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MASTER'S THESIS

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Uncertainty analysis of weight estimating in the Oil & Gas industry

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Main objective is to analyze uncertainty with respect to WEPS (Weight Estimating and Project Screening) and Ramboll's methods for weight estimation and how it performs. The reason for evaluation of an already implemented and well used tool is the high demand for continual improvement of precision tools and low margin of error. The intention with the thesis is to bring to attention areas of concern and suggest solutions to minimize the uncertainties. Another part is to analyze performance of WEPS and look at alternative solutions. This required research on relevant topics. Some internal literature is available in Ramboll and some information is attained through attending WEPS development meetings. The thesis is in some degree built on industry standards and theory about risk and uncertainty management. The risk picture is presented with a bow-tie diagram, which the key uncertainty issues are derived from and further evaluated. The results are uncertainty related to the following key issues: input values, model sensitivity, experience and data material. These issues are categorized in Conceptual- and Operational - uncertainty. Methods for how to minimize, eliminate or control the uncertainty are evaluated. It is found that conceptual uncertainty could be handled by training of estimating team in relevant topics for estimation. It is also found that information management could impact and minimize the related uncertainty. Operational uncertainty is normally handled by the use of weight allowances and weight budgets. This is assessed as a well functioning method for managing weight constraints for indefinable elements and unforeseen consequences. The model accuracy and uncertainty of WEPS is analyzed according to class B estimate. The results are compared with as-built data and a simpler alternative method. This alternative method is created by the author for the purpose of this thesis. The analysis is done by estimation of ten projects by each method in two separate rounds and study of the results. The result from the first round show that WEPS gives poor base estimate but it is often just one or two factors that contribute to this error. Over all the analysis shows that it is possible to achieve significant result for B estimate and points to evidence that also C and D estimate is possible. These classes have not been fully tested in this thesis. Reason for not testing these classes is mainly the needed for a professional estimator, which can secure sufficient and confident estimates for the analysis. This is not available for the analysis. The unexpected result is that the alternative method performs better both according to accuracy and uncertainty. This is probably due to restriction in time for analysis. The evaluation of WEPS show that WEPS is a highly technical, adaptive and detailed method for estimation of weight that meets the requirements for class B set by the industry standard TR1244. It gives the estimator full control and many possibilities in all aspects of the estimation process. There are aspects of conceptual - and operational - uncertainties present. Some methods for managing the total uncertainty are introduced. The final conclusion must be that the WEPS method has some areas of concern related to uncertainty and accuracy. The alternative method for estimating which is introduced show promising result.

Børge H. Sand

Preface

This thesis marks the finalization of my master study in industrial economics at the University in Stavanger, spring 2011. The master thesis is written in association with Ramboll Oil and Gas Norway.

Purpose of this assignment is to perform an uncertainty analysis of WEPS and Ramboll's method for weight estimating. This is an estimation tool made and used by Ramboll for weight estimating in the Oil and Gas industry. WEPS is analyzed both qualitatively and quantitatively according to estimating theory, risk management, project management and engineering practices. In the first part of the thesis a traditional uncertainty analysis is performed. In the second part WEPS is compared to an alternative estimating method comparing accuracy and uncertainty.

This assignment has been a learning process and has given the author significant knowledge and understanding of weight estimating. The process has also demanded knowledge in engineering management, practical project management and applied statistics. A prerequisite for the thesis was that the author learned to use two applications; WEPS and @Risk, to perform estimates and analyses.

Objective of the thesis is restricted to cover weight estimation of new projects in the Norwegian continental shelf. Further the thesis is restricted to evaluation of level two in WEPS. Some of the central material available at Ramboll is confidential and has limited the amount of interactions with exterior parties. Due to use of confidential data in this thesis some information will not be revealed.

I want to thank Ramboll for the opportunity to write this thesis. Particularly: Ole Johnny Paulsen, Morten Simonsen, Magnus Mobech, Deon Paul Fouchè and Alex Montgomery, for sharing their insight and expertise in relevant subjects. I also want to thank Kristin Roll for guidance and advice through the thesis.

Definitions

As-built data:	Data collected from a project describing the final state of the project.
Estimator:	The person that perform the estimate.
Estimate:	Calculation to approximate a future size or value (TR1244, 2009).
Discipline:	Field of study or a branch of knowledge in engineering these are: electrical, piping, HVACE, corrosion protection, fire and safety, etc.
Bulk:	Items from the discipline that contribute to the weight such as: electrical items, piping components, instruments, safety items, etc.
Hook-up work:	Work that has to be performed after mating to substructure or between prefabricated modules or skids.
Benchmarking:	Process of continuously measuring and comparing estimate or factors against comparable processes in known as-built data.
Decision basis:	Information material available for management to use when undertaking a decision.
Decision gate:	Formal method to conclude and accept products or activities from a particular phase of the project.
Layout:	Graphical presentation of a platform.
Explanatory variable:	Variable used to describe the relationship (input) and predict the output.
Response variable:	Estimated variable or the output.
Conceptual uncertainty:	Uncertainty related to the analysis and related model.
Operational uncertainty:	Uncertainty related to internal processes and project execution.
Master equipment list:	List which contains all equipment that will be installed on the platform.
Model:	Simplification representation of the real world (Aven 2008).
Uncertainty (risk):	Lack of knowledge about something (quantity) (Aven 2008).
CV-value	CV-values is a measure of the standard error of a random variable over the mean value for the same variable (WEPS user manual 2009).
Outliers	Observation that is numerically distant from the rest of the data

Abbreviations

WEPS:	Weight Estimating and Project Screening
MEL:	Master Equipment List
DG1:	Decision Gate number one
MTO:	Material Take Off
FEED:	Front End Engineering and development
NPV:	Net Present Value
PMCC:	Pearson's product-Moment Correlation Coefficient
CV-value	Coefficient-of-Variation-value

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1 Introduction

1.1 Background for thesis

The Oil and Gas industry is a competitive and technologically intensive industry. The projects are very extensive and can involve capital expenditures of several billion NOK. Projects of this magnitude require a stock of qualified personnel, equipment and tools to achieve adequate and cost efficient solutions.

During early stages of an Oil and Gas project it is crucial for project management to make critical decisions. These decisions are the foundation of the project. Project management has to decide which concept and solution is best suited for that particular project. The information to base these decisions on is often incomplete and is considered to involve considerable uncertainties. Management must have confidence in the basis for decision making. The basis has to be carefully put together and one important part of this is cost estimating. Weight estimation is one of the key bases for the cost estimation process. This results in demand for precision tools and qualified professional employees to handle weight estimation.

WEPS is an advanced weight estimating program for the Oil and Gas industry. The software is created and mainly used by Ramboll. WEPS is a detailed and advanced tool that demands qualified experienced professionals. It is widely used and is considered to be a reliable and well proven solution.

1.2 Objective of the thesis

The main objective of the thesis is to analyze uncertainty with respect to WEPS and Ramboll's methods for weight estimating and how it performs. The main aspects to research:

- Which level of uncertainty is present in weight estimating and which aspects contribute to the uncertainty?
- How does weight estimation with WEPS perform and how does it compare to alternative methods?

The WEPS tool has been used for twenty years to estimate weight in Ramboll. The reason for evaluation of an already implemented and well used tool is the high demand for continual improvement towards improved precision and towards lower margin of uncertainty. The thesis will bring to attention areas of concern and suggest solutions to minimize the uncertainties.

1.3 Research questions

Based on the objective of the assignment, the following questions have been asked.

- What does the risk picture look like, is there a need for risk management?
- Which uncertainty is present when using WEPS and associated methods?
- In what way can these uncertainties be mitigated?
- How does the WEPS method perform against an alternative method?

The risk picture is evaluated using a bow-tie diagram and the total risk picture is discussed. The bow-tie is used to map uncertainty in connection with WEPS and underlying methods. The following are evaluated in greater depth: sensitivity analyses of relevant factors, program sensitivity to errors and deviating data and the magnitude of knowledge needed to create satisfactory estimates. The underlying data material is evaluated for abnormalities, errors and trends. Methods for elimination, diminishing and handling the uncertainties will be discussed.

WEPS performance is tested by estimation of 10 individual projects. The accuracy of total topside weight and total discipline weight will be analyzed. Results are evaluated against as-built data and requirements from industry standards for class B estimates. The method is also compared against an alternative estimating method which is produced by the author. The following evaluation criteria are selected for comparison: accuracy on total weight, total discipline weight and total estimate uncertainty.

The final results which can be viewed in chapter 6.2, show that WEPS and the alternative method perform within the requirements set by TR1244 for class B. By the use of approximately the same limited time, the alternative method is better for achieving both accuracy and uncertainty for a class B estimate. However, this does not mean that the alternative method is generally the best method. Class B estimates can be rather easily achieved and since it is not possible to test the methods for class C and D it is impossible to conclude which is the overall best method. It is, however possible to conclude that the alternative method performed best related to uncertainty and accuracy for class B estimates when reduced amount of time and experience is available.

1.4 Thesis structure

Table 1 describes the structure and content of the thesis.

Table 1: Thesis structure and content

Objective	Chapter	Content
Assignment	1. Introduction	The introduction gives background information for the thesis, objective and intentions, research questions, delimitations and how the thesis is structured.
	2. Background	Gives a short introduction to Ramboll, why weight estimation is important and how it is performed today.
Literature	3. Theory	Describes relevant theory about project management and planning, uncertainty, alternative weight estimation methods, WEPS-method and @Risk-method.
Process	4. Method	Describe the analysis which is conducted in order to answer the research questions.
	5. Data	Presents an overview of the amount of available data, characteristics of the data and how the data should be handled.
Analysis	6. Results	Presents results from the uncertainty analysis and the evaluation between WEPS and the Alternative method according to the thesis objective.
	7. Discussion	Answer the research questions by using both theory and results to discuss them according to the thesis objective.
Conclusion	8. Conclusion	Conclusion based on purpose and intention of the assignment.

2 Background

2.1 About Ramboll

The following section is taken from a Corporate Presentation Ramboll (2010). Ramboll is an international company with a network of more than 8,500 dedicated specialists in 24 countries. Ramboll was founded in 1945 as "Ramboll & Hannemann" in Denmark. Table 2 describes the key financial figures for the company.

Table 2: Financial figures 2009 cited in Corporate presentation Ramboll

The Ramboll Group	2009
Revenue in EUR million	739,7
Operating margin in %	5,8
Profit before tax in EUR million	28,5
Equity ratio in %	34,8

Ramboll is a multi-discipline engineering, design and consultancy company providing services under seven main service areas:

- Buildings & Design
- Energy & Climate
- Industry & Oil/Gas
- Management & Society
- Infrastructure & Transport
- Environment & Nature
- IT & Telecom

Ramboll`s main Strategy:

To be a leading, international, independent engineering consultancy within oil and gas and offshore wind farms in selected markets (geography and services), and in accordance with the Ramboll Group`s core values.

Vision:

Through the inherent ability of our people, our integrity and business principles, Ramboll strives to create solutions for our customers that balance human and commercial needs and are genuinely insightful and progressive.

Goal:

- To be in the top 20 global peer group
- The revenue in Ramboll Oil & Gas will pass DKK 1 billion
- Profitable growth in revenue on existing and new markets averaging 20% or more.
- Continuously improved employee satisfaction
- Continuously improved customer satisfaction

Ramboll provide weight estimates for Feasibility studies, Screening studies, Concept Studies and Front End Engineering & Design (FEED). Ramboll also provides weight control of platforms in operation. Some of the main tasks in the weight department are establishing weight control procedure requirements for typical offshore projects, establishing and maintaining weight reports during operation of oil and gas platforms, evaluating impact from changes in weight on platforms in operation.

2.2 Why weight estimating?

It is imperative to know why weight estimating is done. Weight is a central evaluation criterion alongside cost and production on an offshore project. Because of limitations within technical concepts and strict standards, weight has to be evaluated carefully. Weight is a dimensioning factor and important for other activities such as: cost estimation, transportation and lifting, substructure capacity, stability analysis and load conditions evaluation of offshore concepts (TR1244, 2009). It is important to understand weight estimating, to fully understand the risk picture and uncertainties. Aven T. (2008) argues the significance of performing dimension analysis early in the lifecycle of the project. TR1244 (2009) states that weight estimation is primarily performed for the reasons below:

2.2.1 Input to cost estimate:

Weight estimate is one of the main inputs for cost estimation. This is because weight describes the quantities in the project. The accuracy and variance of the weight estimation has a direct impact on the cost estimation result. The variance has to be controlled and minimized if the required variance for the cost estimate shall be achieved.

2.2.2 Transportation and lifting analyses:

Transportation and lifting operations are extremely critical and complex procedures. These operations are both expensive and associated with risk for the environment and people, and correct measures shall be taken to mitigate the impact on these elements. The Oil and Gas Industry has high focus on safety and has created strict standards that shall be followed.

2.2.3 Substructure capacity:

When evaluating different concepts, main production data and cost drivers are evaluated, to find the best concept that optimizes oil/gas production and NPV. When the production data is mature, the process department can analyze and produce a list of necessary equipment (MEL). This list is one of the input factors to the total weight estimate. It is vital to dimension the substructure to support the total weight. On floating structures the substructure should provide buoyancy for the total weight.

2.2.4 Stability analysis and load conditions:

These conditions are extremely important for the safety aspects. The substructure needs to be dimensioned for stability and relevant load conditions. The weight estimate is central in this process as well, especially in the early stages. When the project progresses into detailed engineering the estimated weight is gradually substituted with actual weights or known quantities.

2.2.5 Evaluation of offshore concepts:

Weight estimation is part of the decision basis for evaluation of concepts. Weight is directly and indirectly related to cost as mentioned above.

2.3 How is weight estimation performed today

To help the project management team to decide a key decision basis is put together. In Ramboll this is done by use of a Weight Estimating and Project Screening tool (WEPS). This is a weight estimating software package or a forecasting model.

This section is derived from the WEPS user manual (2009). WEPS uses a database with collection of 19 historical projects. The projects are broken down into construction units and further down into functional areas and on the lowest level into disciplines. At this level the fractions are small "building blocks" that can be individually evaluated for similarity to the new project. The hierarchy model is shown in Figure 1.

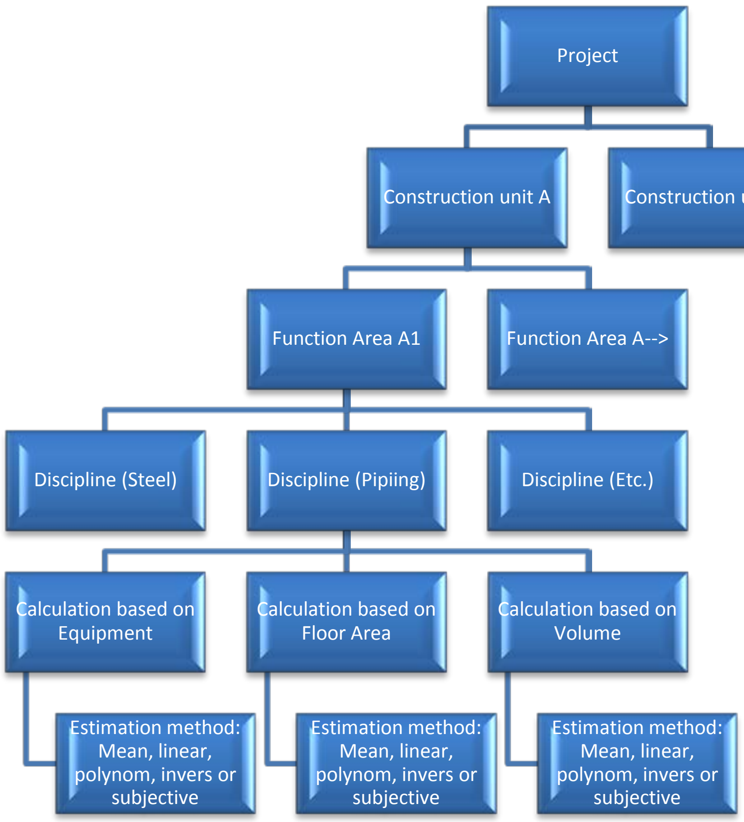

Figure 1: The WEPS Hierarchy

The estimation process uses factor estimating and shows trends in a scatter plot with the use of trend lines. The estimator chooses the mean value or a trend lines from the scatter plot. The selected value should be the most likely value for the new project. This is done for every set of building blocks. Equipment weight is one input value and is derived from the Master Equipment List (MEL) which is a list that contains all equipment at this stage. Area and volume are also used as input values and are measured by use of layout drawings. These input values are highly correlated and is thus used in estimating. The correlation between the variables is a problem for normal regression, this is why the model is used as prediction model and not as an explanatory model and this topic is more discussed in chapter 7.3. There are pros and cons in relation to the model used by WEPS these are presented below.

Pros: The high detail level makes this method relevant for most types of concepts and unique features that a project may have. This level of detail makes it possible to realize specified accuracies for all types of projects. The method shows the data in every step of the estimation process graphically. This makes it easier for the estimator to se trends in the data and selection of the most probable values. The method has a special function for benchmarking between projects. This makes it possible to control what has been done in the estimation process and to evaluate abnormalities in the estimate. There are substantial uncertainties related to the input values. WEPS has a method where the estimator can benchmark and evaluate input values separately against other projects with similar values. Due to the unique characteristics of the method, WEPS is versatile and adaptive.

Cons: Due to the detail level and amount of calculations that needs to be accessed through the process, the method can be time consuming. Since the process uses relationships between historical data and the estimated project a high level of competence is needed. The estimator needs to have knowledge about the projects in the database and experience in the industry. A 25% CV-value (Coefficient-of-Variation) is put on the input values to represent the related uncertainty. This value is constant for all estimation classes. This can contribute to wrong interpretation of the true model uncertainty. The method used for measuring and defining functional areas may vary from project to project.

3 Theory

In this chapter relevant theory and methods will be presented which will be used through the thesis. It is important to have a clear picture of the environment surrounding an estimating process and where uncertainties come from. This is why theory about project management and planning is relevant. Project management is commonly considered as a method for planning and control of activities. Uncertainty is a major challenge when it comes to planning and control. There is uncertainty related to the occurrence of results from activities and processes, but there can also be considerable uncertainty related to the conditions under which they occur. There is a general understanding that project normally involve risk in some way and size Klakegg et al. (2010, p.405).

3.1 Project management & planning

To further understand the situations and conditions under which Ramboll perform weight estimation, the following theory about engineering management and requirements of cost classes is relevant. It is also relevant when creating a correct uncertainty picture and for creation of the alternative estimating method. As stated in the background information Ramboll provides estimating for Feasibility studies, Screening studies, Concept Studies and Front End Engineering Design (FEED). These are located between Decision Gate 1 (DG1) and Decision Gate 3 (DG3) in Figure 2. A decision gate is a formal method to conclude and accept products or activities from a particular phase of the project. The figure displays a normal flowchart of project phases and activities in a typical offshore project.

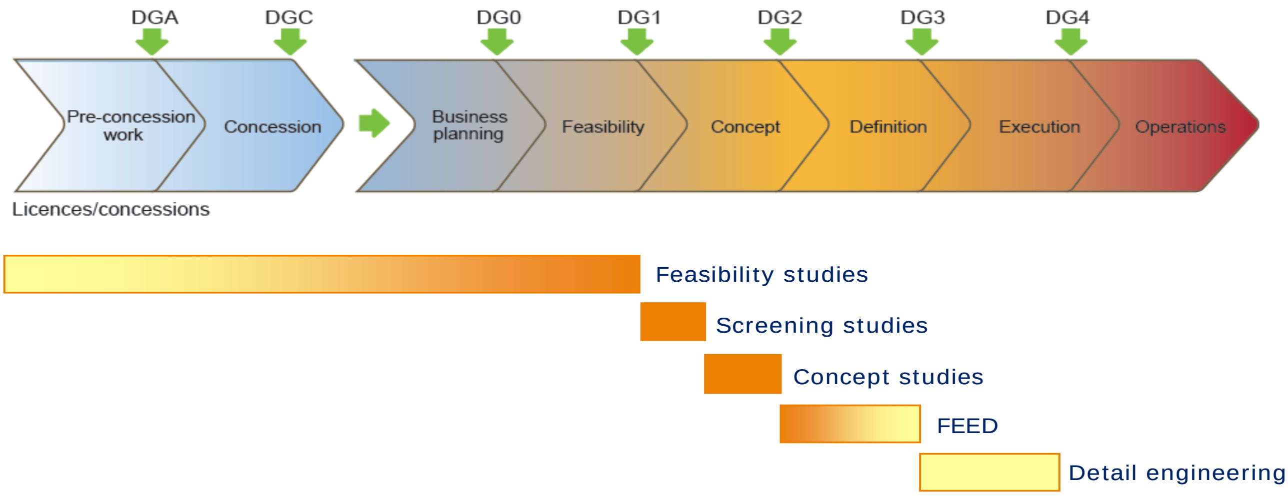

Figure 2: Project phases derived from (Corporate presentation Ramboll, 2010).

Following is an overview of the different studies in figure 2 and related cost classes. Weight estimation is performed in different stages of project development as mention above; each estimate is assigned a cost class. These classes introduce weight accuracy requirements for weight input, used in cost estimating. These requirements should be achieved by the weight estimating process. Class B will be used when comparing WEPS to the alternative method. The following three chapters are derived from TR1244 (2009). TR1244 is a governing document that present technical requirements for cost estimate classes for offshore projects. This document is produced by Statoil which has a central role in the Norwegian offshore environment.

3.1.1 Feasibility studies & Screening studies: class B

Class B is used in connection with feasibility studies and concept screening studies. The aim of a feasibility study is to express the technical and economical feasibility of a business opportunity. The aim with screening studies is to remove less suitable concepts from the selection process. The general detail level in these studies shall be limited. Simple analytical models and as-built data from previous projects can be used. In some areas higher levels of detail may be necessary to demonstrate feasibility.

In the feasibility study it is important to identify possible business development pitfalls such as: health, safety and environment, corporate integrity, social responsibility and corporate reputation in general. In concept screening it is important to also focus on characteristics and unique features of each concept. The following are the main requirements from TR1244 relevant for weight estimating of class B.

- Estimate should be based on: equipment list and the equipment layout
- Weights should be split on equipment, structural and bulk
- Bulk should be split on disciplines
- The requirement for weight accuracy is +/- 25% with a confidence level of 80%

3.1.2 Concept studies: class C

The purpose of concept studies is the selection of concept and further definition and documentation of the selected concept. For this level of definition a class C estimate is required and will form the basis for FEED. It is important that the amount of detail of the concept is sufficient so all stakeholders can accept the conclusion. The following are the main requirements from TR1244 relevant for weight estimating of class C.

- Estimate should be based on: Equipment list and the equipment layout
- Centre of gravity should be calculated
- Weight should be split: equipment, structural and bulk
- Bulk should be split on disciplines
- The requirement for weight accuracy is +/- 15% with a confidence level of 80%

3.1.3 FEED: class D

The idea of the FEED phase is to further detail, define and document the business case base on the selected concept. It is important to secure the final project and the applications to authorities. The enhancement of the technical definition is critical for success in the FEED and project execution phases of the project. This will reduce the amount of late project changes during the detail engineering phase and lead the way for successful project execution. The following are the main requirements from TR1244 relevant for weight estimating of class D.

- Estimate should be based on: equipment list and the equipment layout
- Centre of gravity shall be calculated
- Weights should be split: equipment, structural and bulk
- Bulk should be split on disciplines
- MTO for designed structures and sized piping to support the estimated weights
- Lifting weights shall be prepared
- The requirement for weight accuracy is +/- 10% with a confidence level of 80%.

As mentioned is class B used in the analysis of WEPS and the alternative method. TR1244 establishes technical issues that need to be assessed in order to perform estimates in the different classes. It is imperative that the specification established in TR1244 is adopted and assessed for each individual project. This governing document is developed for worldwide application and therefore has to be amended if special cases occur. Special cases can be specific local legislation, special operating conditions or local business and industry practice that challenge these requirements.

3.2 Uncertainty

Since the basis for this thesis relates to the analysis of uncertainty, some short definitions of relevant aspects are included:

Klakegg (2003) cited in Austeng et al. (2005, p.17) defines uncertainty as the absence of knowledge about what the future will bring. The difference of information needed for a safe decision and the information available at present time. Can lead to positive or negative outcomes according to expected results, this contain both risk and opportunities. Whereas Aven (2003, p.23) states that uncertainty relates to the lack of ability to predict a correct value and is expressed by a probability distribution of the observable quantities. Within psychology and sociology uncertainty is often related to observed behavior and interpretation of underlying motives and values (Hetland, 2003).

Uncertainty analysis is defined by Klakegg (2003) which is cited in Austeng et al. (2005, p.17) as the systematic method for identifying, describing and calculating uncertainty.

Estimate uncertainty is also defined by Klakegg (2003) in Austeng et al. (2005, p.17) which has been adapted to weight estimation. Uncertainties are related to weight elements or factors that influence the project weight. Estimate uncertainty describes consequences of circumstances as a continuous distribution. It seems that Aven (2003) shares this view point.

Austeng et al. (2005) presents three different types of uncertainty which are used in this thesis.

3.2.1 Conceptual uncertainty

Andersson (2003) cited in Austeng et al. (2005, p.60) define *"Conceptual uncertainty concerns the uncertainty originating from an incomplete understanding of the structure of the analyzed systems and its constituent interacting processes. The uncertainty is comprised both of lack of understanding of individual processes and the extent and nature of the interactions between the processes".*

Andersson's definition of conceptual uncertainty can be used related to the estimation of weight. In this case the uncertainty depends on the lack of understanding about the weight factors and what drives and influences the weight. It is also a function of the level of maturity of the engineering input.

Svensk Kärnbränslehantering (2004) states the following in Austeng et al. (2005, p.60). The estimator (expert) should discuss ways of treating the conceptual uncertainty by addressing the following set of questions:

- Is there any form of conceptual uncertainty related to the estimation model?
- Are there uncertainties related to the model in which the input parameters have been derived?

- In relations to the previous question, is it possible to express the conceptual model uncertainty by the parameter uncertainty in the given model?

These questions will be investigated in this thesis and they will be answered in the chapter 7.1.

3.2.2 Operational uncertainty

Operational uncertainty is another type of uncertainty which needs to be addressed. Christensen and Kreiner (1991) cited in Austeng et al. (2005, p.63) define operational uncertainty as the uncertainty that relates to an efficient execution of projects. This can be uncertainty from inside and outside the project that can be calculated or estimated and then mitigated or eliminated in the project phases. Some of the operational uncertainty can be handled already at the stage of defining the goal or purpose with the project, leading to reduced uncertainty for the following planning phase. In the same way reducing the uncertainty in the planning phase leads to a reduction in the following execution phase.

They further discuss that operational uncertainty is affiliated to organizing and execution of projects, and is relatively independent of circumstance and industry. A typical characteristic of operational uncertainty is that it is reduced as the project evolves. This is due to maturity of information and that the organization learns more about the process they are dealing with. The uncertainty can be reduced by systematic and realistic planning that leads to feasible goals, but also by information management and project management. Some of these elements are very important and will be addressed in relation with weight estimate and weight management in this thesis.

3.2.3 Contextual uncertainty

The third type of uncertainty is contextual uncertainty. Christensen and Kreiner (1991) cited in Austeng et al. (2005, p.64) states that, projects have a component of contextual uncertainty that is impossible to calculate. Contextual uncertainty contains changes that can be substantial if the project is in a turbulent environment or if the project owner is in doubt about the relevance for the project. The contextual uncertainty is unexpected and unpreventable so the project strategy should be to mitigate exposure to certain conditions of concern. The uncertainty can be traced back to the project surroundings. This type of uncertainty relate to those aspects of the project that cannot be controlled or calculated. This type seems to impact mostly on project level and is not that central in the estimation process. This is why this type of uncertainty is excluded from the analysis and this thesis. But it is an important issue and relates to if projects shall be executed or not. One option of dealing with this is to exclude this type of uncertainties in the estimation process and assign a specialist team to investigate this component on a project level.

3.2.4 Uncertainty and risk picture

Risk and uncertainties are closely related and this is why it is a suitable subject to investigate. It is important to evaluate the whole risk picture and this is something that Aven (2009) have stated. The historical data gives some understanding and feeling about the risk involved. In this case the risk about not achieving an estimate within the requirements set by the TR1244 standard. Assuming that the future weight philosophy will not differ significantly from the historic data we can achieve good predictions about the future. However, the road from historical data to future estimates can result in problems and unforeseen consequences. (Aven 2009) "*To fully express risk we need to look beyond the historical based data*".

This is interesting according to this thesis and points out that the uncertainty analysis should not only focus on the available data, but look for other traces of uncertainty. The bow-tie is a tool for graphical illustration of the risk involved in activities. The bow-tie can give an assessment about the key issues (Aven 2008). For the earliest estimates it should be enough to do a simplified risk analysis. Standard and more advanced risk evaluation could be evaluated for estimates of class D. These types of uncertainties or risk are normally dealt with by establishing a weight budget and adding weight allowances TR1244 (2009). Weight budget and allowances is evaluated below. Risk analysis can highlight issues that impact the future weight or the current estimate and are therefore a good tool.

3.2.5 Weight budget

The use of weight budgets is well known in the industry for dealing with weight growth due to incomplete information. This is a great method for dealing with operational uncertainty and is in line with Austeng et al. (2005) main idea.

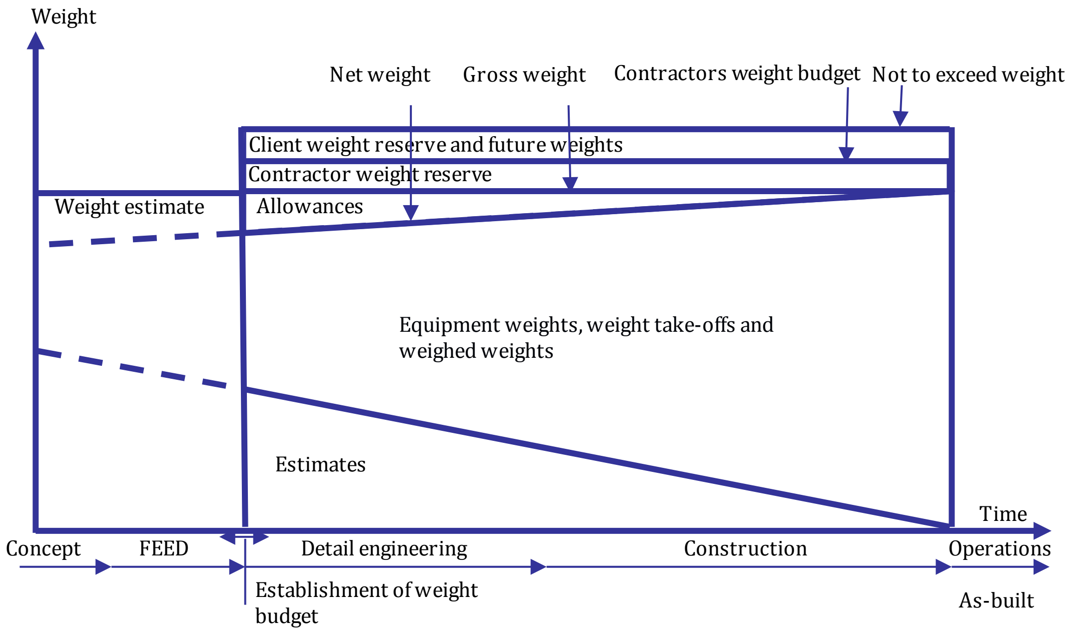

Figure 3: Weight budget (General Weight Development over time 2010)

Figure 3 shows that the weight reserve is added after the FEED, this varies from project to project. The line indicating allowances is dashed in the Concept and FEED phase due to the variety of allowances in use. The weight budget is established early in the project to represent the different aspects of the weight and reserves. Net weight: Weight without any allowances is achieved by estimation from early design documents or MEL and also defined weight e.g. equipment. Weight allowance: weight add-ons to account for expected universal growth due to immaturity at the current project stage. Weight allowances can be expressed either as percentages on each item or as a total sum of weights. Gross weight: sum of the net weight and weight allowances. Contractor weight reserve: weight add-ons restricted by the contractor and purpose is to account for possible design growth due to expansion of the preliminary design concept. Client weight reserve: weight add-ons restricted by the client and used to deal with any variation orders to the contractual design concept. Not-to-exceed weight (NTE): maximum acceptable weight for any given loading condition. Often limit is set based on lifting capacity on cranes or on floating capacity on hull (floaters).

In weight estimating (the time before detail engineering) there might be some known weight (MTO) and some weight allowance but mostly estimated weight. Weight budget is a great tool for dealing with indefinable weight elements and sums up weight process in a project.

3.3 Methods for weight estimation

To be able to construct an alternative method, it is important to view different methods that have been used. TR1244 suggests the following for estimation methodology. The estimated weight should cover both identified and unidentified or unspecified elements and presented as expected values, resulting in the inherent as-built weight.

The first method can be analytical models based on relevant previous projects for early stage estimates such as class A and partly class B. The estimation process assumes functions and capacities, and the weight is scaled based on earlier projects as-built data.

The second method can be used when there is sufficient knowledge about the project and the main equipment. The master equipment list (MEL) will be the basis for the discipline weights by application of weight factors. The method is used for class B and class C estimates, and to some degree, class D estimates. Weight can be estimated from the use of the following principles:

- Area/volume requirements and layout drawings can be created from MEL information. Bulk- and structure- weight can be estimated from area/volume density factors.
- Equipment weight for each system can be established. Bulk and structure weight can be estimated based on as-built factors for the applicable systems.
- When the MTO is established for the disciplines the MTO can be used for determining the weight per discipline. Allowance shall be added for undefined items. This method is used in combination with as-built factors for class D estimates.

The alternative estimating method will be based on the first method but detail description can be viewed in chapter 3.5. WEPS is similar to the second method and can utilize the three principles above. In each case it is always the estimators that decide in each case which principle to base the calculations on.

3.4 WEPS estimating method

The method that WEPS uses and how it works is essential, when performing uncertainty analysis. This chapter will describe how WEPS works and which method it uses. Figure 4 presents an overview of the WEPS method and constraints.

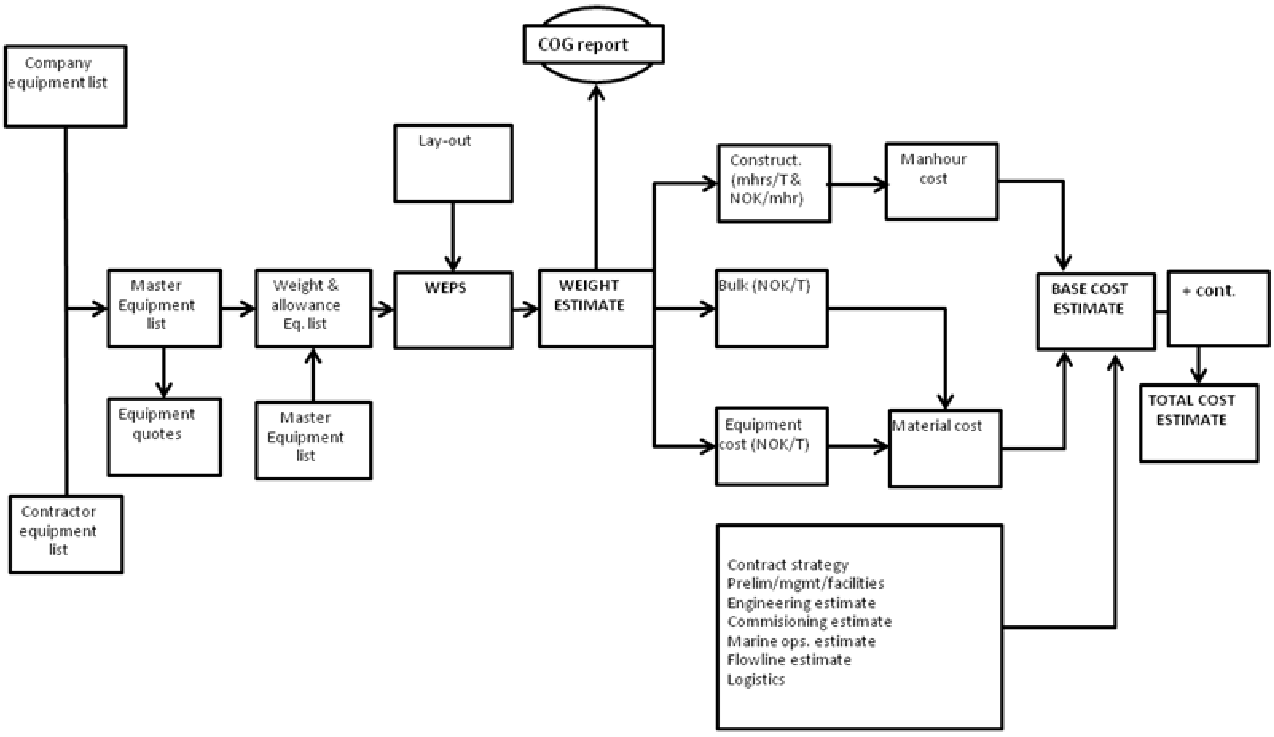

Figure 4: WEPS process (WEPS presentation 2011)

This section is based on the WEPS user manual (2009). The estimating methodology that is available in WEPS can be classified into two categories. One uses the mean factor estimate method. The second consists of regression as a prediction methodology for bulk factors. In both situations the result is calculated from a set of historical as-built data that is representative for the specific discipline. The estimator can choose which historical data items to use in the calculation.

3.4.1 Estimation model

The historical database consists of multiple projects that are split up into construction units, function areas and disciplines. For each calculation the estimator has to choose the input value to base the estimate on; Equipment weight, area or volume. When input is selected the estimator has to choose the trend line that best represents the data. There are four options, the mean value or linear, inverse or polynomial trend line. This process is done for every discipline in every function area in all construction areas. By this method the estimator has hundreds of possible calculations.

There is an understanding in the industry that the percentile split between the different disciplines often is almost the same for all "similar" projects. The estimate is normally benchmarked against historical percentage splits so that differences may be investigated. This will not be done in this thesis, because the intention is to compare the true estimate. This is also an operation that can be carried out after estimating in both methods.

3.4.2 Factor estimate

The data presented in the scatter diagram is factorial. The purpose of the factor estimate is to minimize problems related to the differences in the size of the projects. The unique characteristics of every project in the database vary and have to be considered carefully. Some of these characteristics can be viewed in chapter 5. Data.

3.4.3 Regression models

There are three different regression models available, which can be used to estimate factor values; linear, inverse and second-degree polynomial. In all models the explanation variable is the selected function area input variable. The response variable is discipline bulk factor values.

$$\boldsymbol{Linear}: \boldsymbol{Y} = \boldsymbol{\alpha} + \boldsymbol{\beta x} + \boldsymbol{\varepsilon}$$

$$\boldsymbol{Inverse}: \boldsymbol{Y} = \boldsymbol{\alpha} + \boldsymbol{\beta}\frac{\boldsymbol{1}}{\boldsymbol{x}} + \boldsymbol{\varepsilon}$$

$$\boldsymbol{Second\ degree\ poly}: \boldsymbol{Y} = \boldsymbol{\alpha} + \boldsymbol{\beta_0 x} + \boldsymbol{\beta_1 x^2} + \boldsymbol{\varepsilon}$$

Equation 1: Regression models applied in WEPS (WEPS user manual 2009)

Equation 1 shows the available regression lines. Output is estimated bulk weight factor for the specific discipline in the function area. The reason for using just one explanation variable is to leave room for the estimator to use expert experience to evaluate each case. It has never been a goal to make the process independent of the estimator. A central principle in this WEPS is that the estimator knowledge is always superior to the statistical model, regardless of the number of variables. Problems that appear due to spurious effects and the use of one explanation variable, is discussed in chapter 7.3 Statistical relevance.

3.4.4 Uncertainty in WEPS

The regression model uncertainty is calculated from the standard error of the residual and the standard error of the estimate. The finale bulk weight estimate results from two components of uncertainty. One is the uncertainty resulting from the regression model; the other is the uncertainty resulting from input value. The resulting estimate uncertainty or variance is calculated in Equation 2.

$$\boldsymbol{Var}(\boldsymbol{I} * \widehat{\boldsymbol{Y}}) = (\boldsymbol{Var}(\boldsymbol{I}) * \widehat{\boldsymbol{Y}}^2) + (\boldsymbol{Var}(\widehat{\boldsymbol{Y}}) * \boldsymbol{I}^2) + \left(\boldsymbol{Var}(\boldsymbol{I}) * \boldsymbol{Var}(\widehat{\boldsymbol{Y}})\right)$$

Equation 2: Final variance for discipline bulk weight estimated (WEPS user manual 2009)

In Equation 2 and is used to denote Input value and expected factor value, the correlation between them is supposed to be zero.

In WEPS the uncertainty of factors and estimate is displayed in all calculations as a CV-value. Equation 3 shows how Coefficient-of-Variation is calculated. WEPS user manual (2009) defines CV-values as a measure of the standard error of a random variable over the mean value for the same variable. This is the standard error of the estimate as a percentage of the estimated value. It is normal procedures to assign a CV-value to the input values in WEPS. These are normally set as default to 25%.

$$CV_{\bar{x}} = \frac{S_{\bar{x}}}{\bar{x}} * 100 = \frac{\frac{S_x}{\sqrt{N}}}{\bar{x}} * 100$$

Equation 3: Calculation of CV-value (WEPS user manual 2009)

3.4.5 Best and Worst CV

WEPS presents the best and worst CV-values for all estimates. The best CV-value is calculated on the basis that there is no correlation between functional areas in the construction area. The worst CV-value is calculated on the basis that there is full correlation between the function areas in the construction area. This means that there should be done an evaluation of the resulting CV-value for the total estimate. It is normal procedure to evaluate the resulting CV-value as the middle value between best and worst. Best and worst CV-value of the total estimate is the result of a Monte Carlo simulation. The analysis is based on the central limit theorem and a 68% confidence interval. It can be performed on the basis of normal distribution or a lognormal distribution, and can be displayed as a cumulative or a non-cumulative distribution. The analysis performs 1000 simulations. The analysis results in the total statistical estimate uncertainty.

3.5 Alternative estimation method

According to the objective and intention an alternative estimation model is compared against WEPS. This model needs to be established. The two methods utilize the same database but the calculations and the way the use relationships in the data differ. The data available is analyzed to find relationships that can be used in the estimation process.

The analysis described and evaluated relationships by correlation and scatter plots. Pearson's product-moment correlation coefficient (PMCC) has been selected to show relationships in the data. PMCC was developed by Karl Pearson from an idea introduced by Francis Galton (Pearson n.d.). Correlations between all disciplines and input values are evaluated. Some strong correlations are detected and the method will use a combination of estimation between disciplines and input values. This method use factor estimation the same way WEPS do to minimize the difference in size of the projects.

Each discipline weight will be estimated separately and then summarized for the whole project. Each discipline estimate can vary within a distribution. This distribution is constructed from the available data and fitted for each discipline into a Risk Pert distribution. The calculations are done with the use of a fully functioning trial version (@Risk 2011). A Monte Carlo simulation is performed on the basis that the disciplines are variables. 5000 simulations are performed, each providing total topside weight and discipline weight. The result is a distribution of the most probable result that the estimate could take. The result will be a total topside dry weight and weight for each discipline. The objective of this method is to create an adequate result for a class B estimate.

WEPS calculates all estimates from the three input values; equipment, area or volume. This method focuses on relationships between disciplines, for instance: Instrument is strongly connected to piping. Table 3 shows the correlation between discipline and input values.

Table 3: Bulk and input correlation

	P	S	E	F	H	I	L	R	Equi	Vol	Bulk+Equi
P	X	0,821	0,809	0,659	0,614	0,786	0,686	0,623	0,795	0,737	
S	0,821	x	0,959	0,782	0,922	0,630	0,947	0,658	0,859	0,899	0,949
E	0,809	0,959	x	0,799	0,929	0,769	0,967	0,535	0,835	0,924	
F	0,659	0,782	0,799	x	0,683	0,769	0,803	0,502	0,666	0,721	
H	0,614	0,922	0,929	0,683	x	0,527	0,931	0,619	0,732	0,812	
I	0,786	0,630	0,769	0,769	0,527	x	0,678	0,340	0,593	0,661	
L	0,686	0,947	0,967	0,803	0,931	0,678	x	0,555	0,759	0,901	
R	0,623	0,658	0,535	0,502	0,619	0,340	0,555	x	0,449	0,478	
	Sum of correlations factors										6,695

The reason for selection of the blue path is the strong correlation between Structural and Bulk+Equipment. Another is that Steel and Piping are the two largest contributors to weight and this way they can be calculated direct from the input values and optimized. Area is not an option due to missing data. The correlations scatter plots with trends can be seen in chapter 10.3. There may be other routes that can lead to an even better estimate but this has not been evaluated due to time constraints.

The estimation method is put together as shown below:

- Piping = $Equi * median\left(\frac{P}{Equi} factor\right) * distribution\ of\ \left(\frac{P}{Equi}\right)$
- Electro = $Vol * median\left(\frac{E}{Vol} factor\right) * distribution\ of\ \left(\frac{E}{Vol}\right)$
- Fire and Safety = $Vol * median\left(\frac{F\&S}{Vol} factor\right) * distribution\ of\ \left(\frac{F\&S}{Vol}\right)$
- HVAC = $E * median\left(\frac{H}{E} factor\right) * distribution\left(\frac{H}{E}\right)$
- Instrument = $P * median\ \left(\frac{I}{P} factor\right) * distribution\left(\frac{I}{P}\right)$
- Architect = $E * median\left(\frac{L}{E} factor\right) * distribution\left(\frac{L}{E}\right)$
- Corrosion protection= $P * median\left(\frac{R}{P} factor\right) * distribution\left(\frac{R}{P}\right)$
- Structural = $(Eui + bulk) * median\ \left(\frac{Stru}{Equi+bulk} factor\right) * distribution\left(\frac{Stru}{Equi+bulk}\right)$
- All disciplines are summarized for every simulation and results are displayed as a distribution

Discipline distributions and resulting estimates can be viewed in section 10.3. Appendix 3. The reference database should be evaluated for relevance to the estimated project. Only the projects that are considered “similar” in input values should be used in each calculation. This should be done to exclude project that can be considered incompatible according to concept, size or purpose. For more detail on the available data please see chapter 5. Data.

3.5.1 Data management

Since the data material is used in different ways in the two methods it had to be checked and controlled. The author manually checked all the project material relevant for this thesis. Some items were discovered and discarded or excluded from the analyses. Some of the errors related to missing data from certain projects. This would not be a problem for WEPS due to the high level of detail. However it is a problem for the alternative model. This is because it estimates disciplines on project level. Another error in the data material is that in one project the sum of discipline weight was summarized wrong.

3.5.2 Graphical method for visualizing of relationship

The relationship between two variables is clearly displayed in a scatter diagram (Bower 2000). Excel is used to produce the scatter diagrams and display the relevant relationships. The purpose is to visualize the data and discover if there are any abnormalities in the data. Anscombe (1973) argues the importance of investigating the correlation graphically. The correlations used in the alternative method have been evaluated according to Anscombe's work.

To show the importance of graph evaluation an example from his work will be reproduced. His article mainly relates to regression analysis but it is also valid for factor estimation.

Table 4: Four data sets with 11 data pairs

n	x1	y1	x2	y2	x3	y3	x4	y4
1	10	8,0	10	9,1	10	7,5	8	6,6
2	8	7,0	8	8,1	8	6,8	8	5,8
3	13	7,6	13	8,7	13	12,7	8	7,7
4	9	8,8	9	8,8	9	7,1	8	8,8
5	11	8,3	11	9,3	11	7,8	8	8,5
6	14	10,0	14	8,1	14	8,8	8	7,0
7	6	7,2	6	6,1	6	6,1	8	5,3
8	4	4,3	4	3,1	4	5,4	19	12,5
9	12	10,8	12	9,1	12	8,2	8	5,6
10	7	4,8	7	7,3	7	6,4	8	7,9
11	5	5,7	5	4,7	5	5,7	8	6,9
Average	9,0	7,5	9,0	7,5	9,0	7,5	9,0	7,5
R^2	0,67	0,67	0,67	0,67	0,67	0,67	0,67	0,67
Pearson correlation	0,82		0,82		0,82		0,82	

Four data set with: $\bar{X} = 9{,}0$, $\bar{Y} = 7{,}5$, $R^2 = 0{,}67$ and regression line Y = 0,5x + 3,0. The four cases have the same average, correlation and R^2 but the distribution varies.

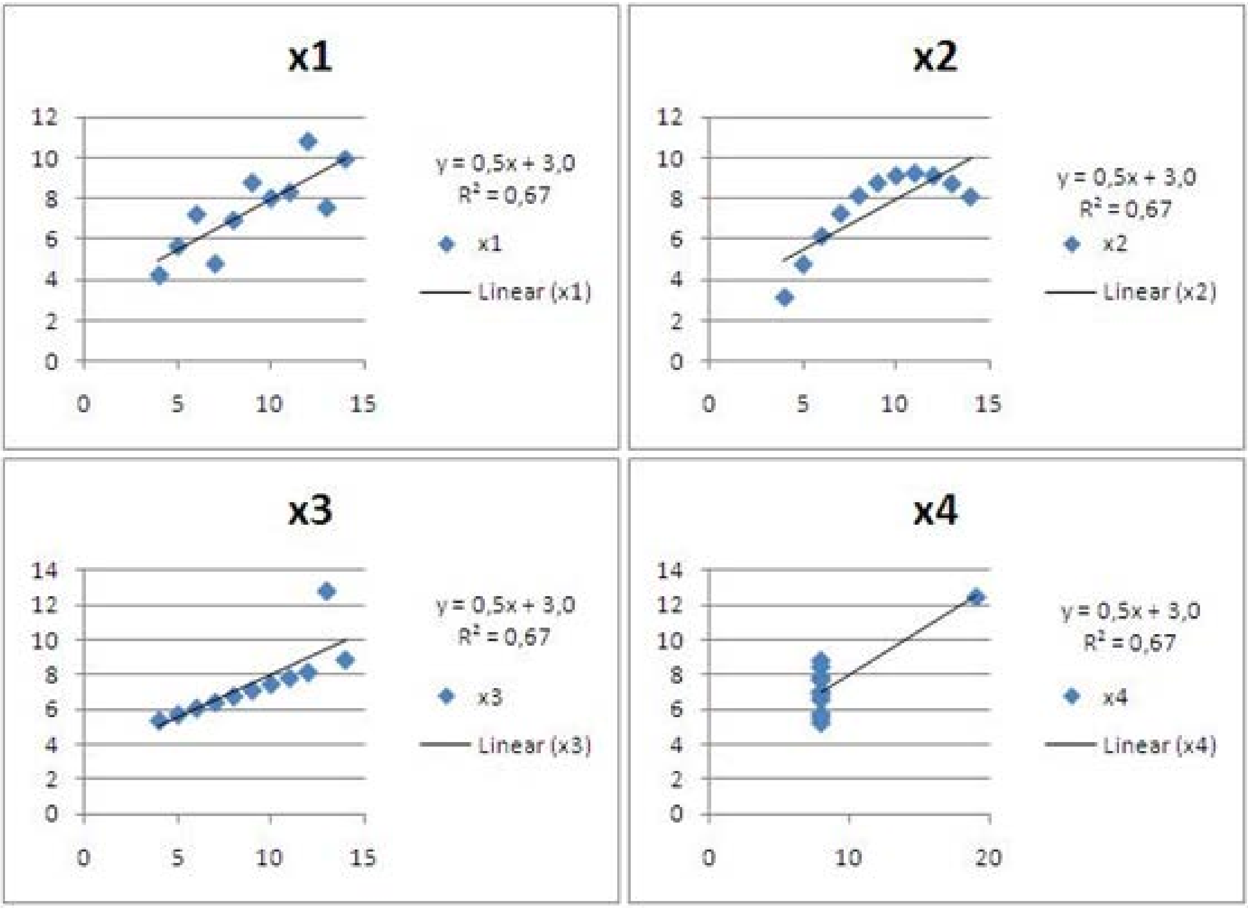

Figure 5: Four scatter diagrams all sharing the same attributes

The four cases in Figure 5 show that the data material is not fully evaluated only by statistical numbers. Anscombe (1973) main idea is that graphs can "... help us perceive and appreciate some broad features of the data, ... let us look behind those broad features and see what else is there". Anscombe's idea has been central in the alternative estimation process.

3.5.3 Most likely value

The method use median value as the measure for the central tendency in the distribution. This is due to characteristics about the median. Walpole et al. (2007) argue that the median value reflects the central tendency of the data set without being influenced by extreme values. Median emphasis on the true "center" of the population and this makes it very useful in estimation. Mean is simply the numerical average of the population. The mean is a location measure that provides a quantitative data center in the sample. This measure is influenced by extreme values (outliers).

4 Method

The Bow Tie in Figure 6 is used to present the risk picture as described in Aven (2008). Uncertain areas and related consequences that need to be addressed are derived from the risk picture.

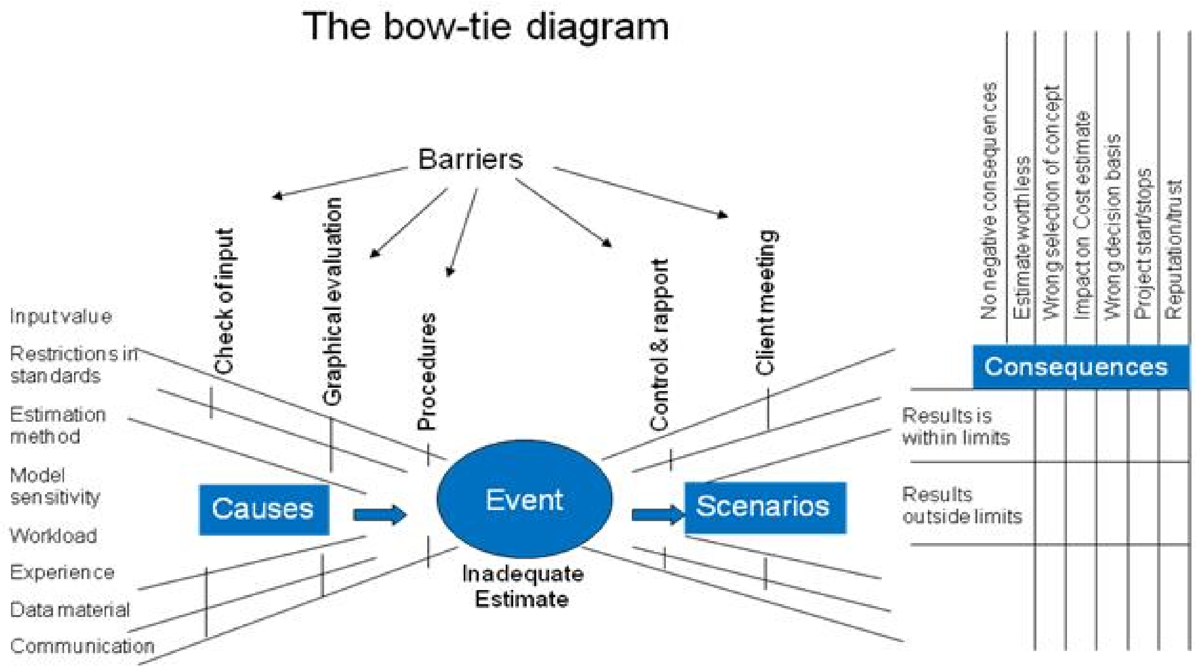

Figure 6: Bow-tie for "inadequate estimate" (Aven 2008)

The areas of interest are: input values, model sensitivity, and lack of experience and data material. The bow-tie is based on the event of "inadequate estimate". This means that the estimate is outside the requirement stated in TR1244. The areas of interest will be addressed in the following sections.

4.1 Uncertainty analysis of WEPS

The main purpose of this thesis is to analyze the method and find factors or areas that contribute to the total uncertainty. Methods for handling and mitigating the uncertainty will then be evaluated. This has required research on relevant topics. It is found that there is not a great deal published on the specific topic of weight estimation. The author has attended WEPS development meetings to learn about the process. The author has also attained knowledge by interaction with the weight estimation environment at Ramboll.

This paragraph is inspired by Aven (2008). To locate uncertainty areas from the risk situation in the WEPS method a Bow-Tie diagram will be established. For the purpose of this thesis the risk picture is restricted to what directly impacts the use of WEPS, the estimation process and the results. The Bow-Tie presents the risk picture, causes and related consequences. From this picture, uncertainty areas are established (Figure 6). These areas are addressed according to suitable quantitative and qualitative methods.

4.1.1 Sensitivity analysis

A sensitivity analysis shall display the model's sensitivity as it relates to variation in the main input variables. The sensitivity analyses are performed by letting the variables; equipment weight, area and volume vary between -30% and +30%. The project for this analysis is randomly selected and the default estimation settings are applied. This means that bulk weight is calculated by the mean value from equipment weight or volume. The result will be shown in a spider diagram.

Each discipline has a default input value which is based on years of estimation experience from the organization and industry. In this sensitivity analysis the default setting is used. Mean is also the default calculation method which is used.

4.1.2 Outliers and fitted regression line

WEPS uses regression lines to display trends in the data material. These lines can be influenced by outliers in the data. Some of the regression-lines have special characteristics that make them less suitable in some areas of the data spread. For instance the Inverse-regression-line might be less suited in areas close to the y-axis. An analysis is performed to explain these relationships and suggest solutions or restrictions.

4.1.3 Evaluation of errors in input

An evaluation of the effects by errors in inputs values will be used to explore consequences and find solutions to detect abnormalities. The method will be to insert errors in the input values and evaluate the results. This is done to find weaknesses and methods to detect these errors in the future.

4.1.4 Information maturity and weight budget

One of the main factors governing overall uncertainty is the maturity of information available. Theory about handling lack of information or immature information is analyzed to suggest solutions. Weight budget and weight allowances are an easy and sufficient method for handling information maturity and related uncertainty. An evaluation of weight budget philosophy will show how uncertainties are managed.

4.1.5 Knowledge and human factor

WEPS is a detailed and complex estimation program that is used in a highly technical industry. This demands broad knowledge and experience from the person doing the estimate. The WEPS method is analyzed to find out what should be expected from the estimating team and organization. Relevant theory from the industry has been researched to find solutions.

4.2 Uncertainty analysis of Comparing WEPS against Alternative method

The theory in chapter 3.3 shows different methods that can be utilized for estimation purposes. WEPS is similar to the second method and can use all the three principals. It is considered to be a strong and complex but somewhat time consuming tool.

The alternative method introduced for weight estimation is created by the author for the purpose of this thesis. This method will be compared and evaluated against WEPS. This is done by estimation of ten projects by each method in two separate rounds and examination of the results. They will be evaluated by these criteria:

- Accuracy
- Estimate uncertainty (Monte Carlo)

The accuracy of both methods is analyzed against the available as-built data. The accuracy is displayed as the total weight of each project as a percentage of the total as-built weight of that project. This will be a measure of how well the method can estimate the correct weight. The same is done for the total discipline weight for each discipline.

It is important to point out that each discipline has a default input value which is based on years of estimating experience from the organization and industry. The estimator can choose to divert from this setting and use another input value for calculation if suited. For estimation purposes it is beneficial to evaluate the result from all the input values before choosing the most probable outcome. In the first round the default setting is used and in the next they may vary to find the most probable outcome. The mean value is also set as the default setting and is used for the first round. In subsequent rounds this may vary.

All estimating processes have been performed under the same conditions and the same amount of "Professional Experience". In the analysis the two methods shall estimate the same project and be based on the same input values. The projects involved in the analyses will contain all construction areas and all function areas. Normally WEPS is not used to estimate turrets or central pipe-racks but they will be included in this analysis. The two methods utilize different relationships in the data and estimate on different levels. WEPS estimate on function areas and the alternative method on project level. The results in accuracy will mainly depend on the base method for expressing trends. The accuracy of total weight will be compared against TR1244 requirements for class B estimate. Class B is selected due to the limited time and experience of the estimator. It is also the understanding that it is the most common class. Only those estimates that do not meet the requirements for class B in the first round will be estimated again in round two.

The total estimate uncertainty is analyzed by a Monte Carlo simulation for both methods for the second round. The uncertainty will be displayed as a CV-value. The uncertainty from the Monte Carlo simulation of WEPS will be calculated by taking the middle value between best and worst CV-value. The uncertainty for the total weight of each project is compared between the two methods and class B requirements.

5 Data

5.1 Amount of available data and relationships

This thesis is written in collaboration with Ramboll and the author has been granted access to confidential information. This is why only limited material is presented in this thesis.

The data available has to be evaluated to get the most exact estimate possible. The data base consists of 19 projects. All the projects are broken down into smaller "building blocks" which are assumed to be independent from each other. By this method the amount of comparable data grows substantially. The data base consists of 4911 items in total. The database is continually growing as new information about projects becomes available. This is essential for the business that Ramboll is operating in.

The method that WEPS uses makes the sample size larger than expected. The method filters the data according to which building blocks contain the different disciplines in the different functional area. This means that one project can contribute with several data items for estimation. This is due to the way the projects are broken down. Unfortunately some projects do not contain all relevant functional areas. This is why sample size may vary between ten and hundred data sets. On these grounds the estimation can be performed with sufficient amount of data.

The analysis of the data showed some abnormalities and they are handled by the program developer. This is typical data that was calculated wrongly, missing or wrongly entered. Out of nearly 5000 data items there were just a few items that needed controlling.

The amount of available data should be considered before an estimation method is chosen. An overview of the 19 projects is presented in Figure 7.

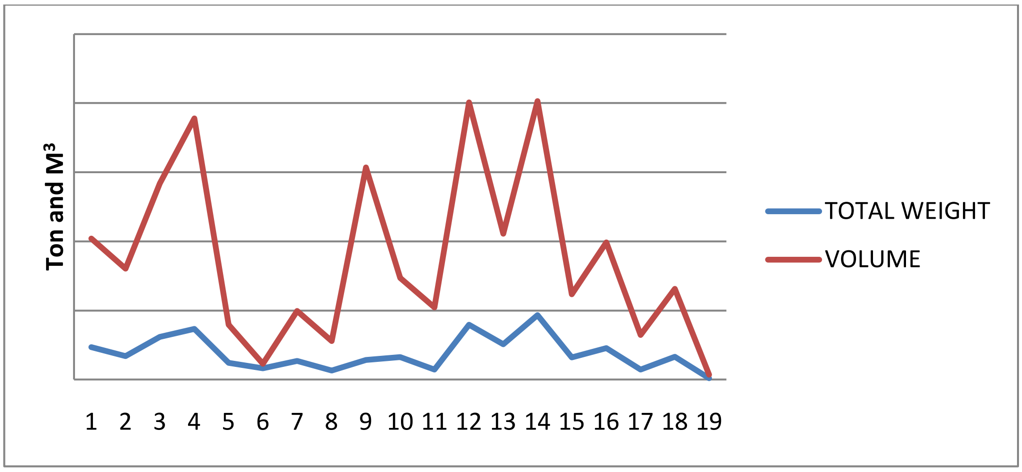

Figure 7: Shows Total weight and volume of the projects

This shows that the projects are diversified in size of volume and weight. Figure 8 show the amount of bulk and equipment weight for the different disciplines.

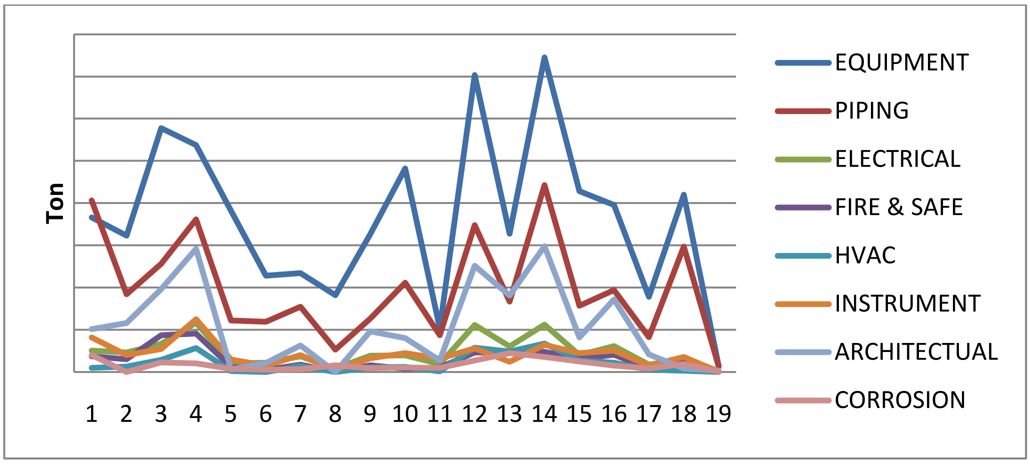

Figure 8: Discipline relationships (database)

Some trends in the data can be seen from the graph, for instance for Instrument and Electrical. The graph also shows that there is great variation in the data. This means that it can be complicated to estimate on project level without any details. This might be a problem for the alternative method. Figure 9 shows total volume and total steel for the different projects. WEPS uses volume as default parameters for estimating steel, the relationship can be seen.

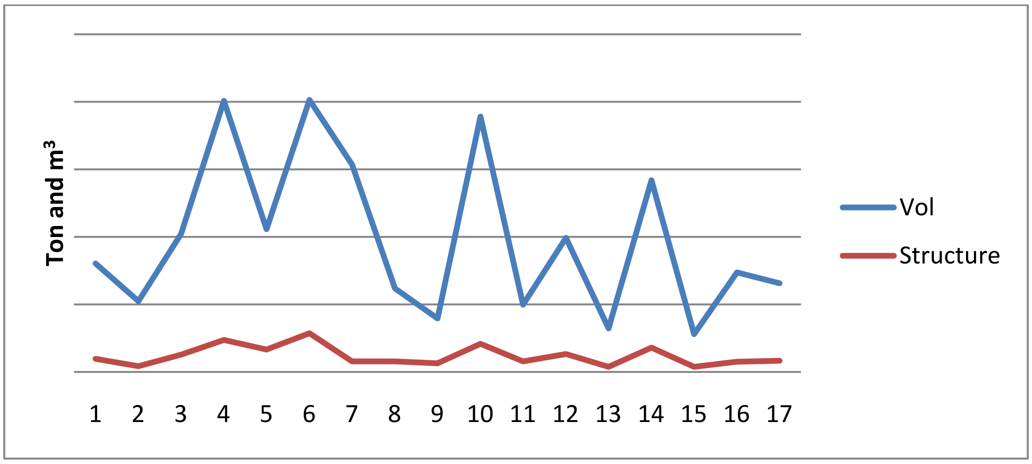

Figure 9: Relationship between total steel and volume (database)

From the figure there is an untraditional relationship between steel and volume for some of the projects. The correlation between volume and structure is 0,899 which is a strong correlation.

In Figure 10 we can see the typical dispersion of equipment weight on function, and construction areas. There are some areas that have no equipment weight, in these areas estimation should be based on something other than equipment. The values on axis and name of project are removed to protect material.

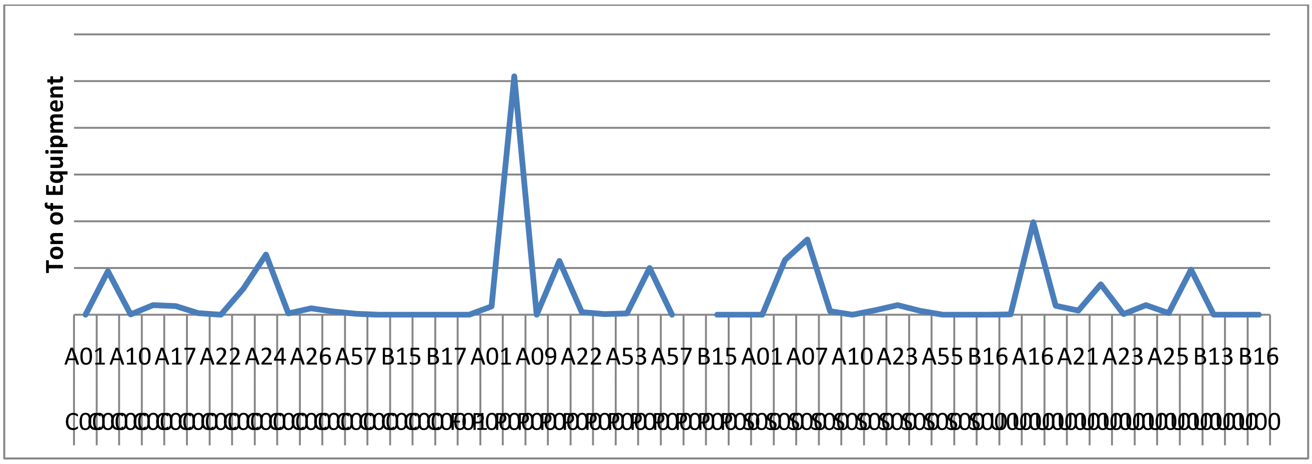

Figure 10: Dispersion of equipment weight on function, and construction areas

5.2 The characteristics of the data (best use - experience)

The estimating team needs to have knowledge about the available data; this chapter will highlight some characteristics of the data that need to be acknowledged by the estimator. There is considerable uncertainty related to how well the estimating team can account for these characteristics.

The data is derived from many different projects with different goals and purposes. Below are some of the relevant data characteristics that are important to check and control when performing an estimate.

- Definition of the different disciplines
- Deck structure
- Substructure
- Platform functionality
- Interaction between other projects nearby

5.2.1 Definition of disciplines (Expert knowledge)

A typical offshore project consists of several participants and there are always many different companies involved. All these companies contribute to the project and impact it even though it is the Oil Company that is the operator and has the overall control of the project. This and the fact that procedures change over time are some of the reasons why not all projects are defined in the same way. This can be a problem for estimation purposes. For instance Fire and safety protection on the pipes can fall under the Fire & Safety discipline or the Piping Discipline. This is a challenge when collecting data and when performing the estimate. It is important that the data in the database is correct and it is used in the correct manor. This means that the estimator should know about each project, how they are defined and their unique characteristics.

5.2.2 Deck structure (Expert knowledge)

Deck design can impact the estimate. The estimator has to use expert judgment to evaluate the situation. There are several types of deck design used today. Structural steel is one of the factors that contribute most to the weight, this is why deck structure and design needs to be evaluated. Some steel design philosophies for topsides are displayed in Figure 11.

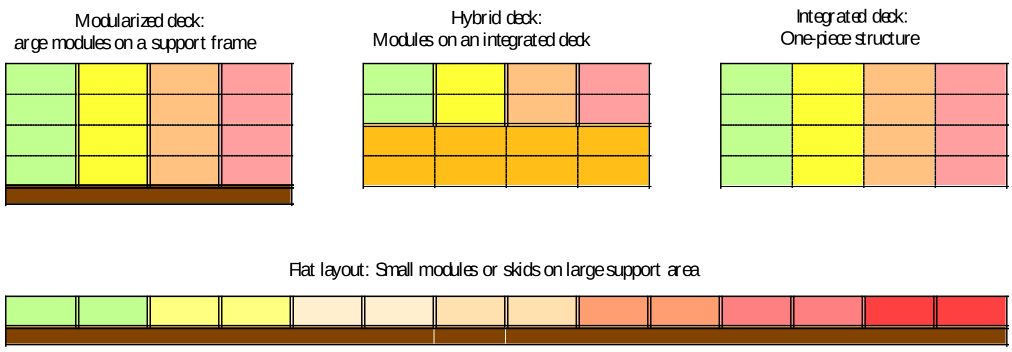

Figure 11: Topside deck structure design (Odland 2011)

The amount of steel and the split between the areas differ in the different designs. When estimating structural steel the estimator needs to take this into consideration.

5.2.3 Substructure (Expert knowledge)

The type of platform or type of substructure can impact the calculation of area and volume input values. The type of substructure impacts the design of the topside. The different concepts may vary in area and volume. This is why the method for calculation of area and volume needs to be controlled. There should be a universal method for calculation of area and volume that does not depend on different concepts. The estimator needs to evaluate the different concepts in the database when estimating. Figure 12 show that there is variation in concepts or substructures in the database. There are some also some missing data.

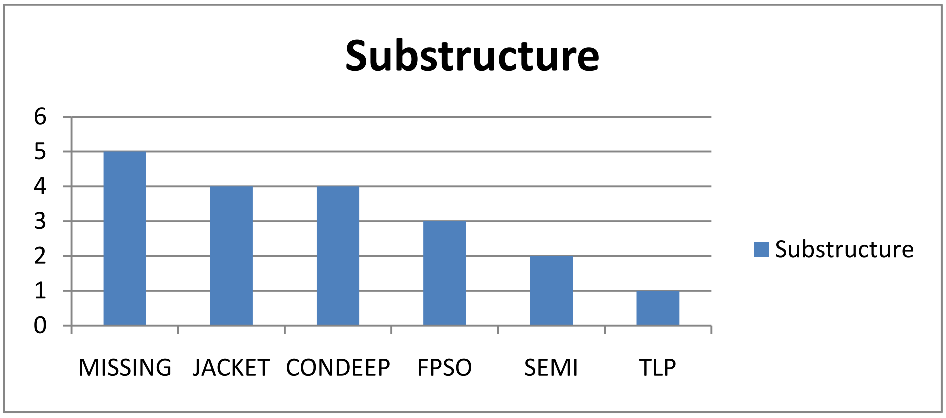

Figure 12: Substructures in the database

5.2.4 Platform functionality (Expert knowledge)

The functionality of each project also differs. This can impact the equipment input value. This is why the different platforms require different quantities of processing equipment, bulk, storage capacity, drilling equipment and utilities. Figure 13 show the different functionality in the data base.

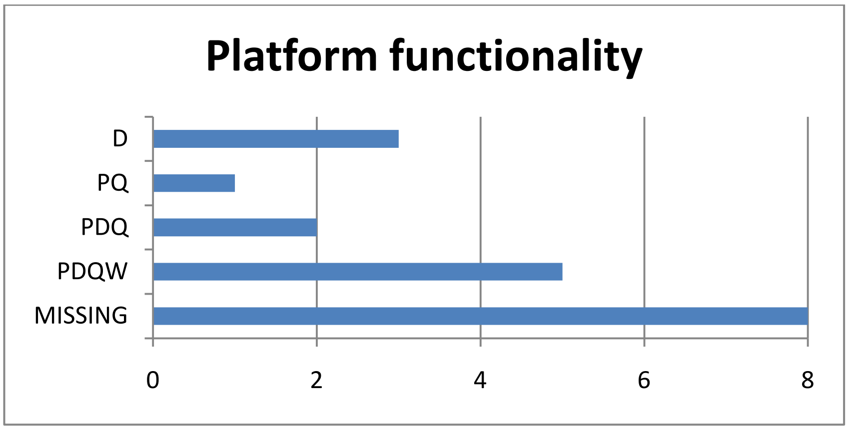

Figure 13: Functionality of the different projects in the database

D = Drilling, P = Production, Q = Living Quarters, W =Wellhead. The estimator is responsible for adapting and controlling these characteristics in relation to the estimate.

The functionality of a platform is a part of the definition of the project. This puts down constraints about the design and construction of the project. The functionality and concept of the platform represents differences in design and weight. Comparing a drilling platform with a full FPSO ship can in some cases lead to problems.

5.2.5 Interaction between other projects nearby (Expert knowledge)

Interaction between platforms can impact the amount of processing equipment or design of the platform. The owner of the platform always wants to produce as much oil and gas as possible. This means that if the platform does not have the processing capacity, oil or gas can be sent to a nearby installation. This means that some projects needs to have equipment to handle excess production. This is something that the estimating team needs to consider when estimating weight.

This chapter has explained some characteristics that need to be addressed when performing a weight estimate. This shows that the estimating team needs knowledge about the industry and knowledge about each project in the database. There is considerable uncertainty contained in the estimator's ability to account for all these issues

5.2.6 Data managing (Expert knowledge)

Advanced weight estimation processes need to be performed by experienced professionals. Each result and every step have to be evaluated to make a consistent and adequate estimate. The estimator can choose to exclude reference data points in each calculation model, which is evaluated to be unrelated. Beside the items already discussed above the estimator needs to manage the data statistically. Some cases that are interesting for the estimator to examine are:

- Amount of data and relevance
- Trends in the data
- Outliers
- Limitations of regression curves

These items will be addressed in the Result chapter of the thesis.

6 Results

6.1 Uncertainty analysis of WEPS

The relevant uncertainties areas and related consequences are derived from the risk picture. Areas of interest are: input values, model sensitivity, and lack of experience and data material. The result from the areas analyzed will be presented in the following sections.

6.1.1 Sensitivity analysis of input values

Sensitivity analysis is a good method to show how input values influence the result. Evaluation of input values (Equipment, Area and Volume) can be pessimistic or optimistic which can produce the wrong basis for an estimate. Equipment is often derived direct from MEL and is considered to be the most precise input value. There can be considerable uncertainty related to area and volume since these are derived from early stage layout drawings.

The sensitivity analysis is performed by letting the input values for Equipment, Area and Volume vary between -30% and 30%. A typical project is selected and the default calculation setting is used. Figure 14 show the sensitivity of input values.

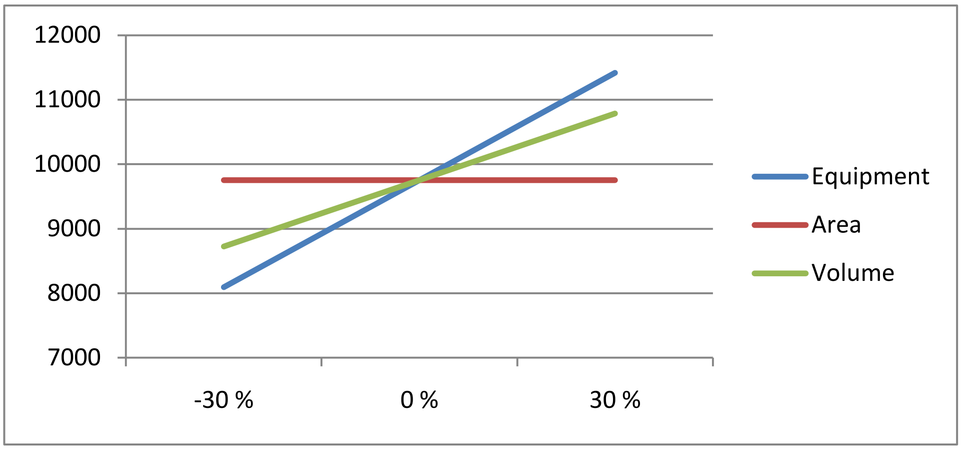

Figure 14: Sensitivity of input values

The figure displays that Equipment is the factor which the estimate is most dependent on. The result is not surprising due to the nature of WEPS. The result shows the importance of correct input values and especially on equipment. This also brings up the importance of information maturity in a project. It is extremely important to have the most up-to-date input values when performing an estimate. This topic will be further discussed in chapter 7.1. Area is not used in the default settings for calculations. This is why the figure shows that the estimate is not impacted by area, and could have been removed from the analysis.

6.1.2 Model sensitivity: outliers, amount of data, trends and regression lines

WEPS uses mean values or regression curves that can in some cases be impacted by outliers. Figure 15 shows a case where there is an extreme value close to the Y-axis and how the regression curves responds.

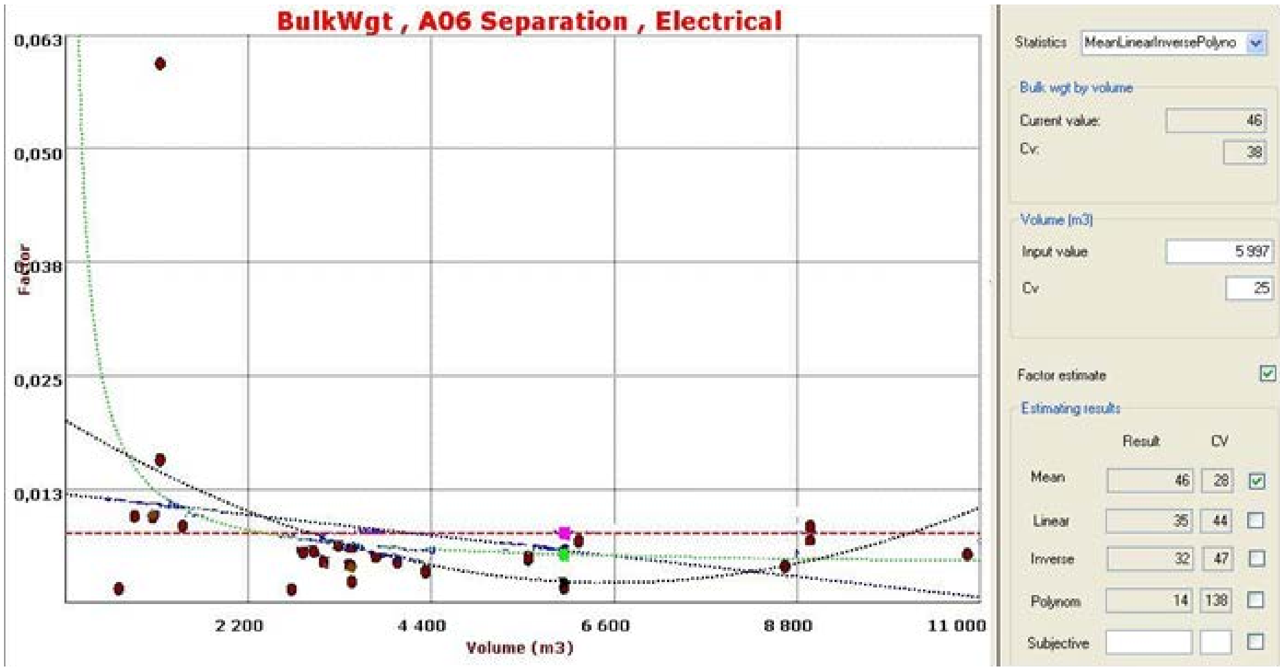

Figure 15: Estimating with extreme value in WEPS

The Y-axis shows the factor volume on electrical bulk weight. The figure show how sensitive the model is to extreme values. These extreme values should be removed from the model if the estimator can conclude that they are inappropriate. This should be based on experience and knowledge about the data. The inverse regression line (green line) will give extreme outputs for inputs under 1000m^3. If the input is in this area, other estimating methods should be used. The polynomial regression line (black line) also shares this problem.

The mean is also impacted by extreme values but in a smaller way. In this case the mean values drops from 46 to 34 tons of bulk by removing of the extreme value. This is due to the characteristics of the mean value (Walpole et al. 2007). Figure 16 is the same case as above but without the most extreme value.

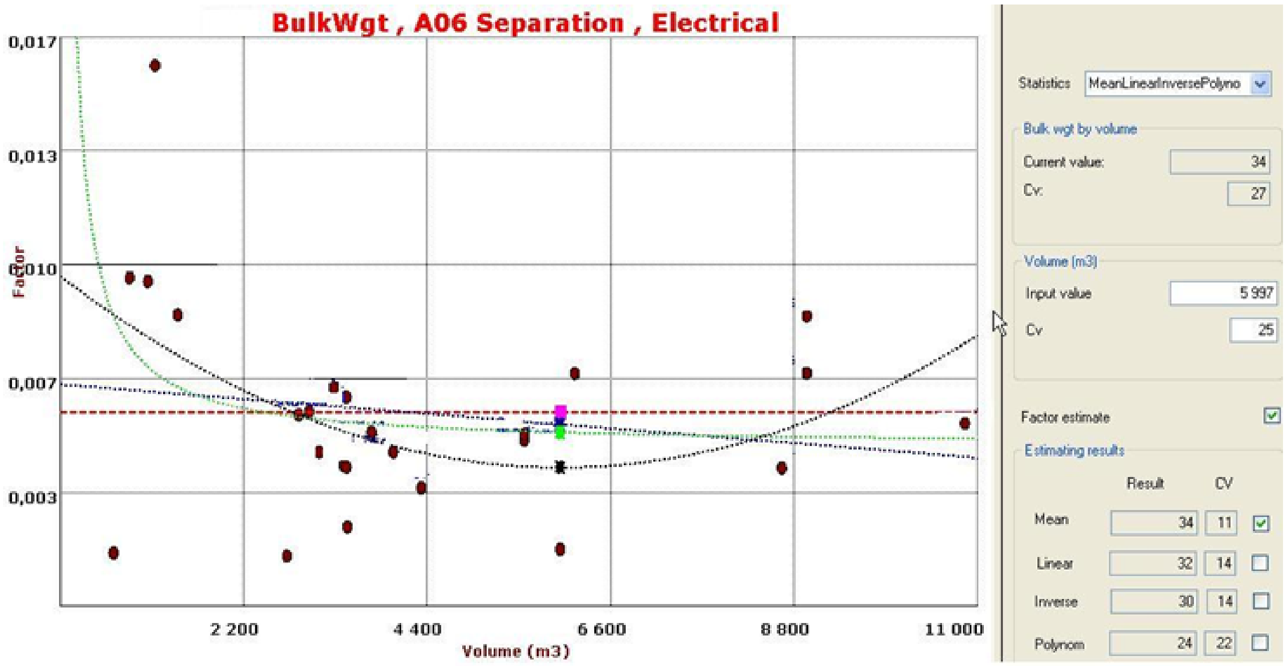

Figure 16: Estimation without extreme value in WEPS

The author suggests the use of median values instead of mean since it is not impacted the same way by extreme values Walpole et al. (2007). The figure shows that the estimated weight and CV factor drops greatly. The identification of the projects is erased to protect the data material.

If the extreme values can be excluded the trends in the data can be evaluated more clearly. In some cases the extreme values can be relevant and therefore cannot be excluded. This shows that there is a great deal of sensitivity related to outliers in the model and related to the regression lines. This means that the estimator has to check every detailed calculation carefully to look for such situations.

The amount of data available for estimation can in some cases be too small to get a sufficient regression analyses. When there are just a few data sets the relevance of the data is critical. In such cases the estimator has to take a qualified decision whether the data can be trusted or an alternative solution should be used. Figure 17 show a challenge that occurs when the amount of data is small. The responsiveness of the model is extreme when there is small amount of data available. The estimator can use the subjective field to overwrite the estimation process. The subjective evaluation can be based on other process data and experience. In this figure the factor is piping bulk weight divided by equipment weight.

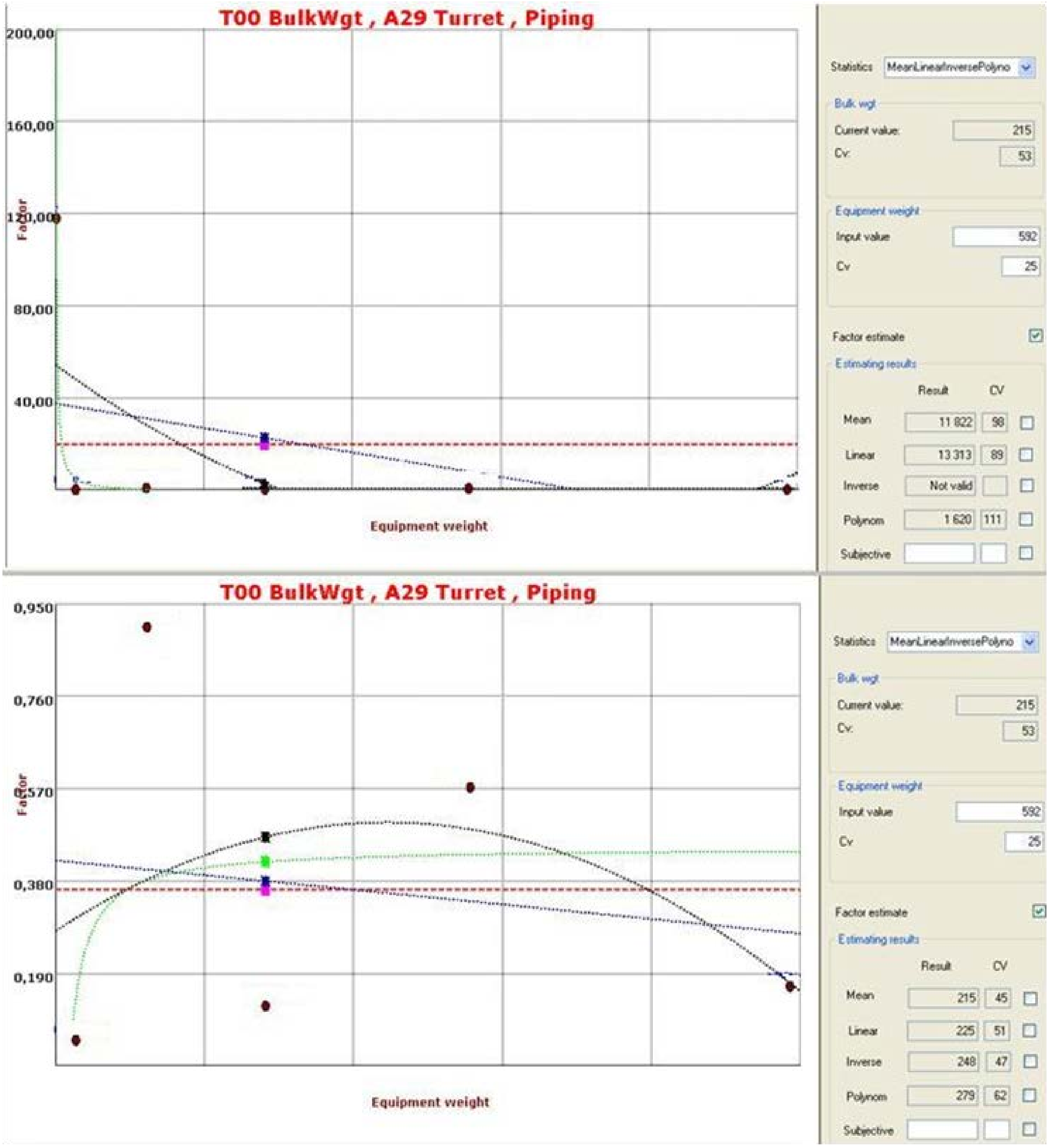

Figure 17: Shows how the model response to small amount of data. (WEPS)

Figure 17 shows that the estimate is reduced from 11822 (mean value) to 215 by excluding one data set. Each discipline has a default input value which is based on years of estimating experience from the organization and industry. When estimating, it is important to control check the results from all the input values before choosing the most probable outcome. The estimating picture can differ greatly based on variations to each input. The mean value is set as the default calculation method but the estimator has to choose which method that gives the most probable outcome in each case.

6.1.3 The human factor: Knowledge and experience (conceptual uncertainty)

The human factor is an important factor when performing estimates of such a complex nature. This is what Aven (2009) states about estimation. The estimator should look beyond the statistical data and look for the actual meaning of the situation. To be able to do this, the estimating team needs to have knowledge and experience in the industry and relevant topics. Through investigation of WEPS and attending development meetings the author has learned about the knowledge that is needed to perform these estimates.

Neyman and Pearson (1933, p. 296) cited in McCloskey & Ziliak (1996, p.97) suggests that it should be up to the estimator to evaluate uncertainty elements and the situation in every given case.

> *"Is it more serious to convict an innocent man or to acquit a guilty? That will depend on the consequences of the error; is the punishment death or fine; what is the danger to the community of released criminals; what are the current ethical views on punishment? From the point of view of mathematical theory all that we can do is to show how the risk of errors may be controlled and minimized the use of these statistical tools in any given case, in determining just how the balance should be struck, must be left to the investigator".*

Due to the characteristics of the data material some situations need to be handled by experienced professionals. These are discussed in chapter 5.2. Other important elements discussed in the previous chapters relate to statistical handling. One important element is the unique characteristics of the project to be estimated. Such characteristics can be new technology or systems, connection to other platforms and so on. For instance, if a new concept is designed, WEPS cannot be used directly without a thorough evaluation of that concept against available data.

Expert judgment is something that is left up to the estimation team to perform and should not be taken lightly. In the industry there is pressure to make solutions and tools that are adaptive, efficient and accurate. WEPS is very adaptive to all sorts of conditions and can be manipulated to be used in many different scenarios.

There is a great deal of pressure and responsibility on the estimator team. This demands significant knowledge and experience from the industry. There is often a team of estimators that contribute to the estimate and they should share all relevant knowledge. It is important that the members of the team complement each other's knowledge to create a vast knowledge base. There should be a leader that can control and function as a barrier against poor estimating. It is important that there is close collaboration between all disciplines and all contract parties. Information is the source of the knowledge that estimator need to make the right decisions (waddell et al. 2008). The process should support open communication and emphasize information flow. It is also important to conduct regular meetings to keep all parties up to date. By following such guidelines sufficient quality can be achieved and a safety barrier can be created.

6.1.4 Information maturity (Operational uncertainty)

This section is in line with the main principles from TR1244. The input values are based on information from the early stages of a project development. There is a great deal of uncertainty contained in this information. At this stage this relates to undefined elements (This is textbook example of uncertainty Klakegg and Aven). Some of this uncertainty can be handled by a weight allowance which is added to the input values. Weight allowances can be viewed as a safety factor for known uncertain quantities. It is also normal procedure to create a weight budget to account for such uncertainties. Weight budget has already been discussed in chapter 3.2.5 Weight budget. In the process the degree of identification of MTO items evolve under way in the project. This leads to weight estimates being substituted for actual known weights. The amount of allowance is also reduced because of the reduction in uncertainty about the weight. Allowances and weight budget are viewed as qualified countermeasures to the uncertainty related from immature information.

6.1.5 Statistical uncertainty

It has already been shown that there are underlying relationships in the data. For estimation techniques it is important to find and utilize these relationships. Neyman and Pearson argued that actual research should depend on substantive not purely statistical significance (McCloskey & Ziliak 1996, p.100). This is why the thesis has pointed to aspects that impact the uncertainty in other ways than statistically. There is also a need to address the statistical uncertainty of the model; this will be partly done by looking at performed estimates and by a Monte Carlo simulation in chapter 6.2.

Because of the high complexity of the model and the nature of the information the statistical model uncertainty will be shown by estimation of ten projects, estimated by the author. Ten project estimated by a professional estimator is also shown in the graph. They are random projects and default settings do not apply, all are qualified for a class B estimate. Figure 18 shows the uncertainty from the twenty individual estimated projects.

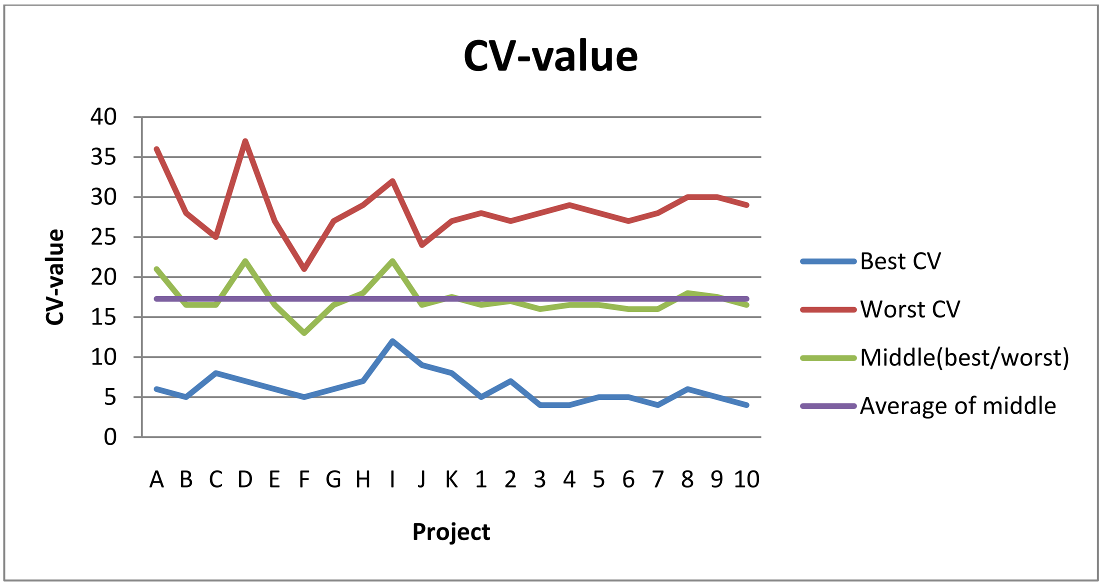

Figure 18: CV-value of estimates done in WEPS

The table shows that the average CV-value is 17% of total topside weight on a 68% confidence level. This CV-value is calculated as the middle value between best and worst CV-value. Project A to K is performed by a professional estimator and 1 to 10 by the author. The graph display best CV-value (blue), worst CV-value (red), the middle value between them (green) and the average of the middle values (purple). Figure 18 show that estimates done by a professional vary more and this is probably due to unique project factors. For detailed calculations of CV-values see chapter 3.4.4. This result is also based on a CV-value of 25% on all input values which is normal procedures. By comparing against TR1244 requirements this is sufficient enough for class A and class B estimate. It should be pointed out that this estimate has not been adjusted for discipline split. It should also be pointed out that this is done solely by the author with limited expert experience and limited time. Figure 19 shows how total topside CV-value changes with increasing CV-value on input values.

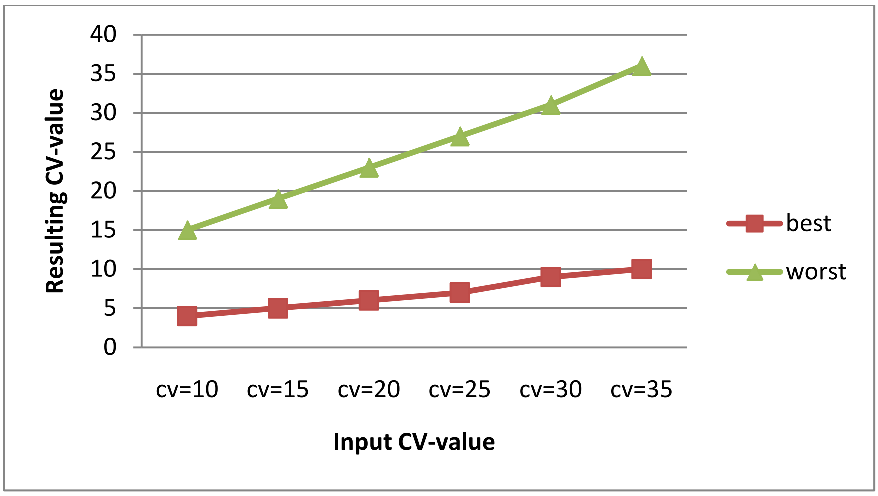

Figure 19: Resulting CV-value by increasing CV-value on Input values

Figure 19 is based on a typical estimate and default estimation settings. The graph shows that the gap between best and worst line is increasing with increasing CV-values on the input values. The CV-value should be used with caution. The default value of 25% is based on experience. The CV-value should be related to the confidence the estimator has in the input values after allowance are added.

6.2 Uncertainty analysis of WEPS and alternative method

The theory in chapter 3.3 shows different methods that can be utilized for estimation purposes. WEPS uses the second method but can utilize all the principles. The program is considered to be strong and complex but also time consuming. Especially when it comes to rather inaccurate estimations such as class B estimates. As a part of this thesis objective an analysis of the accuracy and uncertainty of WEPS is performed. The results have been compared with as-built data and a simpler alternative method.

6.2.1 Accuracy and CV-value

Accuracy in this thesis means closeness between the measured quantity (estimated weight) and the true quantity value (as-built weight) (JCGM 200 2009). The first round of testing shows the expected results through the use of default settings. This means that only the mean value is used for calculation. Default settings also apply for the input values. The following experiment is performed with the same condition and without any adjustments for any of the methods. Table 5 shows how accurate both methods are compared to as-built data; estimates methods can be viewed in chapter 3.4 WEPS estimating method and 3.5 Alternative estimation method.

Table 5: first estimation attempt without any adjustments

PROJECT NUMBER (A)	WEPS ABS(DIFF) (B)	EXCEL ABS(DIFF) (C)
1	14 %	13 %
2	34 %	16 %
3	12 %	25 %
4	48 %	29 %
5	87 %	1 %
6	14 %	8 %
7	1 %	12 %
8	214 %	7 %
9	11 %	12 %
10	179 %	10 %
AVERAGE	61 %	13 %

Column (B) shows the absolute value of the difference between WEPS estimate and as-built data in percent. Absolute value of ((WEPS estimate in % of as-built) – 1). Column (C) shows the same for the @Risk estimate. Absolute value of ((@Risk estimate in % of as-built) – 1). This means that 0% in Table 5, Figure 20 and Table 6 show that the estimate is correct according to the as-built weight. The table shows the alternative method has a better accuracy when no adjustment has been done to influence the result and use of default settings. Default settings are defined in chapter 4.2. It is also worth pointing out that WEPS seems to overestimate significantly.

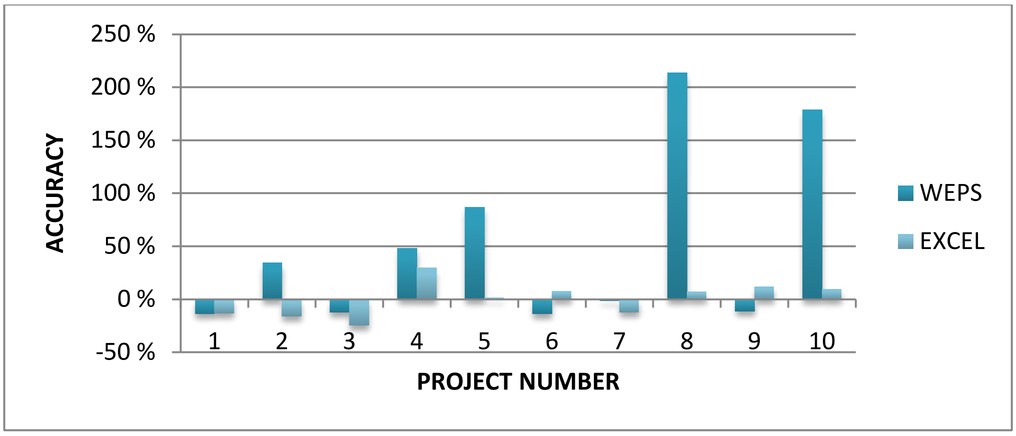

Figure 20: Graphic display of the accuracy

To show that sufficient results can be achieved, a new round of estimating is performed with the use of "expert knowledge". Only estimates worst than +/-25% will be selected for the second experiment and redefined. In this round default settings does not apply, meaning that all techniques can be used. The new results are compared in Table 6.

Table 6: Second estimation attempt with adjustments

PROJECT NUMBER (A)	WEPS (B) ABS(DIFF)	CV-VALUE (C)	EXCEL (D) ABS(DIFF)	CV-VALUE (E)
1	14 %	17%	13 %	9%
2	17 %	17%	16 %	10%
3	12 %	16%	25 %	9%
4	4 %	17%	10 %	10%
5	9 %	17%	1 %	9%
6	14 %	16%	8 %	9%
7	1 %	16%	12 %	9%
8	5 %	18%	7 %	9%
9	11 %	18%	12 %	10%
10	4 %	17%	10 %	9%
AVERAGE	9%	17%	11 %	9%

Table 6 shows that the results from both methods are considerably improved. The CV-values are based on a 68% confidence interval according to the central limit theorem. An even higher degree of accuracy can be achieved, but this is not the purpose of this experiment. The total estimate uncertainty will be analyzed with a Mote Carlo simulation in section 6.2.2.

Table 7 shows the accuracy at discipline level and some considerable variations. This can be related to individual project characteristics that are significantly different from the data. Another explanatory factor for some of the large differences in discipline accuracy is the time factor in this experiment. Some of the individual calculations are not evaluated fully.

Table 7: Discipline accuracy from WEPS estimation

WEPS method									
Project	PIPE	ELECTRICAL	FIRE & SAFE	HVAC	INSTR	ARCH	CORR	STEEL	TOTAL
1	94 %	104 %	94 %	201 %	99 %	103 %	95 %	83 %	86 %
2	96 %	109 %	196 %	1183 %	63 %	129 %	97 %	124 %	117 %
3	58 %	92 %	129 %	339 %	64 %	99 %	61 %	92 %	88 %
4	141 %	150 %	134 %	187 %	130 %	118 %	131 %	78 %	96 %
5	114 %	105 %	79 %	78 %	82 %	104 %	55 %	87 %	91 %
6	86 %	123 %	151 %	196 %	104 %	122 %	83 %	84 %	86 %
7	167 %	171 %	74 %	174 %	164 %	102 %	138 %	86 %	99 %
8	192 %	195 %	95 %	95 %	370 %	95 %	40 %	91 %	105 %
9	136 %	193 %	281 %	163 %	112 %	81 %	112 %	69 %	89 %
10	104 %	173 %	121 %	412 %	150 %	1445%	101 %	86 %	104 %
Average	119 %	142 %	135 %	303 %	134 %	240 %	91 %	88 %	96 %
Median	109 %	137 %	125 %	192 %	108 %	104 %	96 %	86 %	94 %

Table 8: Discipline accuracy from Excel estimation

In these two tables the estimated weight is shown as percent of as-built weight. 100% means that the discipline weight is estimated correct ((estimated weight / as-built weight) * 100).

Alternative method									
Project	PIPE	ELECTRICAL	FIRE & SAFE	HVAC	INSTR	ARCH	CORR	STEEL	TOTAL
1	90 %	84 %	90 %	94 %	81 %	70 %	95 %	84 %	87 %
2	61 %	136 %	164 %	625 %	33 %	194 %	48 %	76 %	84 %
3	46 %	98 %	92 %	154 %	45 %	102 %	40 %	76 %	75 %
4	133 %	192 %	329 %	214 %	101 %	160 %	159 %	130 %	110 %
5	139 %	105 %	93 %	24 %	121 %	26 %	140 %	120 %	101 %
6	111 %	90 %	155 %	93 %	121 %	78 %	101 %	112 %	108 %
7	116 %	102 %	55 %	72 %	106 %	73 %	115 %	82 %	88 %
8	177 %	175 %	95 %	95 %	363 %	95 %	52 %	98 %	107 %
9	117 %	20 %	75 %	20 %	108 %	21 %	215 %	132 %	112 %
10	73 %	104 %	80 %	362 %	119 %	827 %	101 %	121 %	110 %
Average	106 %	111 %	123 %	175 %	120 %	165 %	107 %	103 %	98 %
Median	113 %	103 %	93 %	95 %	107 %	87 %	101 %	105 %	104 %

Table 8 show that some of the errors cancel each other out when it comes to total accuracy. The alternative Excel method is also slightly more precise over all with regards to discipline bulk weight. Both methods performed within TR1244 requirements based on the accuracy of the total weight alone. The results are shown in % due to confidential data.

6.2.2 Monte Carlo simulation of estimate uncertainty

A Monte Carlo simulation has been performed to analyze the uncertainty of all estimates for both methods. The result from Project 1 is shown in Figure 21 and Figure 22 together with a summary Table 9 for all projects. More results from each project and each method can be viewed in appendix 1 and 2.

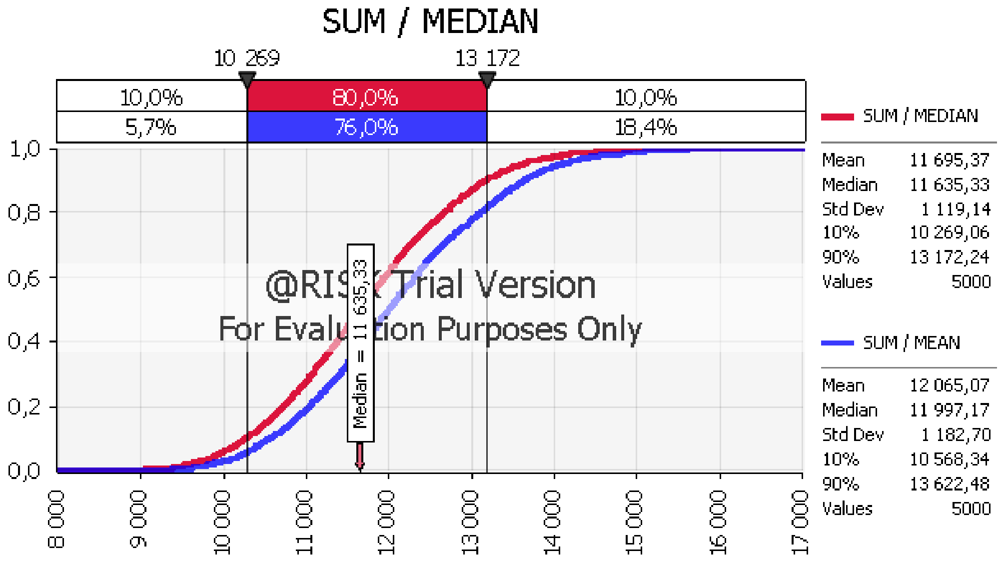

Figure 21: Project 1(@Risk) Result from Monte Carlo Simulation

The @Risk model in Figure 21 performs two calculations one based on the mean value and one on the median value. The red normal cumulative distribution curves show the probability of each outcome. Probability is placed on the Y-axis and outcomes on x-axis. The median value has been chosen to use in this thesis and is pointed out in the graph.

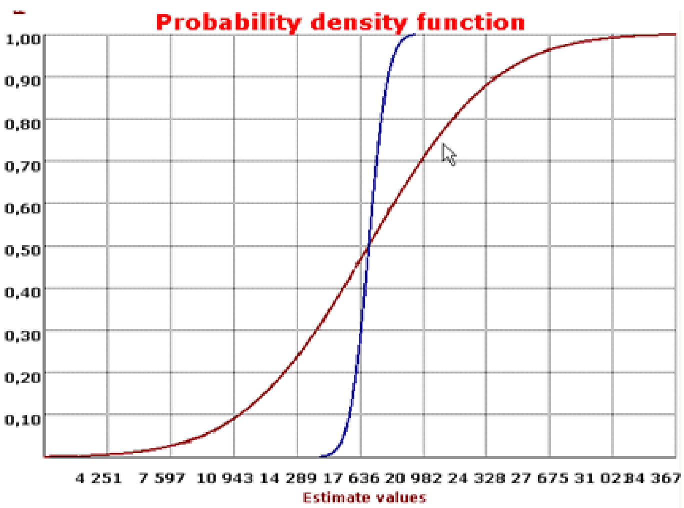

Figure 22: Project 1 (WEPS) Result from Monte Carlo Simulation

Figure 22 show the graph from the normal cumulative distribution curve from the Monte Carlo simulation in WEPS. In each estimate there are performed two calculations; one is based on the worst and the other on the best CV-value. The curve representing the best CV-value is the blue line and the red representing the worst. From these figures and Table 9 it is possible to conclude that 80% of the scenarios are within +/-25%, which is the requirement of a class B estimate.

Table 9: Result from Monte Carlo Simulation (confidence interval)

	WEPS method		**Alternative method**	
Project	80% conf.int.		80% conf.int.	
1	-22 %	22 %	-12 %	13 %
2	-23 %	23 %	-12 %	14 %
3	-21 %	21 %	-12 %	13 %
4	-23 %	23 %	-12 %	14 %
5	-21 %	21 %	-12 %	13 %
6	-21 %	21 %	-12 %	13 %
7	-22 %	22 %	-12 %	13 %
8	-23 %	23 %	-12 %	15 %
9	-23 %	23 %	-13 %	14 %
10	-21 %	21 %	-12 %	14 %

Table 9 gives the 80% confidence interval for both methods. Since the alternative method is based on median values this interval is slightly skewed. The result is that the alternative method is more certain to give a precise estimate. It is important to point out that the result from WEPS is based on the middle value between best and worst curves. WEPS user manual states that a CV-value of 25 is added to all input values before estimation with WEPS. This is based on the assumed uncertainty of the input values.

6.2.3 Source of error in the analysis

Some of the reason why WEPS is slightly less accurate in this experiment is probably due to insufficient time and experience spent on every step in the analyses. WEPS is a sensitive and detailed program that needs to be treated correctly with sufficient time and experience.

Compared to WEPS the alternative method is more rigid and gives no alternative selection of values. In WEPS the estimator can choose linear, polynomial, inverse or the mean value if suited.

The methods are based on the same projects that are estimated. But due to the wide spread of data this should not give any considerable advantage according to the accuracy.

There are some areas which are normally not calculated by WEPS due to limited information on these areas of the topside. For the purpose of this thesis it is included and can be a contributor to the error.

In WEPS it is normal procedure to add a CV-factor to the input value this due to uncertainty about the information that the input values are based on. This is not done in the alternative method where input values are treated as known values.

7 Discussion

7.1 Conceptual uncertainty

From what Svensk Kärnbränslehantering (2004) has stated in Austeng et al. (2005, p.60) about "conceptual uncertainty", the estimator should discuss ways of treating it by addressing the following set of questions:

- Is there any form of conceptual uncertainty related to the estimation model?
- Are there uncertainties related to the model from which the input parameters have been derived?
- Relating to the last question, is it possible to express the conceptual model uncertainty by the parameter uncertainty in the given model?

These questions will be addressed in this chapter. The sensitivity analysis shows that equipment weight is what the model is most sensitive to. This would be expected because WEPS bases most of the calculations on the equipment factor. This is also considered to be one of more precise and developed input factors. But not every area has equipment and this is why WEPS needs to have alternative input values.

Alternative input values available are Area and Volume. There is considerable conceptual uncertainty contained in these factors. This is due to problems related to calculation of area and volume on topsides. WEPS deals with this by comparing equipment-area-volume against each other. By this approach input values can be evaluated for relevance and variables such as concept and platform purpose. By the use of this function the estimate obtains a control barrier to minimize the uncertainty. The uncertainty of the input values is normally set to 25% without any extensive evaluation in each case. The resulting statistical estimate uncertainty is rarely used as a true measure for uncertainty in Ramboll today. The reasons for not using this as a valid description of the uncertainty are due to the undefined nature of the information and variation from project to project. This value is normally set as default to 25% but is there enough evidence to assess the use of such a general value for all classes? The author argues that if the resulting CV-value should have any relevance, the input values should be based on the confidence level presented in TR1244. Which, if adopted gives input value an uncertainty level of 25% for class B, 15% for class C and 10% for class D. By this method even more valid grounds for evaluation of the resulting CV-value can be achieved. There is a need for a best as possible "true" value for the resulting model uncertainty. The client often wants to have an evaluation and a number for the total uncertainty. The author believes that this can be achieved by the use of input CV-values in according with TR1244 and with the use of a Monte Carlo simulation.

WEPS should be viewed as a tool for structuring and evaluation of data. The program is easy to understand and a good tool to visualize trends in the data. But the result in chapter 6.1.2 shows that the model is highly sensitive to outliers. The estimator has to use care and a great deal of knowledge to make a good estimate. This means that the estimator needs to control all small calculations manually which can be time consuming. Please see the result section in chapter 6.2.1 of the thesis to get an overview of expected results with and without expert evaluation.

The theory in chapter 3.2 explains that instead of only looking at the statistical database the estimator should look for a broader understanding of the actual meaning of the situation. Trends can stipulate what the expected estimate should be for the different disciplines. An estimator needs to use wide and extensive knowledge from the industry to account for all those variables that are not represented in the model.

Conceptual uncertainty originates from incomplete understanding of the system and how systems work together (Austeng et al. 2005). One method of dealing with conceptual uncertainty could be to evaluate the estimators and train them in relevant topics. These topics are central to estimation methods: statistics, econometrics, engineering, information management, uncertainty/risk and analytical skills. The estimators are central in the process and have to take many demanding decisions continuously, so giving them the best possible knowledge and understanding should be prioritized Waddell et al. (2008). This view is also supported by Hill (2009, p.627) that states that people are the linchpin of a firm's organizational architecture.

7.2 Operational Uncertainty

Christensen and Kreiner (1991) cited in Austeng et al. (2005, p.63) argues that characteristic of operational uncertainty are reduced as the project evolves. This is due to maturity of information and that the organization learns more about the process they are dealing with. The uncertainty can be reduced by systematic and realistic planning that leads to feasible goals, but also by information management and project management. From Aven (2009) the statement that caution should be used when adopting statistical analysis to describe risk. Due to the assumptions related to such analyses, and that there is a great deal of risk related to surprises in such analyses. By adopting this for weight estimating we can see that surprises or unforeseen consequences can be controlled by systematic and realistic planning and information management but caution should be used.

This is what has normally been done by project estimation, planning and control functions through the use of weight allowances and weight budgets. This is assessed as a well functioning method for managing weight constraints for indefinable elements and unforeseen consequences. This is a typical example of operational uncertainty and how organizations handle this. No extra method of control seems to be necessary related to this aspect.

7.3 Statistical relevance

Statistical significance is a very old idea but the first use of the word significance within the statistical arena seems to relate back to John Venn in 1888 cited in McCloskey & Ziliak (1996). McCloskey's and Ziliak's main point, also shared by Venn, is that a difference can be permanent without being "significant" for science or policy. And a difference can be significant for science or policy and yet be insignificant statistically. This is a very interesting statement and is highly relevant to this thesis and estimation purposes.

The amount of data available for estimation can sometimes be small from a statistical point of view. WEPS is operating on the fundamental principal that the data is factual data from constructed projects. In other words we can be certain that the data is correct and we can establish constraints between the data. The data is compared on the ground of benchmarking and knowledge about each data set in each calculation.

The reason for the use of regression model as a prediction model can be explained from what Pearl (1998) stated. If the purpose is to estimate the effect of one variable (A) on another (B) by analysis of the statistical association between the two, it should be evaluated that the association is not produced by factors other than the effect analyzed. The presence of spurious association, due to influence of extraneous variables this is called confounding. This is true for the input values equipment, area and volume. It is a known fact that all these factors are strongly correlated and depend on each other (spurious). This is the reason for using the regression model as a prediction model and not as an explanatory model. The use of equipment weight, area and volume as input values are well established factors that is "known" from design and the industry to impact weight.

Due to the strong correlation and dependency between the variables, multiple regressions are not a suitable option related to estimation. The relationship between the variables would result in the statistical phenomenon Multicollinearity.

Another important statistical element is the use of CV-values as a true measure for uncertainty. CV-values can sometimes present a misleading picture of the true uncertainty. This is supported by Figure 18 in chapter 6.1.5 by looking on ten projects done by a professional estimator. There can be unique characteristics of the project to be estimated that can conflict with the resulting CV-value. For instance, if the estimator knows that the estimate should be closely related to one or two projects, instead of the central tendency. Which means an adjustment in the estimation process to reflect this knowledge, could return a poor value. This is because a part of the value is based on how well the estimate relates to the tendency in the data. This is why the estimator has to evaluate the CV-value in each case and decide where the resulting CV-value for the estimate is located between worst and best value.

The author suggests that the best/worst CV-value interval should be used as an indicator for the statistical uncertainty of the estimate. In statistics uncertainty or variation is represented by a confidence interval (Walpole et al. 2007).There is little evidence for putting an exact number on the uncertainty. This is due to the complexity of the estimate and the limitation of the input information. Alchian (1950) concur and argues that under uncertainty, each possible action that may be chosen is identified with a distribution of potential outcomes, not with a unique outcome. But the interval representing the uncertainty should be defined as best as possible. The method for visualizing the uncertainty graphically that is used today is supported by the following. Pang, Wittenbrink & Lodha (1996) argues the importance of visualizing uncertainty in the data when performing analysis. This is assessed as a good method for analyzing the statistical uncertainty and in WEPS this is represented by two distribution lines in the Monte Carlo simulation. There are many contributors to the overall uncertainty that is not represented by the CV-value. The use of CV-values alone as a measure for the true uncertainty can lead to false interpretation of the level of certainty. This is why an uncertainty study should be connected to the estimate. However if it is desirable to obtain a confidence interval to represent the overall uncertainty, it should be based on requirements from TR1244 and the discussion in the third paragraph of chapter 7.1, which relates to the use of CV-values on input values. The interval should be attained by a Monte Carlo simulation. There are several critical decisions that have to be made through the analysis by one person (estimator). What to base them on and how to control them could preferably been documented in a policy.

7.4 Uncertainty analysis of WEPS compared to alternative method

The accuracy and the statistical uncertainty of WEPS are compared to an alternative method and as-built data. This is done by analyzing the estimate of ten projects and performing a Monte Carlo analysis of the same projects.

The result in chapter 6.2.1 shows that WEPS gives us a poor base estimate but it is often just one or two factors that contribute to this error. This is easily corrected by looking for extreme values in the estimate. Another item of concern is the high CV value for the WEPS estimates. For every step in the estimation process WEPS gives CV-values and these should be used as indicators to keep the CV-value low. In the resulting estimate the estimator needs to evaluate where the CV-value is located in the interval between best and worst CV-values. The result from the first round is not surprising since WEPS need to be assessed by experienced professionals.

In the next round those estimates that is outside +/-25% of accuracy, which equals the class B estimate requirements, are re-analyzed. The results from round two in chapter 6.2.1 show that requirements for class B estimate are achieved. The analysis to check if class B estimate could be achieved is a success. The next step is the result from the Monte Carlo analysis which is presented in chapter 6.2.2. It is based on the Normal cumulative distribution curve. The alternative method is superior when it comes to the confidence in the accuracy. But it is important to remember that is based on the objective of achieving a class B estimate. Both methods are within the requirements stipulated in TR1244 for class B.

Over all, the analysis shows that it is possible to achieve significant results for class B estimates and points to evidence that also class C and class D estimates are possible. These classes have not been tested fully in this thesis. The reason for not testing these classes fully is the lack of experience and time needed to secure sufficient analysis. The unexpected result however, is that the alternative method performs better both according to accuracy and uncertainty. This is probably due to time constraints for the analysis and the lack of experience required to obtain sufficient results. The alternative method is simple and can give reasonable estimates quickly but with limited details. WEPS is more time consuming but yields more detailed calculations and gives the estimator more chance to control the outcome. WEPS can also be used in many fields and for many purposes that are not supported by the alternative method.

By the use of approximately the same limited time, the alternative method is better related to achieving both accuracy and uncertainty for a class B estimate. But this does not mean that the alternative method is generally the best method. Class B estimates can be rather easily achieved and since it is not possible to test the methods for class C and D fully it cannot be concluded which is the overall best method. It can, however, be concluded that the alternative method performed best for class B estimates with the least amount of time and experience required.

It is important to evaluate any source of error when performing an analysis which can be viewed fully in chapter 6.2.3. Some of the most important sources are time, experience of the estimator, limitations in the alternative methods and the fact that all areas on the topside are estimated the same way.

8 Conclusion

8.1 Uncertainty analysis

Theories about Project Management, Risk management and Industry Standards give evidence of a demand for precision tools for weight estimation and evaluation. Industry standards stipulate the requirements for such methods and tools. These requirements should be the focus area for the company and the estimator. This is why it is interesting to perform an uncertainty analysis of WEPS; Ramboll's weight estimation tool.

The issues that is explores are:

- What does the risk picture look like, is there need for risk management?
- Which uncertainty is present when using WEPS and coherent method?
- In what way can these uncertainties be eliminated, diminished or handled?
- How do WEPS and coherent method perform against an alternative method?

The risk picture is presented in a bow-tie diagram, from which the key uncertainty issues are derived and further evaluated. The results are the following key uncertainty areas: input values, model sensitivity, experience and data material. These issues are categorized in Conceptual- and Operational-uncertainty. Methods for how to diminish, remove or control the uncertainty is evaluated.

The estimators are central in the process of dealing with conceptual uncertainty. They take many demanding decisions, so giving them the best possible knowledge and understanding should be prioritized Waddell et al. (2008). This view is also supported by Hill (2009, p.627) that states that people are the linchpin of a firm's organizational architecture. The following topics are relevant for training: statistics, econometrics, engineering, information management, uncertainty/risk and analytical skills. It is important for the company to always maintain a core of highly educated and experienced professionals. If this is achieved the estimators can take correct actions according to statistical and engineering problems which may minimize the uncertainty. A control barrier should also be erected to control estimates and check that all estimators have a sufficient amount of training. It is also important to point out that CV-values on input values should be used in according with TR1244 and the relevant estimate class.

Operational uncertainty is due to maturity of information. The organization learns more about the processes they are dealing with as the projects mature. The uncertainty can be reduced by systematic and realistic planning that leads to feasible goals, but also by information management and project management (Christensen and Kreiner 1991 cited in Austeng et al. 2005, p.63). This is what has normally been done in the industry through the use of weight allowances and weight budgets. These are seen as necessary tools for project planning and control within engineering management. What Aven (2009) states about aspects which is not represented by statistical analysis, namely surprises. Give basis for a qualitative analysis of the uncertainty situation and this method for dealing with these issues.

The second part of the thesis contains an analysis of accuracy and uncertainty of WEPS compared to an alternative method. The objective is to achieve an estimate within the requirements set by TR1244 for a class B. This is done by estimation of ten projects by each method and assessment of the results. Both methods have performed under the same conditions and the same amount of "Professional

Experience". The accuracy of total weight and total discipline weight are compared. The accuracy of both methods is analyzed against the available as-built data. Class B is selected due to the limited time and experience of the estimator. It is also understood that this is the most commonly produced class of estimate. Only those estimates that do not meet the requirements for class B in the first round are estimated again in round two. In the first round the default setting is used, and in the next they may vary in order to find the most probable outcome. The mean value is also set as the default setting and is used for the first round, but in the next round this may also vary. The total estimate uncertainty is analyzed for the second round by a Monte Carlo simulation. The alternative method is created by the author for the purpose of this thesis.

The final result which can be viewed in chapter 6.2.1 show that WEPS and the alternative method perform within the requirements set by TR1244 for class B. By the use of approximately the same limited time, the alternative method is better related to achieving both accuracy and uncertainty for a class B estimate. But this does not mean that the alternative method is generally the best method. Class B estimates can be rather easily achieved and since it is not possible to test the methods for class C and D it is impossible to conclude which is the overall best method. It is only possible to conclude that the alternative method performed best related to uncertainty and accuracy for class B estimates with the least amount of time and experience required.

The alternative method seems to be a valid method for estimation of total topside weight and discipline weight. The method is simple and can give reasonable estimate quickly but in limited details. The method needs to be fully developed according to detail level and usage areas to be able to use it as a fully functioning estimation tool. This is not the intention with this thesis.

WEPS is more time consuming but yields more detailed calculations and the estimator more chance for controlling the outcome. WEPS has many areas of usage and for many purposes that is not supported by the alternative method. WEPS produce advanced result but needs to be used by a professional estimator.

Source of error related to the analysis of WEPS and the alternative method can be viewed fully in chapter 6.2.3. Some of the most important sources are time, experience of the estimator, use of CV-values on input values, limitations in the alternative methods and the fact that all areas on the topside is estimated the same way.

Limitations and shortcomings with these result is that class C and D is not fully investigated due to the high level of knowledge needed to yield sufficient result. To get sufficient result for these classes a professional estimator should have performed all estimations. This is not available for this thesis. It would have been interesting to check an estimated done by a well experienced professional estimator against the alternative method. This would have required that estimate and as-built data are available for the same project. This is not the case due to the amount of years from estimate to as-built data and also the problem of access to as-built data.

WEPS is an essential part of Ramboll's weight estimation business. In according with Ramboll's strategy and vision WEPS should be continuously improved according to human, commercial, and customers' needs. Hopefully this thesis has evaluated some areas that could improve and enhance the process. The data material is the center of the estimation process and should be maintained and the organization should seek to quire more data. This may be achieved by mutual beneficial contracts with Oil Companies.

The author evaluation of WEPS is that WEPS is a highly technical, advanced, adaptive and detailed method for estimation of weight that meet the requirement for class B set by TR1244. WEPS has many purposes and can be used to complex and precision exercises. It gives the estimator full control and many possibilities in all aspect of the estimation. WEPS is flexible and can be used in all sorts of industries or fields where data is available and built after a hierarchic model. There are aspects of Conceptual- and Operational- uncertainties present. Some methods for managing of the total uncertainty have been introduced. The model accuracy and uncertainty has been evaluated and some areas of concern have been established. An alternative method for estimation has been introduced with promising result.

The final conclusion of the thesis is that all the issues that have been researched have yielded interesting and relevant results. Some solutions are introduced to minimize and handle the resulting uncertainty discovered.

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10 Appendix

10.1 Appendix 1: Results from alternative method

The Monte Carlo simulation from the @Risk model is presented in figure 23-32, two calculations is performed, one based on the mean value and one on the median value for each project. The normal cumulative distribution curves for each project can be viewed below. In the cumulative curve the probability is placed on the Y-axis and outcomes on x-axis.

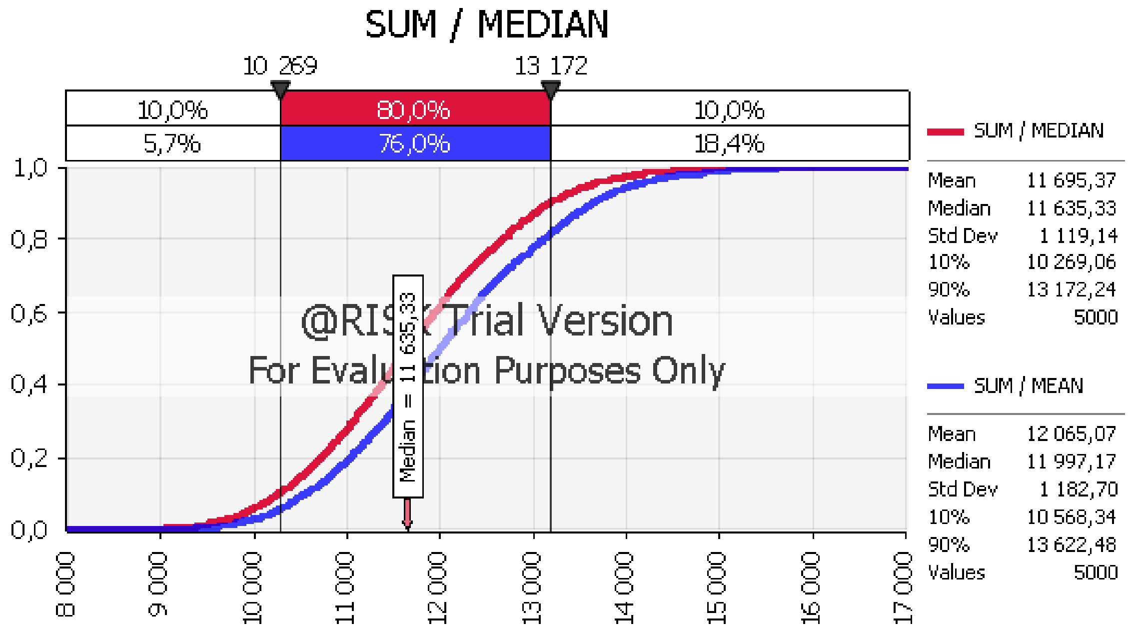

Figure 23: PROJECT 1 (@Risk)

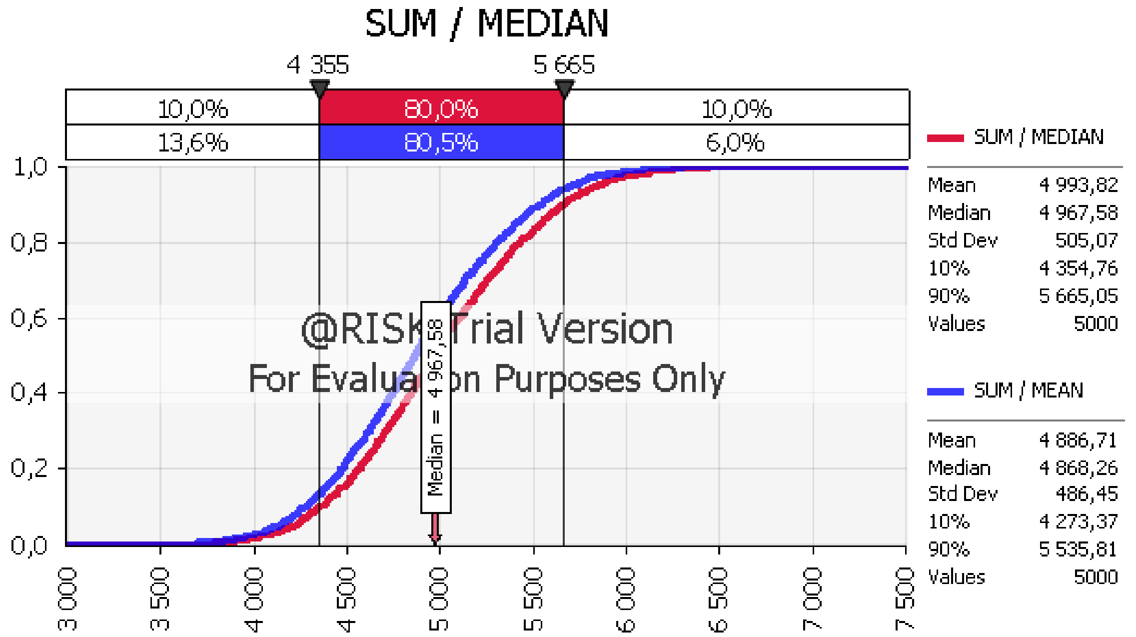

Figure 24: PROJECT 2 (@Risk)

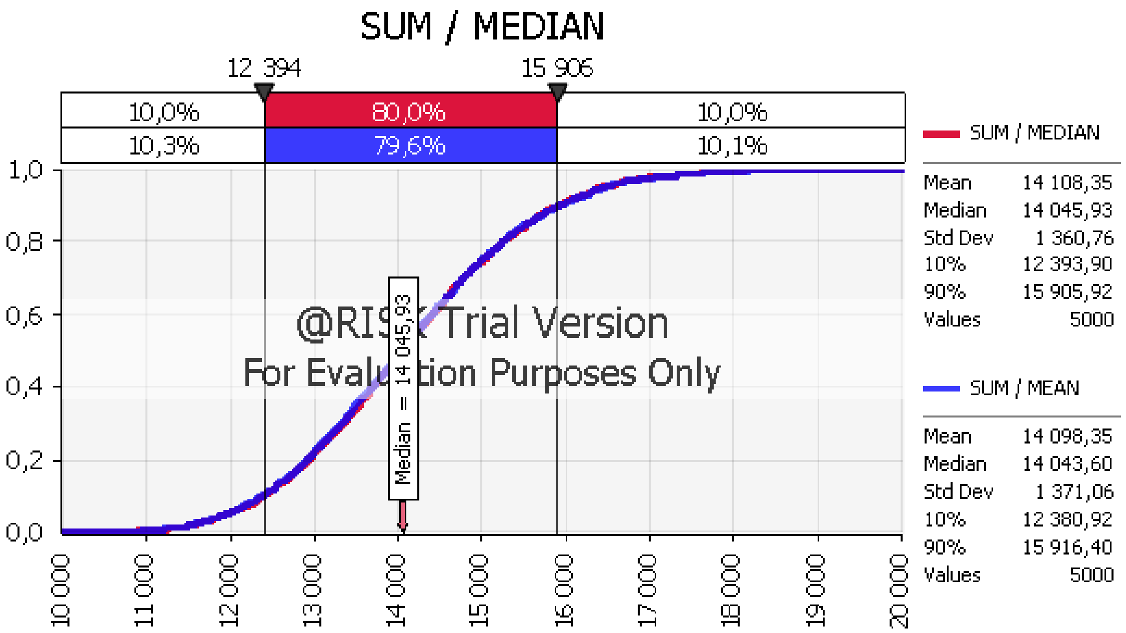

Figure 25: PROJECT 3 (@Risk)

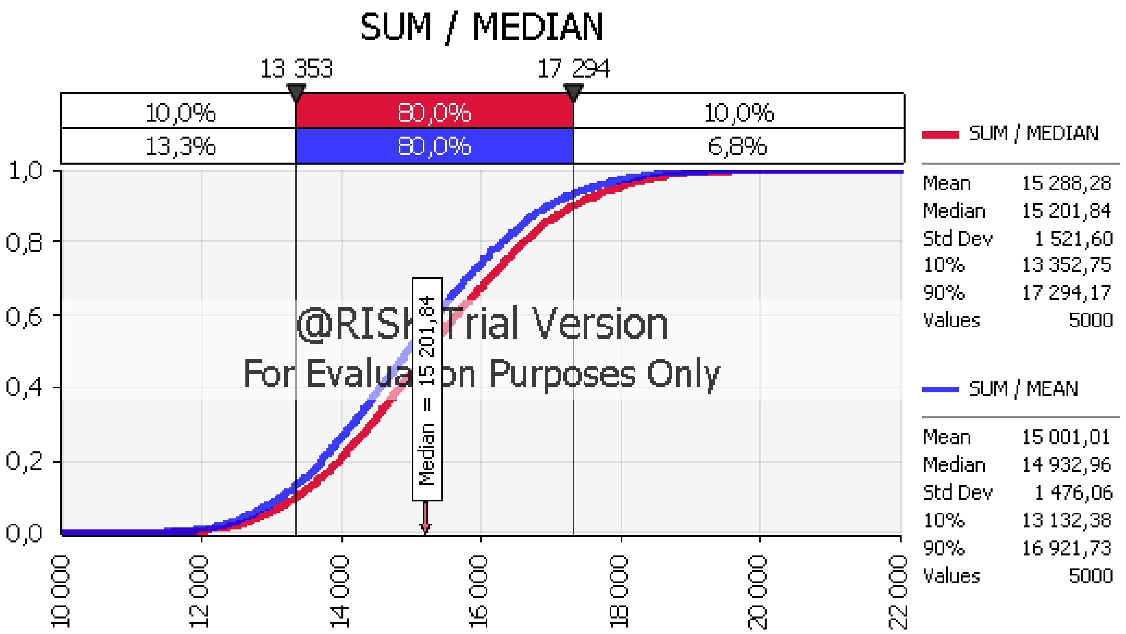

Figure 26: PROJECT 4 (@Risk)

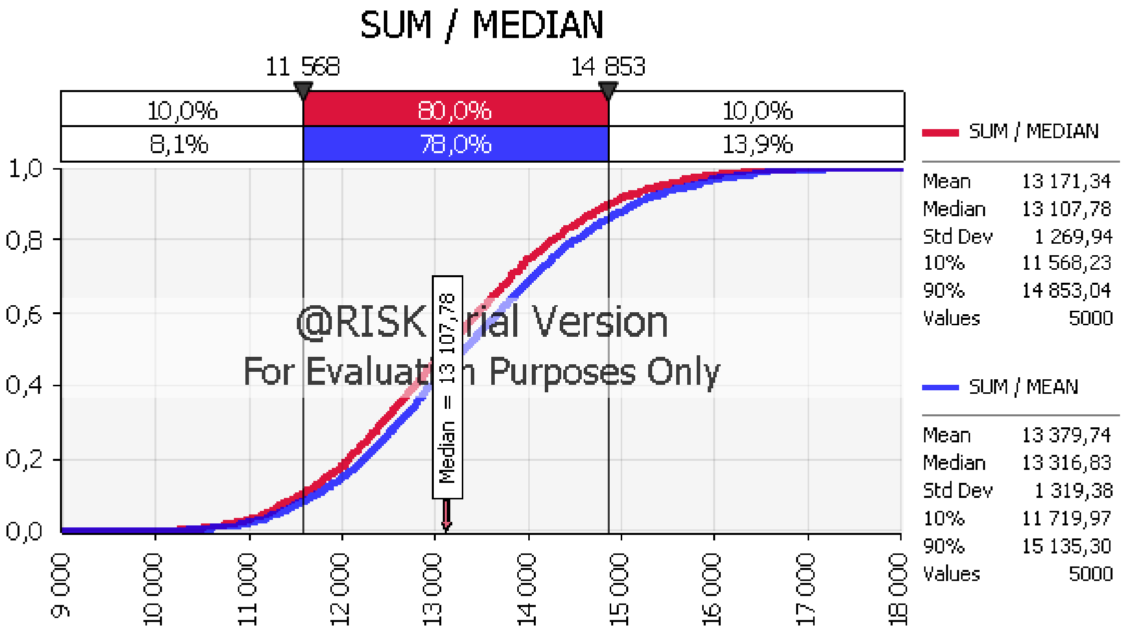

Figure 27: PROJECT 5 (@Risk)

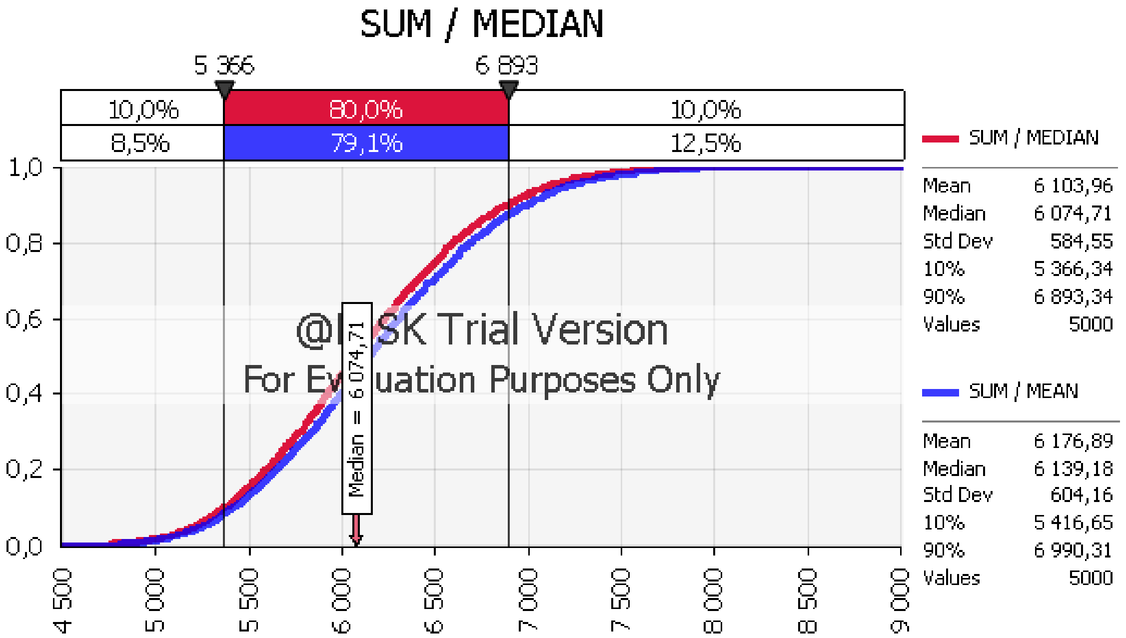

Figure 28: PROJECT 6 (@Risk)

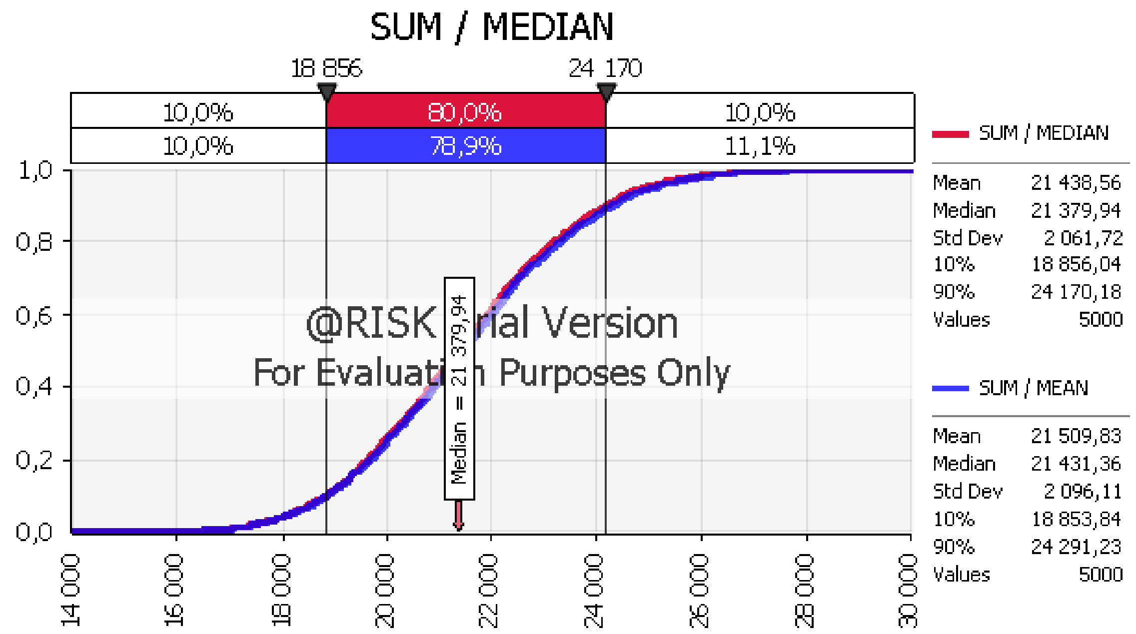

Figure 29: PROJECT 7 (@Risk)

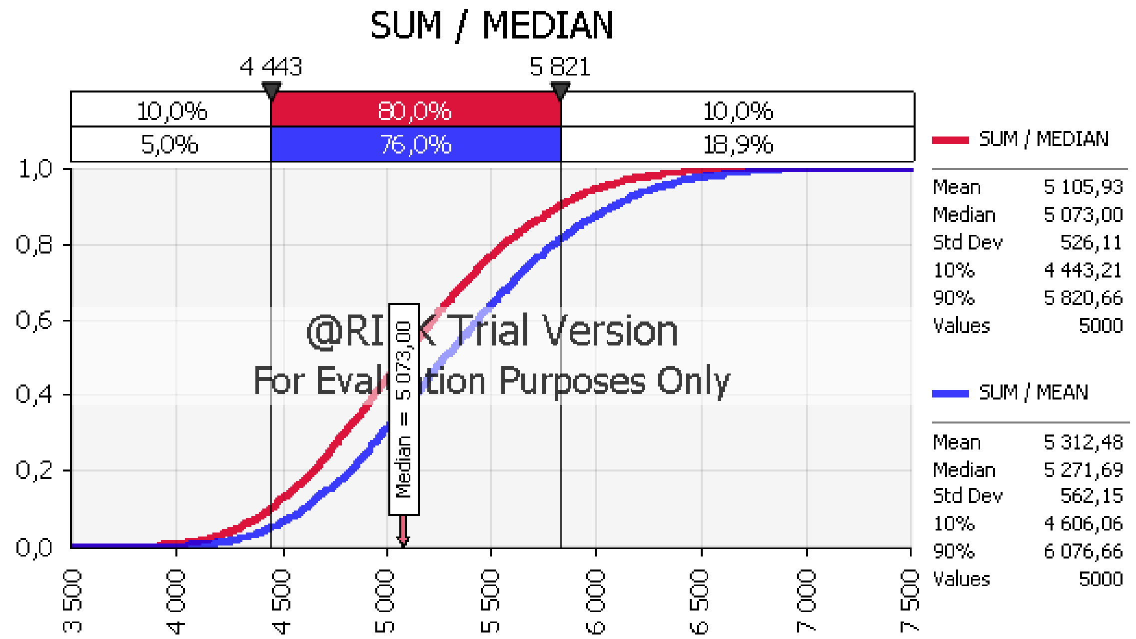

Figure 30: PROJECT 8 (@Risk)

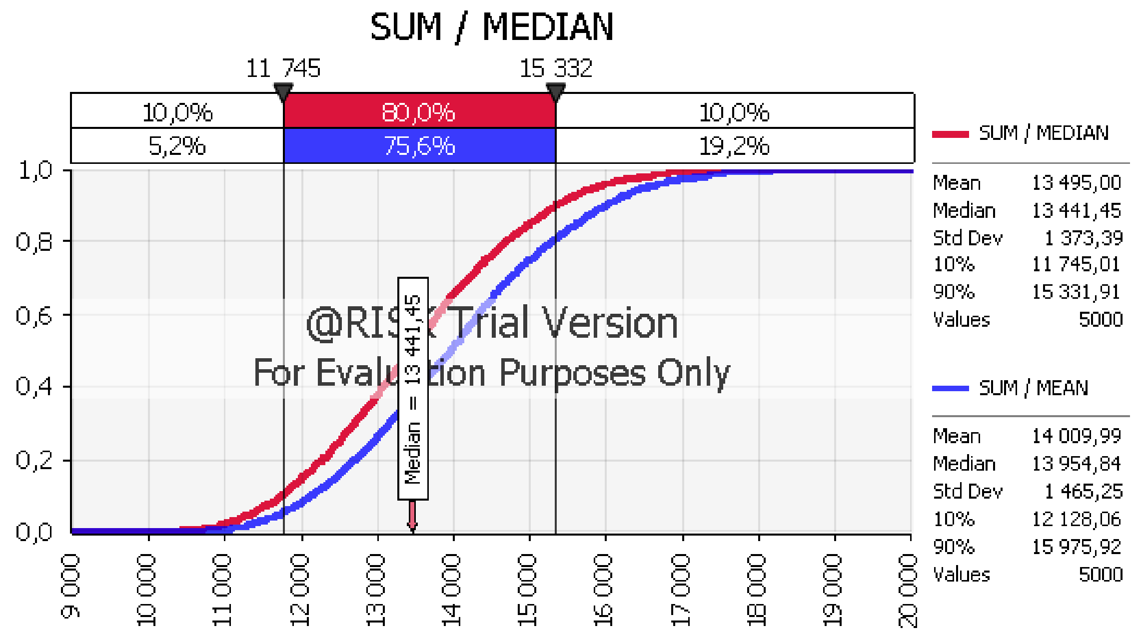

Figure 31: PROJECT 9 (@Risk)

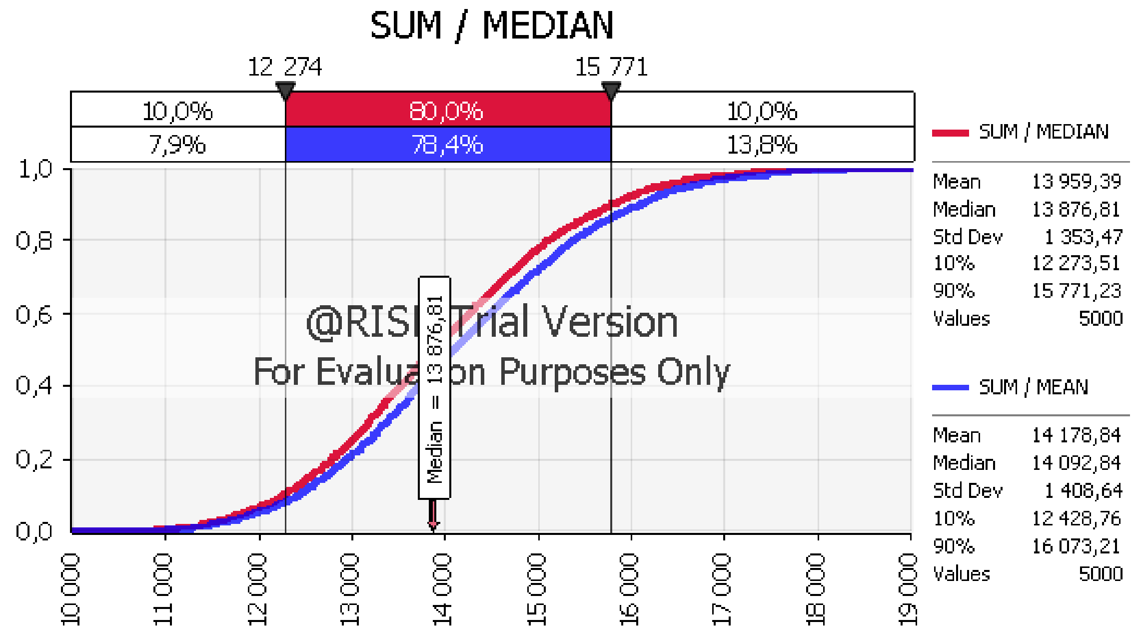

Figure 32: PROJECT 10 (@Risk)

Appendix 2: Results WEPS

The Monte Carlo simulation from the WEPS model is presented in figure 33-42, two calculations is performs one based on the best CV-value and one on the worst value for each project. The normal cumulative distribution curves for each project can be viewed below. In the cumulative curve the probability is placed on the Y-axis and outcomes on x-axis.

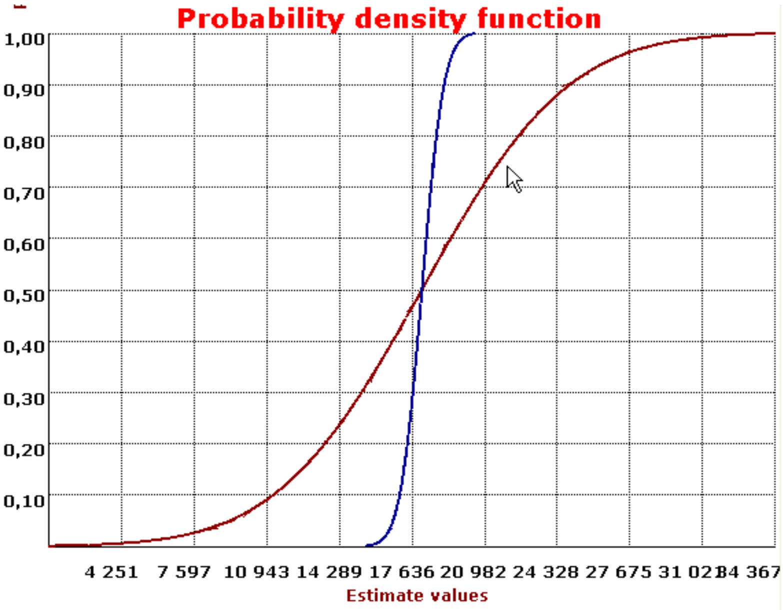

Figure 33: Project 1. (WEPS)

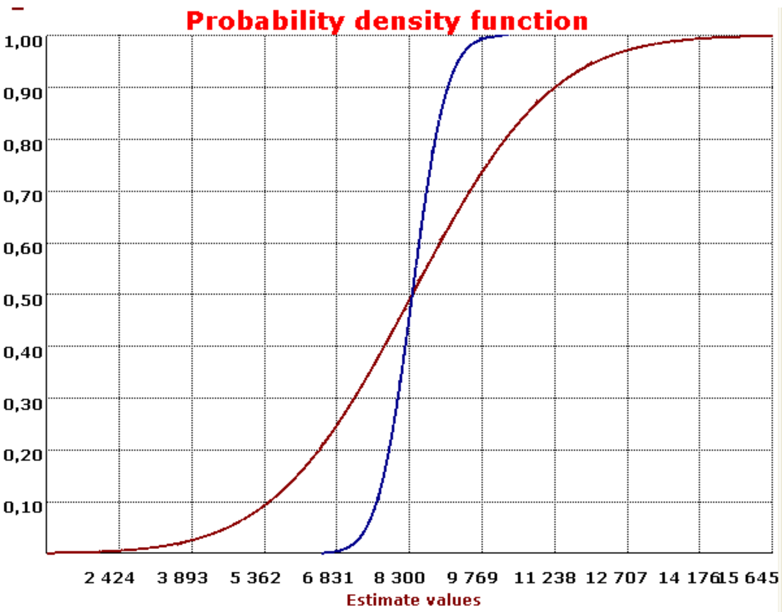

Figure 34: Project 2. (WEPS)

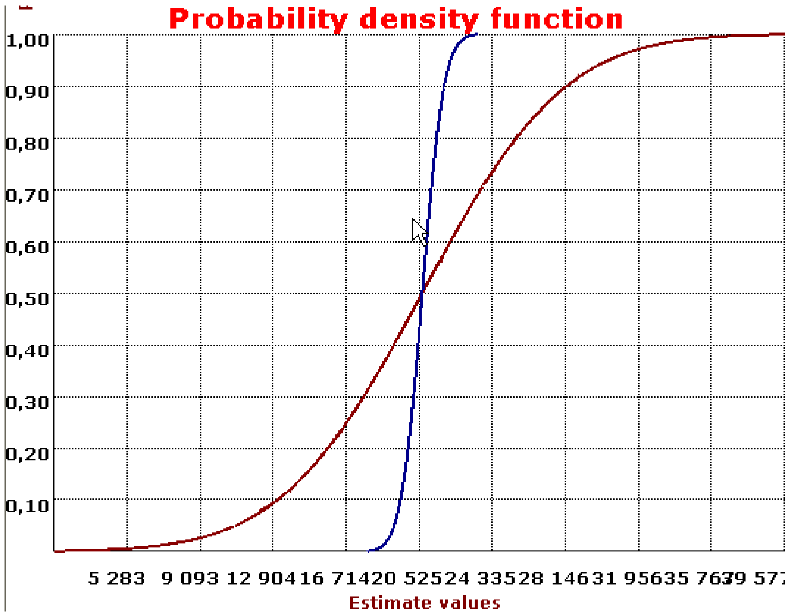

Figure 35: Project 3. (WEPS)

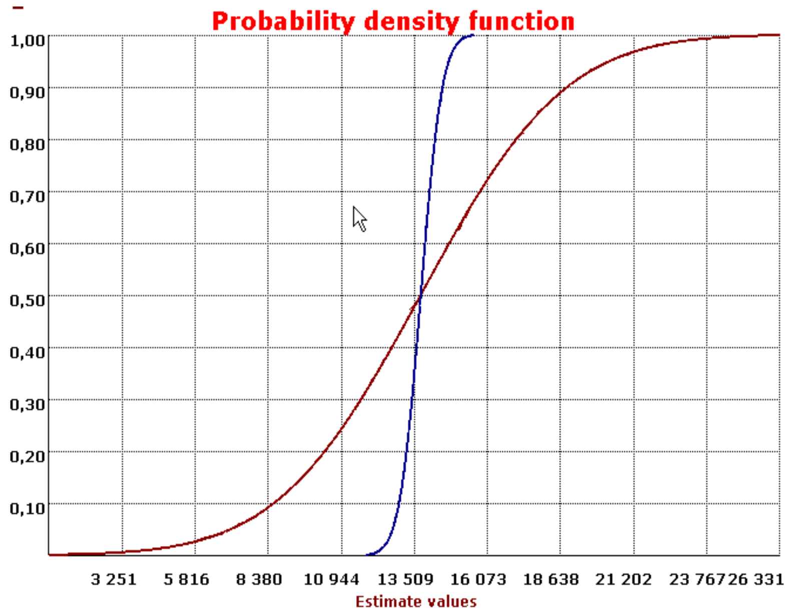

Figure 36: Project 4. (WEPS)

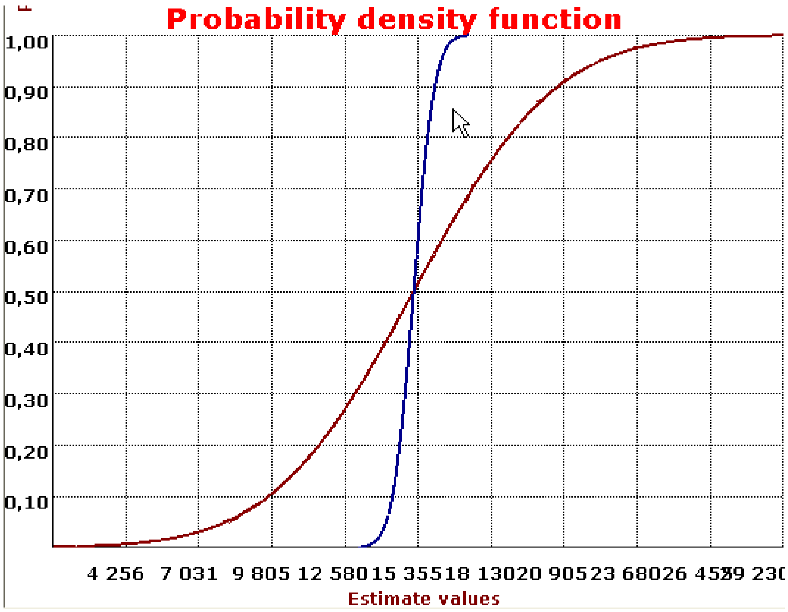

Figure 37: Project 5. (WEPS)

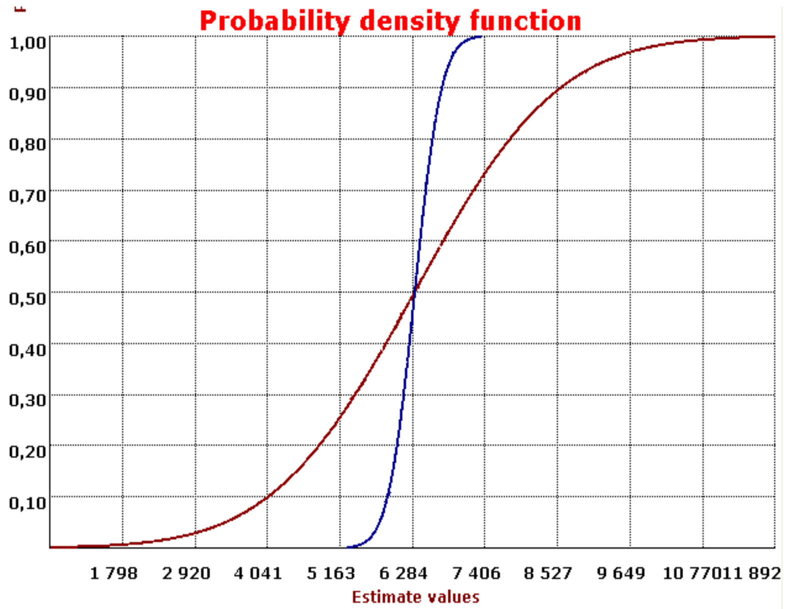

Figure 38: Project 6. (WEPS)

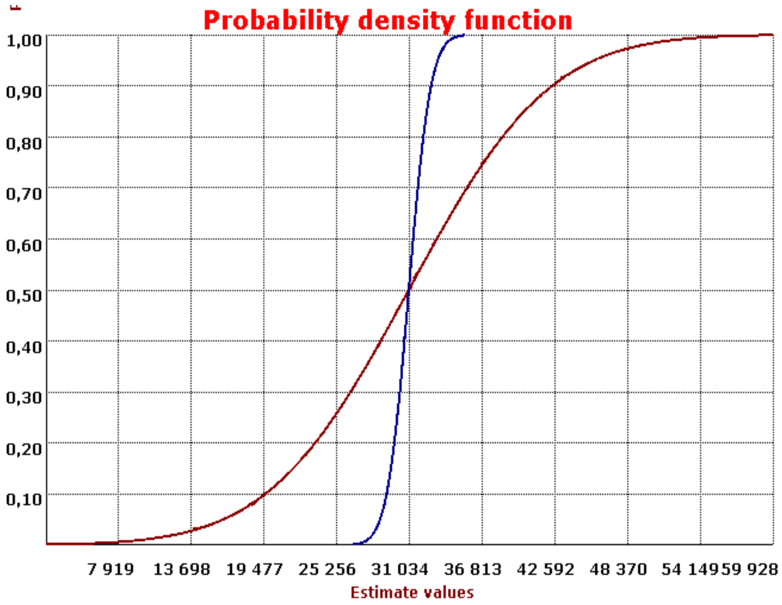

Figure 39: Project 7. (WEPS)

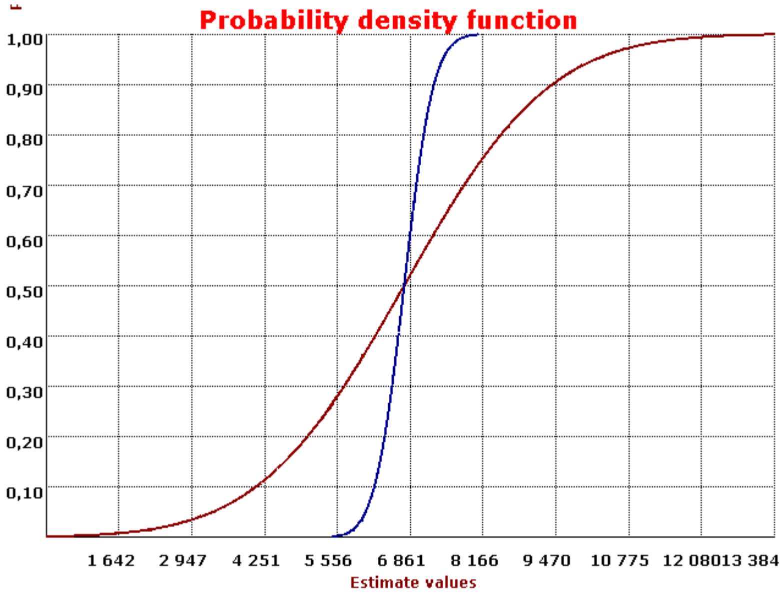

Figure 40: Project 8. (WEPS)

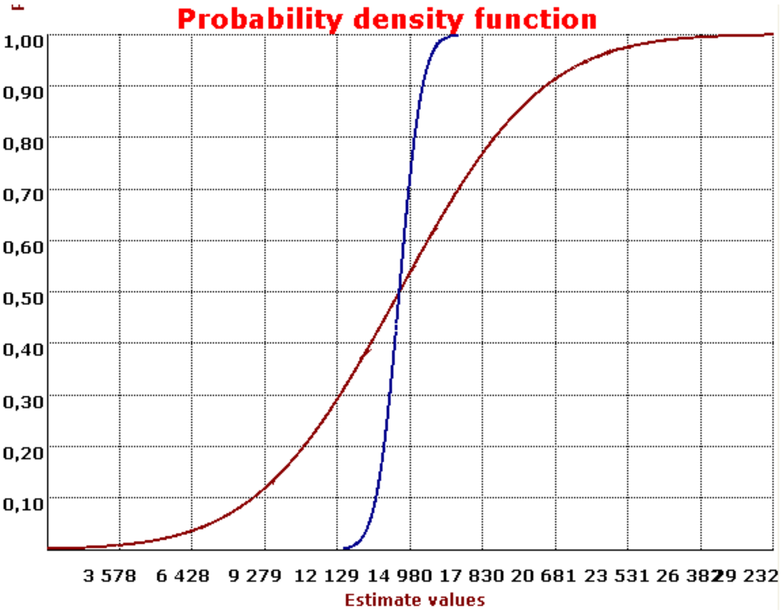

Figure 41: Project 9. (WEPS)

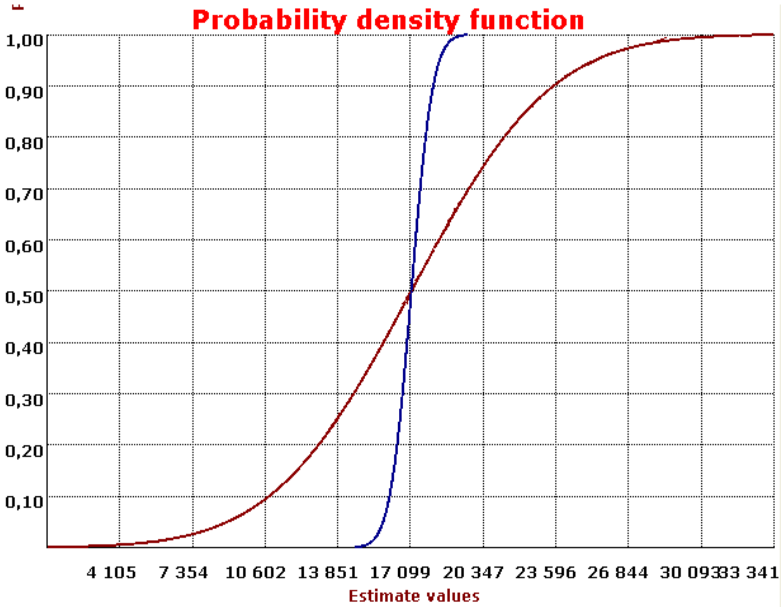

Figure 42: Project 10. (WEPS)

Figure 43 display the split between Equipment, Bulk, Structural and Total Weight for each project in the analysis between WEPS and @Risk.

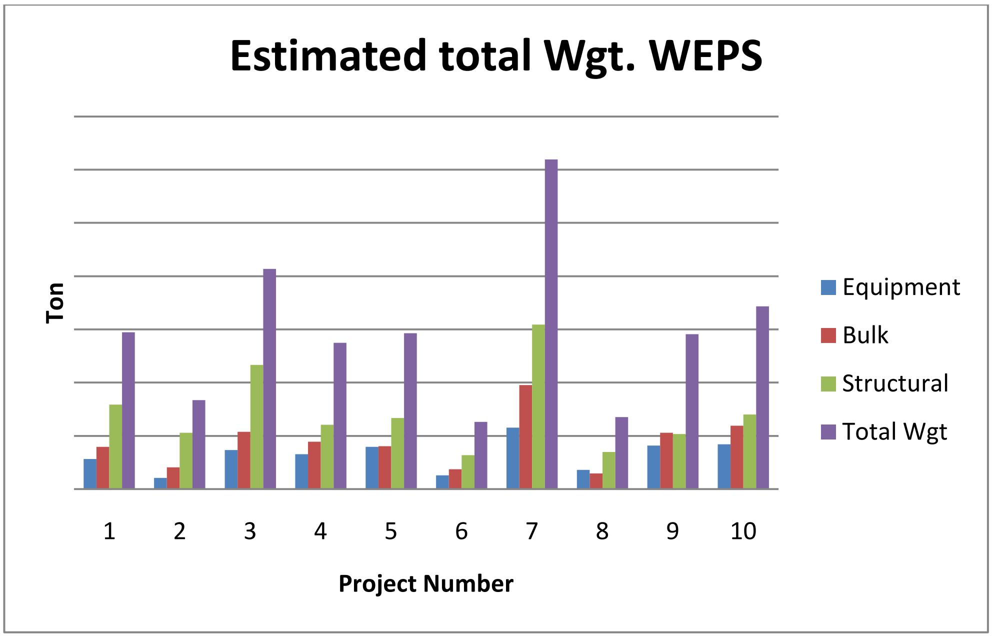

Figure 43: Estimated weight split

Figure 44 show the CV-value for each project and the average value of the projects in the analysis.

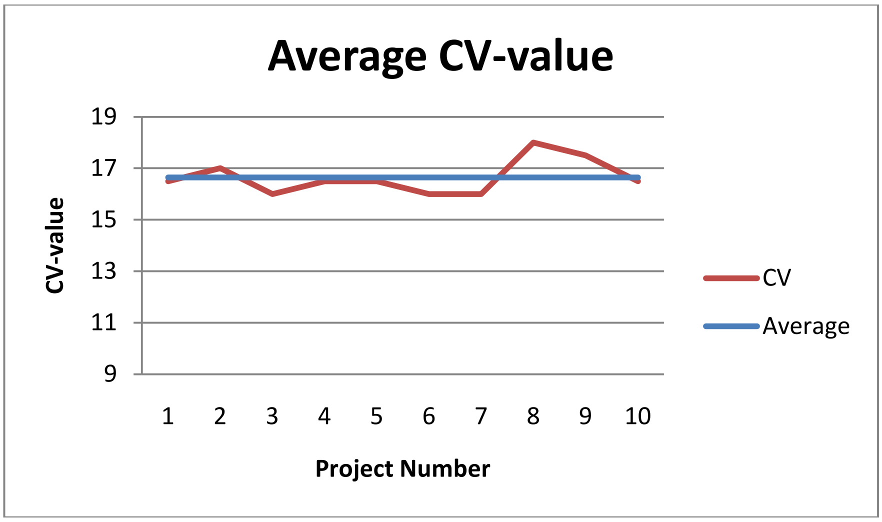

Figure 44: Resulting CV-value of each project

10.2 Appendix 3: Correlation scatter plots with trend line

Appendix 3 Show correlations scatter plots and distributions of discipline-weight-factors for each discipline. These scatter plots are used as basis for the alternative method to find relationship which can be used for estimation purposes.

HVAC:

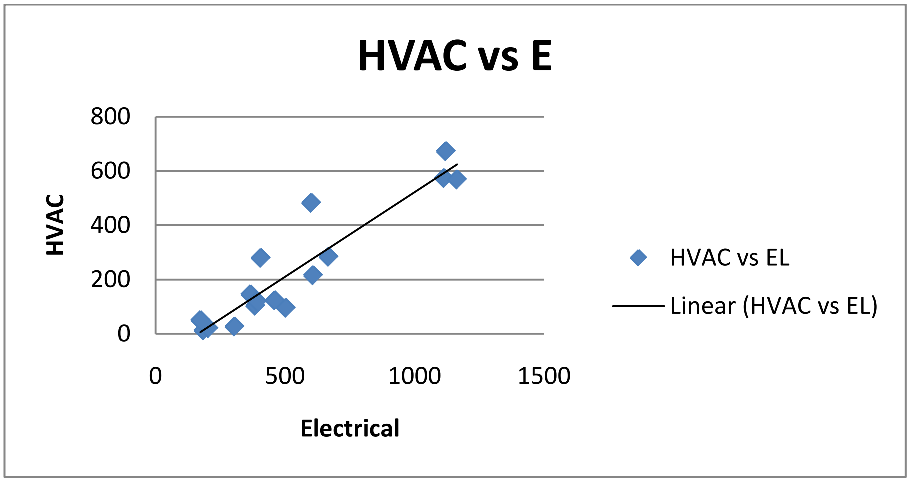

Figure 45: Correlation between HVAC and input Electrical

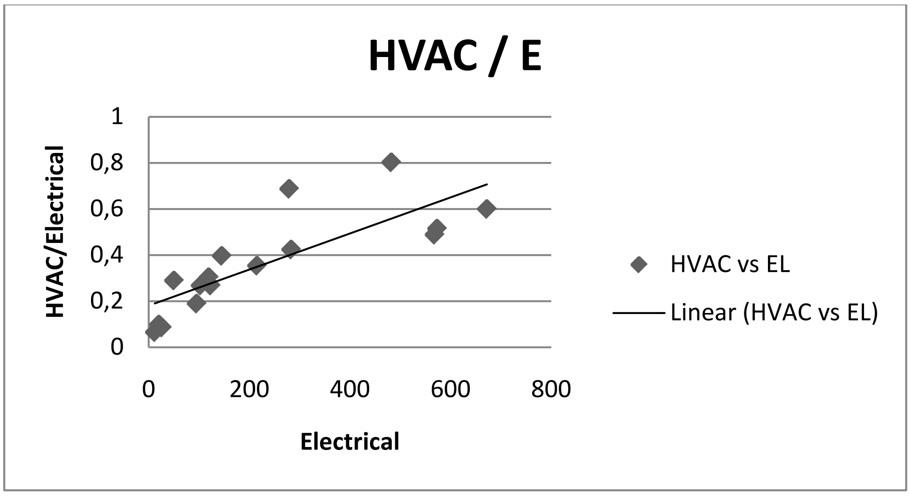

Figure 46: Factor of HVAC/Electrical

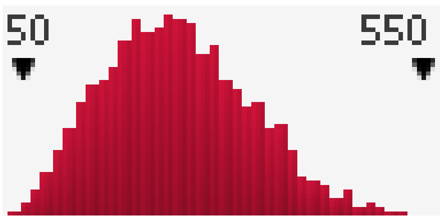

Figure 47: Distribution of the median factor of HVAC/Electrical used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor HVAC/E.

Piping:

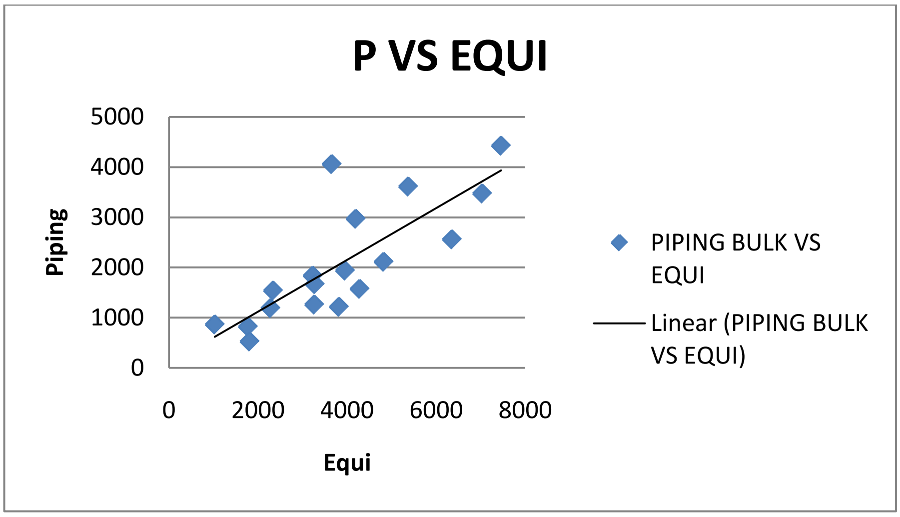

Figure 48: Correlation between piping and input Equipment

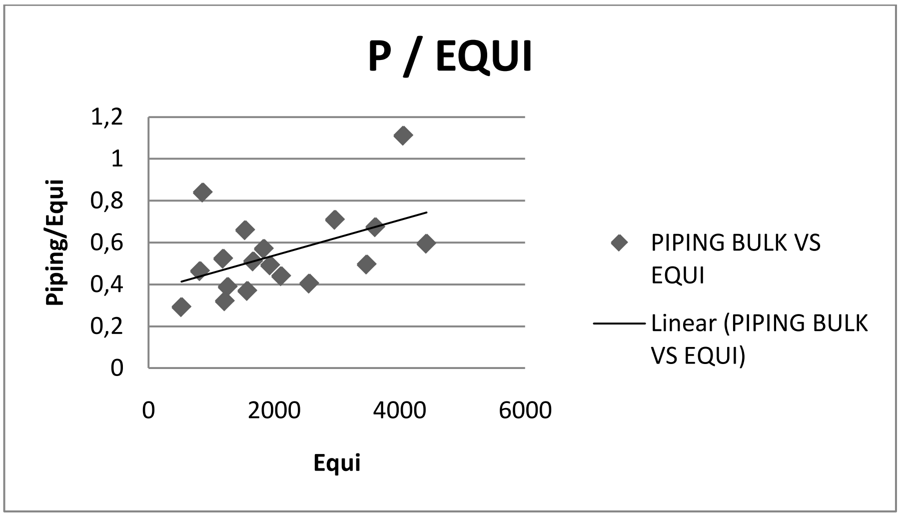

Figure 49: Factor of piping/equipment

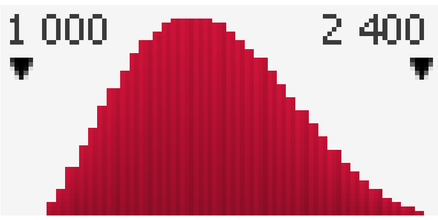

Figure 50: Distribution of the median factor of piping/equipment used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor P/Equi.

Corrosion:

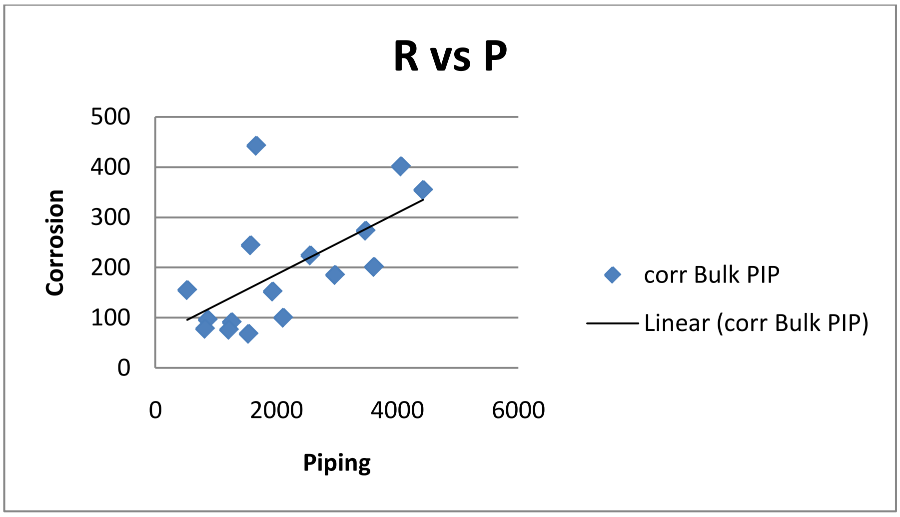

Figure 51: Correlation between Corrosion protection and input Piping

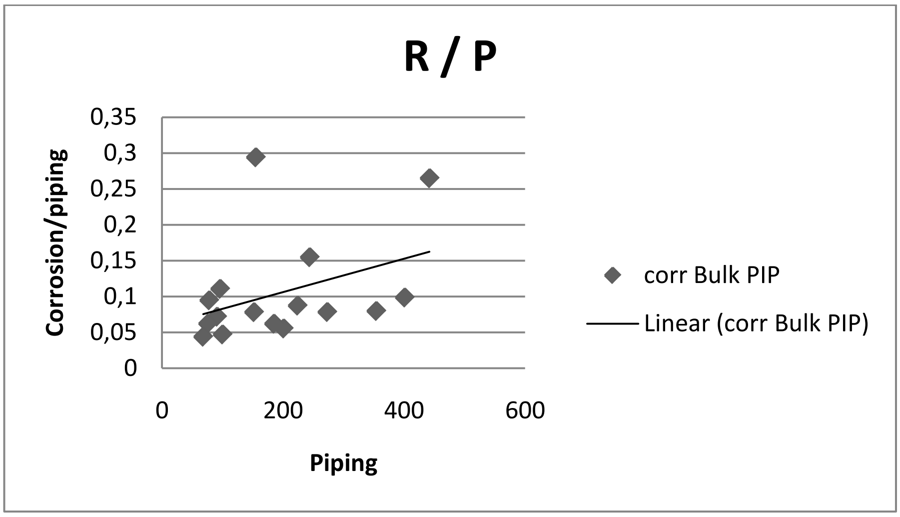

Figure 52: Factor of piping/equipment

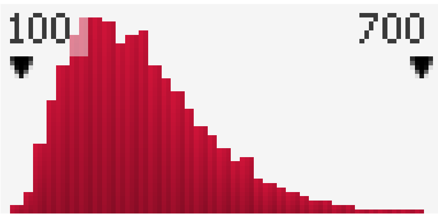

Figure 53: Distribution of the median factor of piping/equipment used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor R/P.

Architectural:

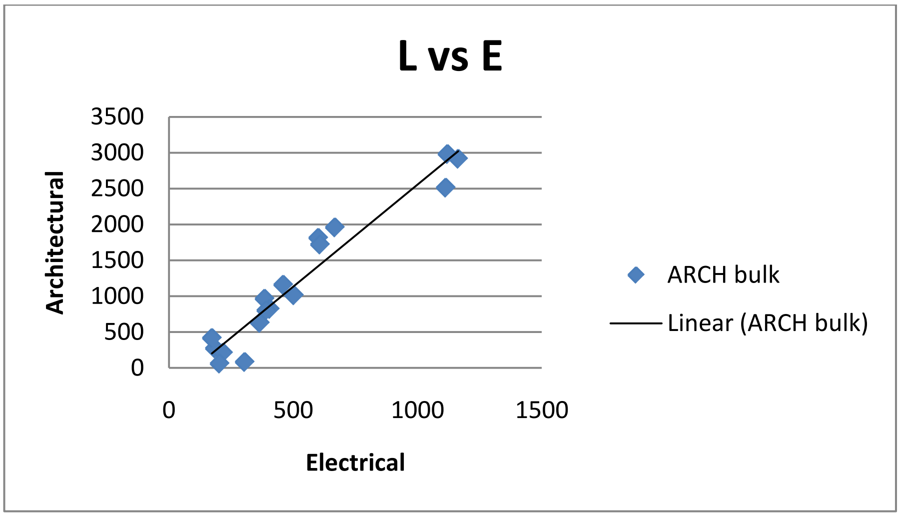

Figure 54: Correlation between Architect and input Electrical

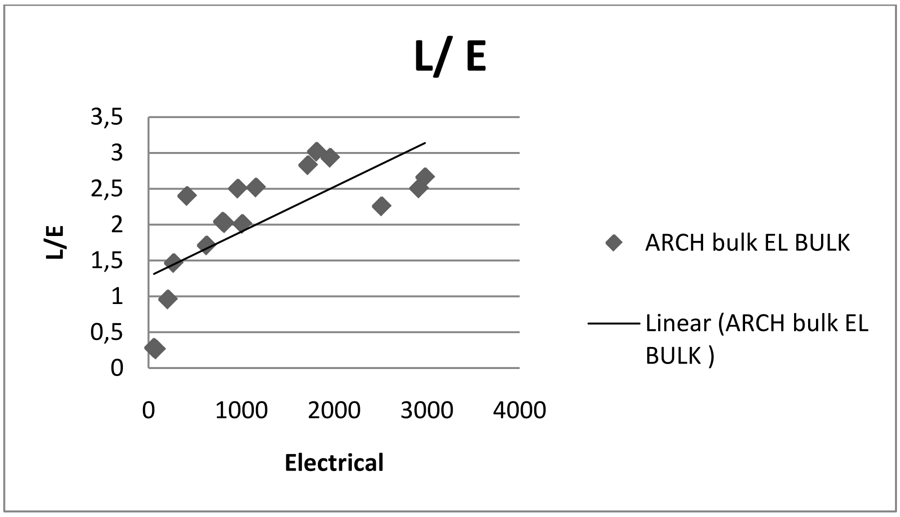

Figure 55: Factor of Architect/Electrical

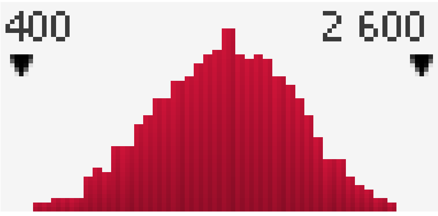

Figure 56: Distribution of the median factor of Architect/Electrical used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor L/E.

Fire & Safety:

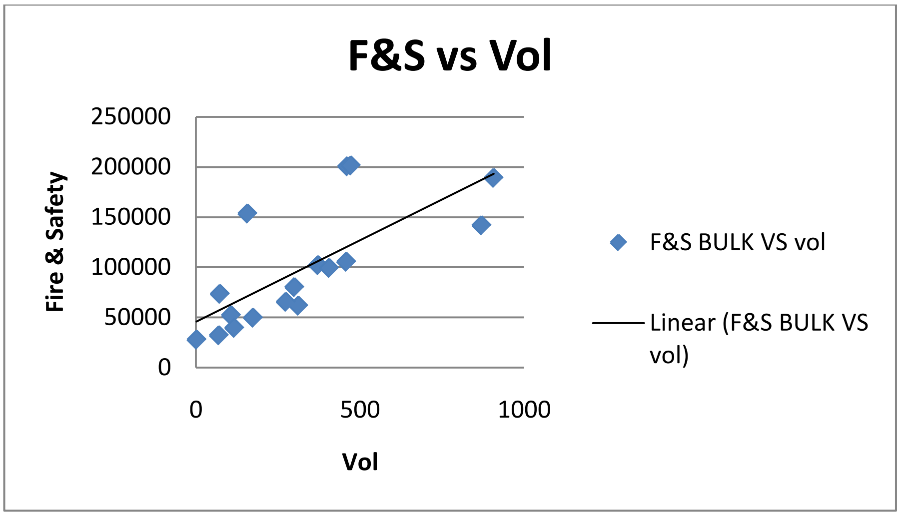

Figure 57: Correlation between F&S and input Volume

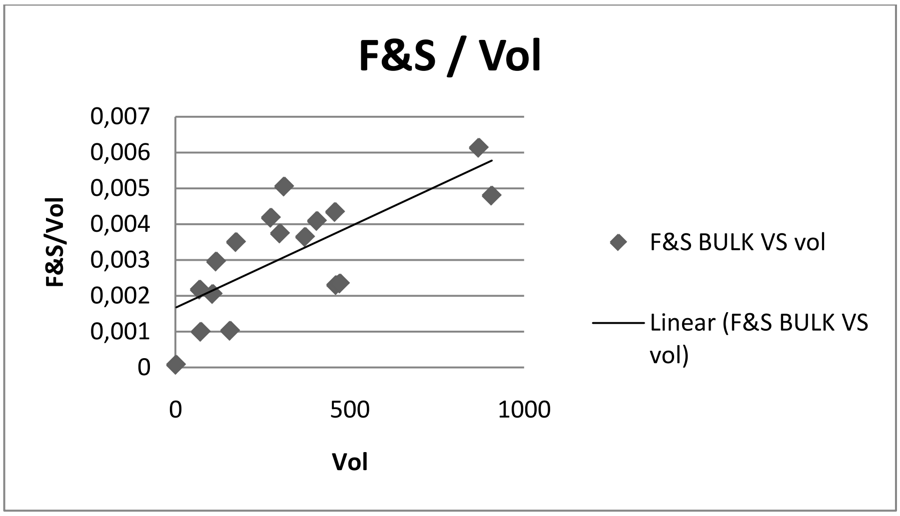

Figure 58: Factor of F&S/Volume

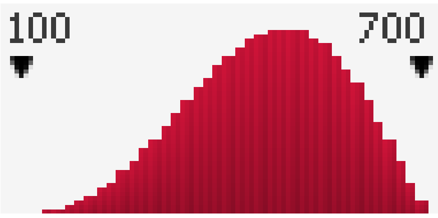

Figure 59: Distribution of the median factor of F&S/Volume used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor F&S/Vol.

Electrical:

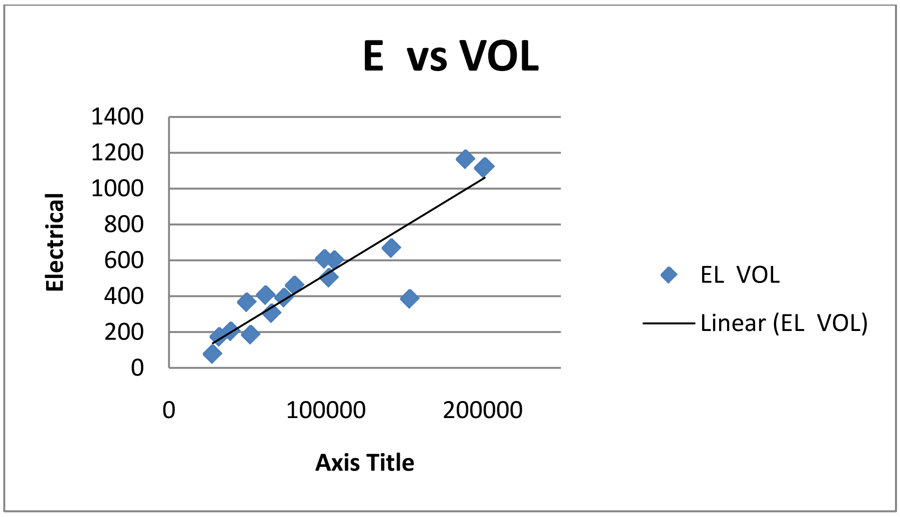

Figure 60: Correlation between Electrical and input Volume

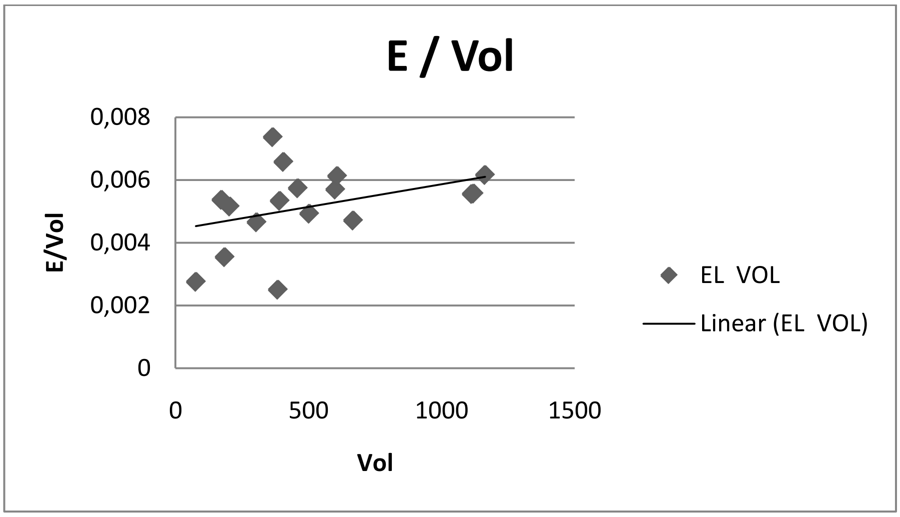

Figure 61: Factor of Electrical/Volume

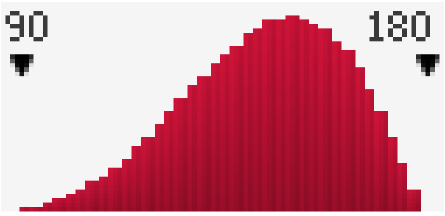

Figure 62: Distribution of the median factor of Electrical/Volume used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor E/Vol.

Instrument:

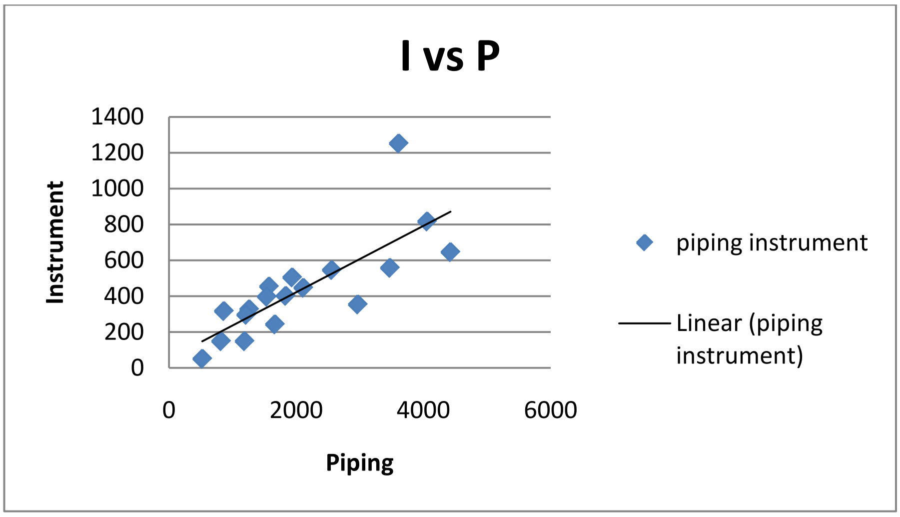

Figure 63: Correlation between Instrument and input Piping

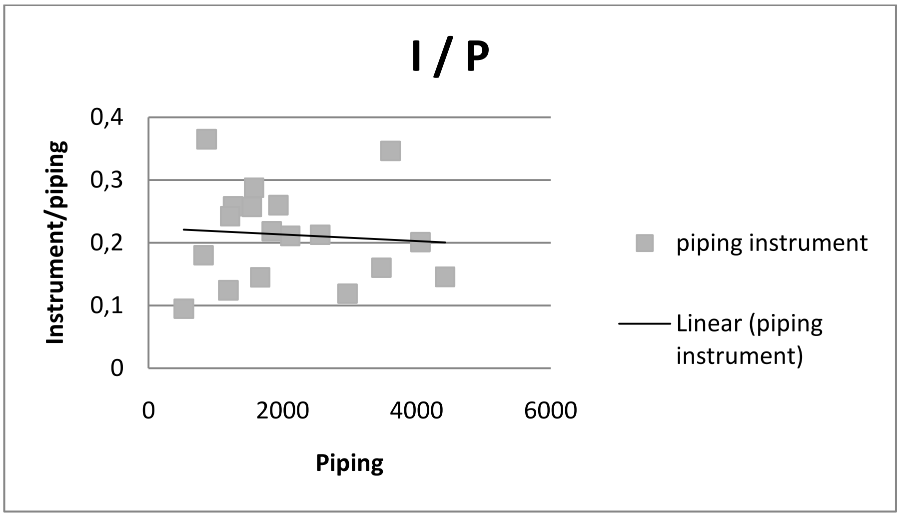

Figure 64: Factor of Instrument/Piping

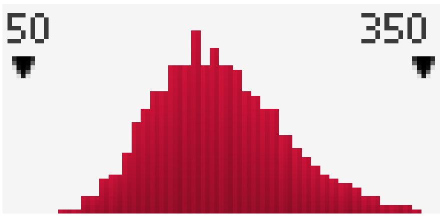

Figure 65: Distribution of the median factor of Instrument/Piping used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor I/P.

Structural steel:

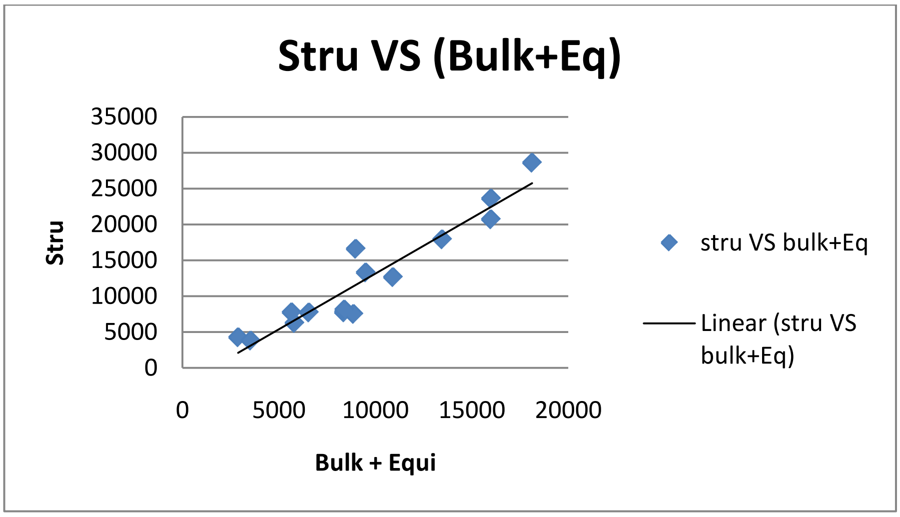

Figure 66: Correlation between Steel and input Bulk+Equi

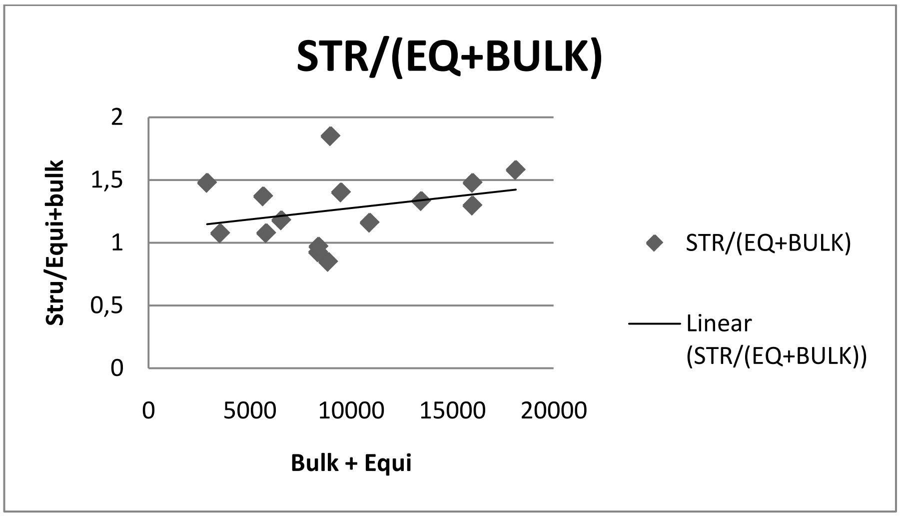

Figure 67: Factor of Steel/Bulk+Equi

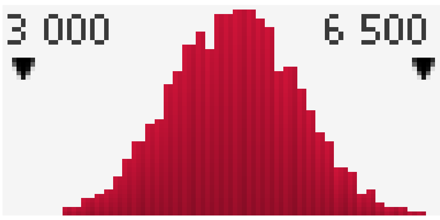

Figure 68: Distribution of the median factor of Steel/Bulk+Equi used in @risk

The distribution is used to determine the most probable factor. On the x-axis is the factor STRU/(Eq+Bulk).