Quantifying the Economic Value of Hydrologic Software: A Grounded Theory Approach

Master's Thesis

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Resume

The topic of the thesis is an economic value of hydrologic (numerical water simulation) software. Dutch research institute and specialized consultancy Deltares is facing a challenge – shifting business models, from the conventional license fees and support income to the open source environment. Open source software implies no more lump sum purchase revenues for the institute, while complex scientific software requires extensive investments to keep up the state of the art technology development. To adjust the business models, but also to justify the rationale for the governmental subsidies, the proof of the economic value created by the use of hydrologic software raises a question.

After investigating the existing economic literature, however, it proved obvious that no economic valuation framework exists for quantifying the economic value created by the use of scientific software. The research is hence focused on two goals. Firstly, on the development of the valuation framework, and secondly, on the quantification and assessment of business/economic value of Deltares hydrologic software packages.

The method employed in the research was chosen according to the circumstances. Qualitative exploratory research, and more specifically – Grounded Theory approach is suggested to be used in the fields that have not been studied extensively before. It entailed interviewing, transcribing, coding and comparing the interview material to conclude with the emerging framework.

The sample included seven Dutch engineering consulting bureaus, two of them – smaller but highly specialized companies, and the rest – large international companies, falling into top 10 engineering bureaus in the Netherlands. As suggested by Grounded Theory, additional interviews were sought as more questions were arising.

Proposed method of valuation is based on layering economic value in different levels – project level, organizational level and unanticipated value. As a case valuation, an attempt to quantify the value of Delft3D and SOBEK software packages is illustrated. The closest estimate for the project level value is based on the number of modelers working with the hydrologic software within the companies, and the multiplier of the direct value is offered as a possible spread of direct value on the organizational level. Unanticipated value is impossible to estimate at this state of research.

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I would like to thank Lucas Janssen, Maaike van Aalst, Frank Hoozemans and Edward Melger for providing an interesting practical problem, with the possibility to re-define and delimit the topic according to my own academic interest. At the same time, they kept me aware that the results of the analysis will add new insights in the Delta technology sector in the Netherlands. I would like to especially thank for the support and time they devoted for discussions, information and contacts they helped me to establish.

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Without the open-mindedness of Deltares and Dutch engineering consulting companies' employees the study would have been impossible. I am grateful to every single interviewee listed at the end of the thesis, who voluntarily dedicated their time, discussed their work routines and expressed their expert opinions. I would like to thank companies Arcadis, DHV, Grontmij, HKV, Nelen&Schuurmans, Royal Haskoning and Tauw for being open and giving consent for making the findings of study publicly available and in this way supporting the credibility of the research.

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"Over the last decade a new technology has begun to take hold in American business, one so new that its significance is still difficult to evaluate". Leavitt and Whisler about the Information Technology, 1958, Harvard Business Review

1 Introduction

Information technology was first mentioned in the academic management research in 1958. The technology development dynamics has exhibited interesting economic phenomena since, such as annual exponential growth of computing power (see Moore's law for reference (Kanellos, 2003)), a dot-com bubble in 2000s and a widespread dependence on the internet today. The industry is still evolving in the ways difficult to predict.

The topic of this thesis is beyond already existing academic frameworks. It focuses on the economic value of scientific software, more specifically – it is a study of hydrologic numerical simulation software packages. Scientific software embeds the knowledge from different disciplines (mathematics and physics among others), to ease the process of design, engineering, or policy and investment decision making based on virtual simulations of reality. For instance, numerical simulation software is widely used in aerospace or automobile industries to test and advance digital prototypes and find solutions for engineering problems. As compared to building and testing physical prototypes, simulation software decreases the cost and time required dramatically.

Nevertheless, the evidently high economic benefits of such software come with costs. The complexity of underlying physics phenomena requires large investment of time and highly specialized knowledge. Embedding algorithms into the source code, testing and verifying performance of the simulations against the reality requires lengthy scientific development process.

Additionally, IT industry dynamics have properties that are difficult to compare to other industries. The value chain is not exactly the one of the physical product; neither can it be fully considered to be a service. Current trends in the industry predominantly are Software as a Service (SaaS) and Open Source business models (Business Insights, 2008). SaaS means that the purchase costs of the software are spread out over time, paid on-demand rather than as a large investment at the beginning. Open source business models indicate that no licenses restrict any party from selling or giving away the software or its components, it does not require royalty or any other fee (Open Source Initiative, 2011).

That implies that traditional revenues from software license sales might soon be absent. Yet, further advancements of complex software packages still require extra investments. How much is the software worth, and what is the direction to follow? To support the investment decisions and determine further direction of R&D, a broader understanding of economic value created through the use of such software packages is necessary.

1.1 Relevance of the topic

The business and economics literature has historically considered IT as a cost, later – as an investment. Nevertheless there exists no framework to quantify the economic value one more step further down the supply chain - **the v*alue created through the use of scientific software packages*.** Software is an intangible asset, and it is hard to estimate which part of the total project value could be assigned to the use of software as such.

The figure 1 below illustrates the arising problem. The size of the circles represents the size of economic value. The first circle depicts costs of production (seller perspective). They have to be higher than the revenues from the product (*sales: licenses & support services*) to justify the investments in software development. At the same time, cost of the product from the buyer perspective, the price that is paid for the product, has to be lower than the value created through the use of it (*economic value: the use of software*) to justify the purchase.

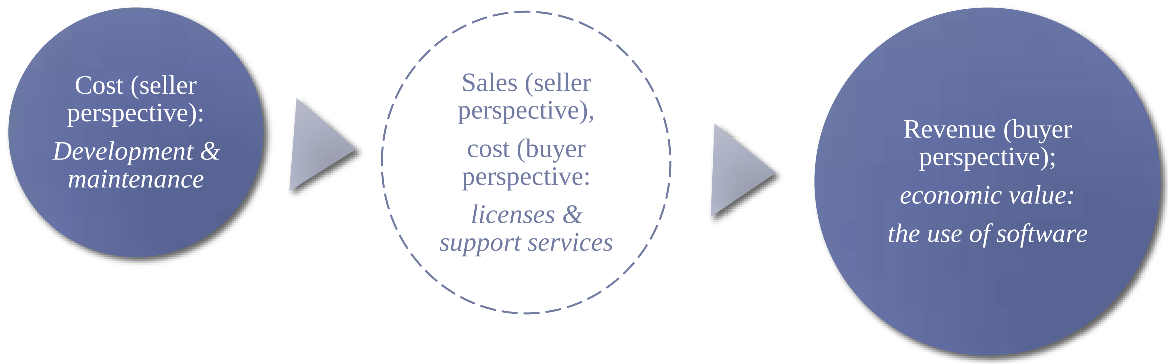

Figure 1: Economic value creation in the supply chain
Source: composed by the author

With the shifting business models to Open Source, and disappearing license costs/license revenues, as demonstrated in figure 1, the economic value that is created from the buyer perspective becomes the only main way to quantify the returns on investment in software development. As a result, the producer of scientific software becomes directly interested in the economic value that the software creates for its users (private companies). Traditionally, this quantification would be directly reflected in pricing. In the case of Open Source, the pricing becomes irrelevant, and the quantification of the return for a user could be used as a basis for the business model innovation.

To sum up, in order to be able to continue investing in further development of scientific software packages, it is essential to adapt to the changing industry dynamics and open source environment, to maintain or create new sources of revenue instead of disappearing sales revenues. How important the software is to its users (business clients), and how much interest they have in supporting and collaborating in the state of the art technology development are the questions that matter. As a base argument for these considerations, the measure of **the economic value of the software to its users** is crucial.

1.2 Area and scope of the research

The case-study examined in this research is the numerical hydrologic (water simulation) software. With the support from Dutch research institute and specialized consultancy Deltares, two software packages Delft3D and SOBEK were set to be investigated; later in the research due to the historic and practical similarity the third package SIMONA was included in the analysis.

Delft3D, SOBEK and SIMONA are complex numerical simulation tools for modeling hydrodynamics (e.g. water flow, waves, water quality and ecology), sediment transport and morphology in the marine, coastal, river and urban settings. The first versions were developed in 1990s in cooperation between public and semi-public institutions in the Netherlands.

Deltares as a semi-public knowledge institute and specialized consultancy is facing a challenge to adapt to the changing software industry dynamics. Software is a main way to explicitly store knowledge developed and accumulated in the institute through the years. Economic value of the software is of interest for the institute. Firstly, a not-for-profit organization is partially supported by the public subsidies; hence it is important to justify the economic value at macro level and the rationale for subsidizing to ensure its continuity. Secondly, being only semi-public, independent revenues remain essential source for investments to enable further development of knowledge and state of the art technology. Therefore, the proof of the economic return from the investments in scientific software is essential, as well as the quantification of its economic value is interesting for the management of further software development.

The economic value by definition is a subjective notion, and it largely depends on the purpose of valuation. For instance, the societal effects of hydrologic software could be enormous. With the help of numerical simulation the appropriate prevention measures against flooding could be taken, the design of the dam could be optimized or the flood forecasting system could reduce the costs of the flood event. However, looking at the economic value in the broadest sense, it is difficult to draw any managerial implications on the resources available, due to the different level of comparison (economic benefits at the societal level vs. investment resources at the organizational level). Hence, it is important to delimit the scope of the economic value that is of influence on the managerial level. Societal scope of such economic value is too large to be directly linked and affected by the single organization.

Delimiting this research to the business value for the direct clients of Deltares gives a good indication and reference for managerial implications. Deltares clients and partners range from (semi-)public institutions to the engineering and consulting companies operating in the field of water/infrastructure. The scope of the research is delimited to the **commercial clients only**, due to two main reasons. Firstly, the economic return from education or public research adds to the already high level of complexity of the topic, since the time span and ways of return on fundamental research expands considerably. On the contrary, the return for the private companies is anticipated to be easier to quantify and could be related to the revenues of the commercial projects that the software is used as a tool for. Secondly, given the purpose of valuation (the managerial implications/investment decisions for Deltares), the economic value for the commercial clients is the first area to assess.

1.3 Existing literature and the notion of economic value

At the beginning of the research and throughout the process, extensive literature review was conducted in search for suitable valuation framework. Diverse alternatives from economic and management fields were considered (for instance, real options valuation approach, which is increasingly popular in making valuations to support IT investment decisions). However, none of the existing frameworks were found to be readily suitable for the particular case of scientific simulation software.

In relation to the topic in the study, the mainstream academic research on Information Systems (IS) focuses on (1) less specialized enterprise software (business support systems such as Customer Relationship Management), (2) the economic value on the macro perspective (how the organizational performance or stock returns increase after the investment in Information System) ((Anderson et al., 2006); (Dehning et al., 2005)), (3) the non-economic performance of software, such as software productivity, task-technology fit or user acceptance ((Brynjolfsson, 1993); (Dale, 1992); (Goodhue, 1995); (King and He, 2006); (Petersen 2011)).

Two streams of research that come closest to the topic in focus offer useful insights into the subject. These are (1) business value from IT and (2) technology and intangibles valuation literature. The former provides suggestions on how the economic value through IT is created and which aspects to consider in valuation, while the latter complements the aspects to look at and additionally offers insights into the methods of valuation.

1.3.1 Business value from IT

Kohli and Grover (2008) gives a comprehensive overview of IS literature, and the future research directions to follow. According to the authors, the IT value in the organization can be **financial** (e.g. ROI), **intermediate** (e.g. process related) or **affective** (e.g. perception related). Hence, it can be proved by gains of productivity through different aspects: process improvement, profitability, consumer surplus, improvements in supply chains or innovation at the inter-organizational level. Additionally, the value is created at many levels: **individual**, **group**, **firm**, **industry** or **process**. Finally, the value of IT is not immediate and is evident with the **time lag**.

The authors identify four important directions of the future research: (1) IT-based co-creation of value, (2) IT-Embeddedness, (3) Information mindset and (4) Value expansion. With the level of analysis of this research based on the single software tool rather than the organizational IT system, the 4th notion is important. Kohli and Grover bring an issue of underestimating the true benefits of IT value, while basing the estimations on ex ante market value or post hoc financial metrics. It is necessary to understand the **intangible value**, such as agility, flexibility, first-to-market, lower prices through electronic markets, higher efficiency through information integration, etc. Hence, the authors suggest to have indirect and intangibles paths to economic value as one out of four directions for future IS research.

Mueller et al. (2010) confirms the complexity of economic value from IS. The authors take advantage of multidimensional benefit frameworks and gradual decomposition of the economic potential context to identify the framework for Service Oriented Architecture valuation. The dimensions analyzed include **operational**, **managerial**, **strategic**, **IT infrastructure** and **organizational** benefits.

Yet another discussion in the literature is about how to look at the Information Technology itself. Nigel et al. (2004) gives an overview of conceptualizations of IT artifact in the previous research as: (1) tool view, (2) proxy view, (3) ensemble view, (4) computational view, and (5) nominal view. Additionally, he suggests the limitations that these points of view might imply. Relevant to the hydrologic simulation software, the tool view and the ensemble view are the significant approaches. First one due to the fact that complex simulation software is mainly used for what it is designed to do, and its purpose is to generate value. This is a usual approach within IT business value. Ensemble view looks at the interaction of the technology and people, organizational co-innovations. As a take away from these classifications, the following limitations have to be carefully considered: tool view tends to disregard the **unintended consequences** from the use of software, and the ensemble view commonly overlooks the **treatment of IT personnel** (IT management and technical expertise), and focus purely on the users within organization.

After reviewing the academic literature related to the business value of IT, no quantification framework for such a value was found. The factors discussed in the research were either qualitative with no suggestions for the measurements, or on the general level, containing large samples of companies with differences of IS investments – seeking the correlation rather than explanation of causality nuances, hypothesizing *if* the economic value is added to the company, and not *how* the value could be quantified. No conclusions of how to measure a software tool within a single company could be made. The more general look at the valuation methods of technology and intangibles had to be taken.

1.3.2 The value of technology and intangibles

Technology valuation challenges come from four main sources: (1) technology is usually embodied in the human knowledge or physical assets, and hence its exact scope is difficult to identify; (2) it is affected by various non-technical aspects; (3) valuation itself is a subjective activity; (4) unlike in the other industries, the balanced price through the market mechanism is difficult to reach, since technology is not widely traded (Park and Park, 2004). Therefore, the valuation methods in practice range from intuitive judgment to the complex real options model.

Similarly to the IT business value literature, technology valuation research stream discusses the importance of intangible value. Unlike other investments with more predictable future cash flows, technology embodies an **opportunity** or **potential value**. That is the possibility to expand the future returns from the current asset by the prospect to improve and develop the asset further (Mayhew, 2010). Consequently, the value of technology is composed from different layers, and the question is how much to take into consideration and what is irrelevant for the particular valuation purpose.

Stephen Mayhew (2010) suggests a few practical steps when evaluating the technology: (1) identify the economic and potential **value drivers**, (2) evaluate the economic and potential value drivers, (3) Assess the relationship between them, (4) develop robust practical scenarios under which value is realized, (5) use simulation tools to model chosen scenarios, (6) use value ranges to represent valuation outputs. Although his suggestions are interesting and relevant, there are a few different standpoints when choosing the approach of valuation.

1.3.3 The methods of valuation

The methods for valuating technology range from **cost based** (book value), **market based**, and **income based** (e.g. Net Present Value). The new type of valuation is emerging – **the real options approach.**

1.3.3.1 *Cost based approach*

Cost based approach is grounded on the economic notion that a client is willing to pay no more than it costs to create that intellectual asset or technology. It could be estimated as a reproduction cost (how much it would cost to create an exact replica of the technology), or as a replacement cost (how much would it cost to create the same functionality, but not necessarily in the same form and appearance) (Park and Park, 2004). The relevant valuation parameters are the accumulated costs incurred (e.g. research funding/costs, legal, Intellectual Property and administrative fees and non-recoverable taxes). Depending on the age of the asset, these costs may be adjusted for depreciation, inflation or exchange rate fluctuations (Mayhew, 2010).

In relation to this thesis topic, cost based approach would be limited to software development costs (the first circle in figure 1). However, this approach is admittedly irrelevant to technology valuations due to its focus on the historic cost, and ignorance towards wealth-creating potential. On the other hand, it is easy to calculate, if the cost data and depreciation factor for technology is available (Park and Park, 2004). It is especially preferred at the early development stages of the technology, when the exact market application and future business potential is yet unknown (Vega-Gonzales et al., 2010).

1.3.3.2 *Market value method*

This approach is based on the equilibrium between what the customer is willing to pay for the technology, and what the company is willing to sell it for (Park and Park, 2004). Traditionally, market defined value estimation is a rather simple and direct method, and could be based on the comparison with similar assets (Mayhew, 2010). However, it is hardly applicable to the specialized technology, due to the lack of the active market where the technology is traded, and where the information, price and comparability are available (Park and Park, 2004). Henry Chesbrough (2006) in his book Open Business Models extensively discusses the limitations to intellectual property pricing, and the lack of efficient markets for patent trading.

1.3.3.3 ***Income approach***

The income based valuation emphasizes wealth-producing capability of the subject technology. The most popular valuation method is NPV (Net Present Value) or DCF (Discounted Cash Flow) of the economic benefit over the life of technology (all future revenues minus costs, discounted with the suitable interest rate to translate to the present value of the capital (Mayhew, 2010)). In the literature it is considered to be well-suited for the valuation of technology and intellectual property such as patents, trademarks and copyrights. The downside is the significant possibility for error (Park and Park, 2004). The difficulties arise when choosing an appropriate forecast period or discount rate (which depends on the risk of the asset or the opportunity cost of capital to the firm and project investors) (Mayhew, 2010).

1.3.3.4 ***Real options method***

This approach takes into account not only the predicted future cash flows, but also the managerial flexibility, the right (not an obligation) to make a decision under fixed terms at a fixed point in the future. In other words, the method assigns a value to opportunities to further improve the revenues through, for example, expansion or different application of the technology than expected. Options methods include Black-Scholes model and compound options models (binomial lattices), and originate from the financial instrument valuations (Angelou and Economides, 2009).

Although theoretically options valuation method is gaining popularity, it is difficult to apply in reality due to several assumptions the method entails. For instance, the variable of volatility (the range of possible future changes in the value of technology) is difficult to estimate, realistic predictions about possible future opportunities are problematic to determine ((Park and Park, 2004); (Vega-Gonzales et al. 2010); (Mayhew, 2010)).

1.3.4 The research topic in the light of existing literature

Existing academic literature discusses a number of useful aspects to take into account when carrying out IT valuation. The individual, group, firm, industry, or the process, operational, managerial, strategic, IT infrastructure and organizational levels of value added are outlined. However, in the business value of IT literature this is done only in the qualitative manner.

Which quantitative measures are the best to be used in evaluation of a single software tool within the company is still not researched.

A more general field of technology valuation entails more extensive discussions about which methods to use for measuring its value. The proposed approaches for quantification are cost, market, income and real options methods. Based on the purpose of this thesis to evaluate the strategic importance of software for its users, historical cost approach is inadequate, since it focuses on the product development process rather than the forward looking process of using and managing the product. The market value cannot be defined due to the intangible nature of software and low duplication costs, which interferes the demand and supply defined market price (traditionally, price of the product increases as its supply decreases – however, the marginal costs of software are close to zero (once the software is developed, the cost of producing additional copy are insignificant)). Furthermore, the real-options approach requires detailed quantitative data and entails a number of assumptions hindering its practical applicability.

The circumstances suggest income based valuation philosophy as a starting point in assessing the economic value of hydrologic software. Yet, how to estimate the income related to the hydrological simulation packages, is a question with no answer in the academic research. It is still unclear which factors to look at for measurement, and how to quantify their value. To be able to suggest a suitable way for quantifying economic value of the software, the process and context of its use has to be investigated in more detail.

1.4 Research question

The economic value which is created through the use of a scientific software packages is not easy to assess. Firstly, no similar research is done on the economic value of numerical simulation software, and no unified framework for valuation exists. Technology largely has an intangible nature as an asset, plenty of aspects are interconnected in the value creation, such as a labor-intensive process of use, high level of expertise required in order to run the numerical simulations and make sense of the results. Secondly, delimiting the notion of economic value and defining the scope of valuation is essential for obtaining meaningful results.

Since the estimate of the value is intended to be a reference for managerial and strategic implications and support for investment decisions, the value notion is delimited to effects within the boundaries of **business value for the direct customers**. That includes cash flows/cost savings related to the software[1], but also indirect business effects, e.g. business and innovative performance of the company, operations optimization, or the additional software products developed on top of the software packages in focus.

Therefore, the ultimate question of interest in the case studied is:
What is the economic (business) value created by the use of the Delft3D, SOBEK and SIMONA software packages among the Dutch engineering consulting companies?

Yet given the current stage of academic research and non-existence of framework to make such quantification, the **research question** for this thesis is stated as follows:
How can the economic value of hydrologic simulation software be quantified?

Furthermore, for the more defined direction of research, the areas of interest are phrased as:

- Quantitative determination of economic effects of Deltares hydrologic software to its users;
- The influence of the products to business and innovative performance of the clients;
- The additional software products (if any) that clients offer on top of Deltares product;

1.5 Structure of the paper

The following chapters in the thesis describe the research process, discuss the data gathered and conclude with analytical implications. Chapter 2 outlines the methodology and research design followed throughout the study, the motivation behind the choice of method and research decisions undertaken. It discusses the role of literature, data collection and treatment. Chapter 3 summarizes the analytical framework that is implied by the context of the study. The framework is used to portray the findings and the case-specific data in chapter 4. It summarizes the qualitative research outcomes to propose a quantitative measure for the economic value of hydrologic software. Chapter 5 contains the summary of quantification in

[1] Further in the thesis word *software* refers to the *hydrologic (numerical simulation) software*, unless otherwise stated

the case analysis. Chapter 6 delineates conclusions and implications, and shortly presents the possible directions for the future research on the topic.

2 Methodology and research design

The *quantification of economic value* raised a question of *how the value is created*. Limited knowledge about the role of the hydrologic software in the value creation led to the choice of the qualitative exploratory research design. Exploratory research can be classified as a part of positivist epistemology tradition, and the main focus of the method is the generalization and abstraction of the empirical data gathered (Stebbins, 2001). It is the opposite of the widespread method of research in the organizational sciences based on confirmation, which entails preconceived hypothesis and framework of analysis for handling the empirical data.

This research began by clearly defining the problem in focus, and the choice of method followed later. According to the traditional qualitative research process, the problem formulation was followed by the literature review and a search for analytical framework. The literature studied and shown to be relevant can ex post be categorized into two sets: (1) business value of IT/IS (Information Systems) and (2) technology/intangibles valuation. Only the absence of existing framework for the quantification of economic value created by the use of scientific software suggested a need for exploratory method for solving the research problem.

2.1 Grounded theory

The scientific inquiry method focused at the emerging new theory and creation of generalized framework rather than verification of an already existing one, was described in a book The Discovery of Grounded Theory (1967) by Glaser and Strauss.

Over decades however the original notion of Grounded Theory was taken into different directions by Strauss and Glaser separately, as well as other researchers (see Glaser, Strauss & Corbin, Charmaz and Clarke). The research philosophy and process differs on critical dimensions, such as interview coding, role of literature and research problem. Despite the ideological differences, there are a few core principles that remain important in all the variations of Grounded Theory (Babchuk, 2009):

1) Theoretical sampling

- As the research progresses, additional questions and ideas emerge. The sample is hence based on the additional data of interest, and cannot be fully pre-defined at the beginning of the research; neither is it based on the representativeness of the population (Charmaz, 2006). The theoretical sampling means looking for the interviewees as a need for theoretical explanation arises.

2) Constant comparison of data to theoretical categories

- Data collected is coded and concepts are categorized;
- The data collection and analysis is simultaneous and iterative;
- The data collected forms and influences the emergence of theoretical categories, which in turn shapes further data collection.

3) Focus on the development of theory via theoretical saturation of categories

- The theoretical sampling should continue until no new theoretical categories emerge from additional data (Charmaz, 2006).

The approach favored in this thesis is based on the work of Charmaz (2006). She describes Grounded Theory as a flexible set of recommendations and not as strict rules to follow. Figure 3 below describes the Charmaz's process of Grounded Theory generation (discussed in more detail in next chapter – Emerging theory, alongside with the framework implied by the research data).

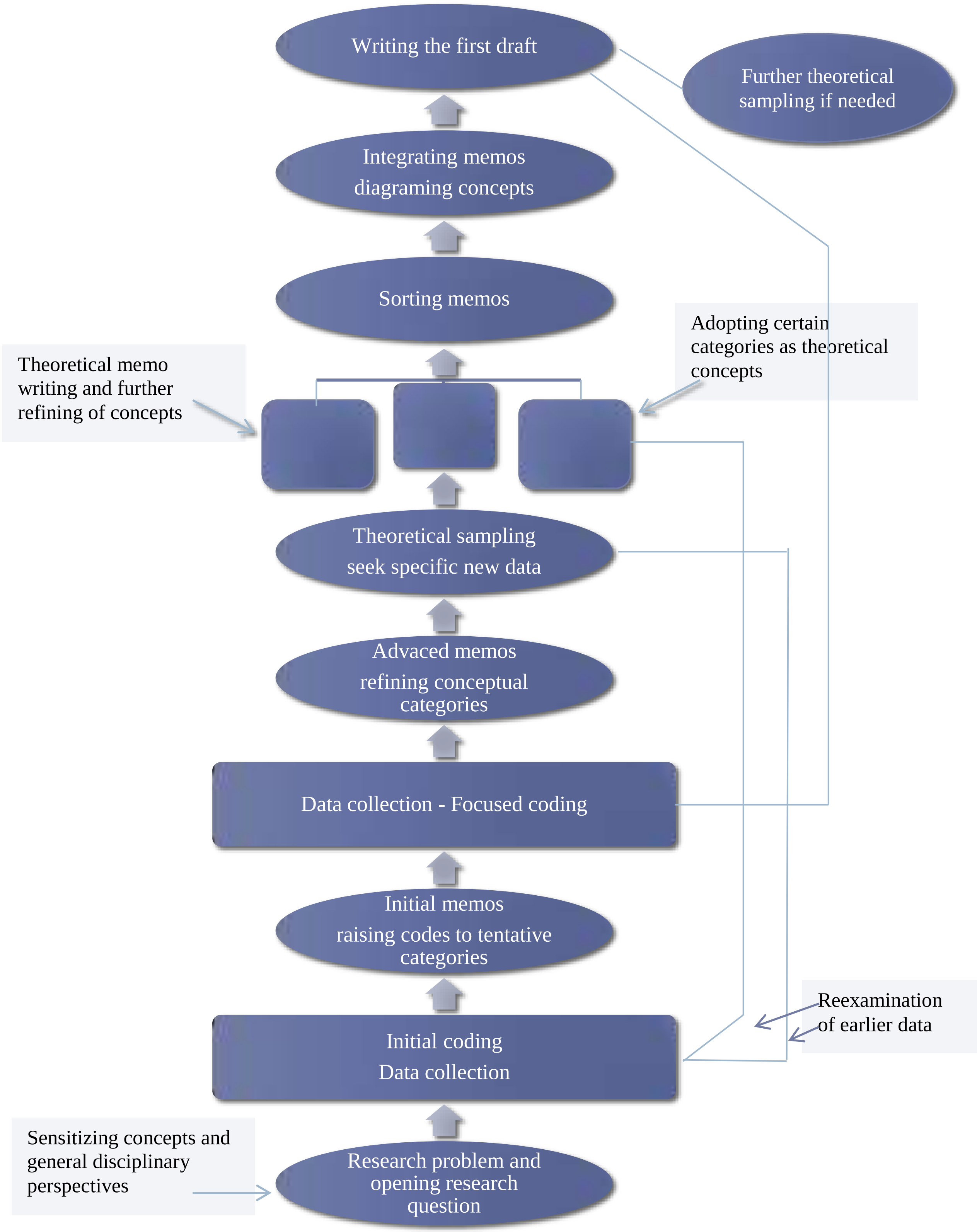

Figure 2: The process of Grounded Theory generation

Source: designed by author according to Charmaz, 2006, p. 11.

2.2 Role of the literature

In the initial concept of Grounded Theory introduced by Glaser and Strauss the conventional practice of literature review was opposed. They stated that the researcher must have minimum preconceived ideas to avoid the early interpretation bias based on the concepts from the literature and unconscious denial of novel emerging theory from empirical evidence. The literature review had to be delayed until the late state of the theory generation, when it could be used as additional data for constant comparison (Dunne, 2011).

More recent views on Grounded Theory discuss the role of literature in a different way. First of all, it is admittedly difficult to have little knowledge about the topic when the decision to carry out a Grounded Theory study is made. There are underlying reasons for choosing the topic, which often indicate the extensive interest and hence the knowledge of the researcher. Secondly, the method is commonly used for the topic with little or no previous research. To assess the lack of previous literature, the understanding of the existing knowledge base is necessary (Dunne, 2011).

According to Fleming et al. (2010), the researcher that starts a study with no previous knowledge about the area might miss the theoretical sensitivity to the data. Hence, the substantive literature awareness is valuable, but the objective treatment of the data and open mind of the researcher are preconditions to the grounded theory development.

As mentioned before, this study started with the problem formulation and a literature review, the method of Grounded Theory was chosen after an extensive overview of the academic research. The discovery of no readily suitable framework led to setting aside the literature until the final stages of the research; however, looking back at the first codes of the interview transcripts, the influence from previously encountered concepts on the formation of the first codes can be traced. Yet the initial interviewing process was carefully designed to listen as much as interviewee has to tell without imposing the subjects of interest, with the purpose to identify the important concepts from empirical data.

2.3 Data collection, analysis and the role of the researcher

At the start of the research, the role of the researcher was passive. As suggested by Glaser and Strauss, the research process was shaped by the research material, with the main goal to describe the phenomena, and not to create the grand theory.

2.3.1 Interview sample

The problem formulation and the goal of the research partially infringed the theoretical sampling principle, which states that the sample size or list of interviewees should not be predefined prior to the research and should not be based on representativeness of the population (Babchuk, 2009). However, the focus of the investigation was economic value of the hydrologic software to the direct clients of Deltares. Coupled with the structural limitations of interviewee time availability (only one or two persons could be interviewed from each of the 7 chosen Dutch engineering consulting companies), part of the interviews had to be predefined and prearranged. However, later in the process a few additional interviews could be scheduled. The main condition of theoretical sampling - including additional interviews as the need for more data arises - was fulfilled.

The empirical data collection process could be classified into four phases, which were overlapping and not subsequent (see figure 4 below). Firstly, the pilot interviews were carried out to gain more understanding about the use of the hydrologic simulation software. The people outside the predefined set of interviewees were talked to. Four pilot interviews were carried out with the employees of Deltares, who were using numerical simulations in their daily work, presumably in a similar way that the consulting companies did.

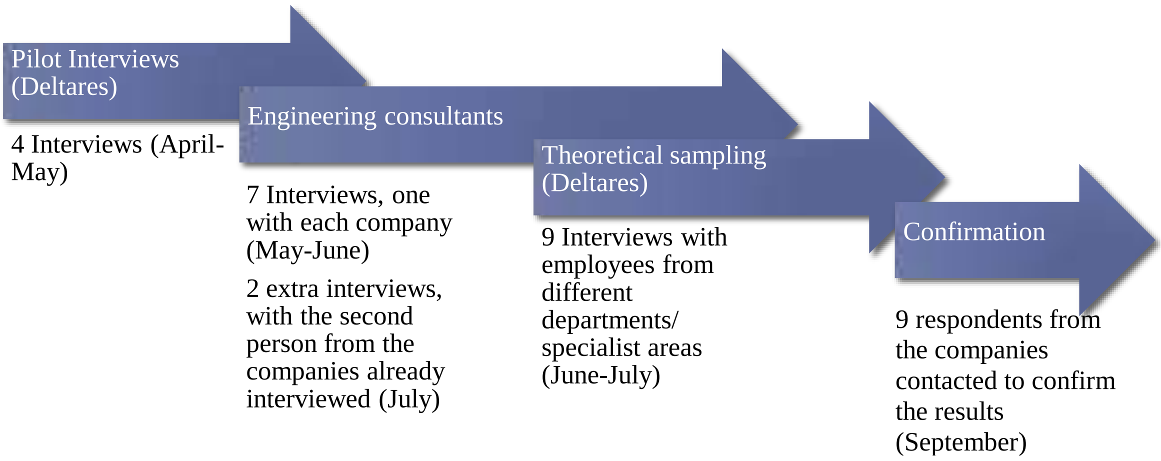

Figure 3: Empirical data collection process
Source: composed by the author

Furthermore, the interviews with seven Dutch engineering consulting companies were carried out. The companies included: Arcadis, DHV, Grontmij, HKV, Nelen&Schuurmans, Royal Haskoning and Tauw. The selection of companies was based on the internal Deltares sales data and suggestions of who their largest Dutch clients of hydrologic software packages are. Five companies in the sample are large international firms that fall into top 10 engineering bureaus in the Netherlands (see Appendix 1 for the overview of the Dutch engineering consulting bureaus) (Technisch Weekblad, 2011), the other two (Nelen&Schuurmans and HKV) are considerably smaller, but fully specialized into the industry sector, and hence important clients as well. The respondents chosen and contacted for the interviews were employees working with the numerical modeling or leading a project team as part of the daily work responsibilities in each company. The total of nine interviews was carried out as part of the partially predefined sample.

Meanwhile, the third phase, genuine theoretical sampling data collection took place. That implied looking for additional data sources as new questions and ideas were discovered. This was both secondary data – more detailed specifications of the software products, industry reports, on-line research, company statements, and internal quantitative Deltares project information – as well as primary data. To gain deeper understanding, additional interviews were carried out with Deltares specialists from different areas – department or sub-department leaders or representatives, employees working in the software center, one additional meeting with the person already interviewed previously had to be arranged. Some of these appointments were less formal and shorter (30 to 45 minutes rather than around an hour for the previous two phases of data collection), and amounted to nine interviews. The names of people interviewed are outlined in the list of references at the end of the thesis.

Finally, at the final stage of the research, the interviewed respondents from the engineering consulting companies were contacted to confirm the numbers used in the case study quantifications (chapter 4).

2.3.2 Interviewing process

The pilot interviews were barely structured, and respondents were encouraged to tell examples of the projects, where and how the software in focus was used, trying to identify the most important notions and topics to further elaborate on. After a few conversations, the interview guide was developed. The topics discussed were focused on all the aspects related to the use of hydrologic software. Even further in the research, the interviews remained semi-structured, with the main topics to cover in mind, but the additional new notions were constantly sought, and the open-ended questions were posed.

As the interviews progressed, the topics to be covered were narrowed down to look for the evidence that the data is accurate and confirm the generality of the fact (yet, it is not the aim of Grounded Theory to confirm the hypothesis, but rather to create them). The final interviews of the phase 2 proved to be increasingly more detailed and more exact about specialist area, but at the same time more difficult to keep the open mind for the new concepts that were never mentioned before. This identifies the possible saturation of the theoretical categories that were created during the research, as part of constant comparison method.

All the interviews at the beginning of the research were tape recorded and transcribed. Commonly cited risk of using tape-recorder for the interviews is the reaction of interviewees limiting their openness (Hermanowicz, 2002). To prevent it, the confidentiality of the recordings was promised. That helped to get the permission to record in every interview conducted. On the other hand, the literally transcripts cannot be appended to the thesis.

The transcripts of interviews proved to be useful. Due to the exploratory nature of the study, as suggested by Charmaz (2006) (see figure 3 above), reexamination of previously collected data was necessary. As respondents were encouraged to talk about their practices, and later these practices were intended to be compared with each other and theoretical categories, this proved to be challenging due to subjectivity. For instance, understanding the exact meaning of what a respondent intended to generalize as “we” (in some cases that meant a project team, while in the others a department or the whole company) required looking back at the exact wording and the precise context of the conversation. That would have been impossible without having interview transcripts.

Not all the interviews were literally transcribed. Every additional interview of one hour required at least few hours to process, transcribe and code. Later in the process, with increasing amount of questions arising and interviews of interest to carry out, the trade-off between the precision of data analysis and the improved understanding of the topic had to be made. Due to two reasons; the level of specialization of the area (numerical hydrologic simulation) and time limitation of 6 months for the research project, the decision was made not to transcribe all tape-recorded interviews. The previously defined phase 3 interviews, that were intended to gain additional understanding of detailed questions, were tape recorded but not transcribed (only interview summaries were made). The records were kept until the end of the research for reference.

During the second half of the research, the number of questions and unknowns seem to be increasing, but the data collection had to slow down to focus on the emerging framework. Although there always was additional data to be investigated, the emergence of new codes or categories was almost over – which identified the saturation of theoretical categories.

2.3.3 Data processing and analysis

To cope with the large amount of interviews and stay organized between the codes, qualitative research analysis software was used. The functionality of Atlas.TI software package enabled multiple coding, easy memoing and extraction of codes for the comparison within and among the interviews.

No predefined codes were used, in order to avoid influence on the interviewing process. Initial codes were created after the first three pilot interviews, when the important notions were starting to emerge. Later on, the redefined codes helped to frame the interview guides for subsequent interviews.

To summarize, the choice for grounded theory method seemed to be an only logical way for carrying out the research. After reviewing the literature with no conclusion of what framework could potentially be used for evaluation, with little academic research on the economics of complex software tools, the open minded exploratory research was an only option consistent with the circumstances.

3 Emerging theory

This chapter outlines the framework for economic quantification, which emerged from qualitative data – through coding of the interviews, comparing them with each other and among the emerging concepts. Both, the process of theory generation and the framework offered are outlined below.

Using the method of grounded theory, analytical framework of the phenomena emerges through the coding and constant comparison of data. According to Charmaz (2006, p. 46), data coding consists of at least two phases: initial and focused coding. Then follows the final stage of theory generation, theoretical coding.

Initial coding is the process of coding the interview transcripts line by line, with the open mind for any analytic direction that the data might suggest. The important notions to pay attention to in the phase of initial coding are (Charmaz, 2006, p. 47):

- What is this data a study of?
- What does the data suggest, pronounce?
- From whose point of view?
- What theoretical category does this specific datum indicate?

Focused coding is a next major phase in sorting out the data. It uses the most common and relevant codes from the initial phase to categorize the data completely (Charmaz, 2006, p. 57). In this phase, the main *categories* and their *properties* are developed. The key notion here is **saturation**, which is a process of grounding the category with the data (through previously discussed theoretical sampling) until no new properties of the category emerge.

Theoretical coding builds on the focused coding phase. It specifies the relationships between previously created categories and generates *theoretical concepts*, the building blocks of emerging theory (Charmaz, 2006).

All the phases are continuous and not subsequent. Constant comparison method means that data conceptualization is taking place while the new data is still being collected. Central to grounded theory generation is the use of **memoing** (memo-writing). **Memo**s are the analytical ideas that the researcher keeps constantly noting down during the whole process of research and analysis. Memos help to produce the categories and their properties from the codes, their inter-relationships and theoretical concepts.

3.1 The process

3.1.1 From initial to focused coding

At the start of the initial coding, the number of codes was very high. As the coding eventually became more focused, the number of frequently appearing codes decreased. While new codes were still emerging, it became possible to group and conceptualize the existing codes into larger categories. For instance, the code family "project phases" through the analysis evolved to the category "project flow", which did include the phasing of projects, but was broader and helped to organize more issues, such as the resources necessary to carry out a project or the emergence of software packages for pre- and post- processing of data.

The interviews too, became more focused on the knowledge already gained and the new questions arising. More detailed insights to support and explain the categories were sought. By mapping and relating categories to each other, the list of core matters were reduced and only the relevant ones remained. These were also the topics that the last interviews were mostly focused on in order to reach saturation of categories.

Table 1 represents (a relevant part of) the categories with comments and their properties. These categories were later clustered and re-classified to reach a structure for conceptualization.

Category name	Description
Accuracy	the complexity of numerical models is growing. However, it does not always directly translate to increased accuracy of the results. The category unifies the factors concerning the complexity-accuracy relation.
Budget	the category related to the direct economic value regarding hydrologic software, size of the projects it is used in, the turnovers of the departments were the researched software packages are used.
Building a model	the category combining the aspects of creating the numerical simulation model (the differences between having to build a new model or just improving on the existing one, time spent on this phase of the project, the tendencies through the years, etc.).
Clients	type of projects and software packages used respectively are directly linked to the type of clients (*Rijkswaterstaat* [2], municipalities, water boards, international clients). The category represents the relationships and influences on the process of using the software.
Expert judgment	the role that expert judgment (employee experience, the need for calculations) plays in connection to the use of software, the limitations of how much to rely on the expert judgment vs. calculations.
Expertise	the category relates to the level of specialization of modelers and the differences between the complexity of numerical simulations within

[2] *'' Rijkswaterstaat is an executive arm of the Dutch Ministry of Infrastructure and Environment. On behalf of the Minister and State Secretary, Rijkswaterstaat is responsible for the design, construction, management and maintenance of the main infrastructure facilities in the Netherlands''* (Rijkswterstaat, 2011).

	different organizations.
Avoiding extra costs	value that is related to software indirectly (such as avoiding the costs of court trial by environmentalists or costs caused by error at the design stage of construction project).
Innovation	emergence of new knowledge and insights due to the use of hydrologic simulation software.
Modeling	dynamics of modeling within the project.
Pre- and post- processing	independent development and use of tools for pre- and post- processing of data within most of the companies.
Project challenges	obstacles related to the use of hydrologic software, such as availability and quality of GIS[3] data.
Project flow	the phases, their length, importance and dynamics.
Resources	all the resources needed for the project (administration, software, hardware, specialist time, training), and their importance.
Running hours	the time that simulations take to complete (could be up to a couple of weeks), and the implications it has.
Software packages used	the discussion of the use of other similar/related software packages and the implications for economic value of Delft3D/SOBEK/SIMONA.
Team composition	number of modelers, team dynamics, seniority.
Time	the effects of using simulation software to the time that the projects take to complete (as opposed to the case of no simulation software)
Trust	the clients attitude towards simulation results, expert judgment.
Intangible value of software	indirectly related economic value
Where in the organization simulation happens	identifying the locus of use simplifies the comparison of its significance within the company

Table 1: The list of main categories
Source: composed by the author

3.1.2 Theoretical coding

In order to identify relationships between the categories outlined in the table 1, Atlas.TI software package was used. It simplified processing of large amounts of data and the procedure of analysis significantly. Finding the necessary quotation for reference or re-coding pieces of text throughout all the interviews would have been tedious work without the software. Similarly, it enabled to make sense out of codes and categories more easily with the help of visualization. Main issues that surfaced from comparison among interviews are mapped together with their possible relations in the figure 5.

[3] Geographic information system

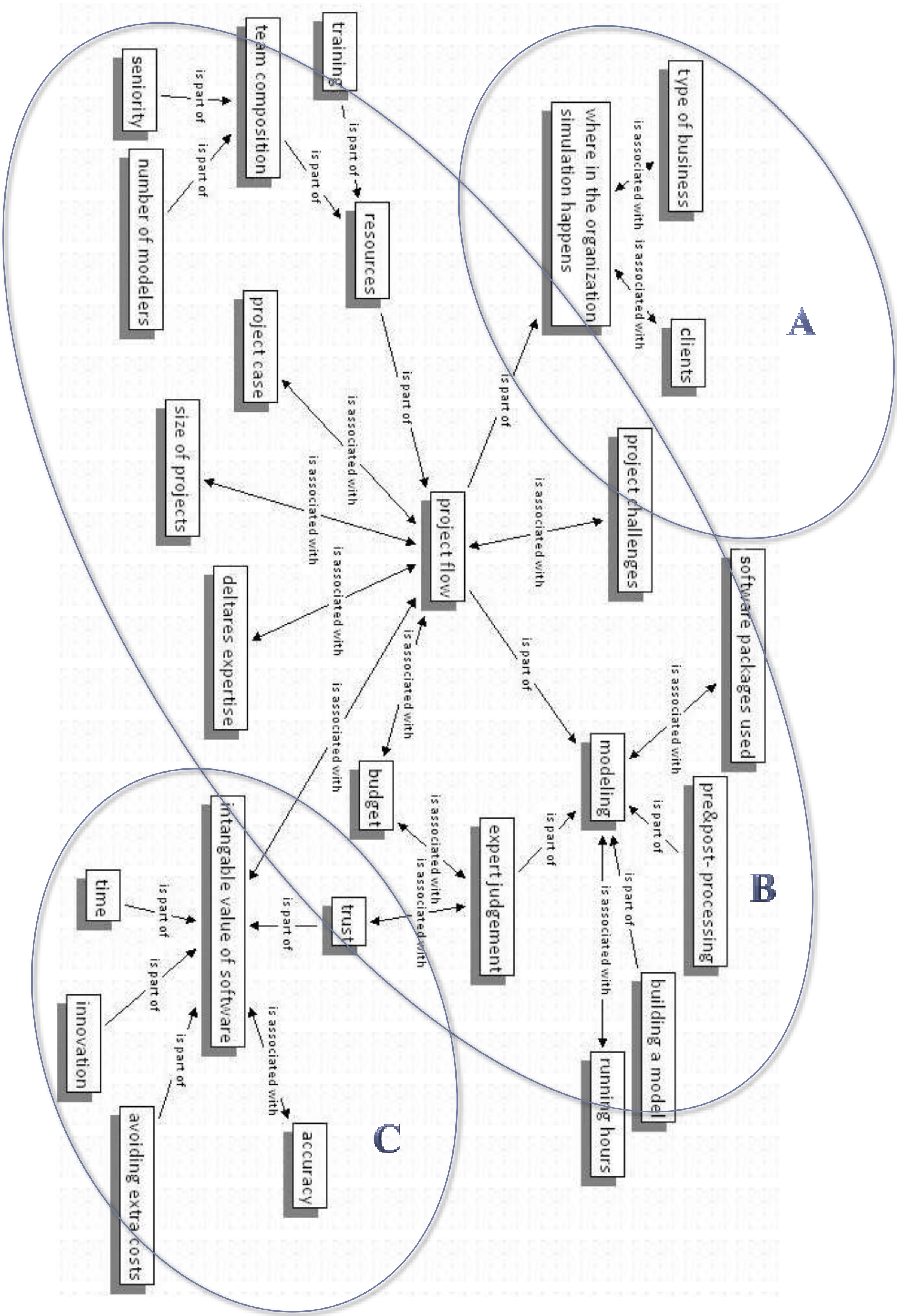

Figure 4: The map of the main categories that emerged through initial and focused coding
Source: composed by the author

With visually mapping the issues at hand, it became easier to identify the most important categories. As it is apparent from the figure 5, project flow was the central concept when discussing value of hydrologic simulation software. The concept related to or contained other frequently appearing categories and sub-categories. Similarly, visual representation helped to dismiss the codes or categories that proved to be less relevant or not important.

The search for relations between the categories with their properties, the use of memos and additional interviews from theoretical sampling led to higher level of analytical conceptualization. As a consequence, the data suggested classification into three main concepts. As it is illustrated in the figure 5, concepts are categorized into three fields, A, B and C. As a consequence of a last stage of research, the theoretical coding revealed that the relevant categories can be assigned to one of the three unifying concepts:

A. Organizational level value;
B. Project level value;
C. Unanticipated value.

Categories which emerged during the earlier phases of coding and constant comparison relate to the three main concepts. Table 2 presents those relationships. Although some concepts contain fewer categories, they are equally important in quantifying the economic value.

Main concept	(Part of the) belonging categories
Organizational level value	Clients
	Type of business
	Where in the organization simulation happens
	Budget
Project level value	Building a model
	Expert judgment
	Expertise
	Modeling
	Pre&Post- processing
	Project challenges
	Resources
	Running hours
	Software packages used
	Team composition
Unanticipated value	Accuracy
	Avoiding extra costs
	Innovation
	Time
	Trust

Table 2: The categories aggregate to the three main concepts
Source: composed by the author

The core concept which unites the three main concepts is identified to be the **role of hydrologic software in the creation of economic value.** Each concept is relevant only in the relation to the role of software. In other words, when looking into organizational level value, the only aspects relevant to the study are those that relate to the role of software. Likewise, the project level value and unanticipated value concepts are focused on the relation with the software as well.

To conclude, the suggested framework emerged throughout coding and constant comparison process, by memoing and reclassifying the codes. The core concept is the role of hydrologic software in the economic value creation, and the framework contains three layers – organizational level, project level and unanticipated value.

3.2 The framework – three levels of value

As concluded above, all three main concepts fit into one core concept: **the role** of hydrologic software. The challenge of economic valuation appeared to be the question of *which part of economic value created within the company can be assigned to the software*. This post hoc can be related to the previously discussed literature of intangibles valuation (technology is usually embodied in the human knowledge or physical assets, and hence its exact scope is difficult to identify (Park and Park, 2004)). Moreover, the emerging framework for analysis could also be related to the aspects of intangibles valuation, which recognized the importance of intangible and opportunity value. The Kohli and Grover pointed out the risk of underestimating the value of IT and overlooking the unintended consequences. Layering the value and breaking down the analysis into different levels could possibly be a good prevention for neglecting important factors in valuation.

The layers of economic value that are grounded in the interview data are depicted in figure 6. They are summarized as: (1) Project level; (2) Organizational level and (3) Unanticipated value. All three are discussed below in relation to the role of software in economic value creation. The main sub-categories of the concepts are listed and explained.

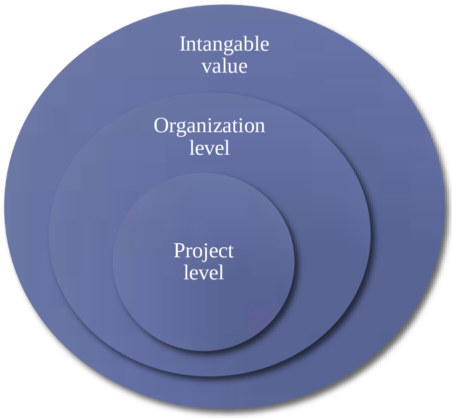

Figure 5: The framework of analysis
Source: composed by author

3.2.1 Organizational level

Five of the Dutch engineering consulting companies interviewed were large global engineering and construction firms, operating in a broad range of industry sectors. Urban areas, infrastructure, industry, energy, ports, water and environment were among the areas that companies operate in. Initially, it was difficult to assess in which of the operational areas the hydrologic simulation software could be used – all of them could have been likely.

However, through the analysis of where exactly in the organization the hydrologic software was used, only specific departments of the companies appeared to have modelers and carry out simulations. Usually, the locus of use could be determined within one or two departments of the company. However, the projects including simulations were very large, and sometimes the other departments were outsourcing the modeling part of the project to the departments with modelers.

The sub-categories of organizational level value, playing a role when defining the scope of economic value are found to be:

3.2.1.1 *Inter-department cooperation*

For the large organizations, modeling projects were sometimes just a part of a larger (design and construction) project. Yet most of the times it was considered to be the basis for further stages of the project, needed for optimizing the design, initially assessing the environmental impacts, etc.

3.2.1.2 *Type of clients for different departments*

The clients in the Dutch water technology market can be categorized into 5 groups. Four of them are public institutions - municipalities, water boards, *Rijkswaterstaat*, public international clients (such as World Bank, Asia Development Bank), and fifth, private firms (national and international).

The type of clients is a good tool for classifying the type of projects, the type and method that hydrologic simulation software is used. For instance, municipalities are the clients who are concerned with the urban waters, and hence the software package SOBEK with 1D/2D simulations is typically used for their projects. Yet the large international projects, for instance related to harbor constructions mostly involve Delft3D simulations. The dynamics of projects could hence be classified by the types of clients.

3.2.1.3 *Number of employees and the number of modelers*

The number of employees within the company, the number within the department which uses modeling versus the actual number of modelers appeared to be a good indication of how much economic value could be assigned to the hydrologic simulation software.

3.2.1.4 *Amount of projects with and without the use of numerical simulation*

Similarly as with the number of employees, the amount and size of projects was found to be a reliable indication of the role of software.

Although the aspects of organizational level relating to the role of hydrologic simulation software were identified, some challenges were faced. The people interviewed were usually those that had modeling as part of their daily work routine. However, those respondents recurrently had difficulties comparing the modeling practices to the larger organizational perspective (e.g. the total number of projects within the larger department as compared to the projects including numerical simulation in the sub-department of the company).

3.2.2 Project level

The project level value is the largest concept with several interconnected sub-categories. The main aspects relating to the role of software are the following:

3.2.2.1 *Project phases*

The analysis of project flow was done in respect of which phases the projects typically entail, whether they are the same or similar across the organizations, how long each of the phases last and which are the most important. Here the project challenges were discussed and could be related to the role of software within the project as well (to be discussed in the next chapter).

3.2.2.2 *Resources*

The resources needed to carry out a project were discussed. Undoubtedly, when it comes to modeling the main resource/expense proved to be man-hours. Administration, hardware and software, employee training, travel costs were among the other resources, but were in all cases considered insignificant by the respondents, as compared to the cost of man-hours spent on a project.

3.2.2.3 *Project teams*

In relation to the main resource, specialist hours, project teams were investigated in more details. The number of employees in the team, their role and experience, the time spent on modeling were factors of interest.

Here subjectivity of the qualitative data created a challenge. As the number of modelers was recognized to be of importance towards the end of interviewing process, looking back at the past interviews created difficulties in assessing the information received before being aware of its significance. For instance, the meaning of the ’modeler’ for the respondents was hard to define post hoc, unless explicitly stated previously. It could have been an employee who uses simulation software few hours per week, while it could have also meant a full-time modeling employee. Yet when analyzing team dynamics and the seniority of the modelers, meanings to the words could be assigned. As a consequence, the term ‘modeler’ later in the thesis is used for a person who is spending most of the time (presumably 85% of his/her working time, as discussed later in the quantification part) on the simulation projects.

3.2.3 Unanticipated value

In search for factors that could be used in quantitative determination of economic value, some indirectly related aspects of value were discovered as well. The major two are:

3.2.3.1 *Trust of the client*

The complexity of simulation models is constantly increasing throughout the years, so are the expectations of clients. Although experienced modelers can sometimes rely on ‘expert judgment’, and are aware that more complex calculations are not necessarily more accurate (for instance, if the data is not precise, the simulation result will not be precise either), the clients do trust complex calculations to be important. Hence, the trust of the client comes as a value of the software as well.

3.2.3.2 *Avoiding the extra costs*

Although usually not anticipated, the use of numeric simulations helps to avoid costs that would occur without the hydrologic software. Two instances are avoiding the error when modeling (e.g. an initial design error could be very expensive in the large construction project), and providing technical basis for the optimal designs (indirectly relates to the trust aspect). For instance, the environmental impact assessment helps to optimize and reduce the effects for the environment. Large engineering consultants are occasionally opposed by environmentalists, which can cause them expenses in court trials, if environmental effects were not initially considered in the project.

In summary, the case-based empirical findings are discussed around the three layers of value, which were identified through grounded theory method. There exist similarities among the aspects discussed in the academic literature and the proposed valuation framework. The project, organizational and unanticipated levels of value could be compared to the business value of IT literature and issues in the economic value of technology. Intangible value plays an important role, and the decomposition of factors is important for avoiding underestimation, assessing the separate benefits – from individual to organizational, from process related, to operational and strategic. The framework implies that the quantitative measure should be considered for every layer separately.

4 Discussion of findings

In the following chapter the findings are discussed in more detail, based on the conceptual framework grounded in the interview data and discussed above. The case discussion starts with the overview of the Dutch water technology sector. In particular, the software products analyzed and interconnected network of market players are described. The background summary is followed by the role of software at the (1) organizational level, (2) project level and its (3) unanticipated value within the Dutch engineering consulting companies interviewed.

The break-down of the factors that surround the use of hydrologic software gives an understanding of its role and possible scope of the economic value created; as a consequence, discussion of findings is concluded with proposing the measure of how the economic value of hydrologic software can be estimated best, together with the illustration of what the quantitative economic value of the Delft3D and SOBEK software packages could be.

4.1 Overview of the industry sector

The Dutch technological competence in water management has developed throughout the years, as a consequence of over half of the country being below the sea level. Coping with the geographic circumstances led the Netherlands to rise as a global expert in the field. Moreover, the sector is now playing an important economic role in the country, with over 180 thousand people employed in the area in a broad sense (including drinking and industrial water, wastewater treatment, hydraulic engineering and maritime industry). Its contribution to the economy is around 20 billion Euros per year (Topteam Water, 2011, p. II).

4.1.1 Numerical hydrologic simulation software packages

The software packages analyzed in the thesis all relate to the surface water simulation. The modeling done with these software packages ranges from one dimensional (1D) to three dimensional simulations (3D). Historically, Dutch knowledge and expertise in the creation of these software packages were aggregated within the public knowledge centers. What was formerly Delft Hydraulics, in 2008 was reorganized to the research institute and specialized consultancy Deltares, unified together with parts of the Dutch Ministry of Infrastructure and Environment (*Rijkswaterstaat*) and the subsurface and groundwater department GeoDelft of research institute TNO (Delft Hydraulics, 2011). Although past links remain important in this highly specialized industry, all three software packages, Delft3D, SOBEK and SIMONA, are today maintained and further developed solely by Deltares.

4.1.1.1 *Delft3D*

Delft3D is a suite used for numerical simulations in coastal waters, estuaries and lake environments. It simulates two dimensional (2D) and three dimensional (3D) water flow, sediment transport and morphology, waves, water quality and ecology, as well as integration between these processes (see figure 7 below for illustration). It is meant to be used by consultants, engineers or contractors, regulators and government officials.

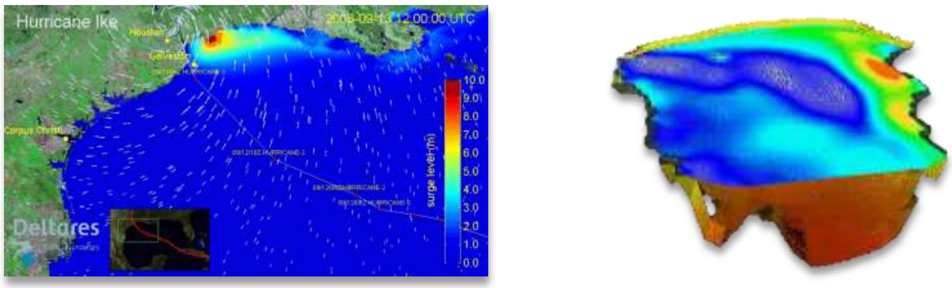

Figure 6: Delft3D hydrologic simulation visualizations
Source: Deltares systems, 20111a

Delft3D suite contains several programmes (modules): D-Flow, D-Morphology, D-Waves, D-Water Quality, D-Ecology, D-Particle Tracking. The former three modules (for water flow, morphology and waves) became open source in 2011. D-Flow is the module necessary to run every other programme (for instance, to make a numerical simulation of the waves, the results from water flow are necessary).

4.1.1.2 *SOBEK*

SOBEK is a one dimensional (1D) and two dimensional (2D) modeling suite, intended for rivers, irrigation and drainage systems, urban water management. It is meant for flood forecasting, optimization of drainage systems, control of irrigation systems, sewer overflow design, river morphology, salt intrusion and surface water quality. It can be used for pipe, river, channel and overland flow simulations. The suite consists of a number of programmes: D-Flow 1D Open Water, D-Flow 1D Pipes, D-Flow 2D Overland, D-Rainfall Runoff Open Water, D-Water Quality 1D, D-Real Time Control (see figure 7 below for illustration).

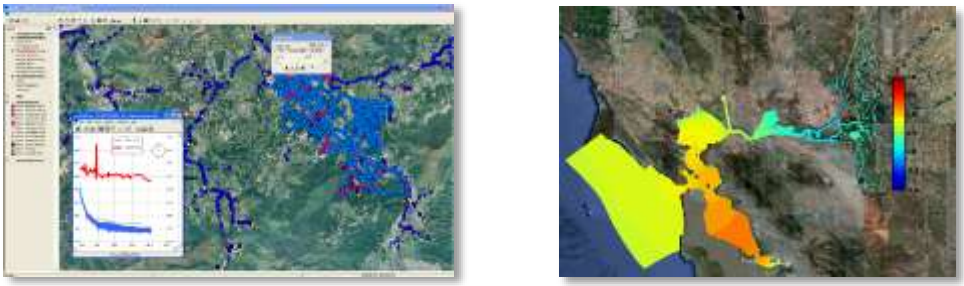

Figure 7: SOBEK hydrologic simulation visualizations
Source: Deltares Systems, 2011c

4.1.1.3 *SIMONA*

Unlike Delft3D and SOBEK, SIMONA was developed by the Ministry of Infrastructure and Environment, and only later given over to Deltares for maintenance and support responsibilities. It has four modules: WAQUA (2D simulation), TRIWAQ (3D simulation), SIMPAR (particle tracking), SLIB3D (sediment transport) (Rijksoverheid, 2011).

The functionality of SIMONA software package significantly overlaps with that of SOBEK/Delft3D. However, some of the Dutch engineering consulting companies use both, SIMONA as well as SOBEK/Delft3D. This is due to a few reasons. For a number of projects which are tendered by the Ministry of Infrastructure and Environment[4], SIMONA software package is one of the requirements for modeling. Moreover, already existing simulation models for rivers or their parts can occasionally be re-used with adjustments for new or continuing project, hence the software package is implied by the project.

4.1.1.4 *Alternative software packages*

Delft3D, SOBEK and SIMONA are the only similar software packages in the Netherlands. Yet, Delft3D has a strong global position. SOBEK is mostly used by the Dutch modelers, and SIMONA is used for the projects in the Netherlands only. Large Dutch companies using SOBEK or Delft3D also operate on the international basis, and hence use the software in foreign projects. Besides the international Dutch firms, Delft3D is renowned all over the world to be one of the best products of this kind.

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[4] E.g. Room for the Rivers (Dutch – *Ruimte voor de rivier*), http://www.ruimtevoorderivier.nl/

With globally distinguished Dutch expertise in the area, there exist a few alternative software packages. First of all, the closest product used for the same or similar purposes is MIKE, developed and owned by the DHI (Danish Hydraulic Institute). Mike has different modules, corresponding to the functionality of Delft3D, SOBEK and SIMONA. MIKE 21 is intended for marine and coastal modeling, MIKE 3 is a three dimensional numerical simulation software and MIKE URBAN can be used for drainage, sewage system simulations, etc. Similarly to the Deltares software packages, MIKE offers functionality such as water quality or particle tracking (MIKE by DHI, 2011). To conclude, it could be considered the only closest competitor product.

From the interviews with the Dutch modelers, explicit conclusions about the pros and cons of both DHIs MIKE and Deltares Delft3D/SOBEK software packages can be drawn. Deltares products are considered to have stronger computational core (the simulation results tend to be more precise). Moreover, with the open-source policy, the calculations are more transparent – a user could theoretically look into what is happening with the input data, while closed source software cannot be investigated in detail, and only the output is known, but not the process how it was calculated.

Yet, MIKE is considered to have much stronger position when it comes to user interface. It is unified between 1D, 2D and 3D simulation models, while Delft3D (3D/2D) and SOBEK (2D/1D) are historically developed separately. Thus even being an expert in SOBEK, it is not easy to learn to use 3D simulations due to the significant differences. In a case of complex simulation software, user interface is an important factor. It requires high technical expertise to be able to use the software, which in turn typically requires a training course.

In addition to the direct alternative MIKE by DHI, there are a few other similar hydrologic simulation software packages around the world. British InfoWorks entails fully integrated 1D and 2D modeling for below and above ground urban and river catchments (Innovyze, 2011), HEC-RAS (Hydrologic Engineering Centers River Analysis System) developed by the US Army Corps of Engineers is intended for 1D flow, sediment transport/mobile bed computations, and water temperature modeling (US Army Corps of Engineers, 2011). However, none of them are actively used in the Netherlands (as assumed from the interviews with the modelers in the seven Dutch engineering consulting companies).

Here it is important to emphasize, that the existence and the significance of the alternative software packages for the same or similar purpose is one of the findings and is interesting for the general picture of the market. However, the valuation against competitor products is out of the scope of the research, due to the nature of the Dutch hydrologic market and the Open Source business models. Open Source reduces the competitiveness and strict ownership of the intellectual property and fosters the cooperation and open use of knowledge and development instead. In addition, in the Dutch market of hydrologic simulations the competition is not a major issue as such, due to historic reasons and tight relationships among local market players. Locally developed software packages have been in the market for years, companies and modelers are accustomed and educated to work with them, the governmental and private clients are used to the format of results. The market relationships are discussed in the following section.

4.1.2 The market network

Throughout the research it became clear that the water technology sector in the Netherlands is closely related. Due to high level of specialization required in the area, close relations develop. The industry experts tend to know each other, either from the recent professional events such as conferences or from the study years at the university.

The market players of interest in this research are delimited to those who are providing the hydrologic software, using it or using the simulation results. This means the developers, users and their clients. As a result of research, the classification to three categories was done:

1) Private companies (engineering consulting firms, all seven interviewed companies fall into this first category);
2) Semi-public institutions (knowledge institutes/universities, including Deltares);
3) Public bodies (governmental institutions, including *Rijkswaterstaat*, water boards, municipalities).

From the interviews with seven engineering companies, the employees within Deltares and their Software Center, the classification of type of projects was achieved as well. The projects that require numerical hydrologic simulation could be classified into three different levels (largely largest to smallest):

1) Harbors;

2) Rural waters;
   a) National waters (coastal and rivers);
   b) Smaller regional rivers;
   c) Lakes;
3) Urban waters.

Interestingly, a certain type of clients usually owns certain type of projects. Generally, urban water projects are administered by the municipalities, small regional rivers – by water boards, while national river projects are normally tendered by the *Rijkswaterstaat*. Harbor projects tend to be owned by port authorities, but mostly international clients.

In conclusion, the type of software packages used, the clients and the type of projects could be plotted in the unified matrix (figure 8). This is a highly aggregated and generalized picture, and a rare case-specific project could fall out of the classification.

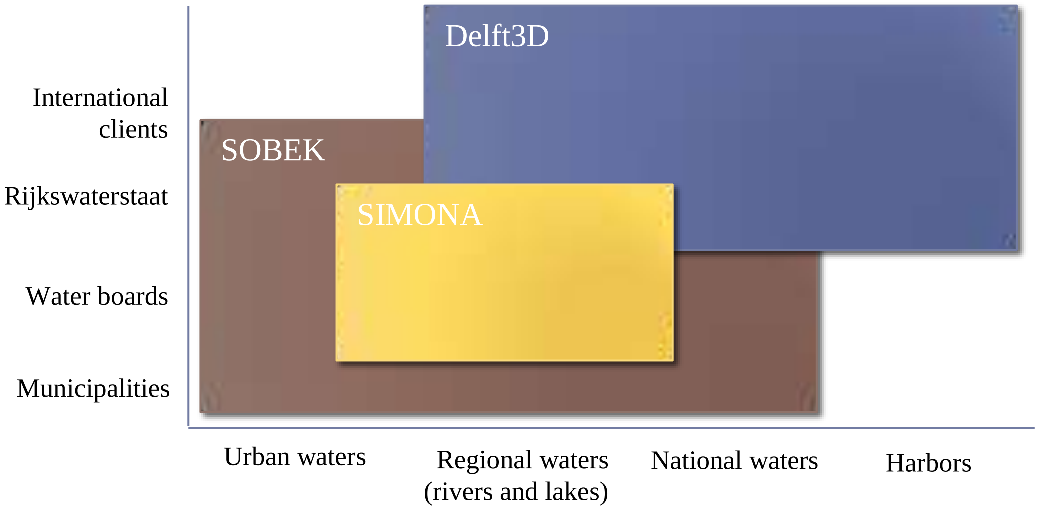

Figure 8: Software packages, main groups of clients and major types of projects
Source: composed by author based on the interview data

Besides the level of specialization allowing this type of classification, the interconnected relationships dominate in the market. Deltares owns Delft3D, SOBEK and SIMONA, and *Deltares Software Center* is responsible for technical development and support activities. Meanwhile, other departments within the company are software users, and co-developers from the practical side. From the first sight, they have a role similar to that of engineering consulting companies. For some projects, Deltares outsources part of the assignment to the consultants and vice versa, sometimes consulting companies outsource the expertise of

Deltares. Yet for the other projects, the institute has a role of evaluating and confirming the results of the projects carried out by the consulting companies. However, the role of Deltares as a user differs from that of the private companies. The level of expertise is usually higher in Deltares, due to the fundamental research and focus on developing the software at the same time. Moreover, non-competitiveness agreement in the Dutch market has been signed between the institute and the companies, which formalizes the relationship too.

As depicted in the illustration below, the Deltares Software Center provides the software for internal as well as external users. Meanwhile, those users have strong two way relationships when carrying out the water technology projects.

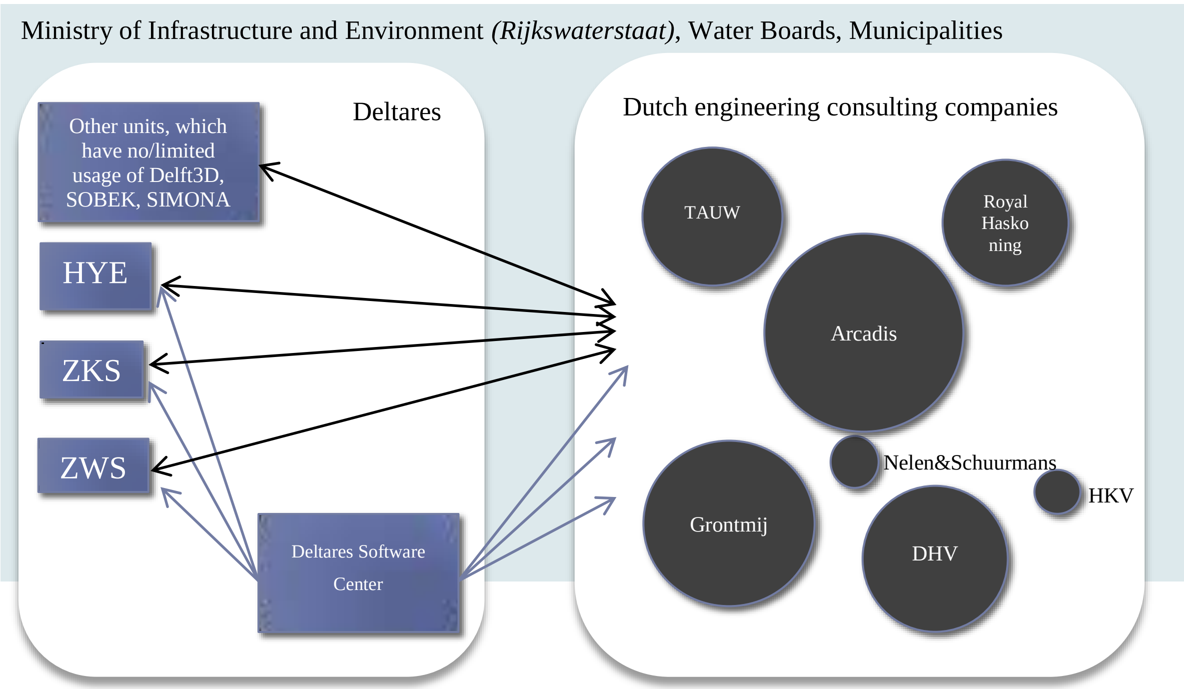

Figure 9: The network of market players in the hydrologic simulations area in the Netherlands
Blue arrows indicate the software packages supplied by Deltares Software Center. HYE is the hydrologic engineering, ZKS – sea and coast systems, ZWS – fresh water systems departments of the institute. Black arrows represent the two way cooperation between the companies in the sample and the departments within Deltares. Engineering consultants included in the illustration are only those that were interviewed during the research.
Source: composed by author

In conclusion, many inter-relations play a role when defining the economic value of software among different organizations. The market situation is interesting to keep in mind when narrowing down the view to a single company level.

4.2 The role of the software in economic value creation

4.2.1 Organizational level value

From the general market picture narrowing down to one-organization perspective, the important factors defining the role of the hydrologic software in economic value creation are (1) inter-department cooperation, (2) type of clients for different departments, (3) number of employees and the number of modelers, (4) amount of projects with and without the use of numerical simulation.

From the interview data it appeared that identifying where in the company software in focus was used exactly was a good start to understand the scope of its economic value. However, it was not obvious from the beginning, due to the fact that not all the interviewees could point out where in the ”theoretical” organizational chart perspective are the departments or people they work with. Moreover, the publicly available organizational charts are not detailed enough. For instance one of the companies, globally operating firm of over 15,000 employees worldwide has a publicly available organizational chart that depicts four business lines, from 2€ billion to 374€ million revenues each. Clearly, this has little help when evaluating the economic value of the software.

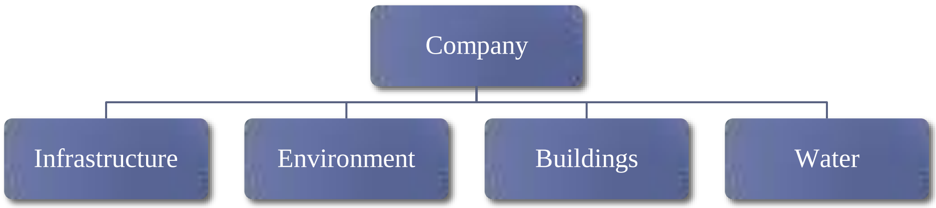

Figure 10: Sample organizational chart
Source: annual report, 2011

Although the precise and detailed organizational charts were not available, an attempt to depict the exact locus of the numerical hydrologic simulation software used in the company was done. The qualitative interviews brought to the conclusion, that in every company, there is only one department that does the simulations. For all the companies interviewed, it was limited to one to three sub-departments.

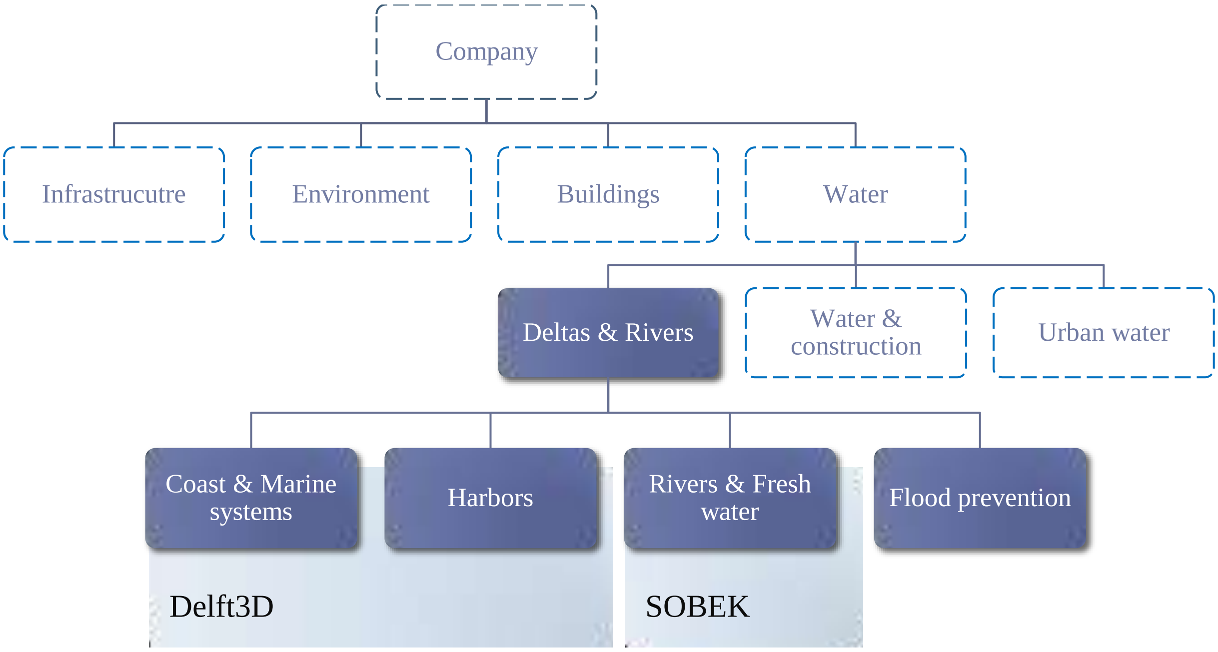

Figure 11: The use of hydrologic software in the organization - sample detailed chart
Source: composed by author

Although the modeling is done only in specific sub-departments in each company, from the organizational perspective there are two types of related projects – purely modeling, and larger building and construction projects. For the specific sub-department of the company doing the modeling, it is always just a modeling project. However, it comes either directly from the client (hence the outcome of the project is the consultant advice based on the simulations), or from another part of the company (which is the case with the construction projects). For the latter case, inter-department cooperation plays an important role and the scope of hydrologic simulations impact on the economic value expands beyond the revenues of the modeling sub-departments.

4.2.1.1 *Inter-department cooperation*

The importance of the inter-department cooperation differs among the companies in the sample, and directly relates to the size and level of specialization. Smallest companies researched, Nelen&Schuurmans and HKV are much more specialized. The modeling activities constitute a large proportion of the whole company revenues. However, most of the company revenues are typically directly related to the modeling activities and do not spread much beyond consultancy advice.

4.2.1.2 *Type of clients*

Besides the inter-department cooperation, the type of clients was important when defining the organizational dynamics. As discussed in the market overview, different clients own different type of projects. Similarly, in the companies that had more than one sub-department which carries out the hydrologic simulations (such as ARCADIS, DHV and Royal Haskoning), every sub-department has different scope of the projects. The departments which have to do with harbor or accordingly international projects are the ones where the economic impact from hydrologic software spreads outside the department the most.

For quantification purposes, as discussed in the next chapter, the attempt to find the multiplier for economic impact was made. The experts assessed that the modeling project could be anywhere between 20% and 100% (for the pure consultancy project). Hence the multipliers are: 5 for large construction projects (e.g. harbors), 3.3 and 2 for the smaller construction and long-term projects that re-use the numerical results from the past projects, and multiplier 1 is used for the projects where the interpreted and analyzed simulation results are directly presented to an external client.

4.2.1.3 *Number of modelers and a number of modeling projects*

The number of modelers as part of total employees in the modeling department and the number of simulation projects as part of total projects in the department were investigated. The measures appeared to be representative and possibly reliable for quantifying the economic value. However, the respondents in the study were employees who had modeling as part of their daily work routine. Not all of them had a feel of the larger picture of economic quantification, and could assign the percentages of, e.g. number of modeling projects per year as a total of department's revenue.

It is indeed a difficult request, since the projects with numerical simulations vary from a few weeks to over a couple of years in length, and the budgets from €2 thousand to a few millions. For the large international departments it is harder to objectively assign such estimations. Moreover, detailed financial project data was not available due to the confidentiality. An attempt to compare the qualitative interview data among companies was done, but in a lot of cases it proved to be unrealistic. The search for the economic value measure was taken down from the organizational to a project level.

4.2.1.4 ***Summary***

The essential conclusion from organizational dynamics perspective is that simulation projects **have an economic impact beyond the department where the numerical simulation takes place**. Here and for the discussion to follow it is essential to clarify the meaning of a modeling project. *It is a project which is mostly carried out with the help of numerical simulation tools, and contains data collection, simulation and interpretation of results*. *The modeling project is mostly carried out by a modeler, or a few modelers and a project leader.* The following section 4.2.2. discusses modeling project in more details. Organizations frequently use modeling project results for larger projects internally. Based on qualitative assumptions and the assessments of the interviewees, the modeling project could be only 20% of the larger project in the company. That means that in these cases the multiplier of 5 can be used to estimate a value of project portfolio, which has relation to numerical water simulation.

4.2.2 Role within the project

Project dynamics was the largest concept that contained the most categories from the interviews. To understand the role of the hydrologic software, the process of how it is used had to be analyzed. Only then the part of the revenues from the whole simulation project could be directly assigned to the economic value of software.

4.2.2.1 ***Project phases***

A modeling project flow varies from project to project, among the companies, and the software packages used. Generally, modeling projects are concluded to have a flow of phases depicted in the figure below. Even though it is visualized in the linear manner, in reality phases are iterative and interrelated; the sequence could slightly vary as well. For some projects, the aim is only to build a model, so the project is mostly finished after setting up the model. For other projects, the models already exist, then the project is a second half of the flow – running and interpreting the results.

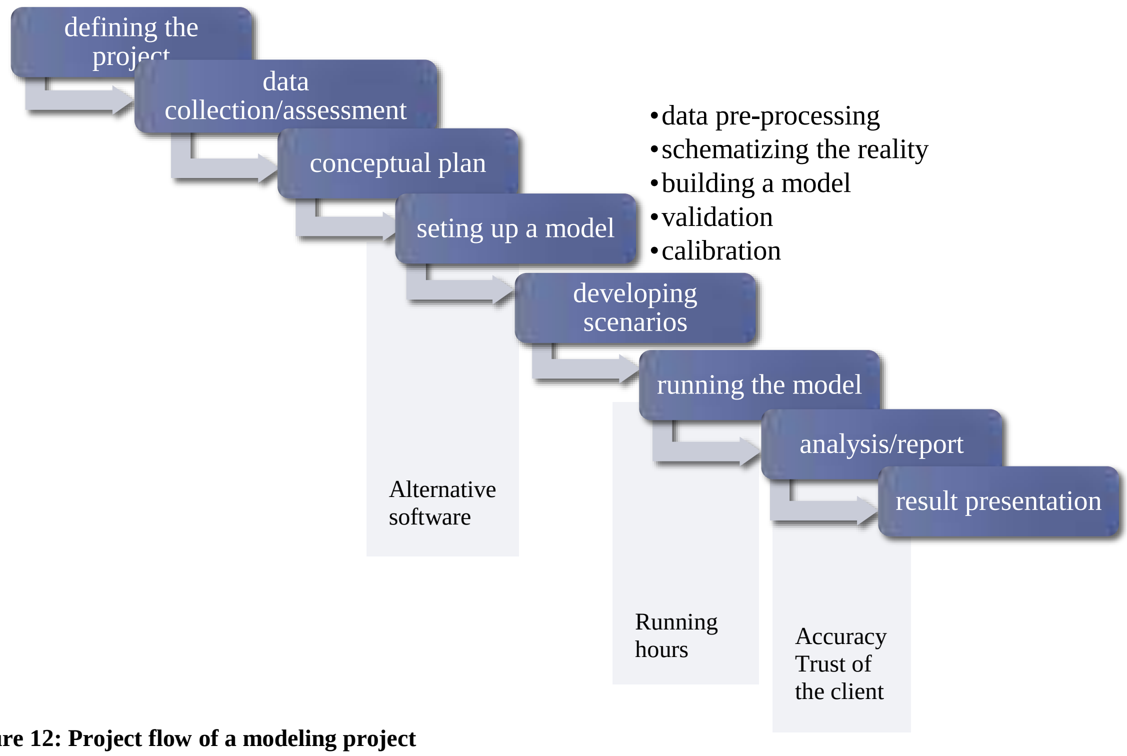

Figure 12: Project flow of a modeling project
Source: composed by author based on the data from the interviews

The length of phases is an important factor for the analysis. It can be split in two parts – the length of actual modeling, and the interpretation of results. The modeling part includes the phases from data collection and preparation to running the model. It was assessed to be anywhere between 30% and 50% of the whole project time, while the interpretation can likewise take 20% to 50% of the time.

The data collection/assessment, setting up a model, running the model and analysis/report phases are discussed in more detail below. **Defining the project** is a phase which requires a lot of interaction with the client, and could continue throughout the project**. Conceptual plan** is important for more complex projects, and it entails an overview how the project will be carried out – which models should be used and when, it can also be done with the help of alternative ‘quick scan’ models. **Developing scenarios** means building alternatives for running a model. The **models then are run** for the different cases. **Result presentation** once again includes most contact with the client. Here the results of the numerical simulation have to be communicated in a right way. The **complexity** and **accuracy** of the calculations are important for building the trust of the customers.

Data collection/assessment phase was regularly a challenge for companies. GIS[5] data of interest are sometimes not precise or not available, and its collection could be a lengthy and expensive process. Some clients, as *Rijkswaterstaat* for instance, are able to provide the readily available data that is needed.

Setting up the model includes building it, validating and calibrating. The phase is sometimes replaced by adjusting the already existing model for the same area. Many of Dutch rivers, for instance, are already modeled a few times, and depending on the circumstances, some models are already available for re-use.

In connection to this phase, the alternative software packages were discussed. The quick-scan models are sometimes utilized at the prior phases, to assess the long-term effects and determine the need of more detailed simulations.

Pre-processing the data and getting it ready for the input into the model is a time-consuming process as well. Most of the companies were independently building their own pre- (and also post-) processing tools – usually simple, possibly in excel, but in some cases more universal ones. As mentioned in one of the interviews – preprocessing takes time, making it faster is saving modeler's time, which means earning money.

Running the model is depicted as a separate phase. Although it could be merged together with building a model, it deserves additional attention. Depending on the complexity of the model, and the software package used (1D simulations are naturally less complex than 3D), the running time of the models differ significantly. It could be from a few minutes for 1D simulation to over a week for 3D. In the case of more complex models, this phase is important to manage properly. If a large model which takes over a week to run, turns out to have an error and crashes, it could affect the timeline of the project.

The internal Deltares data was investigated in the search for relation between the model run time among departments and the budgets of modeling projects. However, no directly generalizable conclusion could be made due to a couple of reasons. Firstly, the amount of time that models run is determined not only by the complexity of the model, but also by the

[5] Geographic information system

technical capacity of the hardware. This might differ among companies, and hence cannot be universally used as a measure. Secondly, the running time is determined by several factors (input variables, data, etc.). The largest projects might have the models that run the fastest; however, it is not always the case.

The **analysis** of the results from numerical simulation is an essential phase in the project – and its significance seems to be increasing over the years. The result interpretation relies on the experience and knowledge of the specialist, and is crucial when dealing with numerical modeling. As commented by many of the respondents, doing the simulation is not difficult – yet, entering unrealistic input would not bring realistic outputs. Only with the interpretation and careful treatment of the data can the numerical simulation be meaningful. The understandable presentation of the complex results for the client with less expertise is in the past years gaining importance. So is the visual representation of the results. Here the data post-processing tools play a role, similarly to the pre-processing discussed earlier.

Additionally, the interpretation/confirmation of the results tends to be done by more experienced modelers, alternatively called *specialists*. Small projects with limited budget sometimes rely on the expert judgment rather than simulations. Moreover, the topics of accuracy were discussed. The clients often believe that more complex numerical simulations yield more accurate results. Yet that does not always hold true, only with the expertise of the specialist input data and the results could be put into context. Sometimes interviewees stated that even before starting the simulation they as experts knew which results to expect. The value of software here is still significant in a sense of trust – since the client trusts the complex calculations more that the qualitative expert judgment alone.

After breaking down the project dynamics into phases and analyzing the role of the software in the modeling project as a whole, an essential question was attempted to answer – how the project would look like without the software packages in focus (or their direct substitutes). Although the expert knowledge plays an important role, the required detail of simulation nowadays is impossible to determine without numerical models. The conclusion was made that without the hydrologic software companies would not have numerical simulation-based consultancy projects, and hence would directly loose **the whole revenue from the numerical simulation projects.**

4.2.2.2 ***Resources***

The list of resources required to carry out the modeling project is short. Operational costs such as administration, hardware and software, and travel costs were considered to be insignificant compared to the **main** cost – the time of the modeler spent on the project. In combination with the conclusions of project dynamics, the number of modelers is concluded to be **the closest estimate for the direct economic value of the hydrologic software studied.** Almost the whole project budget is directly related to the hours that the modeler spends on the modeling project, and the software is the one tool for carrying out the project. In order to detail the role of the estimate, team dynamics was investigated.

4.2.2.3 ***Project teams***

Depending on the size of the project, the number of modelers could vary from 1 to 5 or more. The experience of modelers is an important factor defining his/her role in the project, the time spent on the particular project and the cost of that time. Although the terminology among companies differs, the experience of the modelers can be classified into junior, medior and senior modelers.

A specialist or an expert (name depends on the company) is a senior modeler. Usually s/he does not spend much time in setting up the model and carrying out the calculations. During interviews senior modelers identified that building many simulation models is something they used to do in the past, and now they focus on the analysis and result interpretation. It is about exploring whether the numerical results obtained are realistic, analyzing what they imply. Not all the aspects and questions of the client could be answered by mathematical modeling – some missing aspects have to be filled in by "theoretical" knowledge. Experienced modelers admit that in some cases it is possible to give consultancy advice even before the numerical simulations. Ability to give an educated guess about the results which the calculations would yield comes with experience.

Medior and Junior modelers spend more time on one project, building the model and running the calculations. In the teams of three people, it is usual to have a medior, a junior and a senior modeler, where senior modeler spends less time on the project, unless any unpredicted circumstances (complications in models combined with the pressure of time).

Notably, the number and seniority of the modelers represents not only the costs of the project. The tariffs that a firm charges its clients for carrying out a project are based on the hours of the modelers as well. In this way, the time of modelers work on the project and the tariff charged for the client could represent the revenue of the project. In this way, **the estimate for the revenues from modeling projects can be assessed by the working hours of modelers**.

In conclusion, the inference brought by the software role in the project dynamics is that the number and seniority of modelers in the company is a good representation of direct revenues related to the hydrologic simulation software. The work of modelers is based on having software as a tool to carry out their daily work. **Without it, the current projects which are purely based on numerical simulation would be absent**.

4.2.3 Unanticipated value

On top of direct project level economic value and its broader impact on the activities within the company, there is additional value to the hydrologic software. The two case-based examples were discussed to be (1) the trust of a client and (2) avoiding extra costs, in the previous chapter – Emerging theory. However, unanticipated value is concluded to be not easily quantifiable. This is due to the case-based and intangible nature of the value added.

4.3 Summary

The three layers of value matter when considering the role of hydrologic software in the economic value creation process. *Direct project revenue* is an estimate for its economic impact, based on implication that without software tools firms would lose all the revenue from the numeric modeling projects. A number of modelers is a reasonable measure for such revenue, since it is the single significant resource needed to carry out the project, and modelers spend majority of their working hours on simulation projects. The direct value has also a *broader economic impact in the organization* outside the modeling department in the case of larger construction projects. There, numerical modeling is used as a basis, and later the projects are continued in other departments of a company. *Unanticipated value* is case-based, and cannot be quantified from the qualitative data in the scope of this research.

5 The quantitative measure and case estimations

To evaluate the role of numerical simulation software, breaking down the process of its use and understanding the importance of different factors were imperative. In the framework of three levels of value – project, organizational, and surrounding unanticipated value, the most realistic measure to quantify its economic impact is now possible to identify.

From the beginning of the research, common notions from economic and management disciplines implied the potential points of departure which could have been used for quantification. The importance and relations between the factors such as size of a company's departments where the simulations are carried out (by revenues or number of employees), the time that the modeling takes in the project as a whole, the model running hours, the size, type and number of the projects per year were sought.

In order to solve the problem of data confidentiality and the interview time limitations with the external companies, some pilot investigations were carried out in Deltares internally. The main one was to analyze the quantitative financial project data from the past two years for estimating what the value of software is in the departments where many projects require modeling. However, even with the unlimited access to the data, it proved to be difficult to impossible. There is no single person in the company that could be aware of every project that took place, and assess the part that was based on the modeling (many projects in the industry are long-term and built on the projects from the past). Obtaining the right data could mean talking to every single project leader. Even then, for a project leader it is difficult to assign the percentage of the project that could be recognized to be based on modeling.

Towards the end of the research, the most objective measure started to emerge. It was implied by a few aspects. Firstly, it was concluded that without hydrologic software, the majority of modeling projects would be absent. Hence, not only the project phases that include building and running a model, but also the rest of the phases such as analysis are directly related to the use of hydrologic software. The **whole project turnover can be directly assigned to the value of the software** – without it the company would lose that turnover. Secondly, the only one significant resource comprising the costs of the modeling project was the **hours of the modeler**. Thirdly, the modelers spend most of their time on the modeling projects (including project leading, result interpretation and administration). Hence, the tariff that is charged from the client for the modelers work is a good estimation of **the turnover due to the modeling activities**. In conclusion, **the number of modelers within the company and their tariff** is a most objective representation of the direct value of hydrologic software.

5.1 Economic value on the project level

For estimating the number of modelers, different sources were used. Firstly, the information from the Deltares Software Center sales department was inquired. The modeler from this source meant a person who has signed up for receiving email newsletter about updates, new releases and other information related to the software packages analyzed. With the highly specialized expertise needed to use the software, indeed only the specialists seem to follow the news. However, the number of modelers from this source proved to be greater than the actual amount of active users in the companies. Consequently, the numbers were adjusted to the empirical data from the interviews.

Second obstacle was the overlap between the modelers. There were three software packages investigated – Delft3D, SOBEK and SIMONA. In some cases, the modeler for one package was also considered to be a modeler for the other (e.g. SOBEK modeler sometimes was SIMONA modeler as well). Detailed modeler list was obtained from one of the companies, which identified the number of employees in the sub-department and the ability to use the software (‘*active user*’, ‘*ever used a software package*’, ‘*interested in the software*’ were used as a classification). On the contrary, the other company representative stated that there is no overlap between the SIMONA and SOBEK modelers. Based on the more detailed information it was concluded that in most cases the specialization between Delft3D and SOBEK modelers is clear – an active Delft3D modeler is rarely also an active SOBEK modeler. This is due to several factors – such as the level of expertise required, but also the difference between the types of projects carried out with different software packages. However, the overlap between SOBEK and SIMONA modelers was very high.

With a roughly estimated number of modelers in all the companies, and the implication that they spend most of their time on modeling related projects, the direct value could be estimated. The other required variables for such quantification were the work hours and the tariffs of the modelers. Tariffs represent the revenues from the projects, since they are not a cost for the company, but the price that it charges its client, based on the estimated hours of modelers work needed to carry out the project.

For the yearly revenue estimation, the number of yearly working days was obtained from the Dutch tax office website and amounted to 214 days (Belastingdienst, 2011). The hourly rate estimation that client pays for the company carrying out the modeling project was based on the team dynamics. According to the Andre Oldenkamp[6], the average rates in the industry are 70€/hour for a junior modeler, 90-100€/hour for the medior and 130-140€/hour for the senior modeler. The average effective part of total modeler's working time for the contribution to the projects was assessed to be 85%[6] in the industry. This is to account for the time spent on other activities apart from projects (such as training, company meetings, etc.).

Due to the qualitative nature of study, the quantification is presented in ranges rather than definite numbers, to avoid inaccuracies and differences among companies. The effective part, for instance, could differ by the seniority of a modeler, so does the daily fee. Table 3 presents the quantification of the hydrologic software related turnover per modeler. The quantification which follows from now on is highly generalized and mainly based on the qualitative data and expert opinion rather than financial or administrative statements of the companies, and thus the numbers should be treated with care.

Variable		Lower value	Values assigned	Upper value
Working days per year	(range ± 2%)	210	214	218
Daily fee (8 hours* 95 EUR)	(range ± 5%)	722	760	798
Effective part	(range ± 3%)	82%	85%	88%
Yearly hydrologic software related turnover by modeler		€124,328	€138,224	€153,088

Table 3: Estimating the hydrologic software related turnover per modeler
Source: composed by author from various sources, data based on the year 2010-2011 averages

In this case, the direct, project-related value of the hydrologic simulation software (in other words – the turnover which would be lost if there were no software packages used) could be estimated accordingly by the number of modelers among the companies. However, the value estimations are presented only for Delft3D and SOBEK software packages, and the value of SIMONA is excluded due to the overlap as discussed above.

[6] Andre Oldenkamp, sector manager Water, TAUW

	Number of Delft3D modelers	Number of SOBEK modelers	Number of SIMONA modelers	Delft3D and SOBEK direct value – project revenues (million EUR)
ARCADIS	12	10	15	€ 2.7 - € 3.4
DHV	8	17	11	€ 3.1 - € 3.8
Grontmij	0	23	5	€ 2.9 - € 3.5
HKV Lijn in Water	2	7	4	€ 1.1 - € 1.4
Nelen&Schuurmans	0	12	0	€ 1.5 - € 1.8
TAUW	0	5	0	€ 0.6 - € 0.8
Royal Haskoning	0	20	7	€ 2.5 - € 3.1
Total	**22**	**94**	**42**	**€ 14.7 - € 17.8**

Table 4: Estimating the direct value of software per company
Source: composed by author based on the empirical data, 2011

Throughout the research, different possible measures were looked into. Among other, the estimation based on the department turnover and the percentage of modeling related projects was attempted to carry out, which turned to have a wide range of values per company. However, the variance was enormous and had no consistency among the companies. Emerging measure - number of modelers proved to be the most reliable and explainable based on the type and size of the companies, and could have been easily related to the analyzed project dynamics.

5.2 Economic value on the organizational level

As discussed previously, the multiplier for direct revenues related to hydrologic software is best described by the level of inter-unit cooperation (among the numerical simulation department and the rest of the departments). The level of inter-unit cooperation differs depending on the size and international presence of the company, type and size of the projects, type of clients. For instance, international harbor projects are very large; hence the direct modeling budget has a small percentage in a total project as a whole. On the contrary, fully specialized companies whose projects are finished with the consultancy advice for the external client have no broader impact on the organization then its direct modeling project revenue. Hence the direct project value represents 100% of the economic impact to the company in such a case.

Table 5 represents the direct value based on the revenues from modeling projects, the share that the direct value constitutes in a larger intra-organization project, and hence the multiplier for impact on the company-wide economic value creation. The company-wide economic value is a project portfolio that has numerical hydrologic simulations as a base or a part of the whole project. The broader value cannot be fully attributed to the hydrologic software, but the modeling is presumably used as an important component for this project portfolio. Additionally, the results of numerical simulations from several projects are sometimes used for the long-term projects (e.g. with the perspective of 100 years). In this case, the long-term projects might not directly require carrying out the simulations, but only use the results from already finished projects. Here the value is also related to the impacts from the software on the organizational level.

Company	Delft3D and SOBEK direct value – project revenues (million EUR)	Modeling project as a part of the larger intra-organization project*	Multiplier	The possible value of the projects where hydrologic Delft3D/SOBEK simulation is used as a basis (million EUR)**
ARCADIS	€ 2.7 - € 3.4	25%	4	€ 10.9 - € 13.5
DHV	€ 3.1 - € 3.8	20%	5	€ 15.3 - € 19.1
Grontmij	€ 2.9 - € 3.5	30%	3.3	€ 9.5 - € 11.7
HKV Lijn in Water	€ 1.1 - € 1.4	50%	2	€ 2.2 - €2.8
Nelen&Schuurmans	€ 1.5 - € 1.8	100%	1	€ 1.5 - €1.8
TAUW Group	€ 0.6 - € 0.8	30%	3.3	€ 2.1 - € 2.6
Royal Haskoning	€ 2.5 - € 3.1	30%	3.3	€ 8.3 - € 10.2
Total	**€ 14.7 - € 17.8**			**€ 51.4 - €61.7**

Table 5: Company-wide impacts of the modeling projects, 2011

*The percentage is based on the interview conclusions and the assumptions about the type of projects (e.g. company-wide harbor projects are by far the largest, and hence the size of the modeling part is significantly smaller – and consequently, the multiplier is significantly larger than for the rest of the projects). To refine the multiplier more precisely would require more detailed internal financial data from the companies.

** The value of the portfolio slightly differs from the direct value times the multiplier due to the rounding.

Source: composed by author based on the annual reports of the companies and the empirical interview data, 2011

5.3 Summary

To summarize, the quantitative results from the research should be treated with care. It must be kept in mind that the nature of study was qualitative, and implications were frequently drawn on the opinion of a modeler, and not the quantitative financial data of the companies. The error in estimation could especially be due to the inaccuracy in assigning the number of modelers per company or the importance of the modeling project as a base for the design and construction projects.

For more precise quantification, the research suggests to use the method proposed, which is based on: (1) the estimation on the modeling project revenues according to the number of modelers of the company; (2) the multiplier that expresses what part is represented by the modeling project in respect to a larger intra-organization, design and construction project. However, the detailed quantitative data from the companies would be necessary for confirmation.

Based on the resources available, the results of quantification are represented in the table below. For the context, the number of employees and yearly turnovers of the companies are provided.

Company	Number of employees (Globally, 2010)	Yearly turnover of the company (million EUR, 2010)	The direct value of Delft3D and SOBEK based on the modeling projects revenue (million EUR)	The possible project portfolio with hydrologic simulation as part of the project (million EUR)
ARCADIS	15,000	€ 1,375.0	€ 2.7 - € 3.4	€ 10.9 - € 13.5
DHV	5,000	€ 468.7	€ 3.1 - € 3.8	€ 15.3 - € 19.1
Grontmij	11,000	€ 921.7	€ 2.9 - € 3.5	€ 9.5 - € 11.7
HKV Lijn in Water	75	€ 5.7	€ 1.1 - € 1.4	€ 2.2 - €2.8
Nelen&Schuurmans	45	€ 3.8	€ 1.5 - € 1.8	€ 1.5 - €1.8
TAUW Group	800	€ 93.3	€ 0.6 - € 0.8	€ 2.1 - € 2.6
Royal Haskoning	3,200	€ 338	€ 2.5 - € 3.1	€ 8.3 - € 10.2
Total	**35,120**	**3,206**	**€ 14.7 - € 17.8**	**€ 51.4 - €61.7**

Table 6: Summary of the quantification results
Source: composed by the author

To visually summarize the results of the research and put them into context, the chart below represents the direct value from the modeling projects (the size of the light blue bubbles), as compared to the wider project revenues that have modeling as a part or a basis for further intra-organization activities. The horizontal axis illustrates the size of the companies (as a yearly turnover for the year 2010, million EUR), and the vertical axis represents the number of SOBEK and Delft3D modelers among the companies.

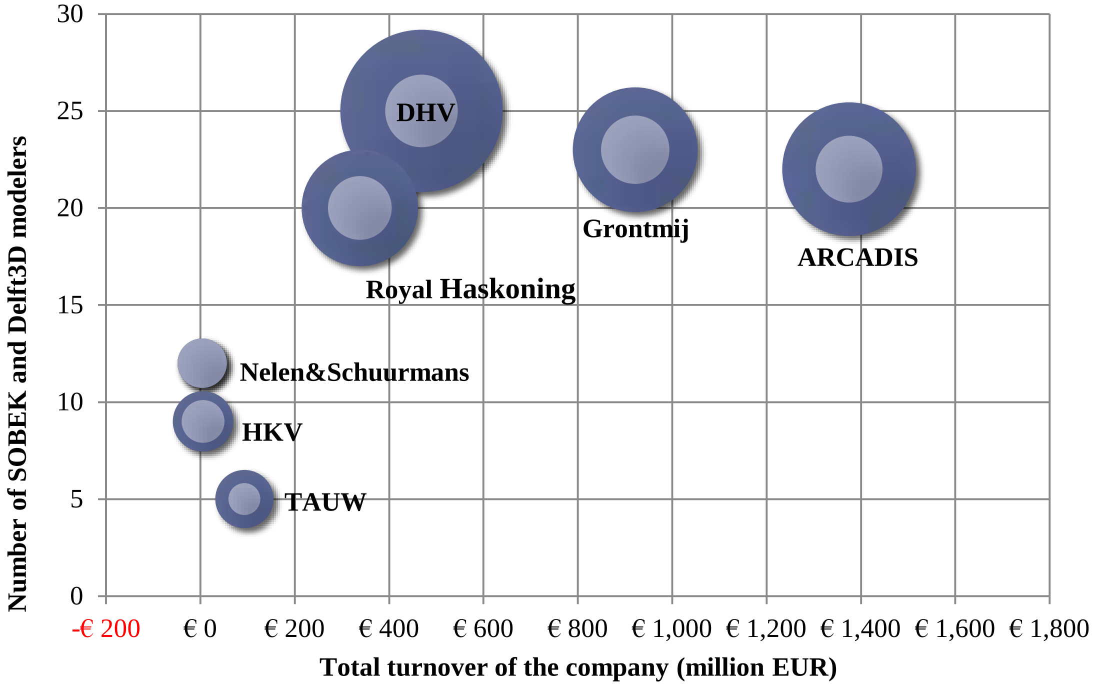

Figure 13: The value of hydrologic software among engineering consulting companies in the sample
According to the analysis framework developed throughout the research, light blue bubbles represent the size of direct value of hydrologic simulation software. The outer dark blue bubbles represent a broader intra-organizational impact, which could have a multiplier of up to 5 in large multinationals.

The organization wide impact is larger in international design and construction companies as compared to the small and specialized firms. This can be explained by the fact that multinational companies focus on large design and construction projects. Hence, the numerical simulation results are a basis or a part of the larger project portfolio. Finally, the direct (project-level value) is least dependent on the size of the company. When looking at the direct revenue from modeling activities within the companies, small but more specialized companies could be not significantly less important as big internationals.

6 Conclusions

In an environment of shifting IT business models, generating revenue to continue the state-of-the-art technology development is an issue to be prepared for. Quantifying the economic value that it creates for business clients forms a good ground for financial investment decisions, formation of partnerships and cooperation relationships. Moreover, for the semi-public not-for-profit research institute and specialized consultancy Deltares, it is important to quantify the positive economic effects of accumulated knowledge to demonstrate the benefit of public subsidies.

With no framework for scientific software valuation identified in the economic literature, the research question of the thesis stated: *how can the economic value of hydrologic simulation software be quantified?* An answer to which would help to answer a case-specific problem *what is the economic (business) value created by the use of the Delft3D, SOBEK and SIMONA software packages among the Dutch engineering consulting companies?*

To understand the role of hydrologic software in the economic value creation the grounded theory approach was taken. By investigating different processes, three concepts important for quantification emerged. The economic value presumably is best estimated at three levels: project, organizational and unanticipated value. As introduced in the literature review, the economic value is a subjective notion, and the purpose of valuation dictates the scope of the quantification. Understanding the depth of the valuation is important, and layering the economic impact gives a broad overview for making managerial decisions.

The only most objective measure for quantifying the direct value from the project perspective was found to be number of modelers. By investigating the project phases, it was concluded that without hydrologic simulation software modeling related projects would be absent and the company would lose the turnover that the projects yield. In the numerical simulation field, the number of modelers could imply not only the cost for the company, but also the revenue, since the clients are charged a tariff based on the hours of modelers work.

The estimation of economic impact on the organizational level is estimated through a multiplier. It takes into consideration the long-term projects which use the results of previous projects and do not entail numerical simulation directly, as well as the larger building and construction projects which use the simulation results as the basis for further project stages. The direct value of hydrologic software, as estimated at the project level, could be a basis for up to five times larger project portfolio.

The unanticipated value could be significant but is case specific. What-if scenarios are hard to create, and would require another research. Hence, the quantification of the unanticipated value is not possible at this state of investigation.

6.1 Implications and contribution of the research

The contribution of the research had a two-fold goal. Firstly, it was the quantification and assessment of business/economic value of Deltares hydrologic software packages. Secondly, an attempt to define a valuation method for scientific software was interesting academically.

The direct (project level) value of Deltares hydrologic software is concluded to be significant among Dutch engineering consulting bureaus in the research sample. The project portfolio that has numerical simulation as a basis could be up to five times larger than the direct revenues from only the purely simulation projects. That has important implications for the institute and for the business clients of hydrological software. Further continuous development of the technology is in the greatest interest of the business customers, and the strong cooperation links should be built in order to have sufficient investments in the upcoming open source environment.

Academically, layering of value is proposed when quantifying the economic effects of hydrologic software. The direct (project level) value should be looked at first, surrounded by the organization-wide impacts and expanded even further by acknowledging the existence of unanticipated value. In the particular case of numerical simulations, the number of modelers and their hourly rate is a good estimate for the direct revenues, while the organizational impacts are assessed qualitatively.

To conclude, the value of scientific software is a complex topic and could be further researched both for refining the details as well as investigating the generalizability. As a qualitative exploratory study, the research provides an overview and the analysis of the economic value creation process through the use of hydrologic numerical simulation software, and presents quantitative estimation, the best that have been possible to achieve through qualitative method.

6.2 Areas for future research

First attempt to investigate economic value of hydrologic simulation software was made based on the grounded theory approach. Grounded theory is a useful method for the area that has not been extensively researched yet, and does not have a unified framework of analysis.

Consequently, it is aimed at proposing the theory which emerges from the data collected, and not confirming the hypothesis that could be predicted in advance.

The method has a lot of flexibility and relies on the theoretical sensitivity of the researcher. However, it leaves plenty of space for further research. First of all, the generalizability of the findings should be investigated. A few apparent areas to focus on could be:

- To confirm the generalizability of the study, a quantitative investigation for the proposed measure in a larger hydrological software commercial users sample;
- To assess the breadth of applicability (whether it is applicable in the whole industry, or just with this specific product), the role of software in the companies that use similar software packages, e.g. software package MIKE by DHI, could be included;
- Comparing with the company practices in the other countries would lead to the conclusions about the importance of the specific market network;
- Generalizing to the highly specialized scientific software packages from other industries would bring implications weather the findings hold for more that hydrologic software.

Due to the complexity of topic and the access to data restrictions, the more detail exploration remains interesting:

- The number of modelers is concluded to be a measure to focus on. Deeper insights into team dynamics and the seniority still necessary for the precision of quantification;
- The multiplier in the company-wide impacts is found to be a second layer value estimate. Yet, the investigation on inter-department cooperation, processes and scope remains unexplored in detail;
- Insights into unanticipated value could be formed as another research topic. The question whether unanticipated value has a generalizable quantification method still has no answer at this point.

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Appendix 1: Top 50 Dutch engineering consulting companies

Omzet en bedrijfsresultaat in miljoenen euro's; omzet en loon per werknemer in duizenden euro's

		bedrijfsopbrengsten 2010	bedrijfsopbrengsten 2009	% verandering	werknemers 2010 in fte	werknemers 2009 in fte	omzet per werknemer 2010	loon per werknemer 2010	bedrijfsresultaat 2010	bedrijfsresultaat 2009	internetsite
1	Fugro, Leidschendam	2280	2053	11	13444	13587	170	46	351,5	367,4	fugro.com
2	Arcadis, Amsterdam	2003	1786	12	15531	14508	129	58	129,7	114,4	arcadis.com
3	Grontmij, De Bilt	922	800	15	9898	7249	93	40	33,1	33,3	grontmij.com
4	Oranjewoud, Gouda	690	412	67	4255	3090	162	50	16,5	17,9	oranjewoud.nl
5	DHV, Amersfoort	469	480	-2	4782	5030	98	41	8,7	12,2	dhv.nl
6	Royal Haskoning, Nijmegen	335	356	-6	3469	3592	97	46	12,2	8,7	royalhaskoning.com
7	Tebodin, Den Haag	210	207	2	2679	2817	78	38	13,6	11,6	tebodin.com
8	Movares, Utrecht	149	149	0	1266	1264	117	60	15,6	16,2	movares.nl
9	Tauw, Deventer	117	119	-1	929	972	126	49	3,0	4,0	tauw.nl
10	Witteveen+Bos, Deventer	105	104	1	899	846	116	46	17,4	19,3	witteveenbos.nl
11	Ingbur. Gem. Rotterdam (IGWR), Rotterdam	96	100	-4	922	1008	104	47	6,6	6,2	gw.rotterdam.nl
12	Iv-Groep, Papendrecht	95	91	4	844	767	112	55	2,6	4,9	iv-groep.nl
13	Deerns, Rijswijk	45	45	0	375	346	120	66	4,3	2,1	deerns.nl
14	Breijn, Rosmalen	42	40	7	305	306	138	48			breijn.nl
15	ABT, Velp	41	42	-1	410	407	100	51	2,2	2,7	abt.eu
16	Innax, Veenendaal	37	39	-6	334	308	110	38	-1,2	1,0	innax.nl
17	RPS, Delft	30	33	-7	291	310	104	45	2,8	4,2	rps.nl
18	BAM Infraconsult, Gouda	30	25	20	240	209	123	52			baminfraconsult.nl
19	Advin, Hoofddorp	29	31	-6	263	297	109	48	-0,6	0,5	advin.nl
20	Goudappel Coffeng, Deventer	27	27	1	244	236	110	54	1,1	1,5	goudappel.nl
21	Ingenieursbureau Den Haag, Den Haag	26	26	0	266	261	97	44	2,0	2,5	denhaag.nl/ingenieursbureau
22	Bartels Engineering, Apeldoorn	23	25	-8	297	324	77	45	0,2	1,1	bartels.nl
23	MWH, Delft	22	23	-5	194	214	113	47	1,0	0,9	mwhglobal.nl
24	Aveco de Bondt, Rijssen	21	19	13	200	192	104	45	1,2	0,9	avecodebondt.nl
25	Inbo, Woudenberg	20	24	-17	214	267	94	50	-1,6	0,4	inbo.com
26	Peutz, Mook	18	20	-7	195	190	94	51			peutz.nl
27	Nebest, Groot-Ammers	18	16	11	163	142	108	44	1,9	2,3	nebest.nl
28	IBU Stadsingenieurs, Utrecht	16	18	-9	162	184	101	56	-0,1	0,2	ibu.nl
29	Ingenieursburo IOB, Hellevoetsluis	16	16	1	164	152	96	43	1,5	1,8	iob.nl
30	DGMR, Arnhem	16	16	0	152	147	103	47	1,0	1,0	dgmr.nl
31	RBOI, Rotterdam	14	15	-1	158	153	91	52	0,5	0,9	rboi.nl
32	Cauberg-Huygen, Maastricht	14	15	-7	147	149	98	50	0,9	1,4	chri.nl
33	Karnel, Bunnik	14	15	-4	146	157	97	42	0,7	0,6	karnel.nl
34	Kragten, Herten	14	15	-9	175	178	80	42	0,9	1,2	kragten.nl
35	SGS Intron, Sittard	13	14	-4	113	105	118	50	2,2	2,4	intron.nl
36	Ballast Nedam Engineering, Nieuwegein	13	13	5	97	92	137	63	1,0	0,5	ballast-nedam.nl
37	Verebus Engineering, Rijswijk	11	11	7	132	124	86	48	0,9	0,9	verebus.nl
38	BK Groep, Velserbroek	11	9	26	93	80	118	44	0,7	0,4	bkgroep.nl
39	Valstar Simonis, Rijswijk	10	10	-1	95	94	109	53			valstar-simonis.nl
40	SchreuderGroep, Leeuwarden	10	9	10	103	99	100	39	0,5	0,7	schreuder.nl
41	LBP Sight, Nieuwegein	10	10	1	103	95	99	52	1,3	1,2	lbpsight.nl
42	DWA, Bodegraven	10	10	4	102	100	99	43	1,2	1,5	dwa.nl
43	Geofox-Lexmond, Oldenzaal	10	10	-6	108	114	91	41	0,0	0,2	geofox-lexmond.nl
44	Strukton Engineering, Maarssen	10	9	12	93	81	103	49	0,2	0,2	struktonengineering.nl
45	TCPM, Apeldoorn	9	10	-10	129	140	73				tcpm.nl
46	Adviesburo Nieman, Utrecht	9	9	1	99	99	92	40	0,3	0,5	nieman.nl
47	Uticon Ingenieursgroep, Eindhoven	8	9	-10	97	107	87	45			uticon.nl
48	Mos Grondmechanica, Rhoon	8	8	0	80	83	102	42	0,0	-0,1	mosgeo.com
49	Evers Partners, Velsen-Noord	8	8	-3	67	74	113	48	1,1	1,0	everspartners.nl
50	IA Groep, Duiven	7	8	-7	80	83	83	45	1,2	1,6	iagroep.com

Cijfers zijn ook ingestuurd door: Tablin, Oldenzaal (6,4 miljoen omzet), KWA Bedrijfsadviseurs, Amersfoort (6,2 miljoen), Sweegers en de Bruijn, Den Bosch (5,3 miljoen), Roelofs, Den Ham (4,3 miljoen), Halmos, Den Haag (3,7 miljoen), A. Palte, Valkenburg a/d Geul (2,9 miljoen) en Ingenieursbureau Harmelen, Harmelen (0,6 miljoen).

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