimating Relation (CER) of the different cost components in the database have to be developed using statistical regression analyses. There can be several reasons why the estimation of the cost parameter is scattered e.g. the poor choice of the cost driving parameter, presence of one or more other cost driving parameters, presence of non-normalized parameter values, data collection errors, inconsistent cost classification or non-linearity of the relationship (ISPA, 2008a).

When all CERs are in place the model has to be calibrated and validated before use. This ensures that the estimating model is a reliable predictor of the costs. For the validation/calibration additional data is required. However, data sets that are available are often extremely small and withholding a few points from the model's development can impact the precision of the parameters (ISPA, 2008a). This limited amount of data is often all used for the development of the model and no additional data is left for the testing of the estimating model. Therefore, the trade-off between accuracy and testability has to be considered while developing the parametric cost model. Additional calibration may be required if the historical data is based on other sources than company history.

After testing the parametric estimating model the results can be used for the purpose for which is was intended. Once more data/information becomes available the historical database may be updated if required.

Cost Estimating Relationships

The CERs are the basis for the parametric estimating method. The CERs should establish a quick and reliable estimation of the future project costs. It is important that for the historical data and the future project costs are comparable. Time, location, currency, productivity, experience and complexity are examples of factors that need to be considered when comparing historical data and future project costs. The correction for dissimilarities is called data normalization and is necessary for the comparability of the data.

The simplest CER is the linear relation between a physical or functional characteristic of a project and the resulting cost. However, there can also be more complex relations between characteristics and costs with corresponding complexity in mathematics. Statistical analyses and optimal fit techniques (least square) are tools that can be used to determine the CER. The mathematical application of parametric estimating is further explained in Appendix A.

3.2.2. Detailed Cost Estimating

Definition

The detailed cost estimating method, or often called bottom-up or analytical estimating method, is typically done at the lowest level of detail. This requires that the project is decomposed into manageable tasks, operations or activities with easy calculation (Chou et al., 2009). The Work Breakdown Structure is an often used structuring process that can be the basis for decomposition of a project (Rolstadås, 2004). During the development of the detailed cost estimate, cost estimators work with engineers to develop the detailed estimate (Government Accountability Office, 2009). The engineer's quantity estimates have to be validated by the cost estimator for which additional data is required.

The detailed cost estimate aims, by going into detail, that all cost components are included and nothing can be overlooked. Also it provides insight into the major cost contributors in the project. Another benefit of the detailed cost estimating method is that the tasks or activities on the lowest level are usually recurring on multiple projects and the data can therefore be reused. The downside of using this method is that it requires a lot of effort to establish, resulting in high costs. Also each project has to be build up separately and insight in the major cost contributors is difficult to determine (NASA, 2008). Furthermore, estimated cost components with different accuracies are summed up and the total confidence level may therefore be hard to determine.

Application

The detailed estimate method is often used in a later stage of the project once actual cost data from the previous stage is available. It is assumed that the actual cost data is a correct predictor for future costs. The tasks of the work breakdown structure are often used as basis for the detailed estimate. Each cost or schedule component is individually estimated on the lowest level of detail by the engineer performing the work and the cost engineer. The estimation can be performed based on the experience of the engineer or on historical data, which in that case must be available.

The mathematical formulae used to determine the total cost are different for each project. It can vary in complexity depending on the amount of cost components required, an example is provided in

3.2.3. Comparative Estimating

Definition

When a new project is similar to another project recently completed, a quick comparison can be made of the salient features (Lester, 2013). The comparative estimating method, or analogous estimating method is based on the costs of major cost components that were used on previous similar projects for which direct and recent experience is available. The costs have to be adjusted for factors that represent differences in size, performance, complexity, time, location and technology (Government Accountability Office, 2009). The relation between size factors is usually not linear, cost capacity factors and economies of scale are factors that determine the relationship (Burke, 2003).

The main advantage of this method is that it generates a quick and easily understandable cost estimate for the project costs. Also this method is very accurate if the new project has minor deviations from the historical project on which it is based. However, such an appropriate comparative project may be difficult to find or not available at all. If not available, this estimating method cannot be used at all. Another disadvantage of the comparative estimating method is that it relies on a single data point. Furthermore, it requires normalization in order to ensure a good accuracy of the estimate. Normalization is necessary to eliminate all special conditions from the estimate and a baseline is created. Normalization can be based on extrapolation of estimating data or expert judgment to make adjustment factors. Extrapolation is used to estimate a value that is outside the range of known values, by assuming the estimated value follows a logical function.

Application

This method is typically used early in a project's lifecycle when insufficient actual cost data are available but when the scope of the project is good enough to make the necessary adjustments. The comparative estimating method is also commonly used as a 'sanity check' for more detailed cost estimating methods or as a rough order-of-magnitude estimate. The sanity check, or sense check, is necessary to verify that the outcome of the estimate also makes sense. This check ensures that there are no extreme mistakes made in the estimate.

Based on experience and historical data the most important cost drivers and corresponding relations for the project can be determined. In order to ensure the reliability of the estimate the relation between the new and historic project should be strong and the sources for comparison must be logical, credible and acceptable to a reasonable person (Government Accountability Office, 2009).

Due allowance must be made for cost affecting factors such as inflation, location, escalation, contractual requirements, etc. which are specific for each project (Lester, 2013; Rolstadås, 2004).

The mathematical application of the comparative estimating method is dependent on the normalization that is required. Often used methods are the Power Law relationship, cost indices and factored estimates. The Power Law relationship is the relationship between two cost components, where one cost component varies a power of another. The power has to be determined based on the considered normalization. Cost indices are normalized or weighted averages for the cost. The normalization is based on factors for inflation, location etc. Factored estimates can also be used to normalize the cost for inflation, location and size (Jelen & Black, 1983). The mathematical application of these normalization techniques are further explained in Appendix A.

3.3. Probabilistic Cost Estimating

Definition

One of the first that mentioned the probabilistic approach, or as he called it 'range estimating approach' was Michael Curran (Curran, 1976). Curran observed that decision makers base their decision on three 'building blocks':

1. Units; the units of service required, units constructed etc.
2. Currency; Euros, dollar, Yuan, etc.
3. Time; time to complete a project

However, he also observed a fourth 'building block' namely risk, which was not always considered by decision makers at the time. Curran was also the first to describe the application of Monte Carlo Simulations as a risk analysis tool. This tool will be explained later on, first a little more background of probabilistic estimating is required.

Probabilistic estimating is a methodology that uses probability distributions for one or more parameters as input for the cost estimate. The probabilistic estimating techniques focus on the risks and uncertainties involved in the project and attempt to quantify the project cost variability. It can be used to answer questions such as: 'What is the chance of exceeding a particular cost in the range of possible costs?', 'How much could the cost overrun?' and 'What are the uncertainties and how do they drive cost?'

The assumption for using probabilistic estimating is that it is more sensible to consider using probabilistic range estimation rather than point estimates, because a probabilistic range reflects the fact that outcomes vary (Elkjaer, 2000). The point estimate of a parameter, whose value is uncertain, is a single value in the range of possible values for that parameter (Garvey, 2000a). Chou et al. (2009) conclude that single value estimate techniques are unreliable and probabilistic ranges will improve the reliability of the estimate.

For this research a separation between project risks and uncertainties is used as explained in Text box 2.

Text box 2: Risks and uncertainties

Risks and uncertainties

Risks and uncertainties are two different concepts. For cost estimating purposes a risk can be defined as the chance of loss. If there are favorable and unfavorable circumstances then risk is the probability an unfavorable event occurs. It can be quantified by using the probability of occurrence and the financial consequences of occurrence (Elkjaer, 2000). Risks that can influence the entire project are called generic risks and could be price rises (inflation), weather conditions, environmental or political factors, etc.

Uncertainty has been defined as 'the indefiniteness about the outcome of a situation' (Garvey, 2000a) or the intangible value that cannot be exactly defined (Elkjaer, 2000). In other words it is the variability that a certain value may become. Uncertainty is used in the case insufficient knowledge about a specific cost item is known.

Application

Contractors often use probabilistic estimating to fix the contingency level of their proposals (Diekmann, 1983). Furthermore, probabilistic methods are used for risk analyses and risk management. The CROW (2010) described probabilistic estimating in a way in which it can be incorporated in the risks as well as the uncertainties.

In order to apply probabilistic estimating first the inputs of the estimate have to be approached by a probability distribution. Also simulation software (Crystall Ball or @Risk) is required to be able to run a Monte Carlo simulation, which is the tool that is used to simulate the estimate's output.

Monte Carlo Simulation

Monte Carlo Simulation is a tool that can be used to develop a probabilistic cost estimating model (Chou et al., 2009). It provides insight in several aspects:

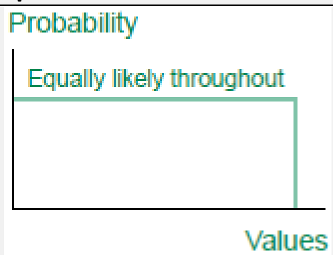
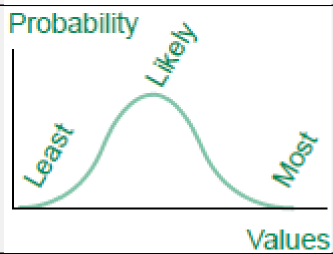
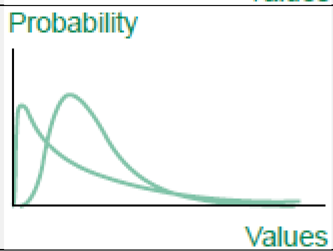
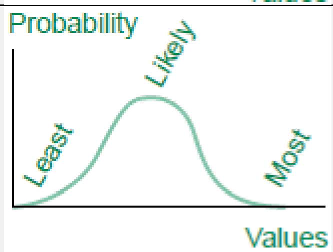
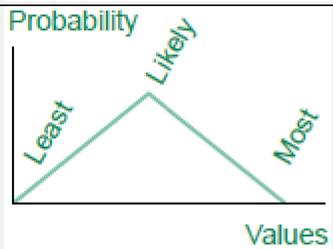
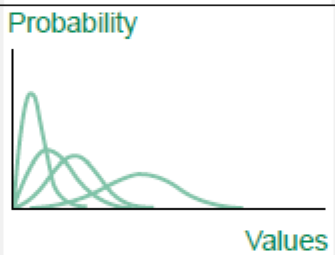
- The range of the cost estimate and the range in which the actual costs will be with certain reliability. In other words it provides insight in the accuracy of the cost estimate.
- The probability that the actual project costs are higher than a certain cost.
- The simulation provides the distribution of most important risk contributions in the project. For these risks mitigation actions may be established. (Van der Meer, 2003)

One of the reasons that Monte Carlo Simulation can be applied in engineering projects, is that decision makers are willing to accept variances from 5 to 10% when decisions are made related to the quantitative values involving risks (Humphreys, 2005b). In order to apply a Monte Carlo simulation it is necessary that the probability distributions of one or more cost components are determined.

Probability distributions

Each cost parameter has its own probability distribution that reflects the reality. A probability distribution is a statistical function that describes all the possible values and likelihoods that a random variable can take with a given range. There are several types of distributions that can be used to model the reality. The distributions that are commonly used in the construction industry include uniform, normal, lognormal, beta, triangular and Weibull (Chou et al., 2009). The shape and characteristics of these distributions are described in 0, where the probability density function (PDF), the cumulative density function (CDF), the expected value and the variance is provided for each of the distributions. The shape and application of these probability distributions are also provided in Text box 3.

Text box 3: Characteristics of probability distributions (Government Accountability Office, 2009)

Distribution	Shape	Application
Uniform		All values within this range are equally likely to occur. Can be used for engineering data or analogy estimates
Normal		The normal distribution is used for outcomes which likely occur on either side of the expected (most likely) value. Often used to assess uncertainty with cost estimating methods.
Lognormal		This function has a fixed minimum and a limitless maximum. It is used to characterize uncertainty in non-linear cost estimating relationships.
Beta		The beta distribution is similar to the normal distribution but also leaves room for positive or negative skewness. It is often used in engineering data and for comparative cost estimating for outcomes that are biased towards the tail ends of a range.
Triangular		The triangular distribution is characterized by three points: optimistic, most likely, pessimistic. It is used to express technical, cost and schedule uncertainties. Especially useful for making probability distribution based on experience.
Weibull		This function can take on the characteristics of other distributions. It is often used in life data and reliability analysis.

The cost components used to estimate the costs of services can be related to one of these probability distributions. There are several statistical tests available that can be used to find the best fit of the mentioned probability distributions on historical data of a specific cost component.

If the probability distribution of a certain amount of cost parameters is determined, the Monte Carlo simulation can be run. In each simulation a random number is obtained from each cost component for which a probability distribution has been selected. This results in a total cost for simulation one, however, by running multiple simulations the total cost will become a probability density distribution. From this probability distribution managers can select a certain confidence level which they are willing to risk in order to obtain the project.

3.4. Cost estimating process

For the cost estimation for projects in the construction industry in general several authors described a standard process for cost estimating for specific types of projects. The Cost Estimating Handbook from NASA (2008) is one of the most complete and comprehensive estimating methodology that has been found in literature (NASA, 2008). NASA executes a variety of types of projects, which highlights the broad use of the methodology described in the Handbook. For this reason, it is an applicable cost estimating methodology that can be used as recommended practice to estimate the services costs. The NASA estimating methodologies also includes the decision for the most appropriate cost estimating methods, and it describes a way in which probabilistic cost estimating can be incorporated in the estimating process. Therefore, this methodology is described in more detail in Appendix C.

In addition to the methodology described by NASA several other authors produced a standard process for the estimation of costs. There are several entities that provide recommended practices for particular parts of estimating such as the Dutch Association of Cost Engineers (DACE), the Chartered Institute of Building (CIOB), the Construction Industry Institute (CII), the International Cost Engineering and Analysis Association (ICEAA), and the Association of the Advancement of Cost Engineering International (AACE International).

Furthermore, there are several government agencies that established estimating standards such as the explained methodology from the National Aeronautics and Space Administration (NASA) but also the Dutch Rijkswaterstaat and Prorail, and the US Department of Defense (DOD), Department of Energy (DOE), Department of Homeland Security (DHS) and the Government Accountability Office (GAO).

The different organizations and their literature are summarized in Table 4 on the next page.

Table 4: Estimating processes

#	Organization	Literature	Source
1	DACE	Cost and Value	(Dutch Association of Cost Engineers, 2013)
2	CIOB	Code of Estimating Practice	(CIOB, 2009)
3	CII	Several Best Practices	(CII, 2013)
4	ICEAA	Parametric Estimating Handbook	(ISPA, 2008b)
5	AACE International	Several Recommended practices, Total Cost Management Framework	(AACE International, 2011, 2012a, 2012b, 2012c)
6	Rijkswaterstaat	Standaard Systematiek voor Kostenramingen	(CROW, 2010)
7	Prorail	Leidraad Kostenraming	(Prorail, 2011)
8	NASA	Cost Estimating Handbook	(NASA, 2008)
9	DOE	Cost Estimating Guide	(US Department of Energy, 2011)
10	GAO	Cost Estimating and Assessment Guide	(Government Accountability Office, 2009)

The Government Accountability Office (2009) established a guide with the best practices for developing and managing capital program costs. However, this guide is also very useful as basis for the estimating process. The methodology used in the guide (Figure 7), largely corresponds with the methodology developed by NASA (2008).

The recommendations that are most common in the mentioned literature are described in the conclusion of this chapter.

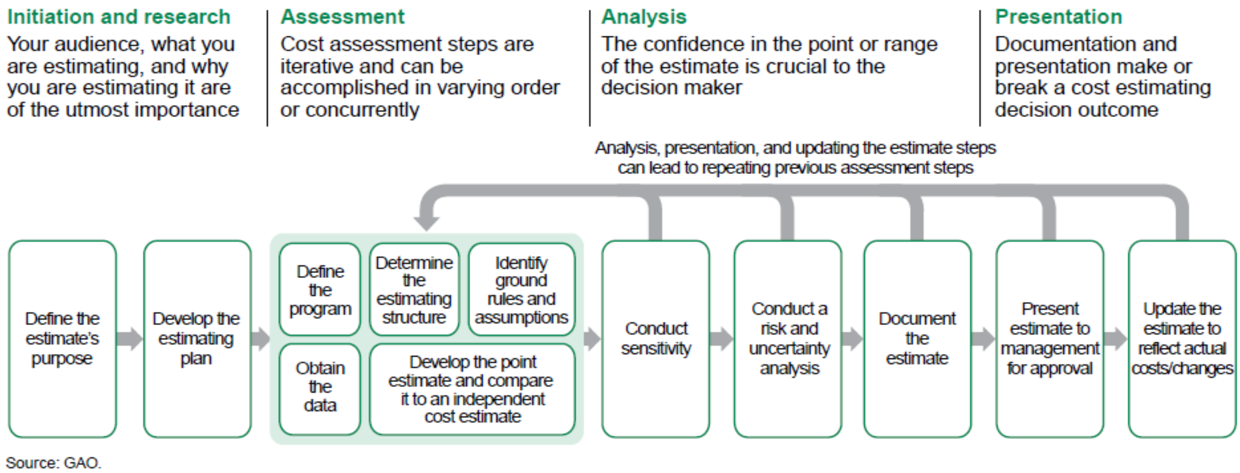


Figure 7: GAO Cost estimating process (Government Accountability Office, 2009)

3.5. Findings

Concluding this chapter the main conclusions and recommendations are summarized and the answers to research questions 1 and 2 are provided. First research question 1 is answered.

1. Which cost estimating methods are appropriate for estimating the cost of services and how should they be applied?

The cost estimating methods found in literature are divided in deterministic and probabilistic estimating methods. The three deterministic estimating methods are parametric estimating, detailed estimating and comparative estimating, which are described in detail in this chapter. The probabilistic estimating method is also described in more detail in this chapter. During the estimation of the cost of services several of the described methods can be combined in order to reach the estimate of the total project costs. In general all the described cost estimating methods are relevant and suitable for estimating the cost of services. However, each method has its own advantages, disadvantages and requirements which determine the most suitable estimating method for a specific case. The advantages, disadvantages and requirements of the estimating methods are summarized in Table 5 on the next page. The table provides an overview which can be used to determine the most suitable cost estimating method.

Research question 2 focuses on the recommended practices for the estimating process.

2. What are the recommended practices with regard to the cost estimating process?

Several literature sources (Table 4) are used to provide the following recommendations:[1]

- The project's scope must be determined prior estimating the costs. [2,4,8,9,10]
- For the cost estimate itself the scope and planning has to be clear as well. The required accuracy of the estimate must be determined as well as the total time that is available to conduct the estimate. [2,4,8,9,10]
- Assumptions that are made during the estimation have to be documented and substantiated. The estimate must be combined with a basis of the estimate which described all assumptions and ground rules.[2,8,9,10]
- Using more than one estimating method provides a higher reliability of the final estimated costs. The comparative estimating method is advised to be used as a 'sanity check' or benchmark. [8,9,10]
- It is important to maintain a database with relevant data of previous projects. This provides primary (and free) information for future estimates. [4,8,9,10]
- It is important to conduct a risk analysis/sensitivity analysis to be aware of the major risks that are associated with the project and their consequences of occurrence. [7,8,9,10]
- Collaboration between cost engineers and engineers is crucial during the preparation of the cost estimate.[4,6,8,9,10]

[1] The numbers behind the recommendations refer to the numbered literature sources from Table 4.

Table 5: Comparison of estimating methods

Cost estimating method	Advantages	Disadvantages	Requirements
Parametric	• Relatively quick and accurate way to estimate costs • Reduced likelihood of serious cost overruns • Reduced cost of preparing project proposals • Multiple decision options for project managers • Model can be used as basis for uncertainty and risk analyses • Easy to combine with other estimating methods	• Documentation of Cost Estimating Relationships (CERs) can be difficult • Traceability of CERs can be difficult • Historical data must be available • Improper use of CERs can lead to serious estimating errors • Maintenance of database with historical data	• Sufficient historical data for statistical analyses • Database with historical data that can be updated regularly
Detailed	• Very high accuracy possible • All cost components are taken into account • Nothing can be overlooked • Parts of the estimates can be reused • Actual cost data of ongoing project can be used as predictor for future costs	• Lot of effort required to conduct the estimate • High costs to establish the estimate • Project's scope must be determined and understood considerably • Confidence level difficult to determine	• Collaboration of the engineers that conduct the work • Work Breakdown Structure • Additional 'sanity' check or benchmark
Comparative	• Very quick way to come up with an estimate • Estimate is easy to understand • Can be used early in project • Can be used even if scope of the project is not complete • Provides quick order of magnitude estimate • Accurate if comparative and recent data is available	• Accuracy is limited • Cost impacting factors have to be determined • Single data point used for the estimate • Normalization required	• Experience or data of a relevant comparative project • Comparison factors
Probabilistic	• Probability of cost overrun is insightful • Improved reliability of the estimate • Range of outcomes is available • Uncertainties and risks are mapped and quantified • Substantiated accuracy of the estimate	• Additional analysis that requires additional effort • Determining probability distributions may be difficult	• Probability distribution of cost components based on historical data or experience • Software to run Monte Carlo simulation

The methods that are investigated in this chapter are comparative, parametric, detailed and probabilistic estimating. Each of these methods has their own benefits and requirements. In general a combination of these methods is used to estimate the costs for engineering and construction management services. The most appropriate estimating method is dependent on the scope and planning of making the estimate itself. This means determining the following criteria:

- **Accuracy**: how accurate do you want the estimate to be? Is a high level estimate or a detailed estimate required?
- **Effort to prepare**: How much effort do you want to put in establishing the cost estimate? What is the budget for making the estimate?
- **Reliability**: What is the desired reliability of the cost estimate and what is the required confidence level and confidence interval?
- **Timeliness**: When should the estimate be finished and when should the key deliverables be ready?
- **Reproducibility**: What are the assumptions that are made during the estimating and where and how are they documented?

These criteria are combined in a framework that can be used to find the most appropriate cost estimating method for different circumstances. The framework starts with the only criterion that is fixed; this is the timeliness or available time and regards the amount of time that is available to make the cost estimate. This amount of available time is split up in short time (several weeks) and long time (one or more months). The second criterion in the framework is the amount of effort that is put in the estimating of the services costs. Deciding the amount of effort is dependent on several factors, among which the desired accuracy and reliability of the cost estimate. There is a limit to the amount of effort, because the effort in making the estimate directly results in overhead costs, which should remain as low as possible. Another limitation to the amount of effort can be the initial definition of the scope, because for an undefined scope it is not possible to make detailed estimates. The criteria timeliness and effort to prepare the estimate are the main parts of the framework shown in Figure 25, which can later be used to determine the most appropriate cost estimating method.

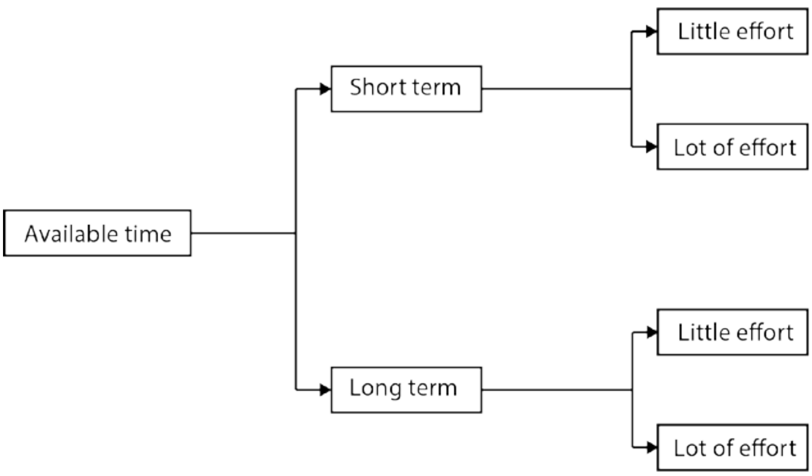


Figure 8: Framework for most appropriate estimating method

4. Analysis of current practice

In this chapter the current practice of the engineering contractor Fluor is analyzed in order to find the answers to research questions 3 and 4:

3. What is the current practice of engineering contractors with regard to estimating the cost of services and which cost components are used in the estimates?
4. What are the characteristics of the market for engineering contractors in the Energy and Chemical Industry that have to be taken into account?

However, before answering these research questions it is necessary to mention that this research is performed in Fluor BV in Haarlem. Fluor is a company specialized in Engineering, Procurement, Construction and Maintenance (EPCM) and is one of the largest companies in this field. Fluor has over 40,000 employees operating worldwide in diverse industries such as (petro)chemicals; commercial and institutional; government services; health-care; life sciences; manufacturing; microelectronics; mining; oil and gas; power; renewable energy; telecommunications; and transportation infrastructure (Fluor, 2013b). Fluor has 30 offices across six continents of which four offices are situated in the Netherlands. The Haarlem Office is the largest office in the Netherlands with over 800 employees and its main focus is on Energy & Chemicals. The estimating of services costs for engineering contractors that work for this industry has also been chosen as scope of this research (see chapter 2.4).

In chapter 4.1 the cost estimating practice of Fluor is explained. This information is based on interviews with representatives for the services cost estimations of multiple offices of Fluor. The interviewees' names, office location and function are listed in Appendix D. These interviews also formed the basis for the accounting of services in Chapter 4.2, in which the most important cost components of the services costs are described. Furthermore, the industry characteristics are described with the focus on market trends, work sharing, contract types, scope of work and project phases. In short, these are important industry characteristics relevant for the estimation of the cost of services and are described in Chapter 4.3. In Chapter 4.4 the influence of location factors on the cost estimation are described. In addition, a literature review is performed to find other cost influencing factors that may be relevant for the estimation of the cost of services. This literature study can be found in Chapter 4.5. The most important findings are used to answer research questions 3 and 4 in Chapter 4.6

4.1. Estimating process

In order to understand the current estimating practice for engineering contractors five interviews are conducted with representatives for the services cost estimating from five different offices from Fluor. The interviewees were the representative for the services estimation of the offices Haarlem, Farnborough, Johannesburg, Gliwice and Madrid. These are the main offices of Fluor within the EAME (Europe, Africa, and Middle-East) region that focus on Energy and Chemical projects.

The questions were focused on the estimating process, the accounting of the cost of services, the functionality and requirements of the estimating tool, and on possibilities to improve the estimating tool and the estimating process. Although there are differences between the offices it is tried here to describe the common approach of the estimating process.

None of the offices used a documentation to support the working methods during the services cost estimating process. The reason for this is that the experience of the services estimators is passed on to each other and the necessity of documentation was never present. The process usually starts with an alignment or Kick-Off meeting in which the commercial terms and the strategy for the proposal are discussed. Furthermore, contractual requirements and the scope of work and the involvement of other execution offices are discussed. The meeting is led by the proposal manager, who is responsible for the final proposal. The size of the proposal team is dependent on the size of the proposal and may include representatives from the sales department, the office manager, lead engineers from different disciplines and representatives from the project controls and estimating department.

After the alignment meeting, usually the leads from different disciplines are responsible to estimate the amount of man-hours they expect to require to realize the project. These leads all have different tools to estimate the amount of man-hours in their discipline. The man-hours are then combined and benchmarked by the proposal manager and the estimating representative. If there are large differences between the quoted man-hours and the benchmark the responsible discipline lead has to explain why he/she is expecting to need more or less hours than the benchmark.

In an optimal situation the discipline leads not only provide the amount of man-hours, but also the man-hours distributed over time and an indicative staffing plan. In the staffing plan it can be seen who is expected to perform the project, or an indication of the experience that is required by the persons that are going to perform the project. This experience is usually indicated by the grade, which is indicative for the person's wage rate.

The services estimator uses the distribution of the man-hours per discipline to add the costs for payroll burdens, overhead, office expenses, non-billable uplift, escalation, contingency, cost of cash and possible business travel and/or assignment that may be required. These cost components are discussed in more detail in chapter 4.2.

During the preparation of the proposal, the proposal team has several meetings to discuss issues and check all costs, man-hours, assignment conditions, business travel etc. are discussed. The final proposal and the estimate have to be approved by office management or depending on the size even the business group management. This is in general the approach during the proposal phase in which the estimate for the cost of services is performed.

4.2. Accounting of Services

Fluor offices in the EAME region (Europe, Africa and Middle East) use various types of tools in order to estimate the total costs of services. The experience with the tools is passed on to new services estimators within the offices and there was never a reason to standardize these tools. However, on this moment there is the wish to standardize the tools for the EAMA region to provide management with the same output style and to make it easier to exchange knowledge between the services estimators in this region. The tools of the offices Haarlem, Farnborough, Gliwice, Madrid and Johannesburg are compared in order to extract the common cost build-up of the cost of services.

The parameters in this cost build up are presented in Table 6. These parameters will be discussed separately to elaborate on the costs included in the cost-parameters and to clarify how the parameters are estimated in Appendix E.

Table 6: Common Cost-Build up Fluor EAMA

#	Cost parameter
1	Wage rate
2	Payroll Burdens
3	Overhead
4	Office/Field Expenses
5	Uplift Non-Billable
6	Escalation
7	Contingency
8	Cost of Cash
9	Other
10	Total Costs

The wage rate or base salary is the salary that an employee receives, but can also be the average wage of a department, discipline, grade, etc. The services estimator chooses for each proposal the strategy which results in the most optimal cost estimate. The strategy options that are possible are shortly discussed.

Named positions

If, for the project, it is known exactly which employees will be working for it, their representative wage rates can be applied as the base salary. This salary is documented by the Fluor's Human Resources department and can be accessed by the services estimator. If the project is actually executed by the proposed employees then the cost estimate will be more accurate than the other strategies. However, it has to be noted that in a proposal stage, where most of the services cost estimates are conducted, it is not probable that all proposed employees will also actually work on the project. Regardless the project phase, there is always time between the proposal and the start of the project (bidding time). For this reason, deployment of the proposed employees is subject to several uncertainties e.g. illness, job changes, holidays, double deployment, etc. It might occur that the same employee is deployed on multiple proposals at the same time. This means that if all the proposals are won, this person is estimated to work on all the proposals. Obviously this is not possible since one person can only work full time on one project at a time. This tendency results in false accuracy of the estimate, which can be taken into account in the escalation parameter explained in Appendix E.

Average discipline/department

If for a reason, it is not known which employees will be working on the project several other strategies are available. One is to apply the average wage per discipline. Project related disciplines in Fluor can be separated in Engineering disciplines and Support disciplines. The relevant engineering and support departments that work on projects are presented in Table 7.

Table 7: Engineering and Support Departments Fluor[2]

Support departments	Engineering departments
P&C Discipline A	Engineering Discipline A
P&C Discipline B	Engineering Discipline B
Project support Discipline A	Engineering Discipline C
Project support Discipline B	Engineering Discipline D
Project support Discipline C	Engineering Discipline E
Project support Discipline D	Engineering Discipline F
Project support Discipline E	
Project support Discipline F	
Project support Discipline G	
Project support Discipline H	
Project support Discipline I	
Project support Discipline J	

For any of these disciplines it is possible to apply the average wage for the estimate. It can be corrected by an uncertainty factor (e.g. +10%) which the estimators deems sufficient. This strategy may be effective if the distribution of labor per discipline of the project is known from historical data.

Average grade

Labor in Fluor globally, as well as several other companies, is divided in labor grades. Basically the higher your grade is the higher your salary is; senior engineers will therefore be in a higher grade than junior engineers. It occurs that the deployment of employees is based on organization charts/staffing plans which describe the typical function for the employer required e.g. senior design engineer. In this case it is possible to translate the function to the corresponding labor grade. The average wage for that labor rate may then be used and a sufficient correction factor applied.

Average discipline/department grade

Another possibility is to combine the division per discipline/department and the division per grade. This result in an average wage per discipline per grade e.g. a senior estimator (where senior can be associated with a certain labor grade). Instead of using an average per grade of the whole company the averages per discipline in which the employee works are used leading to a more specified and realistic estimate.

Discussion

Using named positions, averages of departments, average grade or average by department and grade are some strategies which are commonly used in Fluor. The strategy for each estimate is different and may be any combination of these strategies. The choice for the strategy is dependent on several factors:

- Scale of the proposal: For small proposals more named positions are used due to the larger risks involved.
- Complexity of the project

[2] The departments are anonymous for confidentiality reasons

- Likelihood of availability of the individual
- Duration of the project

No matter which strategy is used, the other cost components of Table 6 are always added to the wage rate. The payroll burdens, overhead and the basic office expenses are always fixed annually. The wage rate, non-billable uplift, escalation, contingency, cost of cash and miscellaneous costs are determined for each project specifically. Determination is based on many factors, which are explained in more detail in Appendix E.

4.3. Industry characteristics

4.3.1. Market trends and characteristics

Engineering Contractors working for the Energy and Chemical Industry are dependent on the demand in this industry. The Energy and Chemical market can be divided in the Oil & Gas Industry, which is the largest part, the Process Industry and a small industry that focuses on alternative energy.

The Oil and Gas (O&G) market is an enormous, fast-growing global market. It is projected that by 2030 the world population will demand 35% more energy than what is currently consumed. Therefore, it is recognized that it is necessary to invest and expend resources to meet oil, gas and chemical demands in the future (WPC, 2012, 2013). This results in long term market growth in the Oil and Gas market as well as in the construction and engineering sector that focuses on Oil and Gas. However, the global economy is becoming increasingly cost-competitive and emphasizes on lower project execution costs. Another trend is that countries are focusing on local-content in their projects through the use of in-country talent. This means more countries are procuring services and goods in their own country. Furthermore, an increasing number of countries are implementing stricter environmental policies.

New resources are found in the most remote locations of the globe, leading to challenges in construction and engineering activities. Projects often become so complex and large that only a few companies are capable of handling the construction and engineering. This is a characteristic of an Oligopoly, where strategic decisions of companies directly affect the few competitors. Barriers to enter the O&G construction and engineering market are high due to the size and complexity of projects that are executed and the expert technological knowledge that is required to execute these projects.

The market relevant for this research is the Engineering, Procurement and Construction (EPC) market that focuses, among others, on Oil and Gas (O&G) projects. Projects in this industry can be diverse and are divided in the upstream sector and the downstream sector.

The upstream sector consists of the development of new sources of supply such as the development of new production fields of oil and gas resources, including the processing and transporting of oil and gas at site. Also the development of new pipelines and LNG (Liquid Natural Gas) projects fall under this sector.

The downstream sector refers to the refining of petroleum crude oil, processing and purifying of raw natural gas and the distribution of the products. Due to the increasing demand, new (petro) chemical refineries/facilities are constructed and existing facilities are modernized, modified or revamped to increase the capacity or to satisfy stricter environmental regulations.

4.3.2. Work sharing

Companies providing Engineering, Procurement and Construction services for projects in the Energy and Chemical industry have to deal with the trends of increasing cost-competitiveness and the focus on local-content in projects of various countries. As a result, companies are expanding their business to growth regions by the use of GECs (Global Execution Centers). This allows the collaboration of multiple offices to work on projects. The use of GECs in the growth regions, often low-wage countries, provides companies the opportunity to work more cost-efficient. In addition, it is easier to establish strategic alliances with local partners in order to address local content requirements that may exist in the contracts.

4.3.3. Contracts

The EPC market for Energy and Chemical projects can be characterized by the use of specific contract types. The main contract types are Lump Sum, Cost Reimbursable, Target Price, Guaranteed Maximum contracts. These are the four most used contracts, although several alternatives are possible. First the contract types are described shortly and after that the risks associated with the contract types are explained.

1. Lump Sum

In a lump sum or fixed price contract the contractor assumes the majority of the financial risk on the project. The contractor agrees to construct the project in accordance with the contract document for a fixed price, arrived at by competitive bidding or negotiation. The contractor receives a fixed price from the client regardless of the difficulties encountered which impact the actual cost to the contractor to build the project. Therefore, it is important that the scope of the project work is well-defined and the contractor has to be able to accurately understand it before the time of bidding. The scope of the work is set in the contract and scope changes (change orders) required by the client are paid additionally based on the cost of the new work, overhead, time and potential rework. The later in a project change orders are issued the greater their costs will be, this tendency is visualized in Figure 9.

The scope of the lump sum contract can be to perform services, where a fixed price is determined to perform a package of services. Another possibility is the lump sum turnkey contract, in that case the contractor has to build the facility as well as start-up the facility to a level of operational status all for a fixed price.

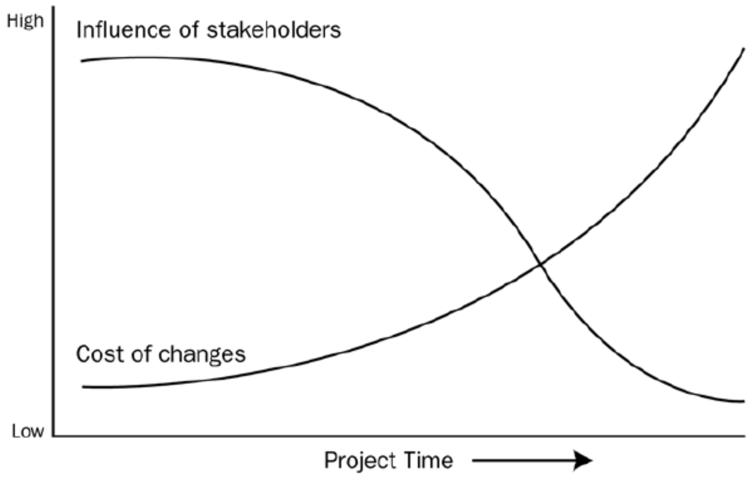


Figure 9: Cost of changes over time (Project Management Institute, 2004)

2. Cost Reimbursable

The Cost Reimbursable contract, or often called Cost Plus contract, is based on the principle that the client reimburses all costs associated with the project. The costs reimbursed include overhead and a fee for the contractor. The payment method and schedule has to be clearly understood by all involved parties. The client accepts to take the majority of the financial risk since most actions or events that occur and affect the cost of the project are controlled by the client. This type of contract is often used when uniqueness of the project, required quality or schedule are important. The risks of the contractor is limited since the client accepts the majority of the risks. However, the contractor has the professional duty to maintain the cost within the project budget. The contractor's reputation is at stake and delivering the project within budget ensures continuity and long term relations. The cost reimbursable contract exists in various forms and this contract type can also be combined with other contract types (e.g. partly cost reimbursable and partly lump sum).

3. Target Price

In a target price contract the financial risks are shared between the contractor and the client. The client reimburses all project associated costs up to an amount agreed upon by the client and contractor. Cost overruns or under runs of the target price are shared between the client and the contractor. The basis on which this is distributed is agreed upon in the contract.

4. Guaranteed Maximum

In the guaranteed maximum contract all costs associated with the project are paid by the client up to an amount agreed upon by the client and the contractor. If the actual price exceeds the guaranteed maximum these additional costs are paid by the contractor solely. On the other side cost under runs are shared by both the client and the contractor on an agreed upon basis. This type of contract is not always regarded as fair since the contractor assumes all risks for cost overruns while cost under-runs have to be shared.

Risks

Figure 10 visualizes the relation between contract type and risk assumed by the contractor or client. In between the cost reimbursable and the lump sum contract several contract types are used.

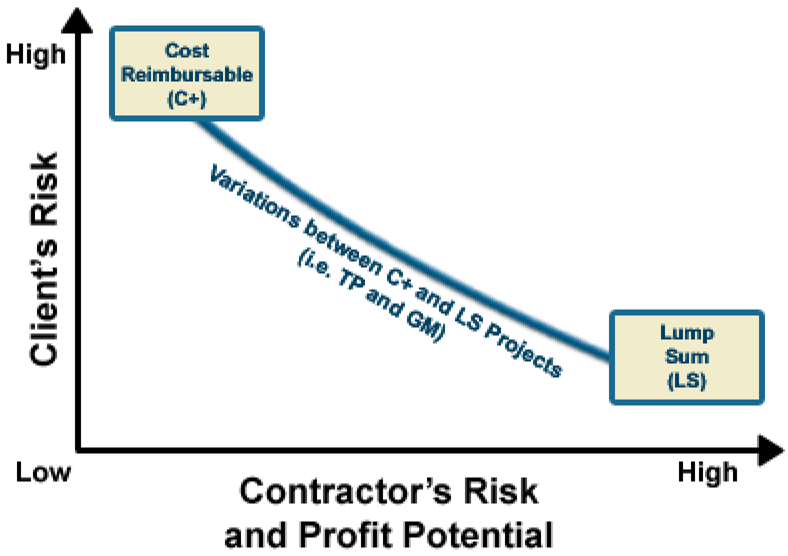


Figure 10: Relation between contract type and risk (Fluor University, 2013)

C+: Cost Plus
TP: Target Price
GM: Guaranteed Maximum
LS: Lump Sum

The risks and the amount of control that client and contractor have are dependent on the contract type. In general, the risk sharing principle works best by which benefits can be gained by both parties (De Ridder, 1994).

In addition to the contract type, other special contractual requirements can occur that need to be considered during the estimating process. Also the type of client and the requirements of the client have to be taken into account during the preparation of an estimate. However, contractors take client considerations often already into account before taking the decision to submit a tender.

4.3.4. Scope of work

Fluor may be involved during the whole construction process of a project from project initiation to the start of the operation. Fluor has the capacity to design and construct new facilities, revamp or expand existing facilities. Services that Fluor provide include the FEED (Front-End Engineering Design), Program Management, Construction Management, self-perform construction, responsibility for procurement of labor, materials, equipment and subcontractors and other consulting services.

The scope, and more specifically the definition of the scope, is a factor that is important to consider while estimating the costs for projects. If the scope is not defined appropriate, a contractor takes additional risks. Also the information that is available for the estimation of the costs may be uncertain if the scope is not entirely clear. The most applicable cost estimating approach is different for each project. Factors such as scope definition have an influence on choosing the most applicable estimating practice. For example there is a difference in estimation approach whether a new facility is constructed or whether an old facility is revamped. Also the size of a project influences the estimating approach.

4.3.5. Project phases

The information and knowledge about the project gradually improves with the life cycle phase of the project. It is generally agreed that once more information is available and increased levels of detail are incorporated in the estimate, this results in improvements in the accuracy of cost estimates and the estimating methods that can be used (Merrow et al., 1979). For this reason the project phases in the project's life cycle are defined. Fluor projects are typically characterized by the following seven project phases:

0. Project Initiation
1. Scope Definition & Conceptual Development
2. Preliminary Engineering, Construction Planning
3. Detailed Engineering, Site Initiation
4. Construction, Final Design, Engineering Support for Construction
5. Checkout, Startup Support
6. Project Close-Out

These seven project phases are indicatively plotted against the life time of the project in Figure 11. In addition, the level of completeness of engineering and construction activities can be seen in this figure. At approximately 30% of the project life cycle the construction planning starts and around 45% effective construction starts to take place. These percentages are indicative and change for each project.

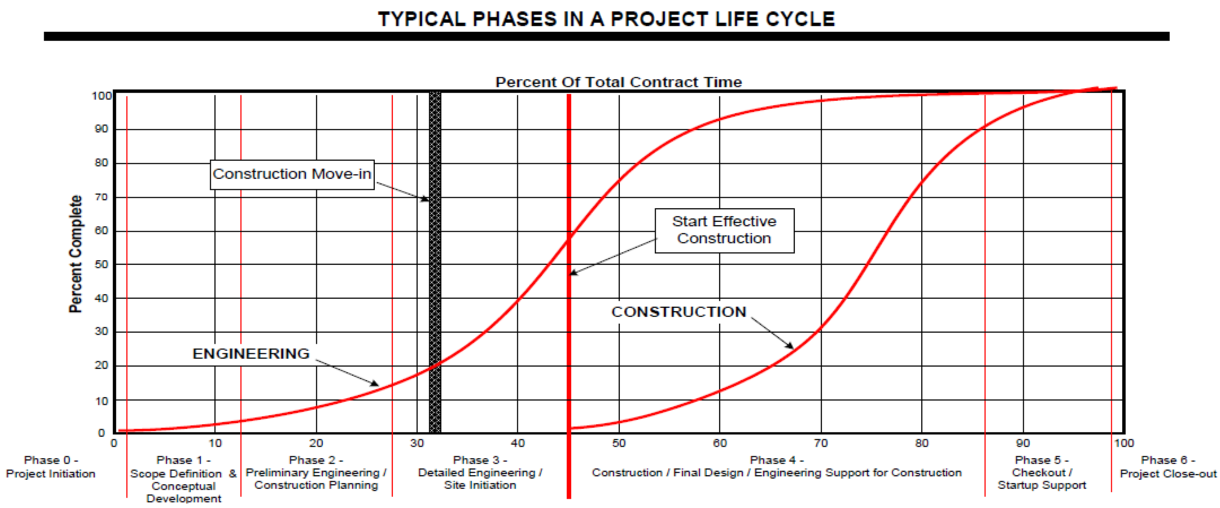


Figure 11: Typical Phases in a Project Lifecycle (Fluor, 2013a)

Table 8 compares the design and build project phases of Fluor with the project phases of the Project Management Body of Knowledge (2004) and the IPA (2013). The reason for this is to interpret the life time phases used in Fluor in comparison with other sources. It can be seen that the life time phases of Fluor largely correspond with the phases of the PMI and the IPA.

Table 8: Project phases comparison (Fluor, 2013a; Independent Project Analysis, 2013; Project Management Institute, 2004)

Project Phases Fluor	Project Management Institute	Independent Project Analysis
Project Initiation	Project conception and initiation	Front-End Loading 1: Business Planning
Scope Definition & Conceptual Development		
Preliminary Engineering, Construction Planning	Project definition and planning	Front-End Loading 2: Scope Development
Detailed Engineering, Site Initiation		Front-End Loading 3: Project Planning
Construction, Final Design, Engineering Support for Construction	Project launch or execution	Execution
Checkout, Startup Support	Project performance and control	
Project Close-Out	Project close	Operation

Three typical phases that exist in the construction of the Energy & Chemical Industry which are directly related to scope and contracts are Front End Engineering Design (FEED) and Engineering, Procurement and Construction (EPC). In the FEED the conceptual design of the project is established and usually (dependent on contract and scope) entails the project initiation, scope definition & conceptual development and preliminary engineering & construction planning. After the FEED phase, in which also an estimate of the construction costs is made, there usually is the decision whether to proceed with the project. If it is decided to proceed, the project goes into the EPC phase for which another contract is awarded. The EPC phase entails the detailed engineering, procurement, construction, start up support and eventually the project close out.

4.4. Location factors

Location factors are conditions that exist in a specific country or location where a project is to be located. Location factors can have a large impact on the cost and schedule of an international project (Walker, 1978). Services performed on a Site Office or Agency personnel coming from the country of the project are affected by location factors. The impact of location factors on services performed in the Home Office of an engineering contractor is considerably less, but may still exist.

Location factors include labor availability, labor productivity, import duties, import licenses, customs, local taxes, language, length of workweek, holidays, inflation, exchange rates, religious customs, local laws, weather and climatic impacts, workforce level of education, workforce housing, communications, and other relevant factors (Humphreys, 2005a). These factors might change within regions in the same country. Remoteness and distance from major cities can have a big impact on the estimate. It is always important to take into account the location factors of the project location. Some of the location factors will be discussed in more detail.

Location factors are also decisive for choices between local labor or importing labor and constraints on the site.

4.4.1. Construction labor local or imported

If construction labor is required for the contract, the first thing to find out is whether construction labor is available in the neighborhood of the project location and whether they have the required technical skills to perform the project and their expected productivity. This is important to decide whether to contract local work force or to import construction labor. Sometimes labor brokers are required to staff the project which might require an additional fee. The payroll burdens of the local staff are probably different and dependent on local legislation. It is also possible to import labor (on assignment), however this may not be legal in every country or may not be possible by contractual agreements. The deployment of work force might also be determined by the language spoken in the project location. The work force may have to be bilingual in order to communicate. Furthermore, tax issues have to be considered, double taxation or substantial extra taxes for expats might influence the decision.

Another possibility is to subcontract part of the work to local subcontractors.

4.4.2. Site constraints

There may be site constraints such as limited storage place, limited infrastructure to the site, absence of water/electricity, difficult soil conditions that could influence the costs.

Furthermore, there are issues regarding the housing and services for the workforce that need to be addressed. Meals, living facilities (camp or local housing) or transportation to the job site may be required in some locations and the costs for these services have to be estimated.

All in all, a lot of different factors have to be taken into account when deciding how to deal with construction labor and Home Office labor.

4.5. Additional factors influencing the estimating process

There are many factors which may have an influence on the estimating process of engineering contractors. A few have been mentioned in chapter 4.1 and 4.2: the market conditions, amount of work sharing, the contract- and client type and requirements, scope of work, the project phases, and location factors.

From literature, additional factors were found, Akintoye (1998) found 24 factors in his study that were involved in costing construction projects. For the more specific cost of services, not such detailed information was found in literature, so the 24 factors analyzed by Akintoye (1998) are used from which the thirteen most important factors for large contractors are considered[3]. These are shown in Table 9 ranked on importance.

[3] All factors that had a score >3.5 in the factor analysis for large contractors performed by Akintoye (1998) are used. This resulted in the top 13 factors influencing project cost estimating practice for large contractors.

It is difficult to develop a general estimating methodology that is appropriate in all circumstances. In fact all the factors from Table 9 are project specific and need to be considered for each project specifically. However, for the completeness of this research it is important to mention in short how the factors influence the cost estimating approach of a contractor.

Table 9: Factors influencing project cost estimating practice (Akintoye, 1998)

#	Factor
1	Complexity of design and construction
2	Method of construction/construction techniques
3	Tender period and market conditions
4	Buildability
5	Scale and scope of construction
6	Project duration
7	Site constraints – access and storage limitations
8	Form of procurement and contractual arrangement
9	Extent of completion of pre-contract design
10	Quality of information and flow requirements
11	Project's team experience of the construction type
12	Location of the project
13	Capability of the firm's construction team

Complexity of design and construction

The complexity of design and construction is not only important for the construction cost but also for the cost of services. The more complex a design is the more engineering work it will require. It is not always easy to determine the complexity of a project in advance but from the scope definition it can already become clear whether there are complexities involved in the design. In general complexities are taken into account into the risk analysis of a project.

Another factor that is influenced by the complexity of a project is that it usually requires a more experienced project team and/or additional engineering time to deal with the complexities. Both these factors have an impact on the services costs.

Method of construction and construction techniques

Although this factor is considered important for construction cost estimating it may be less important for the estimation of services costs. During engineering activities it is a factor to continually take into account and for construction management activities it has already been decided. In the FEED and EPC phase the influence of the construction method on the estimation of engineering or management services is limited to the construction support discipline, which is responsible for the construction methods and techniques. One construction method may require more time to support than the other; however the impact of this additional time on an entire project is very limited.

Tender period and market conditions

The market conditions for engineering contractors performing projects in the Energy and Chemical industry are discussed in chapter 4.1.1. If a contractor is performing a lot of projects at the moment and are operating on full capacity they will be less eager to get more projects, and the other way around if a contractor is working below their capacity they will be eager to get new projects. This consideration is important in taking the decision to tender. After that decision is made (contractor is eager to get the project) the market conditions are important to determine the common market prices for the proposal.

Also the tender period is important as it determines the amount of time that is available to conduct the services estimate. If more time is available different estimating methods may be appropriate.

Buildability

The buildability, or often called constructability, is considered less important for the estimation of services costs for the same reason as explained in the method of construction/construction technique section above. However, if the scope of the project is to perform project management services, the constructability of the construction is considered very important. It requires more support and input from project management if the constructability is very complex. Also it may require more experienced project managers.

Scale and scope of construction

The influence of scope and size (or scale) is explained in chapter 4.1.4. The larger the project the more the estimated averages that are used in the estimation of services cost tend to converge to the actual average (see also the Central Limit Theorem in Appendix A). Therefore, it is not always true that the services estimates for large scale projects require more effort to estimate than small scale projects. The impact of an individual with a very high wage rate on the total services costs is for example much higher in small projects than in large projects (law of large numbers). This exemplifies that the scale of a project does influence decision making during the estimating process. The scope is also important for the decisions made in the cost estimating process. The quality of the tender documents (which is an indicator of the definition of the scope before the estimate is made) is together with the availability of time the largest contributor to inaccuracy in estimates (Akintoye & Fitzgerald, 2000). A solid scope definition is for example required to use the detailed estimating method, by a project with a poorly defined scope the choice for this estimating method is therefore not applicable.

Project duration

Project's can be schedule driven or cost driven or a combination of both, in any case the estimating method may be different. If the project is schedule driven, there are more engineers working at the same time on the project. Also construction may step in while the engineering has only partly been performed. This often causes some rework to be done, which can be taken into account in the estimate. Furthermore, if the time to deliver a project is limited often a more experienced project team is chosen to realize good progress.

Also the phase of the project is a factor to take into consideration in the estimation of services. As explained in chapter 4.1.5 the quality of information improves with the lifecycle of the project. Furthermore, the project phase indicates the amount of work that has already been performed. The amount of work that still has to be done is therefore also partly determined by the project phase. For these reasons, the project phase is also a factor that determines the estimating approach of a contractor.

Site constraints

As explained in chapter 4.2.2 several site constraints may occur that influence the decision making for the cost estimating practice. For the estimation of the cost of services, the influences of site constraints are more limited compared to that of the entire construction costs. Still for example additional engineering work may be required to deal with the site constraints. Or more experienced people will be selected for the project to be able to deal with the site constraints.

Procurement form and contractual arrangements

The most occurring contract types and the associated risks are described in chapter 4.1.2. Additional contractual requirements may lead to more risks for the contractor, which in that case have to be analyzed in the risk analysis of the cost estimate. In the cost estimation of services the contractual arrangements regarding business travel and assignment costs are specifically important to consider. The business travel and/or assignment costs can be reimbursed by a prearranged rate. However, if this is not stated in the contract it is important to accurately estimate the number of visits to the client or project site as well as the number of people on assignment. This same applies to the associated costs that come with such trips and/or assignments.

Extent of completion of pre-design

The extent of completion of the pre-design determines on a high level the availability and quality of the information that is available during the estimation process and thereafter. Also it determines how much work still has to be performed. The amount of work to be performed is one of the most important factors of the total cost of the services. For these reasons, this factor is important to consider during the cost estimating process.

Quality of information and information flow

It is logical and also often emphasized in literature, that the quality of information about the project is an important factor that affects the accuracy of the final estimate (AACE International, 2012c; Datta & Roy, 2010; Lester, 2013). In addition, the information flow between the client and the contractor and the communication within the contractor’s organization are important to guarantee the availability of the information to both parties. Both quality and availability of information are important factors that may influence the decision for the most appropriate estimating method under the circumstances.

Project team’s experience

Part of the estimate of services is to plan the amount of work that the project is expected to take. This is normally done by estimating the amount of man-hours required to perform the project. As part of the estimation of this amount of man-hours an estimator can already consider the organization of the project team. If this project team is experienced with the type of project to be performed, the estimator can decide to reduce the amount of man-hours under the assumption that the experienced project team can perform the work faster than the average project team. This is an example as to how the experience of the project team can influence a decision during the estimating process. Another consideration is that the average salary of an experienced project team may be higher than the average team. Multiple of such considerations can be made and that is why this factor is important.

Location of the project

The ways in which the location of the project can affect the estimating process are explained in the chapter location factors 4.2.

Capability of the firm's construction team

This factor is not so interesting for the estimation of the cost of services in the FEED phase because this is only important during construction. During the EPC and especially during the construction management the capability of the construction team is an important factor to take into account. An inexperienced construction team requires more support and management than an experienced team. Because of this the impact of the capability of the construction team on the services costs in these phases is more important.

This factor may also be applied on the engineering team instead of the construction team. The driver behind this factor is in fact productivity, which is the efficiency in which a team performs the project. The productivity on average improves with experience and should be considered as explained under section project team's experience.

4.6. Findings

The intention of this chapter was to provide an answer to research questions 3 and 4. First research question 3 will be answered.

3. What is the current practice of an engineering contractor with regard to estimating the cost of services and which cost components are used in the estimates?

The current estimating practice of the engineering contractor Fluor is that the required amount of man-hours and the corresponding wage rates and costs are estimated separately. The engineering departments and the project/proposal manager are responsible for the man-hours estimate and the services estimator is responsible for adding the corresponding costs and cost components. The multiplication of the man-hours and the corresponding wage rates and cost build up result in the cost of service (where all cost components that are required have to be included). The cost components that are used in order to estimate the costs of services are shown in Table 6 of chapter 4.2. Some of the cost components are fixed per project (payroll burdens, overhead, office expenses and exchange rate) and the others have to be determined for each project specifically (wage rates, uplift for non-billable costs, escalation, contingency, cost of cash, miscellaneous costs and the amount of man-hours).

The fourth research question, which is also answered in this chapter, is:

4. What are the characteristics of the market for engineering contractors in the Energy and Chemical Industry that have to be taken into account?

The factors that have to be taken into account during the estimating process for engineering contractors in the Energy and Chemical Industry are explained in chapter 4.3 – 4.5. The factors that are important for estimating in this industry (in order of occurrence from chapter 4.3 and 4.4) are presented in Table 10. In chapter 4.4 the most important factor is the location factors, which is the collective noun for all factors that can be attributed to the project location. Due to the versatility of all these factors these are not mentioned here again, see chapter 4.4 for this information.

Table 10: Factors influencing project cost estimating practice from the industry

#	Industry factor
M1	Market condition
M2	Amount of work sharing
M3	Contract type
M4	Contract requirements
M5	Client type and requirements
M6	Scope and scale of work
M7	Project phase
M8	Location factors

The above mentioned factors are not entirely complete, therefore a literature review was performed which resulted in 13 additional factors presented in Table 11.

Table 11: Factors influencing project cost estimating practice from literature

#	Factor
L1	Complexity of design and construction
L2	Method of construction/construction techniques
L3	Tender period and market conditions
L4	Buildability
L5	Scale and scope of construction
L6	Project duration
L7	Site constraints – access and storage limitations
L8	Form of procurement and contractual arrangement
L9	Extent of completion of pre-contract design
L10	Quality of information and flow requirements
L11	Project's team experience of the construction type
L12	Location of the project
L13	Capability of the firm's construction team

There is some overlap between the industry factors and the literature factors, and not all literature factors are relevant for the cost estimation of services. The factors that are relevant can be combined in seven categories of factors: Project information, Contractual arrangements, Location factors, Project team requirements, Market conditions, Complexity and Project duration. The categories exist of one or more factors from the industry or literature and the results are presented in Table 12[4]. The categorization is performed to

[4] Two factors from literature: Method of construction (L2) and Buildability (L4) are not included in the categories because there are not relevant for the decision making during the estimating process. All the other factors are placed in one of the categories.

Table 12: Categories of factors influencing project cost estimating practice

Project information	Contractual arrangements	Location factors	Project team requirements	Market Conditions	Complexity	Project duration
Scope and scale of work (M5)	Contract type (M3)	Location factors (M8)	Amount of work sharing (M4)	Market conditions (M1)	Complexity of design and construction (L1)	Project duration (L6)
Project phases (M7)	Contract requirements (M4)	Site constraints (L7)	Project team experience (L11)	Tender period and market conditions (L3)		
Scale and scope of construction (L5)	Client type and requirements (M5)	Location of the project (L12)	Capability of construction team (L13)			
Extent of completion pre-contract design (L9)	Form of procurement and contractual arrangements (L8)					
Quality of information and flow requirements (L10)						

The findings of research question 3 and 4 are used as input for Figure 12, which is the framework that can be used to structure the factors that have an impact on the cost estimation. The separation is made between qualitative and quantitative factors and the quantitative factors are further separated in factors that are fixed and variable per project.

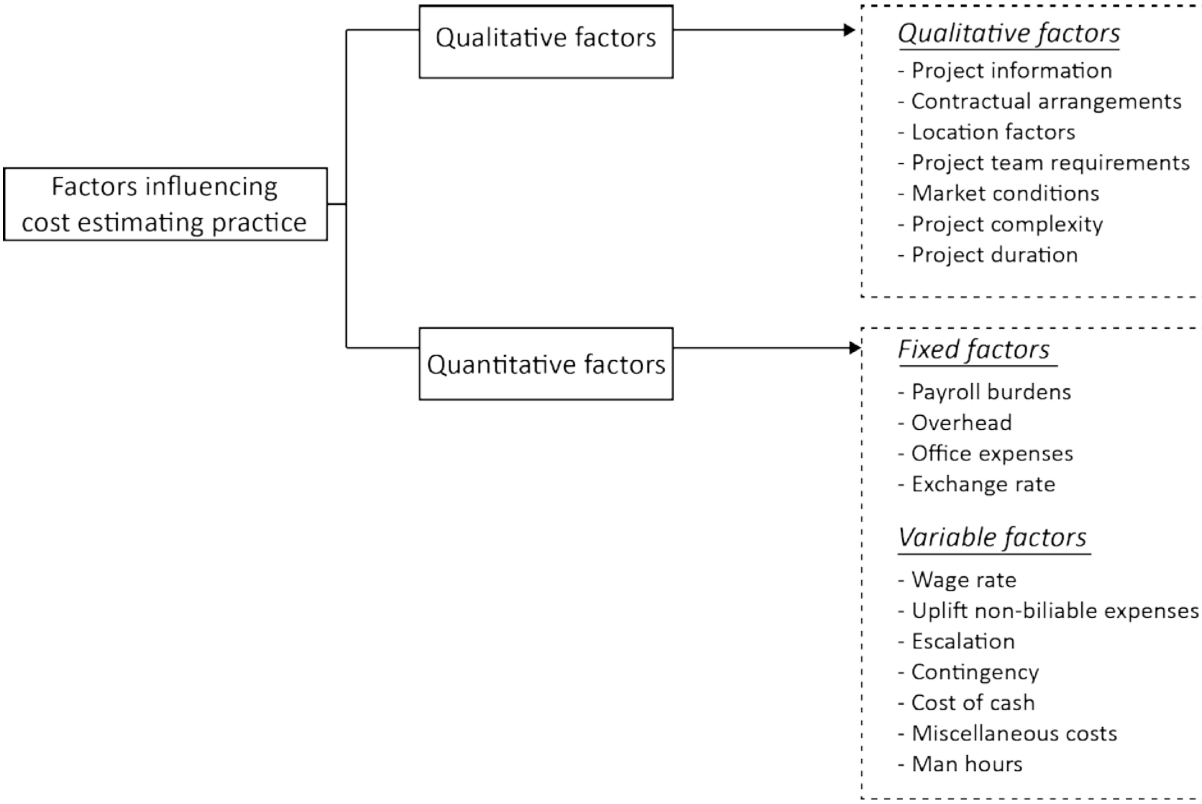


Figure 12: Framework of factors influencing cost estimating method

5. Analysis of cases

This chapter consists of multiple analyses of several projects, which were necessary to answer the following sub question:

5. What causes differences between the estimated costs and the actual costs of services?

First a sensitivity analysis is performed on a project to find out the most important cost drivers that occur in the estimation of the costs of services, the approach and results are explained in chapter 5.1. The most important cost drivers are further analyzed with a study of six projects, where the initial cost estimates are compared with the actual occurred costs in chapter 5.2. The chapter is concluded with the findings (chapter 5.3), where the results of the analyses are used to answer the research question 5.

5.1. Sensitivity Analysis

It is important to find out the critical factors in the estimates of the costs of services, because improvements in the estimation of these factors will have the largest impact on the quality of the costs estimates. By performing a sensitivity analysis it is possible to find these critical factors and also see their impacts on the total services costs.

After performing the sensitivity analysis on one project it already became clear what the dominant factors are in the services costs. However, to validate the results, a second sensitivity analysis is performed on another project. This provided similar results and gave sufficient cause to conclude that these are in fact the critical factors. However, before going into the details of the results it is important to understand how the sensitivity analysis is applied.

Application

In Chapter 4 a distinction is made between qualitative factors and quantitative factors. The sensitivity analysis focuses on the quantitative factors, and more specifically on the quantitative factors that are variable per project. This is chosen because it is not relevant to look at factors that are fixed rates as these cannot be changed in this case. The variable factors, however, are subjected to changes and therefore more interesting to investigate with regard to the influence these factors have on the entire project estimate. These variable quantitative factors, which are also shown in Figure 12 of chapter 4.6, are wage rate, man-hours, uplift for non-billable expenses, escalation, contingency, cost of cash and miscellaneous costs such as business travel and assignment costs.

The sensitivity analysis is a deterministic procedure that explores what-if situations. For this case a deviation of -10% and +10% of the initial value is chosen for each of the variable cost components. The basis for this sensitivity analysis was a historic cost estimate for the services of two Front End Engineering Design (FEED) projects. The FEED-phase entails the conceptual development and basic engineering of the project. For this project, and for most projects in Fluor, there are eighteen disciplines collaborating to realize the project. Table 7 of chapter 4.5 contains all these eighteen disciplines. The estimated man-hours and the wage rates are divided over these disciplines, and used separately as input for the sensitivity analysis. The details of the sensitivity analysis are elaborated in Appendix F. This Appendix contains more information about the inputs and the results of the analysis. The results are also summarized in the next section.

Results

From the sensitivity analysis it was found that the wage rates and the man-hours per discipline had the most impact on the total estimated costs. All other variable cost components had an influence of less than one percent of the total costs. The results call for a deeper analysis of the amount of man-hours and corresponding wage rates, which will be performed in chapter 5.2.

5.2. Comparison of cases

The second step of the analysis concerns the influence of the amount of man-hours and the corresponding wage rates. These factors are further investigated with regard to the accuracy by which they are currently estimated and the potential differences between estimated and actual man-hours and labor costs. This is done by analyzing six Front End Engineering Design (FEED) projects that are executed by Fluor. For the comparability the same project phase is used of the different projects. The FEED analysis phase is particularly chosen, because in this phase the amount and influence of scope changes are supposed to be limited. The purpose of this phase is namely to define the scope in more detail. Another reason for choosing this phase is that the influence of location factors is limited. Most of the work is done in the office location and the impact of the project's location is still limited. The projects have all been performed in recent years (2007-2013) and had more or less the same market conditions during these years.

The amount of projects that could be analyzed was limited to six projects. Construction and engineering projects in the Energy and Chemical industry are characterized by their large scale and high complexity (see chapter 4.1). Engineering contractors, such as Fluor, only perform a limited amount of projects per year. This causes that there is no abundance of historical projects that are performed and that are available for the data analysis.

In Chapter 4 the qualitative factors that have an influence on the estimating practice have been described. By the choice of FEED-projects the factors project information, location factors, market conditions and project duration are more or less the same. However, the projects still differ on the factors contractual arrangements, team requirements and complexity. An overview of the characteristics of these six projects is provided in Table 13.

Table 13: Overview of FEED-projects[5]

Project	Contract type	Industry	Scope definition	Complexity	Scale	Duration
1	Reimbursable	Chemicals	Sufficient	High	Normal	10 months
2	Reimbursable	Chemicals	Moderate	Very high	Large	11 months
3	Reimbursable	Downstream	Poorly defined	Very high	Normal	9 months
4	Reimbursable	Chemicals	Sufficient	Normal	Normal	9 months
5	Reimbursable	Downstream	Sufficient	Normal	Normal	10 months
6	Reimbursable	Chemicals	Sufficient	High	Very large	9 months

The prior estimated labor costs of the six projects and the estimated man-hours are compared with the actual labor costs and actual man-hours. The man-hours and labor costs are compared per discipline of Fluor. The results of this analysis are presented and discussed in detail per project in Appendix G.

[5] The complexity and scale are determined based on comparison of the project's scope and discussions with representatives from Fluor.

In Table 14 and Table 15 the overview of the analysis of the six FEED-projects is provided of the man-hours and labor costs respectively. The data has been corrected for large scope changes that were approved by the client. These large scope changes resulted in incremental awards and are added to the estimates. However, there have been other scope changes and not all these scope changes resulted in an incremental award. Furthermore, additional project specific information explains the reason for the overrun of hours of a certain discipline, this specific information per project is further explained in Appendix G.

The first column of the tables consists of the eighteen disciplines of Fluor. Subtotals have been created for the engineering, procurement and contracting and project support disciplines. The other columns consist of the six projects that are analyzed. The resulting accuracy of the man-hours is shown in Table 14 and the accuracy of the labor costs in Table 15. The difference between the actual and estimated costs/man-hours is divided by the estimated costs/man-hours. The resulting value is presented in the tables. The (sub) totals are calculated in the same way by using the estimated and actual totals of certain disciplines.

Table 14: Comparison man-hours projects

Man-hours	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Engineering Discipline A	8%	31%	114%	-3%	11%	-10%
Engineering Discipline B	-14%	1%	-23%	19%	75%	28%
Engineering Discipline C	13%	32%	99%	-6%	16%	-35%
Engineering Discipline D	7%	205%	16%	74%	146%	77%
Engineering Discipline E	-10%	13%	80%	3%	6%	-13%
Engineering Discipline F	59%	-28%	N/A	-13%	-40%	24%
Subtotal engineering	**1%**	**24%**	**70%**	**5%**	**24%**	**-3%**
P&C Discipline A	25%	-14%	1%	-16%	10%	103%
P&C Discipline B	N/A	21%	179%	-75%	68%	567%
Subtotal P&C	**25%**	**-1%**	**71%**	**-28%**	**27%**	**180%**
Project support Discipline A	-2%	56%	351%	97%	25%	121%
Project support Discipline B	N/A	-32%	-51%	-95%	N/A	-9%
Project support Discipline C	-20%	45%	87%	6%	137%	-3%
Project support Discipline D	15%	8%	60%	-44%	59%	-6%
Project support Discipline E	-65%	-35%	-81%	21%	296%	36%
Project support Discipline F	-88%	-56%	44%	24%	38%	-30%
Project support Discipline G	0%	-51%	48%	0%	112%	34%
Project support Discipline H	N/A	68%	-73%	-79%	179%	29%
Project support Discipline I	N/A	15%	1189%	-3%	40%	7%
Project support Discipline J	-99%	50%	48%	-8%	-29%	260%
Subtotal project support	**15%**	**17%**	**82%**	**-10%**	**74%**	**23%**
Total man-hour accuracy	**4%**	**20%**	**74%**	**-1%**	**36%**	**12%**

Table 15: Comparison labor costs projects

Labor costs	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Engineering Discipline A	-1%	23%	119%	-2%	0%	-9%
Engineering Discipline B	-23%	31%	-15%	40%	69%	39%
Engineering Discipline C	29%	52%	199%	18%	23%	7%
Engineering Discipline D	-9%	237%	152%	276%	142%	73%
Engineering Discipline E	-3%	31%	142%	20%	57%	-12%
Engineering Discipline F	63%	-5%	N/A	18%	-44%	49%
Subtotal engineering	**-1%**	**38%**	**104%**	**32%**	**27%**	**11%**
P&C Discipline A	10%	28%	-19%	30%	3%	133%
P&C Discipline B	N/A	6%	122%	-52%	61%	474%
Subtotal P&C	**10%**	**18%**	**38%**	**12%**	**22%**	**223%**
Project support Discipline A	-5%	58%	213%	81%	-50%	197%
Project support Discipline B	N/A	-26%	-100%	-95%	N/A	10%
Project support Discipline C	-18%	61%	71%	7%	172%	-18%
Project support Discipline D	21%	22%	131%	-43%	55%	28%
Project support Discipline E	-49%	-40%	-83%	37%	274%	91%
Project support Discipline F	-79%	-37%	-19%	13%	17%	-21%
Project support Discipline G	-2%	-49%	111%	-3%	75%	79%
Project support Discipline H	N/A	57%	-71%	-76%	125%	48%
Project support Discipline I	N/A	16%	899%	8%	13%	23%
Project support Discipline J	-99%	38%	178%	-12%	-77%	226%
Subtotal project support	**34%**	**27%**	**32%**	**-7%**	**-6%**	**42%**
Total labor cost accuracy	**5%**	**33%**	**76%**	**20%**	**14%**	**31%**

For the objective analysis of these projects a qualification is given to the accuracy from very high to very low accuracy according to Table 16.

Table 16: Qualification of the accuracy

Accuracy	Qualification
<5%	Very high
<20%	High
<50%	Medium
<100%	Low
>100%	Very low

The main observations and conclusions about this analysis are:

- The total man-hours (last row Table 14) of two projects are estimated with very high accuracy, one project with high accuracy, one project with medium accuracy and one project with low accuracy.
- The total labor costs (last row Table 15) of one project is estimated with very high accuracy, two with high accuracy, two with medium accuracy and one with low accuracy.

- In 16 of the total 18 disciplines there exist both over- and under-runs of the man-hours (positive and negative values). This shows that the results scatter in both directions: it is not that clear that for example the hours of the process department always overrun.
- In 5 of the 6 projects the increase per man-hour of the labor costs is more than the estimated man-hour cost (the last rows of Table 14 and Table 15 are compared). Only in project 5 the total labor cost decreased with respect to the increase of the man-hours.

With the project specific information that is explained in Appendix G the following conclusions can also be drawn:

- Not all data points that occurred were estimated e.g. project information management in project 1 is not estimated. That there are hours and labor costs for this discipline is definitely the result of a change of scope. The exceptions for this are the engineering management discipline, the engineering management hours and costs may be estimated under project management and HSE engineering which is sometimes included in the process engineering discipline.
- If the scope of a project is poorly defined, which was the case in project 3, then it can be expected that the estimate has a low accuracy. However, this does not mean that the accuracy of the average wage rate is low as well. In project 3 the labor costs per unit man-hour was estimated very accurate (74% overrun of the man-hours and 76% overrun of the labor costs).
- Reasons that are mentioned for the differences between the estimated and actual man-hours are a poorly defined scope before the estimate was made (project 3), 'small' scope changes (project 2, 5 and 6) and the limited time that was available to conduct the estimate (see Appendix G).
- There could have been strategic decisions to reduce the man-hours or labor costs estimates in order to win the tender (see Appendix G).

The results of this analysis are further analyzed and visualized in Figure 13, where the accuracy of the engineering disciplines' man-hours are plotted against the accuracy of the engineering disciplines' wage rates. The source of one of the data points (Engineering discipline D project 4) is indicated for easy understanding.

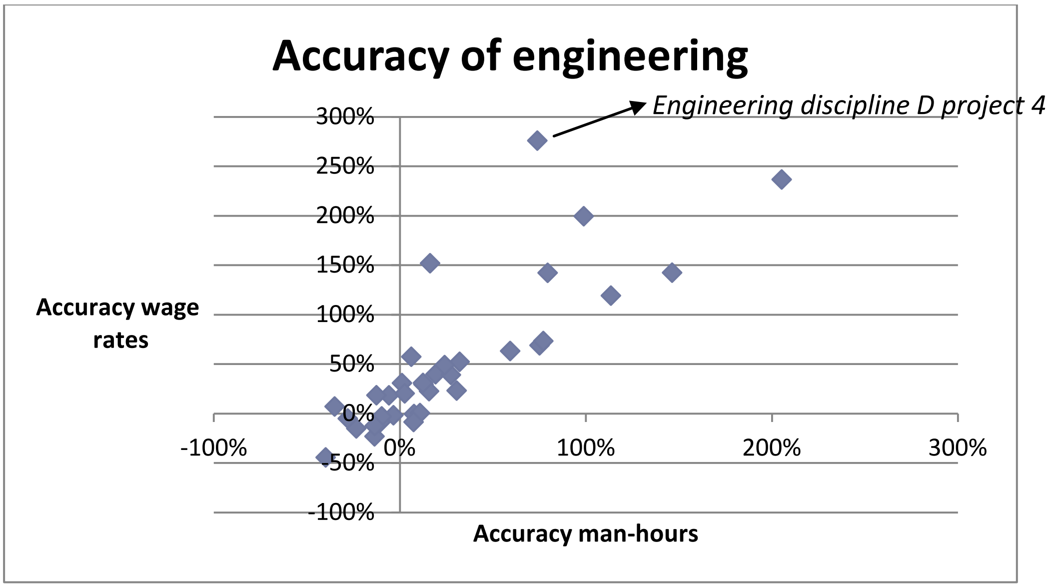


Figure 13: Accuracy of man-hours and wage rates of engineering disciplines

It can be seen that the majority of the data points is estimated with at least medium accuracy (<50%) and that the other data points show some extreme underestimations (which might come from scope changes).

In literature there are some theories that explain why it is not likely that projects remain within the scheduled amount of man-hours, see Text box 4.

Text box 4: Explanation of increases in man-hours

Man-hours

When it is asked to estimate the duration of a future task or event it is often underestimated (Roy et al., 2005). The actual time of the activity is usually more than what was planned for. The Parkinson law and the student syndrome are two mechanisms that explain this.

- The Parkinson law holds that once a fixed estimate is made, the work expands to fill the available time and the actual task duration has little or no chance of being realized in time much less than its planned duration (Khamoosi & Cioffi, 2013).
- The student syndrome indicates the tendency to wait until the end to finish a task. Many people wait until the last possible moment before a deadline to fully commit to the task. This causes that contingency used in the estimate may be wasted.

The accuracy of the man-hour estimates of the project support disciplines (also including the procurement and contracting) are plotted against the accuracy of the wage rates in Figure 14. The source of one of the data points is again shown (Project support discipline project 3).

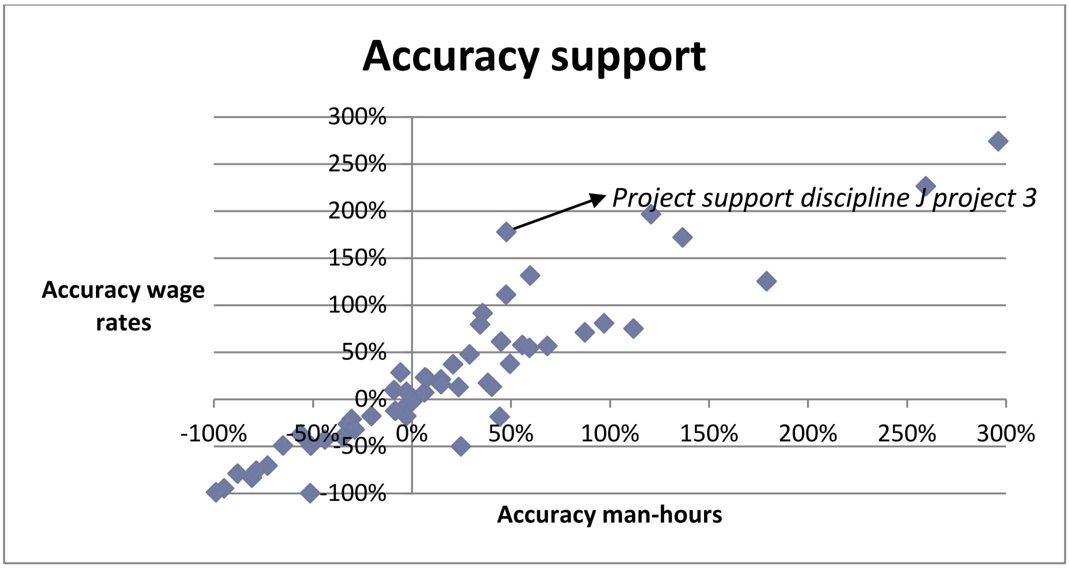


Figure 14: Accuracy of man-hours and wage rates of support disciplines

The data points for the support disciplines are more scattered compared to the engineering data, which means that the accuracy of measuring the project support services costs is lower. This may have been expected, because by making estimates for the man-hours the engineering disciplines are often asked to make estimates, while for a lot of the project support disciplines the estimates are made based upon a benchmark (certain percentage or benchmark of the total hours known from historical data).

Also, in the project support accuracy figure the data scatters in both directions (cost under runs and overruns), while for the engineering the outlying data point of the services costs were mostly cost overruns.

Another observation is that although the data points of the project support disciplines are more scattered, the accuracy of estimating the wage rate per man-hours (variance from the imaginary diagonal through the figure) is better. To prove this, the correlation between the man-hours' subtotals and totals mutually as well as between the man-hours and the labor costs are calculated in Table 17 and Table 18. The correlation between the accuracy of the engineering, support, procurement and contracting and the total hours is calculated in Table 17. For this correlation calculation the (sub) total man-hours of the projects are used[6], because the data sets must be of the same size (6 data points).

Table 17: Correlation coefficients man-hours

Data set 1	Data set 2	Correlation coefficient
Total	Engineering	0.953
Total	Project support	0.910
Total	Procurement and contracting	0.185
Engineering	Project support	0.771

The increase or decrease of the total amount of man-hours in a project is most dependent on the engineering hours (largest correlation), but also the project support hours have a large influence. Also there is a correlation between the increase in engineering hours and the increase in project support hours.

The correlation between the engineering, p&c, project support and total hours with the corresponding labor costs is shown in Table 18. The correlation is taken over the individual values of the disciplines in the group and not over the subtotals (each data point of Table 14 and Table 15 are compared). This gives a more reliable result.

Table 18: Correlation between man-hours and labor costs

Category	Correlation coefficient
Engineering	0.820
Procurement and contracting	0.984
Project support	0.965
Total	0.943

There is a correlation between the in/decrease in man-hours and that of the labor costs. Therefore, increases in man-hours will also result in increases in labor costs. This correlation is weakest in the engineering discipline, which could also be observed by comparing Figure 13 and Figure 14.

[6] The (sub) totals refer to the sub totals and total of Table 14. For example in the first row of Table 17 the total accuracy of each of the six projects are plotted against the subtotal accuracy of the engineering disciplines.

5.3. Findings

Returning to this chapter's sub question, it can be said that there are numerous reasons for changes between the estimated and actual costs. The sensitivity analysis showed that the man-hours and the wage rates are the largest contributors to the total cost of services. For this reason, also changes in these factors are the largest cause for changes between estimated and actual costs. The analysis of the six FEED-projects showed that there can be multiple reasons for changes between the estimated and actual costs such as changes in scope, poorly defined scope definition before estimating, client influence/decisions, management decision making during the execution and work shift between offices. Such changes are extremely difficult to predict, and therefore also difficult to use in the cost estimates.

6. Methodology development

In this chapter a cost estimating model is developed that could be an addition to the current estimating practice. The information retrieved in the previous chapters is used as input for this model. The sub question that will be answered in the course of this chapter is:

6. Could the cost estimating methodology in the current practice be improved by using other estimating methods?

The estimating method that is used to develop the cost estimating model is probabilistic estimating. Why this method is the most appropriate is explained in chapter 6.1. The requirements for developing a probabilistic cost estimating model are explained in chapter 6.2. The development of the probability distributions for the wage rates and the man-hours are further elaborated in chapters 6.3 and 6.4. The probabilistic cost model is further explained with regard to the inputs, the model itself and the outputs in chapter 6.5. The chapter is concluded with the answering of the sub question in section 6.6.

6.1. Choice for improved estimating method

The literature study on estimating methods in chapter 3 provided three deterministic methods and the probabilistic method. For the development of the methodology it is most interesting to use the probabilistic estimating method, because it is the most innovative method, which is currently not used for the estimation of engineering costs in Fluor. Furthermore, it provides more information about the uncertainties that are associated with the estimation of the man-hours and its corresponding wage rates. As could be seen from Chapter 5, the difference between the estimated man-hours and the actual man-hours can be large and the uncertainties in this are currently estimated in the man-hour contingency. By using probabilistic distributions instead of the man-hour contingency, the impact of the uncertainties becomes clearer and may lead to better information for the decision making of management.

It was also indicated in the literature study (chapter 3.3) that the disadvantage of the probabilistic method is that it is an additional analysis and requires additional effort to use. This must be somehow compensated, because this is directly in contradiction with the research goal, which is to take into account the effort that is required for the estimating. Therefore, the benefits of using the probabilistic method should compensate for the additional effort. In a way the application of the probabilistic method does exactly this.

The current estimating practice is that the man-hours are split up in disciplines, and further in labor grades, and if required even in named positions (see chapter 4.2). This breakdown of the hours requires a lot of effort and is subjected to changes. By using the distribution of wage rates within the disciplines as input for the estimate it is no longer necessary to breakdown the hours. This could compensate for the additional effort that the probabilistic method takes. Obviously, the application of the distribution of wage rates by disciplines should first be verified and validated, before it can be used in practice.

6.2. Requirements

The requirements for the probabilistic estimating method as indicated in Chapter 3.3 are:

- Software to run Monte-Carlo simulations
- Probability distributions of cost components based on historical data or experience

The software @Risk is available in Fluor and can be used to run the Monte-Carlo simulations. The probability distributions of cost components are not yet available and should be established based on historical data or experience. Primarily it is most interesting to look at the distributions of the man-hours and wage rates per disciplines as these proved to be the factors that have the most impact on the total costs, as explained in the Sensitivity analysis of Chapter 5.

6.3. Probability distribution wage rates

For the development of the probability distributions of the wage rates for each of the disciplines it is necessary to have salary data per discipline. This information was made available by Fluor, but is not presented in this report due to confidentiality reasons; it contains wage rates by discipline and by labor grade. By using the amount of persons in the labor grade relative to the total amount of persons in the discipline it is possible to establish a probability of a certain wage rate within the discipline. The probability distribution can be established by fitting a probability distribution to the series of data. This is one of the functions that are included in the @Risk software. The results of the distribution fitting are presented in Appendix H. This appendix also contains the detailed information of how the distribution fitting is performed, this will be explained here shortly as well.

Initially it is tried to fit a continuous probability distribution function, because the uncertain cost elements are continuous in reality and because there are multiple well-known continuous probability density functions with adequate characteristics (see 0) (Kujawski et al., 2004).

It can be seen in Appendix H that not every distribution fits perfectly to the data. Therefore, if these inputs are used for developing the probabilistic cost model, the results of this model will also not be as accurate as it could be. The data fitting is dependent on the way in which the salary data is distributed. For example some data sets had two or more peaks in the probability density graph. None of the probability density functions have the ability to fit on two or more peaks. However, there are also distribution fits that are almost perfect. In Table 19 the goodness of fit is ranked from very good (++) to very bad (--). The rating is based on the visual interpretation of the probability density function and the cumulative density function from Appendix H.

For the distributions that are rated sufficient (+/-), good (+) and very good (++) the distribution fit is used as input for the probabilistic estimating model. For the other four disciplines, for which the goodness of fit was very bad, it has been tried to divide the current distribution in two or more smaller distributions. The results of this proved to be even worse and therefore, another approach was tried. This approached used the raw salary data to create discrete probability distributions. These discrete distributions are developed by inputting the data points of the salary data with the corresponding probabilities. The discrete distributions are shown in Appendix I, for the four disciplines for which the continuous fit was not an option, and used as input for the probabilistic model.

Table 19: Goodness of fit wage rate distributions

Discipline	Distribution	Goodness of fit
Engineering Discipline A	Beta	--
Engineering Discipline B	Beta	++
Engineering Discipline C	Triangular	+/-
Engineering Discipline D	Triangular	+/-
Engineering Discipline E	Triangular	+/-
Engineering Discipline F	Triangular	+/-
P&C Discipline A	Triangular	+
P&C Discipline B	Beta	+
Project support Discipline A	Beta	++
Project support Discipline B	Beta	--
Project support Discipline C	Uniform	+/-
Project support Discipline D	Triangular	++
Project support Discipline F	Beta	+
Project support Discipline G	Beta	--
Project support Discipline H	Lognormal	--
Project support Discipline I	Triangular	+
Project support Discipline J	Beta	+

The discrete functions are used under the assumption that the discrete probability function is more accurate than a bad fitted continuous distribution function. It takes more time to input the discrete probability functions in comparison with the continuous probability functions, and also the inputting of these functions is more error sensitive. Those are the reasons why it is tried to make a good continuous distribution fit initially.

6.4. Probability distribution man-hours

There were two options to establish the probability distributions for the man-hours: based on experience or based on (historical) data. The first option was to submit a survey by the senior personnel of the disciplines that are responsible for the man-hour estimates and let them indicate the range they think the average man-hour estimate has. A triangular distribution can be used to simulate the probability distribution in that case. However, this method is subjective and therefore less appropriate to use in comparison with the second option.

The second option is to use historical data of projects as input and make a distribution fit on this data. The data of the six projects that were analyzed in Chapter 5 can be used to fit the probability distribution on. It is important to mention that the data set of six projects is extremely small and more projects are necessary for an improved and more reliable probability distribution.

Distribution fitting

The small amount of data points that is generated with the comparison of cases described in chapter 5.2 and Appendix G is used to make a distribution fit on. It is chosen to develop two separate distribution fits, one on the engineering man-hours and one on the project support man-hours. Making a specific distribution fit for each discipline is not feasible, because there are only six or less data points available (one for each project). These data sets are too small to create distribution fits. Therefore, the approach with two distribution fits (engineering and project support) is chosen.

Fitting the engineering man-hours

The distribution fitting of the engineering man-hours is performed with the software @Risk, which is also used to develop the final probabilistic cost estimating model. The data, on which the fitting is based comes from the analysis of the six FEED-projects and is shown in Table 20.

Table 20: Differences between estimated and actual engineering man-hours

Man-hours	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
Engineering Discipline A	8%	31%	114%	-3%	11%	-10%
Engineering Discipline B	-14%	1%	-23%	19%	75%	28%
Engineering Discipline C	13%	32%	99%	-6%	16%	-35%
Engineering Discipline D	7%	205%	16%	74%	146%	77%
Engineering Discipline E	-10%	13%	80%	3%	6%	-13%
Engineering Discipline F	59%	-28%	N/A	-13%	-40%	24%

The best fit on the engineering man-hour data is a lognormal distribution. Finding the best fit is based on the Chi-Square, the Anderson-Darling and the Kolmogorov-Smirnov tests, three statistical tests are appropriate for determining the goodness of fit (Dekking et al., 2005). Without going into the details of the mathematics of these tests, the results are presented in Table 21. The lognormal distribution is the best fit on all three statistical tests.

Table 21: Best ranking distribution fitting engineering man-hours

Distribution	Chi-Square	Anderson-Darling	Kolmogorov-Smirnov
Lognormal	3.2	0.3026	0.0957
Weibull	4.4	0.4770	0.1203
Beta	10.4	+Infinity	0.1742
Triangular	12.0	+Infinity	0.2610
Normal	15.2	1.6404	0.2075
Uniform	31.6	10.6188	0.4376

The distribution fit of the lognormal distribution is shown in Figure 15 (PDF) and Figure 16 (CDF). The x-axis represents the percentage under run or overrun of the man-hours, e.g. 0.5 represents a 50% overrun of the man-hours. On top of the graph the percentages increase/decrease are shown. The upper bar represents the percentage based on the input data and the lower bar represents the percentages of the lognormal distribution. The lognormal distribution is used for the probabilistic model and shown in red in the graph. The probability that a project remains within the amount of engineering man-hours that are assigned is 35.1%. The median of the distribution is on a 14.5% overrun, and the mean or average is 27.5% (shown in the legend of the figure).

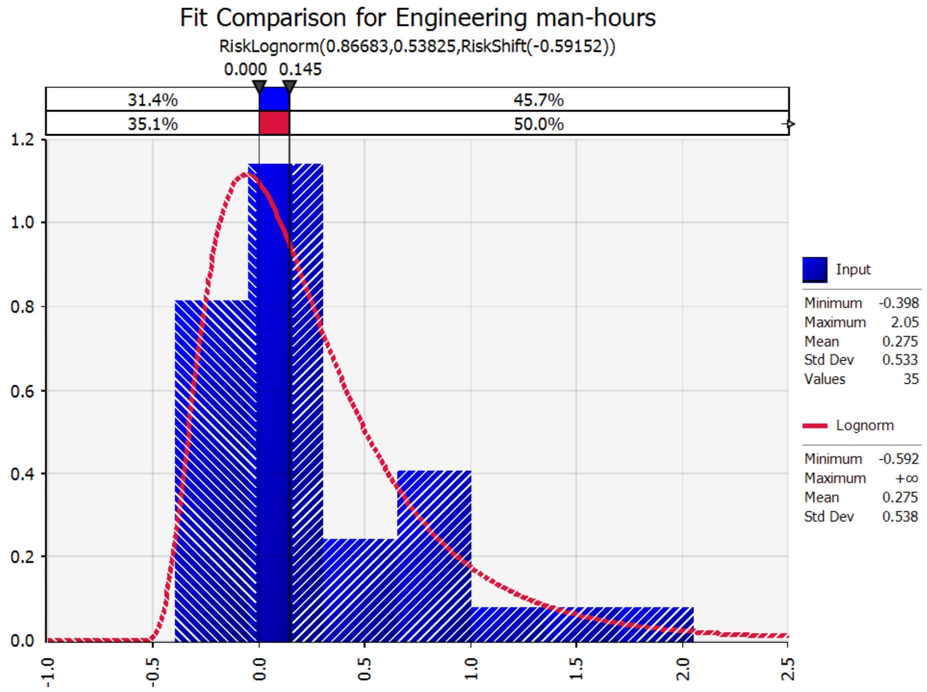


Figure 15: Best probability distribution fit engineering man-hours

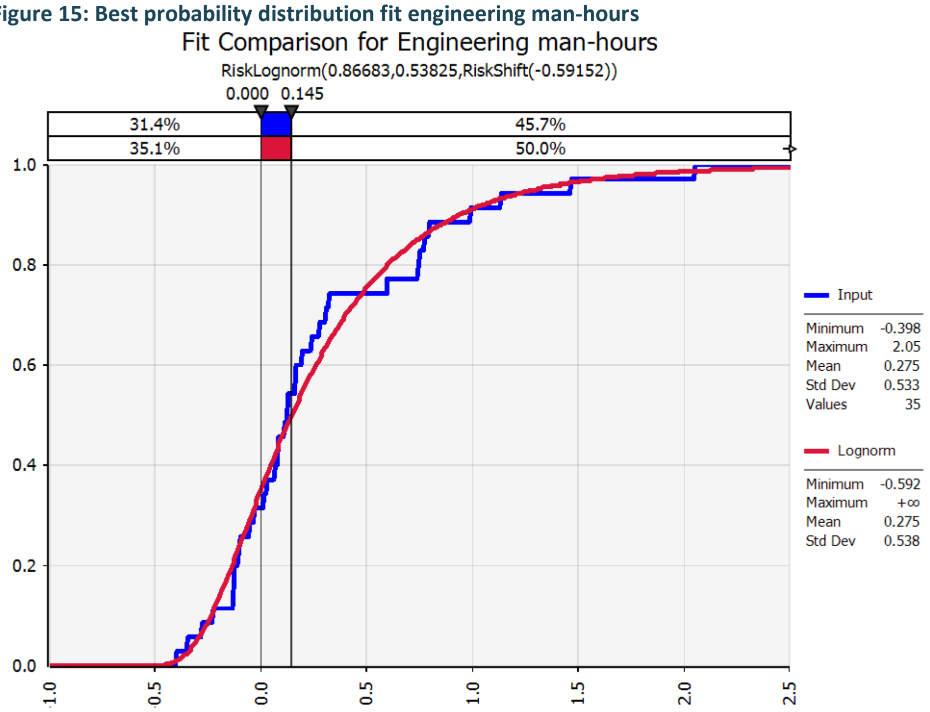


Figure 16: Best fit engineering man-hours cumulative density function

Fitting the project support man-hours

The data that is used for the distribution fitting of the project support man-hours, had to be slightly adjusted in order to create a good fit. The source of the data is the same as was used with the fitting of the engineering man-hours, namely the analysis of the six projects, described in chapter 5.2. However, in this data there are some extreme values that do not reflect the reality. An overrun of the man-hours with 1189% is not very likely to happen, just as an under run of -99%, which is almost impossible. In Appendix G, it is explained that these extreme values result from changes in the scope. To create a distribution fit that better reflects the reality, it is chosen to remove the three largest overruns and the three largest under runs from the data set. The six data points that are removed from the data set are indicated in red in Table 22.

Table 22: Differences between estimated and actual project support man-hours

Man-hours	Project 1	Project 2	Project 3	Project 4	Project 5	Project 6
P&C Discipline A	25%	-14%	1%	-16%	10%	103%
P&C Discipline B	N/A	21%	179%	-75%	68%	567%
Project support Discipline A	-2%	56%	351%	97%	25%	121%
Project support Discipline B	N/A	-32%	-51%	-95%	N/A	-9%
Project support Discipline C	-20%	45%	87%	6%	137%	-3%
Project support Discipline D	15%	8%	60%	-44%	59%	-6%
Project support Discipline E	-65%	-35%	-81%	21%	296%	36%
Project support Discipline F	-88%	-56%	44%	24%	38%	-30%
Project support Discipline G	0%	-51%	48%	0%	112%	34%
Project support Discipline H	N/A	68%	-73%	-79%	179%	29%
Project support Discipline I	N/A	15%	1189%	-3%	40%	7%
Project support Discipline J	-99%	50%	48%	-8%	-29%	260%

On the data set presented in Table 22 the best fit is created based on the Chi-Square, the Anderson-Darling and the Kolmogorov-Smirnov goodness of fit tests. The best fit is a lognormal function on all three goodness of fit tests, and the results of the fitting are presented in Table 23.

Table 23: Best ranking distribution fitting project support man-hours

Distribution	Chi-Square	Anderson-Darling	Kolmogorov-Smirnov
Lognormal	6.4	0.4256	0.0844
Weibull	7.6	0.7414	0.1047
Normal	8.8	1.5609	0.1381
Beta	15.9	1.7468	0.1532
Triangular	25.3	+Infinity	0.2170
Uniform	48.9	17.2078	0.4369

The developed lognormal distribution for the project support man-hours is shown in Figure 17 (PDF) and Figure 18 (CDF). The figures can be interpreted in the same way as Figure 15 and Figure 16. Based on the developed lognormal distribution the probability of remaining within the assigned amount of man-hours for a project support discipline is 40.6%. The median of the distribution is on 14.7% and the average is 27.6%.

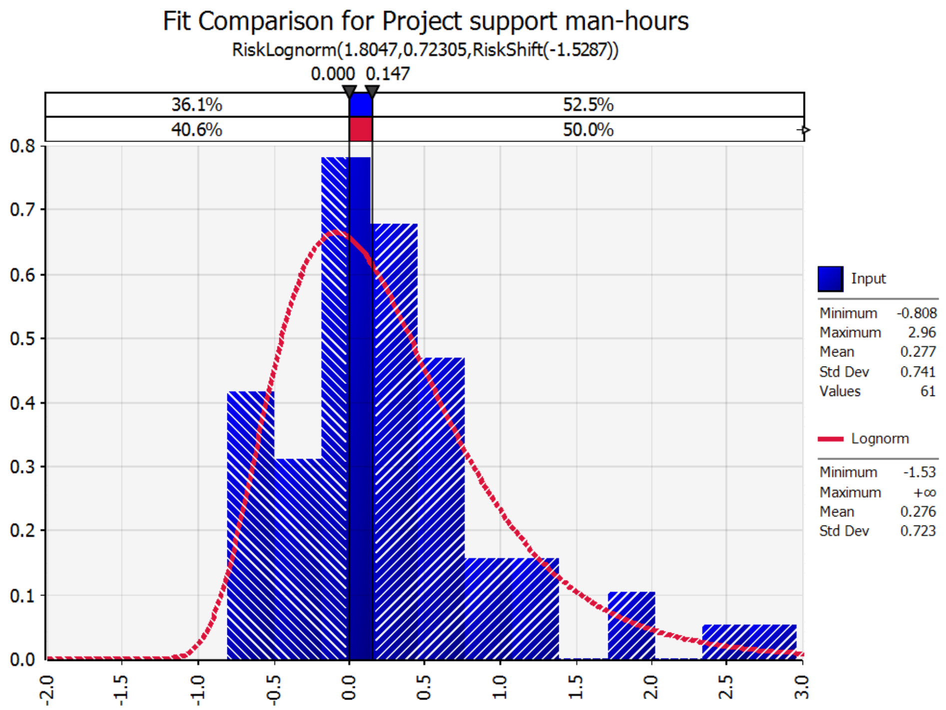


Figure 17: Best probability distribution fit project support man-hours

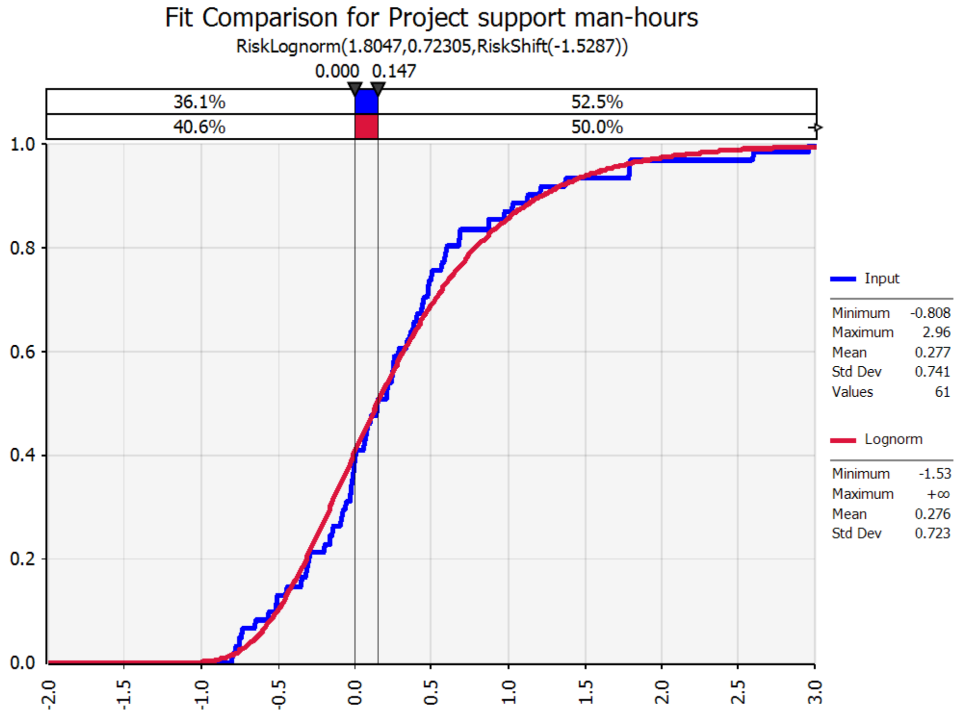


Figure 18: Best fit project support man-hours cumulative density function

Comparing the engineering and project-support distributions

Comparing the distribution of the engineering and project support man-hours the largest difference is in the precision. The standard deviation of the project support distribution is larger (74.1% for the project support distribution and 53.3% for the engineering distribution). The average and the median of the distributions are almost equal.

6.5. Probabilistic cost estimating model development

For the cost estimation of services costs a probabilistic cost model is developed. It requires the software @Risk, because this software enables the model to run Monte Carlo simulations. @Risk is an extension of Microsoft excel, which is the basic format of the model. The model exists of three main spreadsheets, one to enter the inputs, one for the calculations and distributions and one for the outputs. Furthermore, there are some additional sheets added for the backup of the data on which the distribution fitting is based. In this section, first the input sheet is explained and the possibilities that estimators have with regard to entering the input. Afterwards the probabilistic model itself is explained as well as the settings that can be used to run the Monte Carlo simulation. Lastly, the output sheet and the additional possibilities to view the probabilistic outputs are discussed.

Input

In the input sheet the option is provided to use 1) Probabilistic simulation of the wage rates and 2) Probabilistic simulation of the man-hours. Both options can be selected independently. If the probabilistic simulation of the wage rates is selected it will use the before mentioned probabilistic wage rates for each of the disciplines (chapter 6.3). If it is unchecked, the average rate of each of the disciplines will be used.

Wage rates

As explained in chapter 4 the factors project information, project complexity and project team requirements are important for the composition of the project team. For more complex projects a more experienced team is required which will result in a higher average wage rate. Furthermore, the FEED phase often requires a more experienced team than the EPC phase. It is important to compensate for such considerations and in the model the option to increase or decrease the used wage rates (which can be the probability distribution or the average per discipline) is included. This can be done by using a percentage increase or decrease. This value is very specific for each project and therefore there is no quantitative guideline for this included in this research. The complexity, phase, scale, scope, amount of work sharing of the project are the main basis for this decision[7] and an experienced estimator should be able to make a substantiated assumption for the percentage increase/decrease.

Man-hours

For the man-hours it is also possible to use the probabilistic simulation. By default, if the probabilistic option is selected, the model will use the probability distribution of engineering for the engineering disciplines and the project support distribution for the support disciplines. There is also the possibility to overwrite these values. The estimator has the possibility to define the most likely value (the one deterministically calculated) the pessimistic value and the optimistic value for the amount of man-hours for each discipline. These values can be inputted either absolute or relative (as a percentage lower or higher than the most likely value). From this information a triangular distribution will be created. Using this second option, where the pessimistic, most likely and optimistic value have to be defined, is advised. This is more appropriate than using the default

[7] All factors from Table 12: Categories of factors influencing project cost estimating practice of chapter 4 can in some way influence the decision for the in/decrease of the wage rate. However, the mentioned factors are the most important ones.

distribution that is based on the data of the six FEED-projects. Using project specific information to determine the three input values will be more accurate than using a general distribution of engineering and project support disciplines.

To give an idea of what the input sheet looks like, it is attached in Appendix J. Please note that the data that is entered in this input sheet is fictional and made up to give an example how the data could be entered.

Probabilistic cost model

Once the input sheet is filled, the probabilistic cost model is built up with the information of the input sheets and the probability distributions of the wage rates and man-hours if selected. The built up of the costs is done separately for each discipline. Thereby it is indicated which shape the wage rate distribution has. If a probability distribution is entered in a cell, it shows the expected value of this distribution in this cell. In the column to the right of the cells that contain the probability distribution of the wage rate, the average wage rate of the department is shown. This ensures that the estimator can quickly observe the difference between the expected value of the probability distributions and the deterministic value. The same has been done in the column next to the probabilistic man-hour distributions per discipline; here the deterministic (most likely) man-hour estimates are shown.

The probabilistic cost model further builds up the wage rates with the cost components entered in the input sheet. The resulting total rate, where all components are included is multiplied by the man-hours. The total sum of this multiplication for all disciplines is the total costs of services.

The Monte Carlo simulation can be run by entering the amount of iterations (5000 by default[8]) and by clicking the start simulation button. This will generate the probabilistic outputs discussed in the next section.

Outputs

The whole point of the Monte Carlo simulation is to see the probability distributions of selected outputs, given the distributions of uncertain inputs. The outputs that are selected for this are:

- Total of the man-hours (-)
- Bare labor costs (€)
- Average bare labor cost per hour (€/h)
- Home office labor costs (including increase on average, TOWP, payroll burdens, overhead and additional agency costs) (€)
- Grand total costs of services (Home office labor costs plus all expenses, non-billable labor costs, escalation, contingency, subcontracts, cost of cash etc.) (€)
- Average total costs of services per hour (€/h)

These costs are the most interesting components to analyze with regard to the uncertainties that are included in the probability distributions of the inputs. The information that is gathered for these outputs are probability distributions, cumulative probability distributions, regression and correlation coefficients, and statistical information such as minimum, maximum, mean, standard deviation,

[8] Using 5000 iterations is more than sufficient to retrieve a reliable simulation.

variance, skewness and median. Also scatter plots can be created and a scenario analysis is automatically generated. Management can use this generated information to make substantiated decisions for the eventual bidding prices.

6.6. Findings

The probability distributions of the inputs and the development of the probabilistic cost estimating model were necessary to answer the following sub question:

6. Could the cost estimating methodology in the current practice be improved by using other estimating methods?

The probabilistic cost model that is described in this chapter has the potential to improve the current estimating method. The main benefits that are expected are:

- The required effort for using the model is less compared to the current method, where the strategy of using named positions is still used.
- The existing uncertainties in the estimates are better simulated and quantified in probability distributions. It is possible to choose the desired confidence level for the estimate, thereby fixing the reliability of the cost estimate.
- The outputs of the probabilistic cost model contain much more information compared to deterministic calculated outputs. It provides insight in
    - The probability of overrunning or under running the total assigned man-hours
    - The probability of overrunning or under running a particular cost
    - The complete range of outcomes and the standard deviation of the outputs
    - The amount of uncertainties in the services costs

The following chapter continues with the verification and validation of the probabilistic cost estimating model and the potential benefits that are mentioned above will be tested.

7. Results

In this chapter it is tested whether the probabilistic cost model that is described in the previous chapter is an improvement compared to the current practice. The sub question that is answered in this chapter is:

7. Is the new developed estimating method an improvement with respect to the current practice of engineering contractors in terms of quality and required effort to conduct the estimate?

The probabilistic model is first verified and then validate. The verification and the validation of the results of the simulation are two separate things. The validation is defined by the Project Management Institute (2004) as: 'the technique of evaluating a component or product during or at the end of a phase or project to ensure it complies with the specified requirements'.

Verification can be defined as: 'the technique of evaluating a component or product at the end of a phase or project to assure or confirm it satisfies the conditions imposed'(Project Management Institute, 2004). Boehm (1984) established the more informal definitions that can be used for the verification and validation of software as:

Verification: "Am I building the product right?"

Validation: "Am I building the right product?"

First, the verification of the probabilistic cost model is performed in chapter 7.1. Afterwards, the validation of this model is done by testing the model on a project that is recently performed by Fluor, further explained in chapter 7.2. In the findings of the chapter (7.3) the verification and validation are reflected with regard to the improvements in the quality and required effort to conduct the estimate. The model will be tested with the criteria important for the quality of the estimate established in the chapter 2.4. These criteria are accuracy (precision and trueness), required effort to conduct the estimate, reliability, timeliness and reproducibility.

7.1. Verification

The verification of the probabilistic cost estimating model considers the checking if the model is build right and consists of verifying the formulas, cost build-up, internal links and probability distributions in the model. It is important that all these parts are correct and no errors/faults are in the system.

Verification formulas, cost build up and internal links

The formulas are verified by entering the cost estimate of one of the projects that has been analyzed in chapter 5.2. All cost components and man-hours are adopted from the estimate and the option for deterministic calculation was selected. This made it possible to verify the model's formulas and cost build-up with the initially made cost estimate its formulas and cost build-up. The results were almost consistent. There existed some expected changes due to the differences in wage rates (the model uses the latest wage rates, while the wage rates at the time the initial cost estimate was made were different). Furthermore, no errors occurred and the model was verified with regard to the formulas and cost build up.

By using the model it was also possible to verify the working of the internal links in the excel sheets (links between the input, probabilistic cost model and output sheets). These also worked correctly and no problems are found.

Verification wage rate probability distributions

The probability distributions of the wage rates that are used in the cost model still have to be verified. Table 19 of chapter 6.3 lists which of the distributions are considered sufficient. For the insufficient distribution fits discrete distributions are used in the probabilistic estimating model. The probability distributions (continuous and discrete) have been attached as appendix (Appendix H and Appendix I) for visual verification. Also, it has been discussed with the services estimators in Fluor Haarlem if the probability distributions of the wage rates made sense. They confirmed for example the large group of junior engineers in the process department and the shape of the distribution of the project management department, which could be expected. They agreed to use continuous distributions if possible and discrete distributions if not. Furthermore, it is always possible to verify the 50% value of the probability distribution with the numerical average of the department. An additional check is added in the probabilistic model to benchmark the difference in the median of the probability distribution and the average of a department. This difference is indicated as a percentage increase or decrease with respect to the department average in Table 24.

Table 24: Deviations with department averages

Department	Difference median and department average
Engineering Discipline A	-2%
Engineering Discipline B	3%
Engineering Discipline C	2%
Engineering Discipline D	3%
Engineering Discipline E	1%
Engineering Discipline F	-5%
P&C Discipline A	4%
P&C Discipline B	-1%
Project support Discipline A	-5%
Project support Discipline B	-8%
Project support Discipline C	7%
Project support Discipline D	-5%
Project support Discipline E	N/A
Project support Discipline F	-9%
Project support Discipline G	7%
Project support Discipline H	2%
Project support Discipline I	1%
Project support Discipline J	-2%

Table 24 shows the differences between the department averages and the 50% value of the probability density function of the wage rate of that department. All differences are smaller than 10%, which can be expected, because all distributions have a positive or a negative skewness (except from PBS, which has a uniform distribution). Furthermore, it is expected that the differences are not very large. After all, the average represents the mean of all the values in the data range. For these reasons, it is verified that the probability distributions of the wage rate are correct.

Verification man-hour probability distributions

The probability distributions of the man-hours are also discussed with the services estimators in Fluor. They emphasized also that scope changes could explain the large deviations in the results of analyzing the man-hours (chapter 5.2). Therefore, the data on which the probability distributions for engineering and support are based is not expected to be sufficient for detailed man-hour estimates. Also the limited amount of projects is mentioned as a reason for insufficiency. The probability distribution of the man-hours is therefore not verified for detailed estimates of the man-hours and it is important to be aware of this limitation if the cost model is used. However, the distributions are still appropriate for high level (comparative) man-hour estimates with a low precision. The distribution can correct the comparative man-hour estimates for their trueness based on previous projects. This only applies for projects that have the same project phase as the projects on which the distribution is based on (FEED-phase).

The distributions of engineering and support are used by default if probabilistic estimating is selected. If the man-hour estimate is made with a high level of detail, these distributions are not verified and should always be overwritten with project specific values. This can be done by inserting the optimistic, most likely and pessimistic estimated amount of man-hours by the discipline. Based on this a triangular probability distribution is created.

7.2. Validation

In this section the validation of the developed probabilistic cost model is performed. This is important, because it has to be validated that the developed cost estimating model is indeed an improvement with regard to the conditions specified in the research goal:

- Accuracy
- Required effort to conduct the estimate
- Timeliness (ability to prepare the estimate on time)
- Reliability
- Reproducibility

A recently finished FEED-project will be taken as test case in order to validate these conditions. This project is not used during the analysis of cases in chapter 5.2. The initial cost estimate that was prepared to bid on this project is used as comparison. The information that was available in this cost estimate is used as input for the probabilistic cost model. The strategy that was used to estimate the wage rates of this cost estimate is a combination of named positions for key positions and labor grades per department.

The eventual validation compares the by Fluor prepared initial cost estimate and the completely filled in probabilistic cost model with the actual outcomes of the project. Both focused only on the costs regarding the home office Haarlem. The initial estimated and the actual costs of services and amount of man-hours are shown in Table 25.

Table 25: Initial estimated and actual services costs and man-hours for the test project

	Initial estimate	Actual	Difference	Overrun
Total services costs	5.90 million €	7.18 million €	1.28 million €	22%
Man-hours	64414	83230	18816	29%

Inputs for the probabilistic cost model

The cost parameters that are necessary to fill the probabilistic cost model are adopted from the initial cost estimate that was made for this project. By using the same information source as the initial cost estimate the most fair and transparent comparison is guaranteed. The following cost components are taken from the cost estimate:

- Payroll burdens
- Overhead
- Uplift for non-billable labor
- Business services
    - Financial services
    - IT services
    - Office services
    - People services
    - Software charges
    - Special reproduction
    - Company cars
- Agency content
- Agency rate
- Miscellaneous costs
    - Bank guarantee
    - Performance bond
    - Business travel
- Escalation
- Cost of cash
- Event driven contingency
- Distribution of the hours over the disciplines

The wage rates, which were distributed in the estimate over named positions and labor grades per department, are not used as input. The reason for this is that they are included as probabilistic distributions in the probabilistic cost model.

Comparison

The probabilistic cost estimating model has two options to include probabilistic distributions. Both of these options are compared separately and the combination of the options is compared:

1. Only probabilistic wage rates
2. Only probabilistic man-hours
3. Both probabilistic wage rates and man-hours

The result of the Monte Carlo simulation is a probability distribution of the selected outputs. For the consistent interpretation of the results it is chosen to show the 50%-85% range of the probability distributions.

Above the 50% or median, because otherwise it is very likely that the actual costs are more than estimated and below 85%, because otherwise too much uncertainties are taken into account and the eventual price becomes uncompetitive and conservative. In reality the decision for the value can further be based on the eagerness to win the tender. However, in order to make a fair comparison with the initial cost estimate it is chosen to use the 50% value for this.

This difference represents the trueness of the cost estimate, but as is explained in chapter 2, the accuracy of the estimate consists of both trueness and precision. The precision in this case is measured by the standard deviation of the output probability distribution. More specifically, the standard deviation is divided by 50% value of the probabilistic cost estimate, which gives a certain percentage of change.

The accuracy is qualified in the same manner as in chapter 5.2, according to Table 26. Both the trueness and the precision can be calculated back to a percentage, which is why this qualification can be used for both.

Table 26: Qualification of accuracy

Accuracy	Qualification
<5%	Very high (++)
<20%	High (+)
<50%	Medium (+/-)
<100%	Low (-)
>100%	Very low (--)

First option 1, only probabilistic wage rates, is compared with the initial cost estimate and the actual outcomes.

1. *Probabilistic wage rate*

Using probabilistic wage rates provides the opportunity to significantly reduce the effort to prepare the cost estimate. Finding all the named positions and further dividing the other labor over labor grades requires a lot of effort. This was the practice used for this project. By using the probabilistic wage rates this effort is limited, because the division of labor over different wage rates is simulated with the Monte Carlo simulation. This could however have an impact on the accuracy (precision and trueness) of the cost estimate. The current assumption in Fluor is that the division of labor over labor grades, including using named positions, is the most accurate method. This assumption will be tested here, with the created probabilistic model, which simulates the division of labor over different labor grades and can be corrected for the factors **project information**, contractual requirements, location factors, **project team requirements**, market conditions, **complexity** and project duration (see Table 12: Categories of factors influencing project cost estimating practice in chapter 4.6). While all these factors are important in deciding which project team will be working on the project and thus which wage rates are to be used, some are more important than others. The factors have been discussed with services estimators of Fluor in Haarlem, who regarded project information, project team requirements and complexity of the project the most important factors for deciding the project team composition. More specifically the factors that are important are the scope and scale of the project, the project phase, the extent of completion of the design, the amount of work sharing, the expected required project team experience and the expected complexity of the project's design and construction.

Before the test can be executed first all the data from the initial cost estimate that was made for this project has to be taken over and inserted in the probabilistic model. The total costs of services for the test project are simulated with the probabilistic cost model where only the option to probabilistically estimate the wage rates is selected. The results are shown in Figure 19, the blue line represents the initial cost estimate (5.9 million euro), the black line represents the actual costs of the project (7.18 million euro) and the red distribution is the probabilistic simulation of the total costs of services, which is simulated with the probabilistic model. The 50% value is at 6.10 million euro, which is closer to the actual outcome than the initial estimate but still far off.

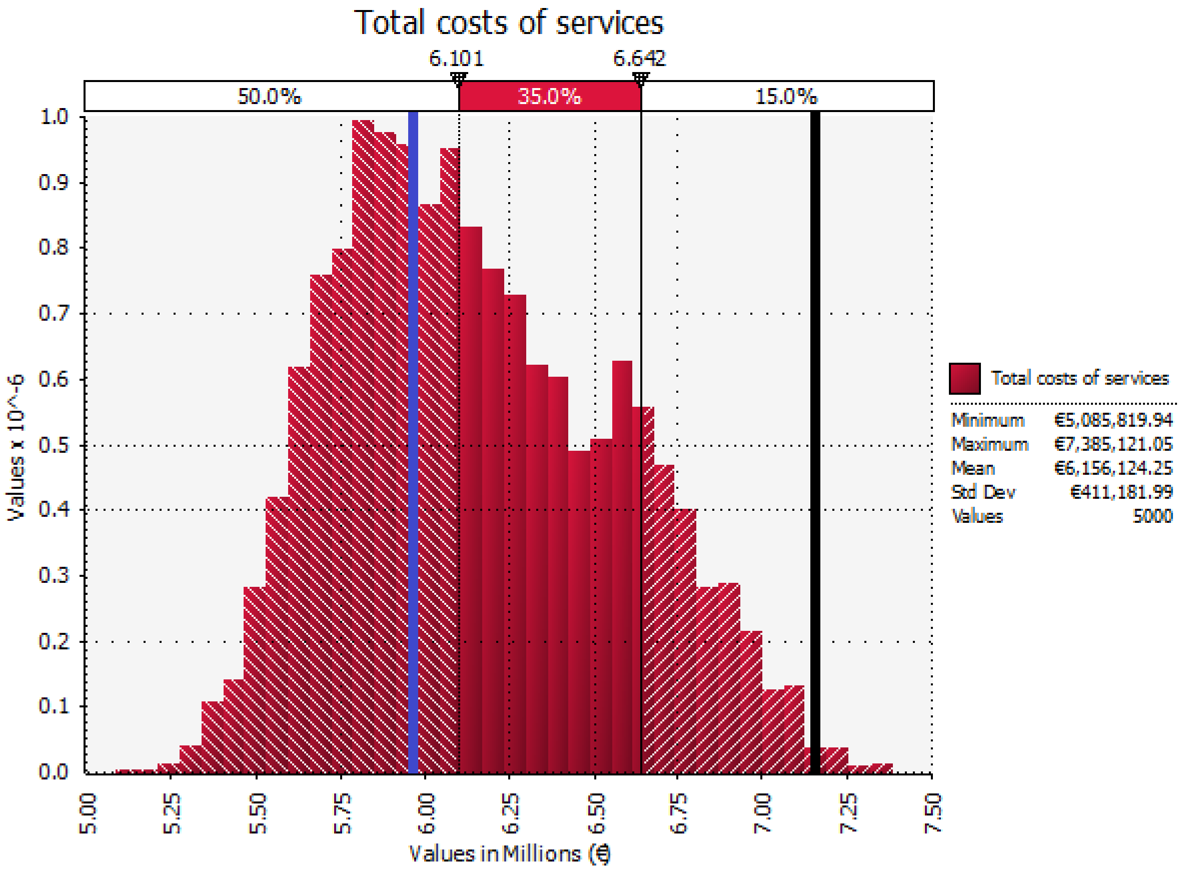


Figure 19: Total costs of services probabilistic wage rates

It can be seen that the 50% value at 6.10 million euro lays a little closer to the actual outcome than the initial cost estimate. Where the initial cost estimate has a trueness of 22%, the probabilistic estimate has a trueness of 18% ($\frac{7.18-6.10}{6.10}$), which is slightly improved. The precision of the initial cost estimate is not known, because it was estimated deterministically. The probabilistic estimate has a precision of 7%, which is calculated by dividing the standard deviation (Std Dev is shown in the legend of Figure 19) by the probabilistic cost estimate (411.181/6.101.000).

That there is an 18% difference between the actual outcome of the project and the probabilistic (and initial) cost estimate can be explained because the total amount of man-hours in this project increased considerably with 29% (from 64.414 to 83.230).

A second test can eliminate the increase in man-hours. The actual man-hours that occurred in the final outcome of the project can be used to check whether the wage rates are estimated accurately with the probabilistic cost model. This results in Figure 20, where the 50-85% range is indicated and the black line represents the actual outcome of the costs of services.

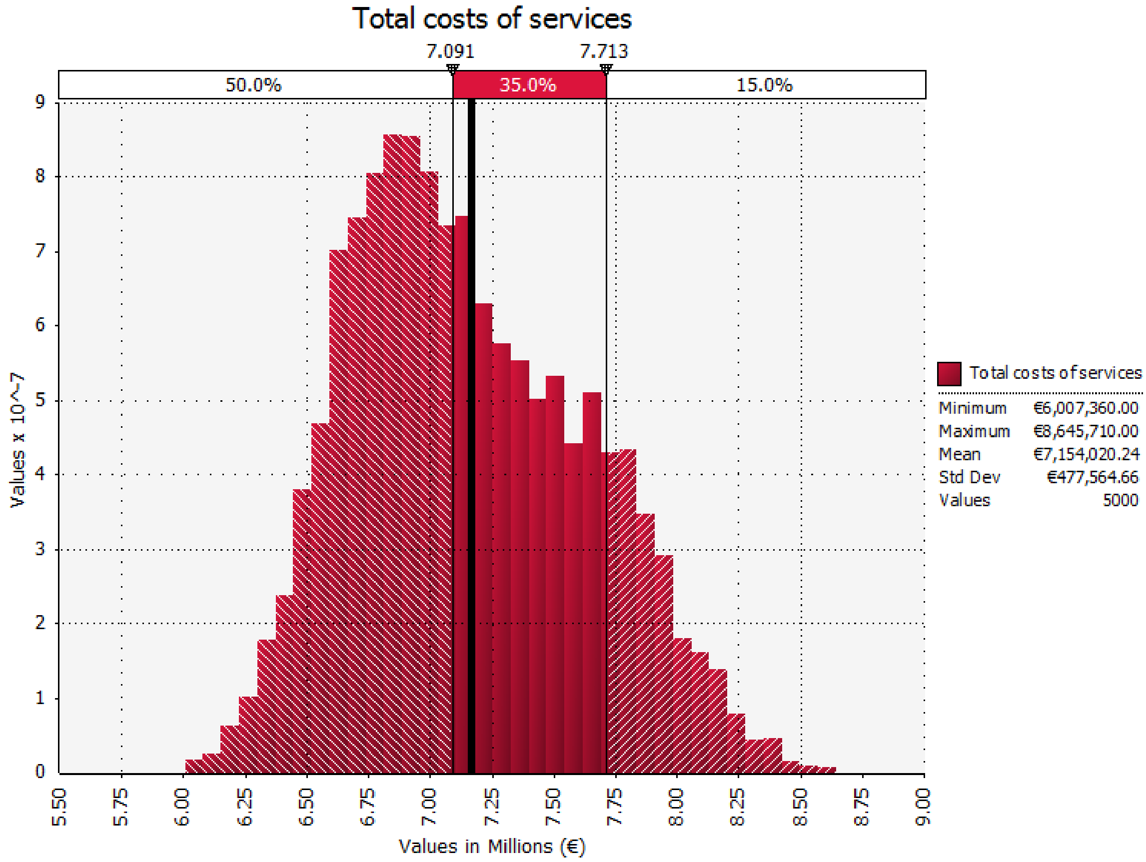


Figure 20: Check wage rates with actual man-hours in model

With this figure it can be seen that the probabilistic wage rates are simulated accurately and the actual costs of services is not far from the median of the distribution. In fact, the trueness of this estimate is only 1%, which is very accurate. The precision remains approximately the same as the previous test and is 7%. The application of probabilistic wage rates is therefore validated.

2. Probabilistic man-hours

Using the probabilistic distribution of the man-hours is expected to improve the trueness of the initially made man-hour estimate. The estimate of the man-hours of the test project was established with a parametric model called Bordereau. This model uses parametric information about the number of equipment pieces and number of services to determine the actual amount of man-hours. The level of detail in this parametric model is not really high, which is why it can be validated here if the probabilistic model improves the trueness of the estimate. The model uses the deterministic averages of the departments for the wage rates. The results are shown in Figure 21, the initial estimate indicated in blue and the actual cost of services in black.

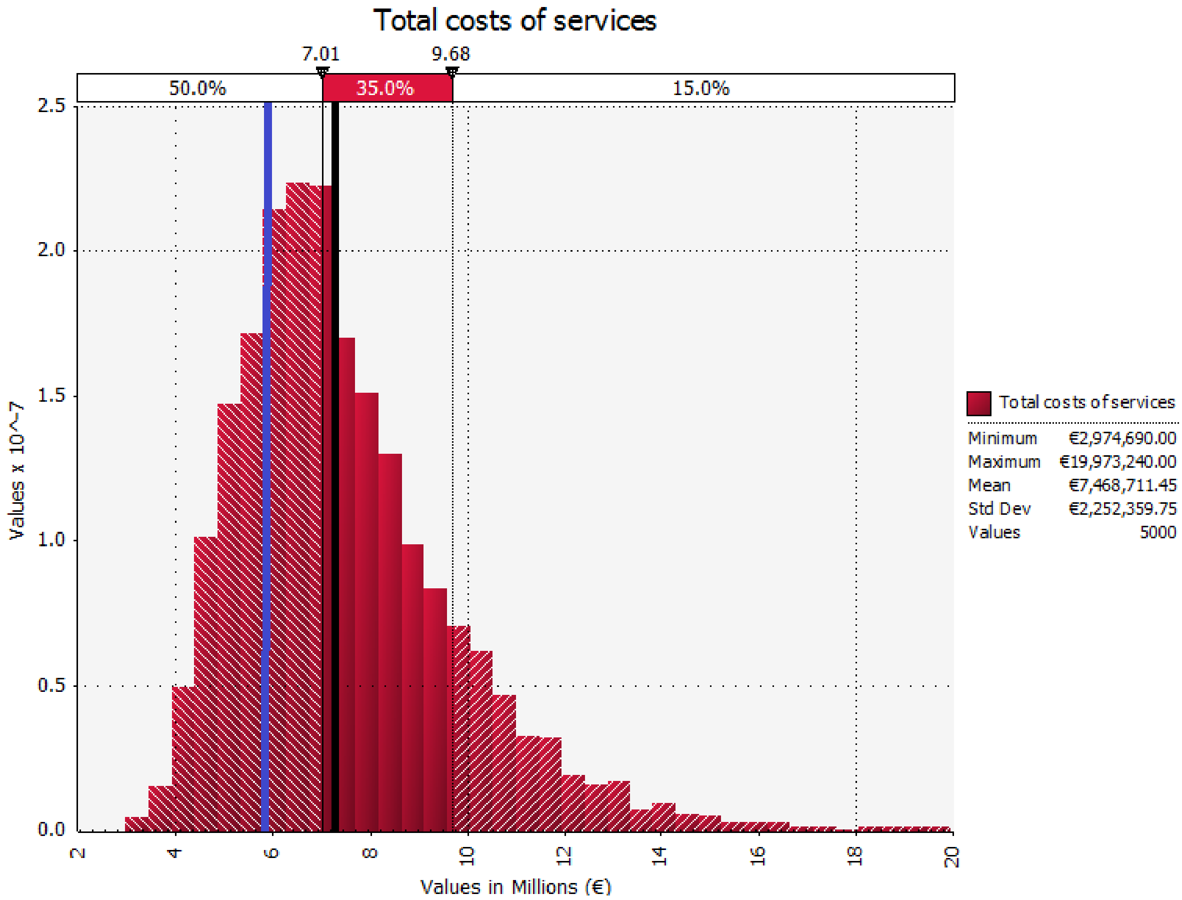


Figure 21: Total costs of services probabilistic man-hours

The figure shows that the trueness of the estimate is indeed improved from 22% to 2%. The actual cost of services is indeed very close to the median of the distribution. Nevertheless, the standard deviation of the distribution is very large (32% of the median), which again shows that this distribution is only applicable for man-hour estimates with a low level of detail.

What is also interesting to see is how the man-hours themselves are estimated with the probabilistic cost model. Therefore, Figure 22 is added to validate that the actual amount of man-hours on this project are also close to the median of the distribution of the man-hours simulated by the probabilistic model. The trueness is improved from 29% to 8% which is considerable. Again, the standard deviation of almost 29.000 hours is very large representing a precision of 38% and can only be used for man-hour estimates with a low level of detail.

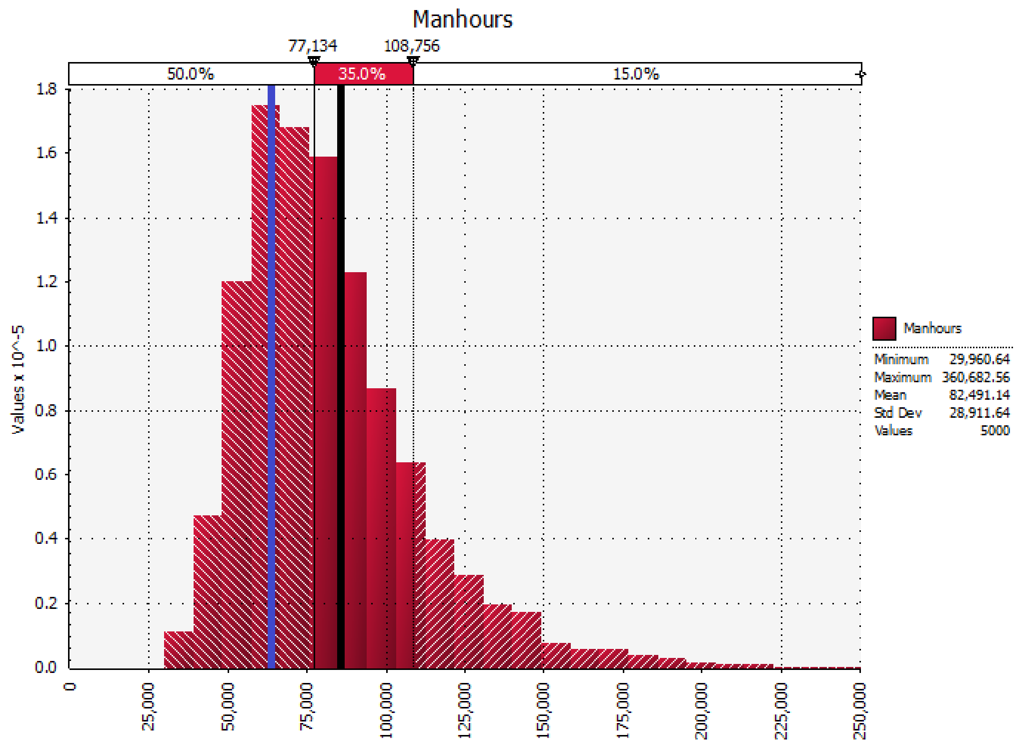


Figure 22: Man-hour distribution with probabilistic man-hours

The validation of the second option in the probabilistic model, where three point estimates are used to create triangular distributions could not yet be validated. For the validation of this option it is necessary to ask the departments that are making a man-hour estimate for a new project to come up with three values (most likely, pessimistic and optimistic). This could be validated in a project in the short future and eventually comparing the results once the project is over. Projects in Fluor usually take more than a year and therefore it was not possible to validate this method during this research. However, it is expected that this method will result in a more precise distribution of the man-hours and total costs of services, because the disciplines have more knowledge about the accuracy of their own man-hour estimates. They can make a substantiated assumption for the most likely, optimistic and pessimistic amount of man-hours. These should be more precise than the current general distribution that is placed over all the estimates of the disciplines.

3. Complete probabilistic model

The benefits of using the combination of probabilistic wage rates and the probabilistic man-hours is that the benefits of both options are combined; less effort required and correction for the trueness of the man-hour estimate. Also it provides insight in the reliability of the total costs of services, based on the uncertainties in the wage rates and the man-hours. The result of the Monte Carlo simulation of the total costs of services is shown in Figure 23. Both the actual and the estimated costs of services are shown in black and blue respectively.

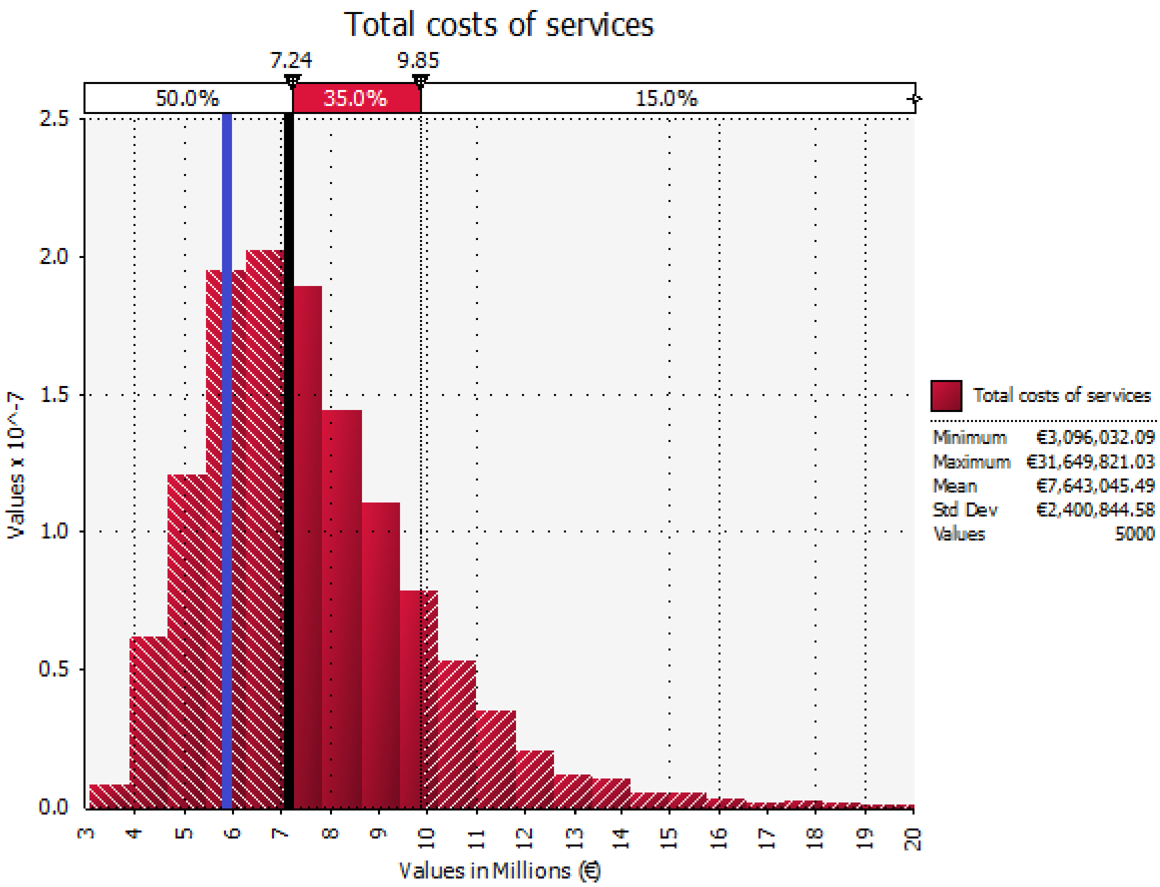


Figure 23: Total costs of services probabilistic man-hours and wage rates

The actual outcome is very close to the median of the distribution, showing that the trueness of the estimate is very good (-1%). However, the precision is not so good; the standard deviation is more than 2.4 million resulting in a precision of 34%. This is caused by the uncertainties that are added in the distributions of both the wage rates and the man-hours. The largest contributor to the uncertainty is the general distribution of the man-hours, which is relatively imprecise.

In the normal, or deterministic, way of estimating the precision of the estimate is not visualized or known at all. With this figure the precision of the total costs of services is visualized and it can be seen that there is quite a large range of values. Further actions should be taken to improve the precision of the estimate; these are discussed in the recommendations section of this research.

Regression analysis

The simulation also includes a regression analysis. This is a statistical procedure that determines the impact of changes in variables on the total services costs. The regression coefficients of the simulation are shown in Figure 24. Regression coefficients are, similarly to a sensitivity analysis, showing which components of a calculation have the largest impact on the total costs. The regression coefficients for the general distributions of the engineering and project support man-hours are the largest.

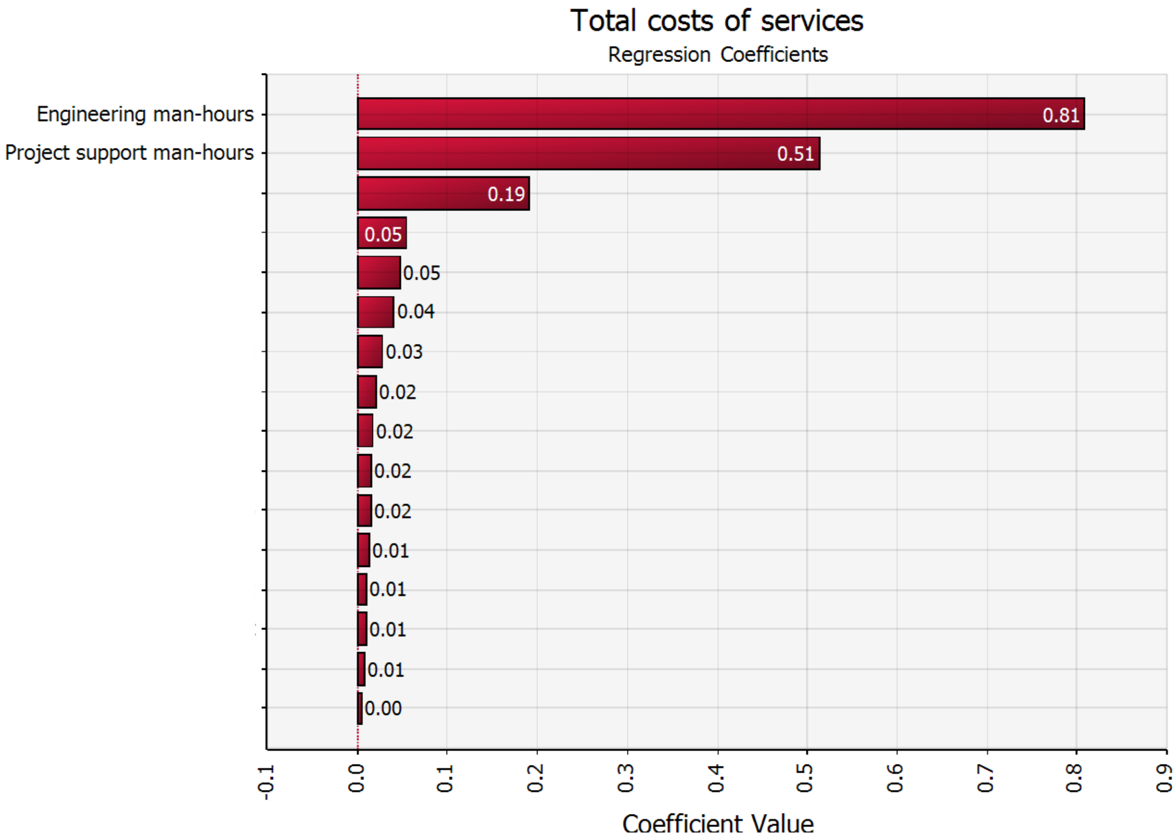


Figure 24: Regression coefficients of the total costs of services with complete probabilistic model

The regression analysis shown in Figure 24 indicates that the engineering and project-support man-hours have the largest (negative) contribution to the precision of the estimate. The precision can be improved by using probabilistic estimating for the man-hours on a more detailed level. Asking estimators to provide a three-point estimate is an example of this. As mentioned before, the option to use this method is included in the probabilistic model but it could not be validated yet. Probabilistic estimating could also be included on an even more detailed level in the tools that the different disciplines are using to estimate the man-hours. Implementing probabilistic estimating at this level of detail can really provide useful information and insight in all the uncertainties of the estimate, but it will require a lot of effort to implement. This consideration between effort and accuracy is an important aspect of this research and in the conclusion of this research a framework is proposed that provides guidelines to deal with this.

7.3. Findings

The results of the probabilistic model are compared with the current estimating practice. The three different options to use probabilistic estimating are validated and verified separately. The results of the validation step are summarized in Table 27.

Table 27: Results of the validation of the different options

Estimate:	Precision	Trueness	Precision	Trueness
Initial deterministic cost estimate	N/A	22%	N/A	+/-
Option 1: Probabilistic wage rates	7%	18%	+	+
Option 1*: Probabilistic wage rates corrected for man-hour increase	7%	1%	+	++
Option 2: Probabilistic man-hours	32%	2%	+/-	++
Option 3: Probabilistic wage rates and man-hours	34%	-1%	+/-	+

What is obvious is that the precision of the deterministic cost estimate is not known, the precision of the probabilistic estimates was good in option 1 and medium in options 2 and 3. The trueness of the cost estimate is in all probabilistic estimates improved with respect to the initial deterministic estimate. Especially, in options 1*, 2 and 3 the trueness of the estimate was very good. Because both the precision and the trueness of the probabilistic estimates are known or improved with respect to the initial deterministic cost estimate, it can be said that probabilistic estimating improves the accuracy of the cost estimate.

The other criteria that are important to compare the results with the current practice are: effort to conduct the estimate, reliability, timeliness and reproducibility.

The different options in the probabilistic model do not change a lot with regard to the timeliness and the reproducibility, which is why these criteria are discussed first.

Timeliness

The timeliness is mostly dependent on the amount of time that the disciplines that perform the man-hour estimates require. In the test project a parametric model developed by Fluor called Bordereau is used as basis for the man-hour estimate. This parametric model is a relatively quick way to estimate the amount of man-hours per discipline. The estimating of the amount of man-hours could be performed in the given timeframe. Also, there was sufficient time to price out individual project team members by named positions. The remainder of the project team is allocated based on labor grade.

The additional effort to use the probabilistic model is really low. If the estimating data is known it is a matter of inputting the data, which will take 5-10 minutes. On the total time that is available 5-10 minutes should normally be no problem. Therefore, regardless which option for probabilistic estimating is chosen, there is no reason not to use the probabilistic model based on time constraints. The only limitation is that if the time for estimating is really compressed the three-point estimates by the different disciplines may not be appropriate. This may require too much time to ask all disciplines for three-point estimates.

Reproducibility

The assumptions, ground rules and basis of the estimate are well documented in the current practice. All estimating data and its sources are described. This current practice of documenting all assumptions, ground rules and creating a basis of estimate should definitely be continued regardless the estimating method or model that is used.

Other criteria

The criteria: accuracy (trueness and precision), effort to conduct the estimate and reliability of the estimate do change with the different possible options in the probabilistic model. Therefore, these criteria are discussed for the possible options separately. The current practice (deterministic approach) is explained first, followed by the three options in the probabilistic model which results are discussed and compared with the current practice. This information is combined in Table 28 and Table 29 and provides the answer to the sub question of this chapter:

7. Is the new developed estimating method an improvement with respect to the current practice of engineering contractors in terms of quality and required effort to conduct the estimate?

Table 28: Comparison accuracy effort and reliability of the current practice and option 1 of the model

	Current practice/deterministic estimate	Option 1: Probabilistic wage rates
Accuracy - *precision*	The precision of the deterministic cost estimate is unknown. What is known is the end result of the estimate, but not how accurate it is. This gives the false assumption that every estimate has the same precision. The wage rates for the test project are estimated in detail, named positions are priced out and the remainder of the labor is divided over different labor grades per department. The man-hours are estimated based on Bordereau, a tool developed by Fluor that determines the amount of hours per discipline based on the number of equipment and services (parametric model). The man-hours are also put into a staffing plan to make a sense check.	In the probabilistic model the salary data of the Haarlem office is included and distribution fits are developed for the wage rates based on that data. The simulation of the model provides insight into the uncertainties in the wage rates for each of the disciplines. The simulation of the test project had a precision of 7%, which is very precise. Because, in the deterministic approach the precision is not known it is hard to tell whether it is an improvement, but at least with the simulation the precision is known.
Accuracy - *trueness*	The test project showed an overrun of 29% of the man-hours and 22% of the labor costs. This means that the trueness of the estimate was not so good. Based on the analysis of the projects there is a tendency to underestimate the man-hours on average with approximately 27.5% (average overrun of the 6 projects). This also happened on this project. Hereby it has to be mentioned that part of the overrun may be explained by scope changes.	The trueness of using the distributions of wage rates depends on the complexity and scope of the project, the amount of work sharing and the expected project team requirements. Based on this, the services estimator should be able to decide the percentage in/decrease that is appropriate for the estimate. The first simulation reached a trueness of 18% of the labor costs. The simulation with the same amount of man-hours as in the actual project showed that the difference between the median of the simulation and the actual costs is very good (1%)
Effort to conduct the estimate	The effort to conduct the estimate is dependent on the strategy chosen. The comparative estimating method requires only a little time. Also parametric estimating can be done relatively fast, this is based on assigning the total man-hours based on an equipment count, number of services and benchmark data for the distribution over the disciplines. The most used strategy is to ask a few disciplines to make a detailed man-hour estimate and based on benchmarks the man-hours of the other disciplines are assigned. In the test project the disciplines are consulted to verify the assigned amount of man-hours estimated with the software Bordereau. The most used strategy for the wage rates is to let several disciplines make a man-hour estimate and allocate the labor based on named positions and labor grades. This strategy was also used in the test project.	Again the effort to conduct the estimate is dependent on the chosen strategy. However, if the detailed estimating method is used, the wage rates can be simulated with the probabilistic model, which requires significantly less time than finding named positions and further dividing the labor into labor grades. The model is very easy to use and only the amount of man-hours per discipline and the basic estimating data are required as input. This is a pre-requisite for every services estimate that is being made regardless the strategy that is used.
Reliability	The reliability is not completely known by a deterministic estimate. There is contingency included for risks and it might be included for the amount of man-hours as well. In the test project only the contingency for business and contractual risks was included. This means that there are no uncertainties included for the man-hours and also not for the wage rates. Another disadvantage of a deterministic estimate is that it is not possible to determine a confidence level for the entire estimate. The total costs of services of the test project were significantly more than the estimated costs including contingency (1.28 million overrun).	The actual costs of the test project were outside of the confidence interval (50-85%). This is caused by the increase in man-hours. Therefore, the model was also tested with the actual man-hours and this showed that the actual costs are perfectly within the confidence interval.

Table 29: Comparison accuracy effort and reliability of options 2 and 3 of the model

	Option 2: Probabilistic man-hours (default and three-point estimates)	Option 3: Complete probabilistic
Accuracy - *precision*	In the probabilistic model there are two options to simulate the man-hours probabilistically. The default option is the one based on the six FEED-projects and adds a large uncertainty to the estimate. The precision that has been reached with the simulation of the test project was 32%, which is quite imprecise. Using the default distribution, which does not contain project specific information, is also not verified for application on detailed man-hour estimates. The application of three-point estimates is expected to improve the precision, because project specific information about the uncertainties in the amount of man-hours will be used. Unfortunately, this option could not yet be validated in this research.	By using both options, the precision of the estimate is completely simulated. The real precision depends on the way in which the man-hours are simulated; the default option provided a precision of 34%, which is not so precise. The three-point estimates is expected to deliver a higher precision, but could not be validated yet.
Accuracy - *trueness*	The default probability distribution improves the trueness of high level man-hour estimates. The validation of the default man-hour distribution on the test project showed that both in the total costs of services and the total man-hours, the default distribution came very close to the actual costs and man-hours, a trueness of 2% and 8% respectively. The project specific information retrieved from the three point estimate, however, is expected to improve the trueness even more. Man-hour estimators are asked to critically review the precision and trueness of their estimate.	Although the precision of the complete probabilistic model is not very high, still the trueness is almost perfect. The difference between the median of the simulation and the actual costs of services is only -1%. This is an improvement, compared to the deterministic average which showed a difference of 1.28 million euro.
Effort to conduct the estimate	The effort to use the default man-hour probability distribution is very low. It will take approximately 5-10 minutes to input all man-hour and estimating data. However, the second option, where all the disciplines have to estimate the amount of hours with three values: most likely, optimistic and pessimistic may take additional time to apply. In the probabilistic model instead of one value per discipline now three values have to be inputted. Furthermore, the estimators of the man-hours require some additional time to explain their choices of optimistic and pessimistic estimates.	It does not require a lot of effort to use the probabilistic model. The model will reduce the effort that is required to divide the labor over named positions, labor grades etc. The default man-hour probability distribution can also easily be used without any additional effort. The estimating with three-point estimate is very likely to take additional effort, but not more than finding the named positions etc. Therefore, the complete probabilistic model will reduce the effort to conduct the estimate.
Reliability	The actual costs are within the confidence interval (50-85%) of the simulation. Also the simulation of the total man-hours of the project was within the 50-85% confidence interval.	The actual costs of services of the test project were just below the 50% value of the complete probabilistic simulation of the total costs of services. So if the 50% value would have been chosen for the estimate, the actual costs would still be within the budget.

8. Conclusions and Recommendation

The content of this chapter consists of the main conclusions and answer to the main research question in chapter 8.1. In chapter 8.2 the recommendations are summarized also for the implementation of the probabilistic cost model. Chapter 8.3 is the discussion of this research and consists of the reflection in 8.3.1, the limitations in 8.3.2 and recommendations for further research in chapter 8.3.3.

8.1. Conclusions

In this section the findings of all the sub questions which are answered at the end of each chapter are combined and used to answer the main research question.

What are the most appropriate cost estimating methods that can be used in the current practice of estimating the costs for engineering and construction management services in the Energy and Chemical Industry?

The methods that are investigated in this research are comparative, parametric, detailed and probabilistic estimating. Each of these methods has their own benefits and requirements. In general a combination of these methods is used to estimate the costs for engineering and construction management services. Which estimating method is most appropriate depends on the scope and planning the estimate itself. The planning and therefore the timeliness (available time) is normally fixed and is used as basis for the framework shown in Figure 25. This framework is used as support to answer the research question. The short term indicates an estimate that has to be finished in a short time, usually 1-4 weeks. Otherwise the long term can be used, which is typically more than one month. The difference between short and long term is important, because other estimating methods can be appropriate if there is more time available. The second criterion in the framework is the amount of effort. The amount of effort put into the estimating results in the possibility to use more detailed estimating methods and in turn in a higher accuracy. However, the effort for proposals directly results in overhead for the company, which should remain as low as possible. This is a tradeoff estimators and management have to make before the estimate is performed. The framework results in four possible options for the wage rates (option 1-4) and four possible options for the man-hours (option A-D), shown in Figure 25. The man-hours and the wage rates are the two most critical factors in the total costs of services (according to the sensitivity analysis performed during this research). The amount of effort for the estimation of the wage rates and man-hours are not necessarily the same, which is why they are separated. First the most appropriate estimating method for each of the options is provided and afterwards guidelines are established that help determine the amount of effort that should be put in the estimation of the wage rates and the man-hour.

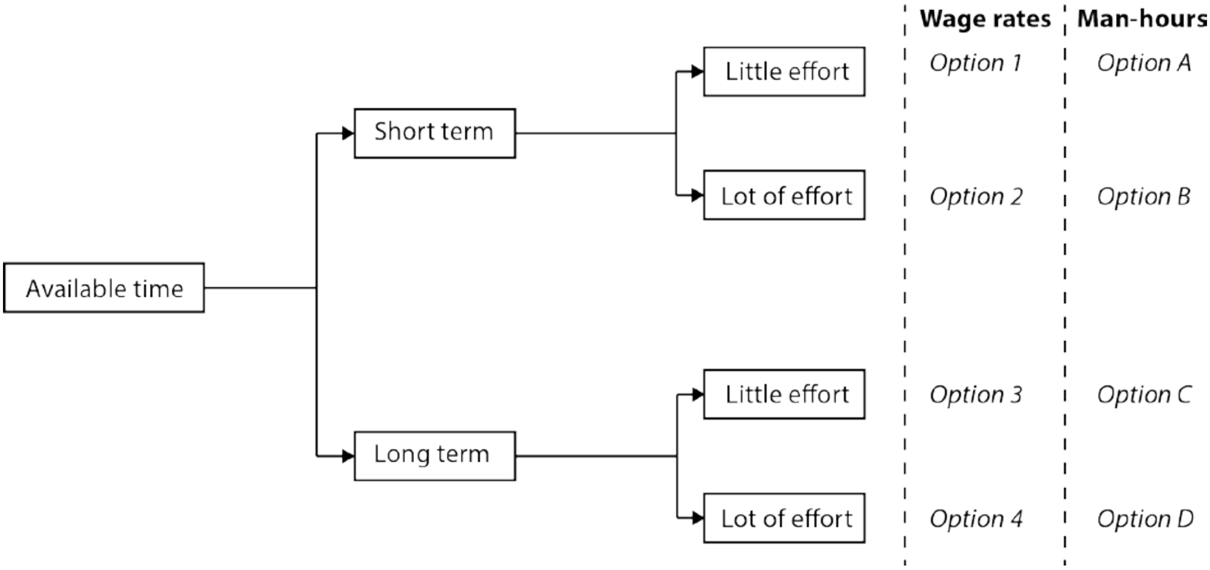


Figure 25: Framework for most appropriate estimating method

The probabilistic estimating method has several benefits such as insight in the probability of cost overruns, a choice for the reliability of the estimate, comprehension of the impact of uncertainties on the costs and insight in the accuracy of the estimate. For these reasons, probabilistic estimating is also beneficial and appropriate for the estimating of services costs. Probabilistic estimating is always used in combination with one of the deterministic estimating methods. How the deterministic estimating methods can be used to determine the wage rates is shortly explained underneath:

- **Comparative estimating**: Use department averages to quickly estimate the wage rates and add a large amount of contingency to be certain the wage rates are not underestimated.
- **Parametric estimating**: Use department averages to quickly estimate the wage rates but adjust the averages with a parameter regarding the expected percentage increase or decrease of the average. This percentage can be determined by analyzing the requirements for the project team based on experience with previous projects or benchmarks. This can also be done thoroughly by consulting the disciplines about their expectations.
- **Detailed estimating**: Figure out which key people are working on the project and figure out the exact mix of persons that is going to work on the project (amount of lead engineers/ specialists/ designer etc.). With this information services estimators can build up the rates in detail.

The most appropriate estimating method for the wage rates for each of the four possible options of the framework of Figure 25 are explained in Table 30. Furthermore, it is indicated how to incorporate probabilistic estimating in the deterministic practice of estimating the wage rates as well as what confidence level (reliability) is appropriate for each of the options.

Table 30: Framework for most appropriate estimating method wage rates

	Wage rates
Option 1	**Comparative estimating:** The probabilistic cost model developed in this research can be used to relatively quickly make an analysis of the possible wage rates per discipline. The reliability of the estimate should be chosen close to the 85% confidence level, because the accuracy of the estimate is not high.
Option 2	**Parametric estimating**: In this option the disciplines should be consulted about the expected increase/decrease of the wage rates. If this is done, the probabilistic cost model can be used here to simulate the wage rates quickly. Because the wage rates are critically reflected by the disciplines and therefore a confidence level closer to the 50% is appropriate.
Option 3	**Parametric estimating**: The services estimator can decide the increase or decrease on average based on experience with previous projects and benchmarks. The probabilistic model can be used to quickly simulate the possible wage rates. The accuracy for this option will not be as high as option two and therefore a confidence level somewhere between 50% and 85% can be chosen.
Option 4	**Detailed estimating**: The probabilistic model can only be used as a benchmark to see the amount of uncertainties. A confidence level closer to the 50% is appropriate here, because a lot of effort has been put in finding out the expected project team and the precise determination of the wage rates.

The framework is also used to provide guidance in finding the most appropriate estimating method for the man-hours. Again first the deterministic estimating methods are explained.

- **Comparative estimating**: Check the amount of man-hours based on other previously performed comparable projects and based on that make an estimation of the expected amount of man-hours per discipline.
- **Parametric estimating**: The man-hours can be determined based on the parametric data regarding the number of equipment pieces and number of services and activities. In Fluor there is a parametric tool available (called Bordereau) that estimates the amount of hours based on these parameters.
- **Detailed estimating**: Detailed estimates of the man-hours can be made by asking the disciplines for a man-hour estimate. The disciplines will look into the scope of the project and prepare a detailed estimate based on that.

For each of the four possible options (A-D) of the framework the most appropriate estimating method for the man-hours are shown in Table 31, in which again the possibilities to incorporate probabilistic estimating model is explained as well.

Table 31: Framework for most appropriate estimating method man-hours

	Man-hours
Option A	**Comparative estimating**: The probability distribution for the man-hours, which is based on the six FEED-projects can be used if it considers a project in the FEED-phase. This will improve the trueness of the estimate and does not require a lot of effort to use. Because the distribution already corrects for the trueness of the estimate and has a low precision a confidence level of 85% will have a double effect and results in a conservative estimate. With this comment in mind the confidence level can be chosen between the 50-85%.
Option B	**Combination detailed/parametric estimating**: This combination means that a few key disciplines are asked to prepare a detailed man-hour estimate and the man-hours of the other disciplines can be determined based on benchmarks of previous projects or based on the parametric model. The disciplines that make a detailed man-hour estimate have to prepare a three-point estimate (pessimistic, most likely and optimistic value). The representatives of the other disciplines should be challenged with the man-hours from the benchmark and also asked for a pessimistic and optimistic value (assuming the benchmark is the most likely value). With the three point estimates triangular distribution can be created and these can be simulated with the probabilistic model for which a confidence level close to the 50% is appropriate.
Option C	**Combination detailed/parametric estimating**: For this option a similar approach as option 2 is appropriate. The difference with option 2 is that due to the effort constraints, not all disciplines are challenged with the man-hours and the key disciplines are asked for a three-point estimate. All information can be gathered and simulated with the probabilistic model. The confidence level that is useful here is between 50-85%.
Option D	**Detailed estimating**: If effort and available time are no limitation, a detailed probabilistic estimate can be established. Probabilistic estimating can be incorporated on a very low level of detail in the man-hour estimating tools of the various disciplines. This could for example be in the required time for a specific drawing or activity. The probability distributions for these variables can be established based on previous projects or by the estimator's experience (three point estimates). The distributions should be simulated with a separate Monte Carlo simulation. If the information of all disciplines is gathered it should provide a very accurate man-hour estimate and the confidence level of 50% is appropriate.

The decision that engineering contractors have to make when they use the framework of Figure 25 is how much effort they want to put in the estimation of the costs of services. Every effort that an engineering contractor puts in estimating, directly contributes to the overhead of the company. Rarely, clients pay for the costs of the proposal. Therefore, engineering contractors want to keep their proposal costs as low as possible. The effort that they want to put in the improvement in accuracy of the estimate mostly depends on the type of contract and the risks associated with that contract type.

Table 32 provides supports in the decision-making of the amount of effort that engineering contractors should put in the estimating of wage rates and man-hours for different contract types. The plus-sign (+) indicates a lot of effort and a minus-sign (-) indicates little effort. Furthermore, for each of the contract types the most appropriate estimating options are indicated for when the available time is short (few weeks) and long (one or more months). This is in accordance with the framework in Figure 25.

Table 32: Amount of effort in estimating wage rates and man-hours of different contract types

Contract type	Effort in estimating		Available time	
	Wage rates	Man-hours	Short	Long
Reimbursable services	+	-	Option 2A	Option 4C
Target sum	+	+	Option 2B	Option 4C
Guaranteed maximum	+	+	Option 2B	Option 4D
Lump sum services	+	+	Option 2B	Option 4D
Lump sum turnkey	-	-	Option 1A	Option 3C

- **Reimbursable services contract**: The engineering contractor gets paid by every man-hour that is spent on the project. The accuracy of the amount of man-hours is therefore not that important, because the engineering contractor will be compensated regardless the amount of man-hours that is actually spent on the project. The accuracy of the wage rates on the contrary are very important, because these determine the rate that is paid by the client.
- **Target sum contract**: The engineering contractor will only receive profit up to a target sum or guaranteed maximum. After that amount of costs/amount of hours is reached, the engineering contractor will only receive the costs for the labor and no more additional profit. The profit per man-hour decreases for the project, which is undesirable. For this reason, both the wage rates and the man-hours will have to be estimated accurately if the available time is short. If the available time is long the wage rates should still be estimated very accurately but it is not necessary to make an extremely detailed man-hour estimate. The accuracy of option C of the man-hour is sufficient here.
- **Guaranteed maximum contract**: This contract type is similar to the target sum, except that after reaching the guaranteed maximum amount of costs the engineering contractor will get no compensation at all. This is very risky, which is why the accuracy of both the wage rates and the amount of man-hours should be very high. This requires putting a lot of effort in the estimating of both.
- **Lump sum services** contract: In this contract it is also very important to estimate the wage rates and the man-hours accurately. The engineering contractor will get a fixed price for performing the services and the total cost of services has to remain within this price. Overrunning this price means the contractor has to pay the additional costs itself. This means that it is important that the total cost of services is estimated accurately (both the wage rates and the man-hours).
- **Lump sum turnkey contract**: In a lump sum turnkey contract the accurate estimation of the cost of services is of less importance, because in this contract the engineering contractor takes the risks of finishing the entire construction of a project for a fixed price. The services costs for engineering, procurement and project management are approximately 10-20% of the total costs of the construction of a project. Because this is only a fraction of the total costs of construction and because the engineering contractor has to pay its employees regardless they work on this project or not, the estimation of the man-hours and the wage rates is of less importance. In this type of contract more effort should be put in the estimation of the material, field labor and equipment.

In addition to the contract type, the other factors that can be for deciding the amount of effort are*:* project information, contractual arrangements, location factors, project team requirements, market conditions, complexity and project duration. All these factors directly or indirectly result in risks for the engineering contractors. The amount of risks, in turn, determines the required accuracy of the estimate and thus the amount of effort. Therefore, it is always important to comprehend all potential risks that can occur and based on that determine the planning and scope of making the services cost estimate.

8.2. Recommendation

The purpose of the recommendation is explained as well as how the recommendation can be put in practice.

Implementing probabilistic estimating

A number of recommendations are established that regard the implementation of probabilistic estimating in the estimation of services costs.

Start using probabilistic wage rate distributions on new projects

By using the probabilistic distributions of the wage rates from different disciplines more experience will be gained with this new method. On the longer term, this method will reduce the effort that is required for estimating the costs of services, while retaining the same accuracy level. First, this method will require some additional effort to use to validate the retrieved results with actual data. It is recommended to first start with using the probabilistic estimating tool as an addition to the current practice and over time, more experience will be gained and benchmarks can be developed for increasing or decreasing the probabilistic distribution based on the complexity, phase and scope of the project. Once such benchmarks are established these can be used to make quick estimates of the services costs. Of course, making sure all the estimating data is correct will always remain part of the estimator's responsibility.

Use probabilistic man-hour estimates on a pilot project

The techniques and methods presented in this report can be applied on a pilot project first. The results of the pilot project will show the additional benefit of using the probabilistic estimating method. While preparing the man-hour estimates, the engineers can be asked to make a pessimistic, most likely and an optimistic estimate of the amount of man-hours their discipline needs. While this is done by all the man-hour estimators from different disciplines, the results can be used to simulate the expected amount of man-hours on the project. This project specific information is extremely valuable to determine the amount of uncertainty in the estimate and to be aware of the chance of exceeding a particular amount of hours.

Incorporate probabilistic estimating on a lower level of detail in the man-hour estimate.

It makes sense to use probabilistic estimating on a lower level of detail than is performed in this research. This is a long term measure, which will require some time to establish. The probabilistic estimating can be used in the tools of the different disciplines by which the man-hours are estimated. This will ensure that the accuracy (precision and trueness) of the man-hour estimate improves. This is caused by the additional information that a probabilistic estimating method uses compared to deterministic estimating methods. This additional information results from the probability distribution of the parameters or activities that are used to make the man-hour estimates. The probability distributions for the activities can be developed by measuring the amount of time that a specific activity requires on a few different projects. Examples of this are the amount of time spent to create a specific drawing, material list or other kind of deliverable. The parameters and benchmarks that are currently used in the man-hour estimating tools can also be updated and verified with this new information.

Improving the probabilistic estimating model for Fluor

The following recommendations regard the possible improvements of the probabilistic estimating model that is developed in Fluor.

Including information of different offices

In the probabilistic estimating model there should be information included of multiple offices of Fluor. The desire to have a database or tool with the information of multiple offices came to light in the interviews that are performed with representative services estimators of different offices. The probabilistic estimating model can be extended with database information containing information regarding the cost components: wage rates, TOWP, payroll burdens, overhead, escalation and office expenses of all Fluor offices. The availability of all data into a probabilistic model saves services estimators a lot of time of waiting and retrieving this information elsewhere. Furthermore, potential scenarios of different offices working on a project can be analyzed with regard to the services costs. This provides valuable and fast information at an early stage in the proposal. Including the cost component data of other offices can be done by retrieving this data by all the Fluor offices and include this in the probabilistic model. The distributions of the different offices can be made on a similar basis as it is done for the Haarlem office. All techniques necessary for this are explained in this research.

Analyze more projects and track data on new projects

The current research in Fluor should be performed on a larger scale with more projects and more data in order to become a verified and validated standard procedure. More data will ensure that the influence of extreme values is reduced due to the large number of values. The methodology used in this research can be used as basis for further expansion of the amount of projects and data. Also, the probabilistic model could be expanded with information of other office locations as mentioned in the previous recommendation. On new projects that are executed, the scope changes and potential influencing factors can be tracked. This may be the only way to retrieve normalized data. By afterwards trying to normalize the data there is always some inconsistency and it will never be sure that the data is corrected for all scope changes and other influencing factors. While by keeping track of the changes during the execution it can be guaranteed that all factors are taken into account and the trueness and precision of cost and man-hour estimates can be retrieved.

8.3. Discussion

In the discussion, the last section of this thesis, a reflection is made on the potential and the limitations of the research in chapters 8.3.1 and 8.3.2. The section ends with recommendations for further research in chapter 8.3.3.

8.3.1. Reflection

With this research the current practice of the engineering contractor Fluor is reviewed and the possibilities to improve the current practice are focused on the use of probabilistic estimating. The main benefits of probabilistic estimating are that the probability of cost overrun is known and insightful, the reliability of the estimate can be determined and conservative estimates can be prevented, the impact of uncertainties and risks on the costs are comprehensible and the accuracy of the estimate is known. Several ways have been proposed to include probabilistic estimating in the current estimating practice of an engineering contractor. Depending on the way probabilistic estimating is used it can either require additional time to use or it can save time compared to the current practice. The validation of the probabilistic cost model that is developed shows that the accuracy of the estimate can be visualized without requiring a lot of effort. Furthermore, it showed that the probabilistic estimating method can correct the trueness of the estimates that are made with the current estimating practice. With this research the foundation for the implementation of probabilistic estimating in the current estimating practice is laid. This started with creating awareness followed by bringing the desire to change to the attention and by providing the required knowledge for the implementation. Now it is recommended to start using the probabilistic cost model and the probabilistic way of thinking in the current practice of engineering contractors to deal with uncertainties and risks in a consistent and transparent manner. If this proves to be successful it can be reinforced by providing feedback and applying the model on more projects.

Another aspect that emerged during this research is the impact of scope changes on the project. This is a main cause of the differences between the estimated and actual cost of services that have been found in the analysis of the FEED-projects. In the analysis a correction is made for the scope changes that were approved by the client. However, not all scope changes are approved by the client. Once a scope change emerges, the engineers and project manager have to discuss whether it is worth to bring the scope change to the client and let him approve it. This is often a long procedure and may require a lot of time before it is finally approved and the engineering can continue. Therefore, it is sometimes chosen to fix the scope change right ahead and continue working. This is obviously not in the benefit of the engineering contractor, but it is an aspect which will improve the reputation of the engineering contractor. If an engineering contractor wants approval for each small scope change, an unworkable situation may be created and the client will think twice before going to this engineering contractor for future projects again. This is one of the reasons that some scope changes slip the ‘correct’ procedure and are implemented directly. It is extremely difficult to eliminate such scope changes from the data of the project close out reports. The recommendation ‘Analyze more projects and track data on new projects’ previously discussed, is a proposed measure that can be used to eliminate these kinds of scope changes.

The probabilistic estimating tool that is developed uses specific company information from Fluor. However, the development of this tool is elaborated and explained and can also be used by other large engineering organizations with their own information. The development of probability distributions is an important part of this. The engineering organization should have a projectoriented workforce, of sufficient quantity that the application of probability distributions makes sense. Furthermore, estimating factors that influence the estimating practice that are developed in this research are specifically focused on the Energy and Chemical industry and should be adapted for other industries.

8.3.2. Limitations

The largest limitation that appeared several times during this research is the amount of projects that are analyzed. Both for the development for the probability distribution for the man-hours as well as for the validation of the cost model a limited amount of projects were available. The problems with the capturing of historical data have been recognized by the engineering contractor Fluor and currently initiatives are taken to improve this in the future. Historical data is an extremely valuable source of knowledge for companies and is vital for making accurate estimates without a lot of effort. Having mentioned this limitation, it is possible to use the information of future projects to improve and validate the developed probabilistic cost model.

Another limitation is the strategic decision making that influences the current estimating practice. The research is performed under the assumption that strategic decision making is not part of the estimates. However, in reality it could certainly be the case that some strategic decisions are made, for example to reduce the estimated man-hours of a project or to overestimate the wage rates a little. Such decisions are dependent on the eagerness to win a project and the strategy used to win a project. In the case such decisions occurred it will result in a high probability of overrunning the amount of man-hours, while these are reimbursed per hours and eventually result in larger profits. Also, if the wage rates are overestimated the actual profit per man-hour will be higher also resulting in larger profits. Such decision making reduces the trueness of the services estimate. However, as mentioned in the scope of this research, this type of strategic decisions are purposely left out of this research because these are extremely difficult to identify and even more difficult to quantitatively determine their impact. In future projects strategic decision making can be documented, making it possible to retrieve normalized unbiased data from future projects.

8.3.3. Further research

Two possible subjects for further research have been identified.

Determining the quantitative amount of increase/decrease of the wage rates for different project circumstances

In the cost model that has been developed for this research there is the option to increase or decrease the probabilistic distributions or the averages by a certain percentage. The framework of factors that impact the estimating practice presented in this report (Table 12), can be used as a first step to determining the amount of increase or decrease. From this framework the most important factors for this decision are the project complexity, project information (scope and phase) and project team requirements (amount of work sharing, required experience). The other factors will also have influence, but the impact is more limited. What could be interesting to research, and has not been done in the research in this report, is to quantitatively analyze the amount of increase and decrease. Guidelines or benchmarks could be established to deal with differences in complexity, information etc. of projects. This information, in combination with the probabilistic cost model, can save services estimators a large amount of time.

The guidelines/benchmarks can be retrieved by analyzing the average wage rates that are used on historical projects. The six FEED-projects analyzed in this research can be used for example. However, this is only a single project phase and there are differences in complexity, scope and contractual arrangements in the projects. Therefore more projects will need to be analyzed to form a basis for determining the quantitative increase/decrease of the wage rates for different project circumstances.

Combining cost and schedule uncertainties

The probabilistic cost model, as discussed in this research, can be extended with schedule associated risks and uncertainties. The combined probability distribution of cost and schedule will be multivariate and can be used to find the probability of achieving a specific cost or schedule. The joint probability distribution has to be defined by the relationships between estimated cost and schedule, see Figure 26 for an example.

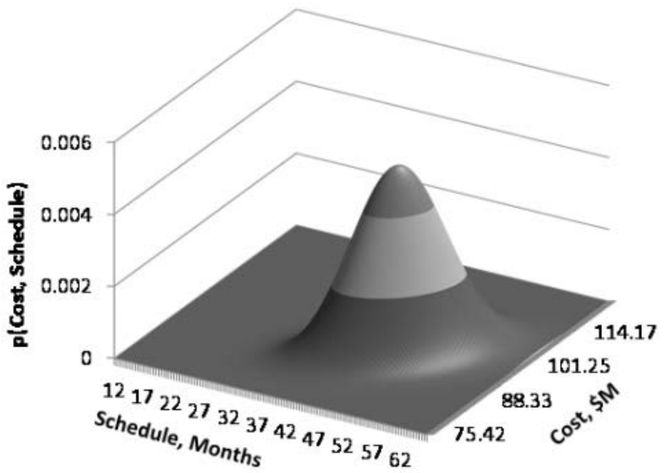


Figure 26: Joint probability distribution cost and schedule (NASA, 2013)

This joint probability distribution can be used for projects that are either schedule driven or cost driven. By schedule driven projects the schedule is fixed, the single probability function of the schedule can be used to find the target value with a desired probability of realizing this within the given time. This value can then be used as input in the joint probability distribution in order to find the range of costs with corresponding probability of occurrence. Vice versa if the project should be realized within a given budget with a desired probability then the schedule can be calculated. Further research into the correlation between both distribution functions and the separate distribution functions of schedule and costs will first be necessary.

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List of terms

Basis of estimate	-	Document that describes how the estimates values were developed and compiled into the finished deliverable
Beta	-	Type of probability distribution – see Appendix B
CDF	-	Cumulative Density Function
Central Limit Theorem	-	Theorem that states that for a large number of independent identically distributed random variables the average has a normal distribution
CER	-	Cost Estimating Relationship
Change order	-	Formal document that identifies and quantifies a change outside of the scope of the project
Contingency	-	An amount added to an estimate that allow for items, conditions or events for which the occurrence and/or consequence is uncertain
Correlation	-	The simultaneous change in value of two numerically valued random variables
Cost of cash	-	Costs that compensate for the pre-financing of a project and to correct for interest
Covariance	-	Measures how much two random variables change together
CSA	-	Civil, Structural and Architectural
DEC	-	Dispersed Execution Center
Deterministic estimate	-	Estimate which output is a single value
Discrete distribution	-	Probability distribution with a finite number of outcomes which can be counted.
Downstream	-	Refining of petroleum, crude oil and processing of natural gas
E&I	-	Electrical and Instrumentation
EPC	-	Engineering Procurement and Construction
Escalation	-	The provision in the estimated costs for an increase in the cost of equipment/material or labor due to continuing price level changes over time
Estimating factors	-	Qualitative factors that influence the estimating practice of engineering contractors
Expected value	-	The weighted average of all possible values
FEED	-	Front End Engineering and Design
GEC	-	Global Execution Center
Grade	-	Labor grade indicating the salary range
HSE	-	Health, Safety and Environmental
ISO	-	International Standardization Organization
Lognormal	-	Type of probability distribution – see Appendix B
Lump sum contract	-	Fixed price contract
Monte Carlo simulation	-	Simulation technique in which a process is simulated multiple times in order to obtain the probability distribution of an unknown variable
Non-billable costs	--	Costs that are not billable to the client or non-reimbursable by the client according to the contract
Normal	-	Type of probability distribution – see Appendix B
O&G	-	Oil and Gas
Office expenses	-	Direct costs related to the use of office services and supplies
Overhead	-	Costs for the ongoing expense of business

P&C	-	Procurement and Contracting
Payroll burdens	-	Labor related costs incurred by a company to cover benefits, taxes and employer insurance carried on employees
PBS	-	Project Business Services
PDDM	-	Project Document and Data Management
PDF	-	Probability Density Function
PIM	-	Project Information Management
PM	-	Project Management
PMP	-	Project Management Professional
Probabilistic cost model	-	A model developed during the research, which uses the software @Risk and the probabilistic estimating method to simulate the services costs
Probabilistic estimate	-	Estimate which output is a range of possible values, visualized with a probability distributions
Probability distribution	-	Statistical function that describes all the possible values and likelihoods that a random variable can take with a given range
QA	-	Quality Assurance
Reimbursable contract	-	Contract type where the client compensates all costs based on pre-determined rates and arrangements.
SBU	-	Strategic Business Unit
Scope	-	Defines the work to be done documented in the contract
Services costs	-	Costs for engineering, procurement and construction management services
Standard deviation	-	Shows how much variation from the average exists
Timeliness	-	The occurring at a suitable time (in-time)
TOWP	-	Time Off With Pay
Triangular	-	Type of probability distribution – see Appendix B
Uniform	-	Type of probability distribution – see Appendix B
Upstream	-	Exploration and production sector of the Oil and Gas Industry
Variance	-	The average of the squared differences from the mean, it measures how far a set of numbers is spread out
Wage rate	-	Hourly rate paid to an employee
WBS	-	Work Breakdown Structure
Weibull	-	Type of probability distribution – see Appendix B

List of Appendices

Appendix A: Mathematical application of Cost Estimating Methods

In this appendix the mathematical application of several of the estimating methods from Chapter 3.2 are explained in more detail.

1. Parametric estimating

Parametric cost estimates can be estimated with the following formula:

$$Y = \sum_i f_i * P_i$$

Where,

Y = Total costs

f_i = parameter cost ratio

P_i = Parameter of interest

It can also occur that the estimating relationship is not linear and other Cost Estimating Relationships (CERs) are necessary such as:

$$Y = \sum_i f_i * p^{n_i}$$

Where,

p_i = Parameter of independent variable of interest

n_i = exponent used to transform p_i

The parameter cost ratio and the (independent) parameter of interest can be determined based on historical data.

2. Detailed estimating

Detailed cost estimates are often composed of various cost components, estimated bottom up. An example of how the mathematical application of the detailed estimate may look like is provided below. However, take into consideration that this method is different for each project.

$$Y = \sum_i Q_i(M_i + W_i * L_i) + \sum_j I_j(C_j)$$

Where,

Y = Total Capital Costs

Q_i = Quantity of work

M_i = Unit material cost

L_i = Unit labor rate

W_i = Unit wage rate

I_j = measure of work in indirect cost elements

C_j = Unit cost for indirect element

3. Comparative estimating

In the comparative estimating method several cost relations can occur. The mathematical application of the Power Law relationship, cost indices and factored estimates are provided below.

3.1. Power Law Relationship

The power-law-and-sizing relationship can be used to estimate the total cost or the cost of a cost component from data about a similar cost component from a previous project:

$$Y = C_N * \left(\frac{Q_y}{Q_N}\right)^m$$

Where,

C_N = Known cost of a previous project

Q_y/Q_N = ratio of size of the new project and the old project

M = exponent describing the economies of scale

3.2. Cost Indices

Sometimes the cost have to be adjusted for time factors such as inflation, this can be done by using cost indices:

$$Y = \sum_i C_{N_i} * \frac{I_{R_i}}{I_{N_i}}$$

Where,

C_{Ni} = Known cost of component

I_{Ri}/I_{Ni} = ratio of the required index to the other index at the time or locale

3.3. Factored estimates

Another possibility is to use factored estimates, where a factor is included for other project costs:

$$Y = \left(C_E + \sum_i f_i * C_{E_i}\right)(f_I + 1)$$

Where,

C_E = Total purchase price of the expenses

f_i = factored for size

f_I = factor for estimating other project costs such as overhead, financial cost, etc.

4. Probabilistic estimating

For the mathematical application of probabilistic estimating, several aspects are important such as the Expected value, Variance, Covariance and the Central Limit Theorem. These aspects are discussed below

4.1. Expected value

The expected value of a cost parameter can be defined as the weighted average of all possible values. The term expected value in essence means the same as the often used term average.

The expected value equals

$$E(X_i) = \mu_x = \int_{-\infty}^{\infty} x f(x) dx$$

Where,

f(x) = probability density function of cost parameter i

If all cost parameters i are correlated such that Y = $x_1 + x_2$, then

$$E(Y) = E(X_1) + E(X_2)$$

The variance in this case is given by

$$\sigma_Y{}^2 = \sigma_1{}^2 + \sigma_2{}^2 + 2\sigma_{1,2}$$

In this formula $\sigma_{1,2}$ is the covariance of random variables x_1 and x_2. If the random variables are independent then $\sigma_{1,2}$ is equal to zero.

If the total cost is the product of independent, continuous, random variables, such that Y = $x_1 * x_2$, then

$$E(Y) = E(X_1) * E(X_2)$$

$$\sigma_Y{}^2 = X_1{}^2\sigma_1{}^2 + X_2{}^2 * \sigma_2{}^2 + \sigma_1{}^2\sigma_2{}^2$$

4.2. Variance

Variance, in probability theory, measures the spread of the values of a certain parameter. Small variance indicates that the spread of the values is very close to the mean or expected value, while a high variance indicates that values are spread out. The square root of the variance is called the standard deviation, usually indicated with the symbol σ.

4.3. Covariance

If there are two or more variables they may or may not have a correlation. This correlation is important to mention, because the correlation between cost components can have a large impact on the degree of risk that is associated with using the variance (Touran, 1993; Wall, 1997; Yang, 2005). This correlation can be measured by the covariance of the variables. If two random variables have no correlation then they are called independent and the covariance will be equal to zero. This means that the sum of the variances of the two random variables behaves in the same manner as the separate variances. The covariance explores the tendency in the linear relationship between the variables, which can be positive, zero or negative.

The formula that can be used to calculate the covariance of two random variables X and Y, denoted by Cov(X,Y) is defined as:

$$Cov(X,Y) = E(XY) - \mu_X \mu_Y$$

The formula that can be used to calculate Pearson's correlation coefficient between data sets X and Y is the following:

$$r = \frac{\sum_{i=1}^{n}(X_i - \bar{X})(Y_i - \bar{Y})}{\sqrt{\sum_{i=1}^{n}(X_i - \bar{X})^2}\sqrt{\sum_{i=1}^{n}(Y_i - \bar{Y})^2}}$$

Where,

r = Pearson's correlation coefficient

$\bar{X}$ = Mean of data set X

$\bar{Y}$ = Mean of data set Y

4.4. Central Limit Theorem

The Central Limit Theorem is a refinement of the law of large numbers. The law of large numbers states that for a large number of samples the average of these samples is likely to reach the expected value of the whole group of samples. The Central Limit Theorem continues on this law and states that for a large number of independent identically distributed random variables $X_1 \ldots, X_n$, with finite variance, the average X_n approximately has a normal distribution, no matter what the distribution of the X_i is (Dekking et al., 2005; Diekmann, 1983). This theorem can be used to approximate the probability distribution of the average of the sum of independent identically distributed variables.

Appendix B: Probability distributions

Each cost parameter has its own probability distribution that reflects the reality. There are several types of distributions that can be used to model the reality. The distributions that are commonly used in the construction industry include normal, lognormal, beta, triangular and Weibull (Chou et al., 2009), these will be shortly discussed. The probability density function (PDF), the cumulative density function (CDF), the expected value (E(X)) and the variance (Var(X)) will be given for each of the distributions.

1. Uniform distribution

The simplest probability distribution is the uniform distribution. It is defined by two parameters, the minimum possible value (L) and the maximum possible value (H), see Figure 27.

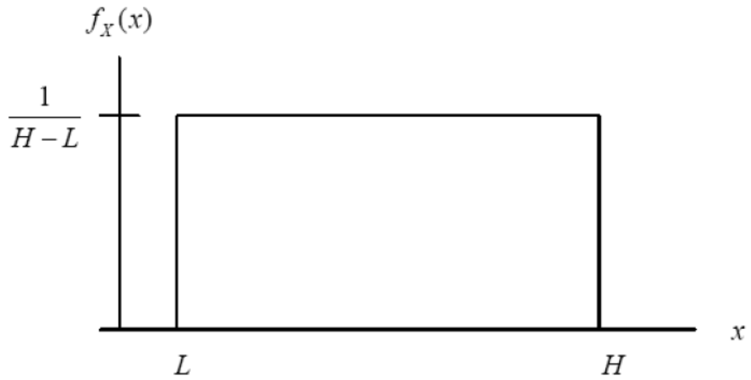

Figure 27: Uniform distribution (NASA, 2013)

The probability density function (PDF) of the uniform distribution U (L, H) is given by:

$$f_x(x) = \frac{1}{H-L}, if\ L \leq x \leq H$$

The cumulative density function (CDF) is given by:

$$F_x(x) = \begin{cases} 0 & , if\ x < L \\ \frac{(x-L)}{(H-L)} & , if\ L \leq x \leq H \\ 1 & , if\ x > H \end{cases}$$

The expected value E(X) is given by:

$$E(X) = \frac{L+H}{2}$$

And the variance VAR(X) is given by:

$$Var(X) = \frac{1}{12}(H-L)^2$$

2. Triangular distribution

The triangular distribution is continuous probability distribution, defined by three parameters T(L,M,H), the lowest possible value (L), the so-called mode (M) and the highest possible value (H) (Garvey, 2000b). A graphical display is shown in Figure 28.

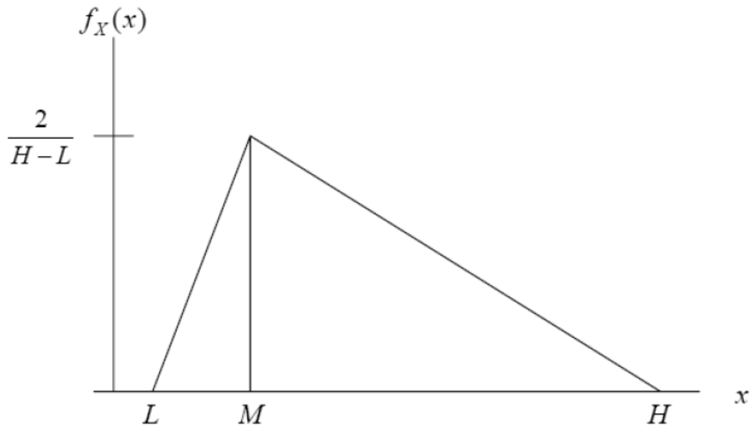

Figure 28: Triangular distribution (NASA, 2013)

The PDF of the triangular distribution is given by:

$$f_x(x) = \begin{cases} \dfrac{2(x-L)}{(H-L)(M-L)} & if\ L \leq x \leq M \\ \dfrac{2(H-x)}{(H-L)(H-M)} & if\ M \leq x \leq H \end{cases}$$

The cumulative probability distribution of the triangular distribution is given by:

$$F_x(x) = \begin{cases} 0 & if\ x < a \\ \dfrac{(x-L)^2}{(H-L)(M-L)} & if\ a \leq x < m \\ 1 - \dfrac{(H-x)^2}{(H-L)(H-M)} & if\ m \leq x < b \\ 1 & if\ x \geq b \end{cases}$$

The expected value is given by:

$$E(X) = \frac{L+M+H}{3}$$

The variance is given by:

$$Var(X) = \frac{L^2 + M^2 + H^2 + LH + LM + MH}{18}$$

3. Normal distribution

The normal or Gaussian distribution is a continuous probability distribution defined by two parameters μ and σ: N(μ,σ) (Garvey, 2000b). The typical form of the probability density function of a normal distribution can be seen in Figure 29.

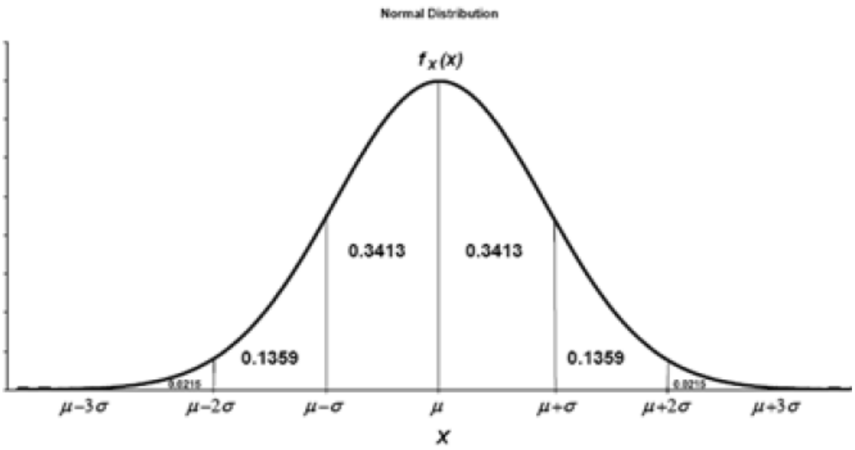

Figure 29: Normal distribution (Garvey, 2000a)

The PDF of the normal distribution is given by:

$$f_x(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\left\{\frac{1}{2}\left[\frac{(x-\mu)^2}{\sigma^2}\right]\right\}}$$

The cumulative probability distribution of the normal distribution is given by:

$$F_x(x) = P(X \leq x) = \int_{-\infty}^{x} \frac{1}{\sqrt{2\pi}\sigma} e^{-\left\{\frac{1}{2}\left[\frac{(x-\mu)^2}{\sigma^2}\right]\right\}} dx$$

The expected value is given by:

$$E(X) = \mu$$

The variance is given by:

$$Var(X) = \sigma^2$$

4. Lognormal distribution

The log-normal distribution is a continuous probability distribution whose logarithm is normally distributed ln(N(μ,σ^2)) (Garvey, 2000b), see Figure 30.

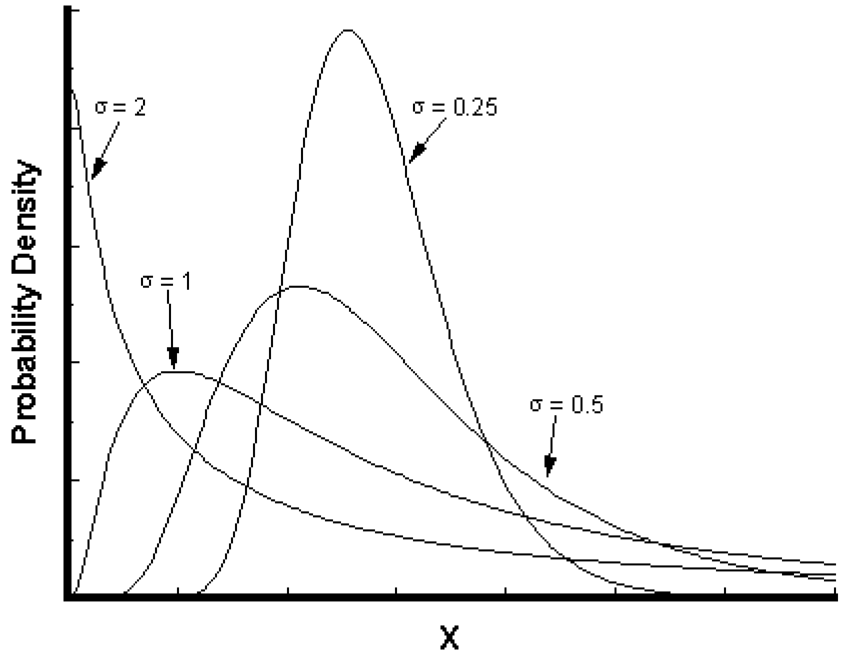

Figure 30: Lognormal distribution (Engineered Software, 2013a)

The PDF of the lognormal distribution is given by:

$$f_x(x) = \frac{1}{\sqrt{2\pi\sigma_y}}\frac{1}{x}e^{-\left\{\frac{1}{2}\left[\frac{(\ln(x)-\mu_y)^2}{\sigma_y^2}\right]\right\}}$$

The CDF is given by:

$$F(x) = P(X \le x) = \int_0^x \frac{1}{\sqrt{2\pi\sigma_y}}\frac{1}{x}e^{-\left\{\frac{1}{2}\left[\frac{(\ln(x)-\mu_y)^2}{\sigma_y^2}\right]\right\}}dx$$

The expected value for the log-normal distribution is given by:

$$E(X) = e^{\mu+\frac{\sigma^2}{2}}$$

The variance is given by:

$$Var(X) = \left(e^{\sigma^2} - 1\right)e^{2\mu+\sigma^2}$$

5. Beta distribution

The standard beta distribution, Beta(α,β), is defined by two shape parameters α and β (Garvey, 2000b). For some visual examples of the beta distribution see Figure 31.

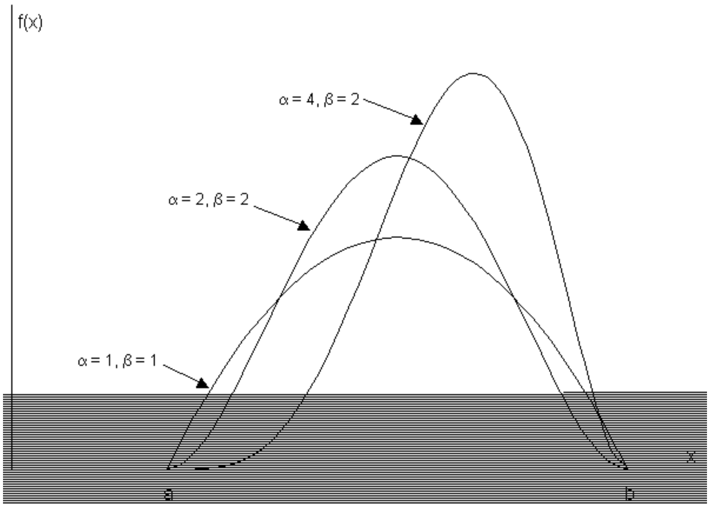

Figure 31: Beta distribution (Hendrickson, 2008)

The PDF of the beta distribution is given by:

$$f_x(x) = \frac{x^{\alpha-1}(1-x)^{\beta-1}}{B(\alpha,\beta)}$$

The CDF of the beta distribution is given by:

$$F(X) = \int_0^x f_x(x)dx \;\; if\ 0 < x < 1$$

This expression cannot be presented in closed form and has to be calculated through numerical integration procedures (Garvey, 2000a).

The expected value of the beta distribution is given by:

$$E(X) = \frac{\alpha}{\alpha+\beta}$$

The variance is given by:

$$Var(X) = \frac{\alpha\beta}{(\alpha+\beta)^2(\alpha+\beta+1)}$$

A special case of the beta distribution, that is also used in the construction industry is the PERT distribution. PERT(L,H,M) is defined by three parameters, the lowest possible value (L), the highest possible value (H) and the mode (M).

The expected value is defined by:

$$E(X) = \mu = \frac{L+4M+H}{6}$$

And the variance is defined by:

$$Var(X) = \frac{(H-L)^2}{36}$$

From the expected value (μ) and the distribution P(L,M,H) the parameters α and β can be derived by:

$$\alpha = \frac{(\mu - L)(2M - L - H)}{(M-\mu)(H-L)}$$
$$\beta = \frac{\alpha(H-\mu)}{(\mu - L)}$$

6. Weibull distribution

The Weibull distribution is a continuous probability distribution named after Waloddi Weibull who first described it in detail. The Weibull distribution is defined by two parameters W(λ,k), the shape parameter (k) and the scale parameter (λ) (Kujawski et al., 2004).

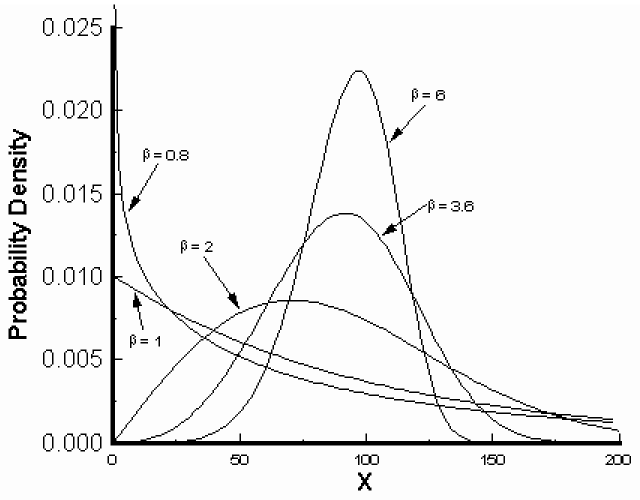

Figure 32: Weibull distribution (λ=100 and β is indicating the shape parameter k here) (Engineered Software, 2013b)

The PDF is given by:

$$f_x(x) = \begin{cases} \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^k} & if\ x \geq 0 \\ 0 & if\ x < 0 \end{cases}$$

The CDF of the Weibull distribution is given by:

$$F(X) = \begin{cases} 1 - e^{-\left(\frac{x}{\lambda}\right)^k} & if\ x \geq 0 \\ 0 & if\ x < 0 \end{cases}$$

The expected value of the Weibull distribution is given by:

$$E(X) = \lambda\Gamma\left(1 + \frac{1}{k}\right)$$

And the variance is given by:

$$Var(X) = \lambda^2\Gamma\left(1 + \frac{2}{k}\right) - \mu^2$$

Appendix C: Cost Estimating Handbook

The Cost Estimating Handbook describes broad cost-estimating topics including the cost estimating process. Their proposed cost estimating methodology consists of twelve steps (see Figure 33).

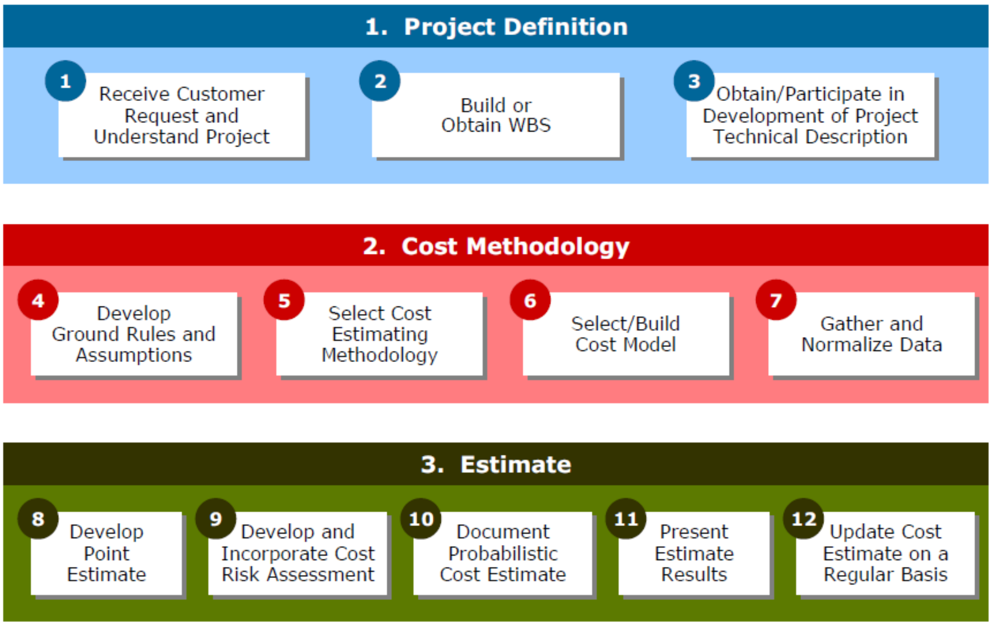

Figure 33: Cost Estimating Methodology (NASA, 2008)

This estimating process that NASA developed is extremely interesting for the purpose of this research. Therefore, the twelve steps will be shortly described, with extra focus on steps 5 and 6 which address the estimating methodologies and the factors that influence the selection of the most appropriate tool.

The first part of the process is the project definition, consisting of three steps.

1. Receive Customer Request and Understand the Project

All relevant project data are gathered and reviewed and the schedule, data, expectations and resource requirements are discussed with the client. Furthermore, the project's needs, objectives, scope etc. have to be evaluated. The four critical elements that any estimator needs are data, expectation, resource and schedule.

2. Build or Obtain WBS

A Work Breakdown Structure divides a project into manageable pieces of work in order to facilitate planning, control, cost, schedule and technical content. The WBS sets a structured framework that can be used to establish the cost estimate. Obviously estimators should first check if there already exists a WBS for the project. If not, a WBS dictionary has to be established that should secure a consistent terminology in all project documents. This can be used to construct the WBS for the entire project.

3. Obtain/Participate in the Development of Project Technical Description

The end result of this step is a common baseline document that describes the project and which can be used as a basis for the estimate. The amount of detail in this document is dependent on the available time to conduct the estimate, project size, technical information that is available, the objectives of the project and the lifecycle phase of the project. It is necessary to identify risks that could significantly impact the estimate at this stage.

The second part of NASA's estimating process is the Cost Methodology. A framework is created that is used in the third part of the estimate. The Cost Methodology consists of four steps.

4. Develop Ground Rules and Assumptions

In this step the ground rules and assumptions (programmatic, technical and schedule) are established in order to define the scope of the estimate. The ground rules and assumptions have to be discussed with relevant stakeholders and documented during the estimating process. It should clearly state which costs are included and which costs are excluded. This step is also important, because it provides a basis for comparison with historical and future projects. The items that should be covered in the estimate are:

- Guidance for interpretation: currency, base year, inflation indices used etc.
- Excluded costs from the estimate
- Percentages or approach used for business services
- Technology assumptions
- Unit quantities and make/buy decisions
- Life Cycle Cost considerations
- Implementation approach
- Schedule Information
- Facility usage (new, modifications, existing)
- Management concepts

5. Select Cost Estimating Methodology

NASA (2008) defines three cost estimating methodologies: Parametric Cost Estimating, Analogy Cost Estimating and Engineering Build Up.

1. **Parametric Cost Estimating**: The Parametric approach uses historical data and mathematical expressions that relate cost with selected, independent, cost-driving variables. A regression analysis can be performed to identify the relationship between dependent and independent variables. The assumption behind this methodology is that the same factors that affected the cost in previous projects will also affect costs in the future. If historical data is available the estimate can be prepared relatively fast. This methodology is normally used when little data about a project is known.
2. **Analogy Cost Estimating**: This type of methodology is performed on basis of comparison and extrapolations to like items or efforts. It requires a database with historical cost data of previous

projects. This cost data will have to be adjusted upward or downward depending on the complexity, inflation, technologies used and other cost affecting factors.

3. **Engineering Build Up Methodology**: This methodology, also called bottom-up estimating, uses the WBS as a basis. Each cost component of the WBS has to be estimated from the lowest level on. Labor and materials are usually estimated separately and for labor extra costs such as fees, burdens and overhead have to be added.

Factors such as lifecycle phase, available time, data and resource availability and cost influence the selection process of the estimating methodology. Also, methodologies can be combined to respond to limitations of these factors. NASA developed a quick reference chart in which the selection is only based upon the project phase, see Figure 34 where Pre-Phase A corresponds to the project's feasibility phase and Phase E to the project's execution.

	Pre-Phase A	Phase A	Phase B	Phase C/D	Phase E
Parametric	●	●	◐	◐	○
Analogy	●	◐	◐	◐	○
Engineering Build Up	◐	◐	●	●	●

Legend: ● Primary ◐ Applicable ○ Not Applicable

Figure 34: Cost Methodology Selection Chart (NASA, 2008)

6. Select/Construct Cost Model

During this step the available cost methodology is reviewed and a suitable methodology is chosen. The methodology directly determines the tool which is going to be used, if no tools are available than a new tool has to be developed. Both existing and new tools need to be validated before usage. The estimator has to be able to defend and underpin the choice of methodology. Excel sheets are often used and adapted to meet the demands of the estimator. Furthermore, different types of commercial software is available that supports the estimating process.

7. Gather and Normalize Data

Data collection can be one of the most difficult and time-consuming tasks during the process of cost estimating. Data can come from different sources e.g. surveys, interviews, model data collection, historical data bases, contracts etc. In this phase of the cost estimating process it is important to collect as much information as possible in order to develop the most accurate cost estimate. Information regards both project specific information as well as the company's cost data. These kind of information are often confidential and should be dealt with as such. At this stage it is also important to start gathering data to support the risk assessment, this can save time in a later stage of the estimating process. The collected information will first have to be normalized, which is the process of adjusting the information with factors such as currency changes, inflation, technical improvement, scope consistency, complexity etc.

After the Project Definition and the Cost Methodology all the necessary information is available and the actual estimate can be developed. The five steps taken in this part all contribute to a defensible and complete cost estimate.

8. Develop Point Estimate

The data that is gathered and normalized in step 7 can now be entered in the cost model chosen/developed in step 6. The cost model has to be verified with the ground rules and assumptions established in step 4. These activities should provide a first estimate, however, this estimate will first have to be adjusted according to the lifecycle of the project with inflation factors which can be added to the cost model. In order to reduce faults the formulas and input data will have to be checked and it is advisable to verify the estimate with historical project data.

9. Develop and Incorporate Cost Risk Assessment

A critical part of cost estimating is identifying risks and estimating the consequences and probability of occurrence of the risks. This results in probability distributions for the cost model uncertainty and for the technical and schedule cost drivers. The cost risk assessment also provides input for risk management during the project, which supports project managers to proactively reduce risks by taking mitigating actions. Assumptions that are made at the beginning of the project may be inaccurate. A sensitivity analysis is a tool that indicates the consequences of variations in the assumptions. It also determines the impact of different risks on the point estimate. The sensitivity analysis and the cost risk assessment provide a basis for the level of unallocated future reserves. The project manager can choose the level of confidence based on a large number of simulations of all probability distributions resulting in a Cost S-curve. The confidence level is most times chosen between 70 and 85%.

10. Document Probabilistic Cost Estimate

This step should provide a written documentation for the cost estimate and all its by-products. Independent cost estimators should be able to deduce the development of the estimate together with all the information and assumptions used during the estimating process. Consistent documentation provides benefits for future estimates, because it contributes to an accurate historic database. During the lifecycle of the project, the estimate should be compared with the actual cost providing a comparison track. This comparison track will also have to be documented along with the other estimating information, the following information has to be documented:

- Estimating methodology used
- Information used for the development of the estimate (Basis of Estimate, Data sources, inflation and other assumptions, net present value etc.)
- Additional explanation of the methodology used
- Description of bidding strategy (this can affect the LCC)
- Sensitivity analyses
- Comparison track estimate and actual cost

Documentation should be started early in the estimating process and should be continued during the entire estimating process and project's lifetime.

11. Present Estimate Results

Estimators have to be able to present and defend their cost estimates. Additionally, consistency between different centers (or offices) promotes completeness and secures the quality of the cost estimating process. The use of the same template can be a mean to reach consistency. Standardization of the cost estimating process over the centers provides opportunities to maintain high quality estimates by knowledge exchange and thorough documentation between centers and customers.

12. Update Cost Estimate on Regular Basis

The purpose of this step is to include lessons learned and customer feedback of estimates in future estimates. Furthermore, by updating the cost estimate during its lifecycle it is possible to give decision-makers more clarity for major cost affecting decisions.

These are the twelve steps recommended for the cost estimating process described by NASA (2008).

Appendix D: Interviews with services estimators

Table 33: List of interviewees in Fluor

Name	Office	Country	Function	Date
Edward Vonk	Farnborough	United Kingdom	Services estimator	November 7, 2013
Malgorzata Kowa	Gliwice	Poland	Services estimator	November 7, 2013
Maria Sanz	Madrid	Spain	Department head Project controls	November 12, 2013
Isabel Nel	Johannesburg	South-Africa	Project controller	November 19, 2013
Rob van Lohuizen	Haarlem	Netherlands	Project controls specialist	Multiple occasions
Martijn Koster	Haarlem	Netherlands	Department head Estimating	Multiple occasions
Ariel Tsitrone	Haarlem	Netherlands	Services estimator	Multiple occasions
Ron Tjioe	Haarlem	Netherlands	Services estimator	Multiple occasions

Appendix E: Cost components in the cost of services

1. Wage rate

The wage rate consists of the following parameters:

- Base salary
- TOWP (Time Off With Pay)

The wage rate has to be corrected by a factor called the TOWP, which is an abbreviation for Time Off With Pay. The TOWP corrects the labor rate for sick days, vacation days, and personal days. It can be calculated with the following formula:

$$f_{TOWP} = \frac{t_{working\ hours,y}}{t_{working\ hours,y} - t_{TOWP,y}}$$

Where,

f_{TOWP} = annual percentage of Time Off With Pay

$t_{TOWP,y}$ = Time Off With Pay; Number of hours with paid leave e.g. sick days, vacation days and personal days (hours)

$t_{working\ hours,y}$ = Number of working hours per year (hours)

$$t_{working\ hours,y} = n_{w,y} * n_{working\ hours,w}$$

Where,

$n_{w,y}$ = Number of weaks per year (52)

$n_{working\ hours,w}$ = Number of working hours per week (in most Western countries a typical work week consists of 40 hours)

The estimator can choose the same strategies for the TOWP as they choose for the base salary (TOWP per named position, average discipline, etc) or they can apply the home office average.[9]

The wage rate can be calculated by multiplying the base salary with the TOWP. The base salary is usually used as input for the estimate of the cost of services.

$$C_{wage\ rate} = C_{base\ salary} * f_{TOWP}$$

Where,

$C_{wage\ rate}$ = Wage Rate (euro/hour)

$C_{basesalary}$ = Base Salary (euro/hour)

f_{TOWP} = TOWP factor

[9] The strategies are explained in Chapter 4.5.

2. Payroll Burdens

Payroll burdens consist of all costs an employer is required to pay to the employee in addition to his/her wage rate.

- Payroll taxes
- Health/Life/Dental and Disability Insurances
- Retirement and Performance Plan Contributions
- Employee benefits (Travel allowances, Training expenses, compensations, etc.)

In Fluor, the wage rate is increased by an average percentage representing the payroll burdens. The subtotal of this is called the Burdened Labor Rate. Each Fluor office calculates its own payroll burdens annually.

Standard-time and over-time

Most of the payroll burdens have to be paid for the standard working time. In the case of over-time, the amount of payroll burdens decreases significantly and the TOWP factor equals zero, since no holiday/sick time exists in over-time. For this reason, it is desirable to take over-time into account separately from standard-time in the estimation of the cost of services.

3. Overhead

The overhead cost of a company can be defined as the ongoing expense of doing business. It represents all costs that cannot be separately contributed to project activities. The following costs are typically included in the overhead:

- Corporate Management
- Office Management
- Sales
- Legal services
- Human Resources
- Accounting
- Administration
- Rent, maintenance, operation and depreciation of the office(s)

Note that the mentioned departments can also work on projects and are not part of the overhead in that case. They will either be charged to the project or they are included in the non-billable uplift, which will be explained later on. This is based on the principle of Activity Based Costing.

The costing methodology Activity Based Costing is used in the preparation of the services costs (Choon & Ali, 2008). All costs that can be contributed to a project activity will also be assigned to that project. This results in a more transparent insight in the project costs and reduces the unwanted effect of projects subsidizing other projects. When work is performed at the office location of the engineering company, i.e. the Home Office, the costs for services can be defined as: 'costs associated with the performance of business activities which can be allocated to particular ongoing projects (engineering, drafting, procurement, estimating, value engineering, document control, expediting, inspection, administration, copying services, telephone costs etc.)' (Compass International Consultants, 2011). In Fluor offices the overhead costs are allocated for each individual person by adding a fixed cost to their representative man-hour rate. The overhead costs are strategically distributed over all offices in Fluor.

4. Office and Field Expenses

As explained all project related office expenses are distributed to the project activities. Office expenses are the general term used for all direct costs related to the use of office services and supplies required to work on the project. It includes, among other all standard office supplies, mail, reproduction, desktop computers/laptops and software and local communication. This is a fixed amount that is determined each year. Furthermore, there can be other types of office or field expenses such as business travel, assignment costs, software costs or miscellaneous costs.

Business travel

If it is necessary, business travel can be charged under the office expenses. Business Travel is charged according to Fluor's internal policies. Business travel is preferably reimbursed at cost and has to be added to the contract.

Assignment costs

The assignment costs are just as the business travel costs charged according to the policies of Fluor. This policy has to be included in the contract and will reimburse the costs for the assignment. If for some reason the client declines the possibility to include the policy in the contract then the costs have to be determined separately. This always has to be done project specifically, because each project and location has different prices.

Software

It may be possible that special software is required by the client. Additional software charges will then be used to reimburse the costs for the licenses. Such costs can be included in the man-hour rate. The term that is used for such costs are SBU expenses.

Miscellaneous costs

In this category all other possible expenses are considered. For example company cars can be charged in this category or if there are costs involved for team-building, or for small reward programs.

5. Uplift Non-billable costs

Project costs can be separated in billable costs and non-billable costs. Billable costs are costs that can be billed to the client directly. There are always costs that for some reason cannot be billed to the client directly. Reasons for this can be client or contractual requirements. Examples of non-billable costs are costs for Project Business Services, administration or specific client requests. Usually a non-billable cost reserve or allowance will be introduced for each project to cover such costs. However, in the estimate, the amount of non-billable costs that is expected to occur for a project has to be estimated. Typically this is done by an uplift of the man-hour rate for each individual.

6. Escalation

In the escalation the costs for increases in the cost of labor, inflation and other cost components are covered that occur due to the continuing price changes during the duration of the project. Risk, uncertainty and currency exchange impacts are not considered in the escalation and should be dealt with separately in the contingency. The escalation can be assessed based on experience and knowledge about the market conditions, agency market, regulation, general industry or regional-wide productivity and other economic factors (AACE International, 2011). For this reason it is recommended that those with the most economic expertise are included in the development of the escalation estimate. They possess the most knowledge regarding trends in wages, markups, premiums, inflation, and productivity factors. In specific micro-economies such as the process plant engineering, procurement and construction, factors such as market strength or weakness can be a dominant price driver of price trends (AACE International, 2011). Macro-economic factors will have to be adjusted for such micro-economic trends. Escalation might also be determined by the contract, which means escalation does not have to be taken into the man-hour rate if the contractual requirements are deemed sufficient.

The escalation can be estimated in many different ways and by many different estimating techniques. The escalation is less amenable to quantification techniques based on empirical project data since the escalation is largely driven by economic conditions. Hence, parametric estimating and input based on project teams' experience (e.g. expected value and range estimating) are not appropriate techniques to estimate the escalation. The estimation of escalation is in general based on the following variables (AACE International, 2012a):

- Project schedule (Start and Finish) – two variable cash flow expended over time
- Indices - cost or price forecast indices.
- Cash Flow Pattern – cash flow within the start/finish boundaries
- Escalation over the cost contingency

The escalation can be determined deterministic or probabilistic. Probabilistic estimating may be appropriate because the estimation involves uncertainties in the base cost values, the time of spending and the index and adjustment factors values. These uncertainties can be quantified by providing a distribution so that management can make effective investment and project decisions and select a escalation budget based on their desired confidence of under run (AACE International, 2011). In both cases dependencies and correlations between the variables have to be established. From practice (AACE International, 2012a) it shows that escalation on cost contingency and project schedule are usually correlated. Furthermore, the cost indices are usually significantly correlated with each other and the cash flow pattern can be treated independent of other variables.

7. Contingency

There are two types of contingencies that are used in the estimation of the cost of services. The first is the Event Driven Contingency, which is an analysis of all the contractual and other potential risks that are specifically associated with the project. These are calculated by brainstorming all possible risks and finding their probability of occurrence and cost if the events take place. All this data is inputted in a Monte Carlo Simulation tool and results in a total cost contingency for the project as a percentage. This percentage is added to the total costs, which are calculated deterministically.

The other contingency that may be used is the estimating contingency in the cost of services. This contingency is added for uncertainties in the scope, quality of data and the estimated man-hours. The proposal manager and engineering lead representatives make a substantiated estimate for the uncertainties resulting in the estimating contingency. This is also usually taken as a percentage increase of the estimated costs.

8. Cost of Cash

The cost of cash has to be taken into account to compensate the costs for pre-financing the project and to correct the price for interest. In Fluor the cost of cash is usually taken as a percentage increase per man hour based on the contractual arrangements.

9. Other

Next to all the mentioned cost components there can be additional costs required that are very project specific. Examples are bank guarantees, insurances, performance bonds, taxes, subcontractor costs, etc. Such costs have to be estimated for each project separately, because they are so various that it is hard to find prices based on experience or historical data. Often quotations for the prices of these components are asked by the bank, insurance company or subcontractor, which can be used in the estimate.

10. Total Costs

All cost components added up result in the total costs for performing the services. The correctness of the estimate of these costs is important, because overruns can result in large financial losses. By the total costs an amount of profit is added. The amount of profit may be determined by the contract or the engineering contractor may decide this. However, as explained in the scope of the research (Chapter 2.4) this research focuses on the cost side and decisions regarding profit are outside of the scope.

Appendix F: Sensitivity Analysis

This appendix is not included due to confidentiality reasons.

For information and questions please send an email to jaschazwaving@hotmail.com

Appendix G: Case studies

This appendix is not included due to confidentiality reasons.

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Appendix H: Cost distribution fitting

This appendix is not included due to confidentiality reasons.

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Appendix I: Discrete distributions

This appendix is not included due to confidentiality reasons.

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Appendix J: Probabilistic Cost Estimating Model

This appendix is not included due to confidentiality reasons.

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