Improving the quality of front-end effort estimations in projects in the context of the healthcare imaging systems sector

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ABSTRACT

This graduation thesis aims to provide solutions for the improvement of the quality of estimations at the first stage (fuzzy front-end) of projects. In order to do so, three research questions were answered: How are the project front-end estimations currently made and by whom? What knowledge sources are used in the process of estimations and to what extent? And what are the main factors that make difficult the practice of front-end estimation and how can they be overcome?

A qualitative research was carried out and four data collection methods were used: literature review, corporate archival records analysis, structured interviews and non-participatory observations. The research is carried out in the context of the Healthcare Imaging Systems industry; a sector that offers interesting characteristics for carrying out the proposed research.

The study does an extensive exploration of how to improve the quality of estimations. A categorization scheme was developed to structure the discussions. It was found that obstacles and solutions can be divided in 6 major categories: Political, Organizational, Methodological, Technical, General and External. The study also has some limitations. The internal validity is limited at some extent due to the number of respondents. Results can hardly be generalized; however, they provide interesting insights as explained below. This limitation is compensated by the fact that all the interviewees possess extensive technical experience in the organization in addition to their managerial expertise thus providing a balanced mix between technical and managerial insights.

Summarizing, the ultimate contribution of this research is to identify the main factors that hinder the practice of carrying out front-end estimations. By analyzing these issues and contrasting them with the good practices found in literature and in a complex environment like that of the Healthcare Imaging Systems sector, this study aims to shorten the research gaps mentioned above and contribute to the body of knowledge of project's estimation.

The main conclusions are that estimations in the context of this industry are carried out primarily using expert knowledge and standard times and that even though current estimations lead to the success of the organization, some opportunities of improvement were found. The high granularity and variety of the obstacles and solutions found in literature and in the empirics makes them quite precise, recognizable and addressable in the case study organization. However, it makes it difficult to consolidate them without losing valuable details.

Acronyms

BU: Business Unit

HPMO: Head of the Project Management Office

IPL: Integration Project Leader

IT: Information Technology

PM: Project Manager

PMO: Project Management Office

WBS: Work Breakdown Structure

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1 Introduction

The importance of the front-end phase of projects has been discussed extensively in the literature for several years already. One of the crucial strategic decisions made during this phase has to do with the expected price and expected cost of the project (Artto, Kulvik, & et.al, 2011). In spite of all the estimation methodologies available, having high-quality estimations remains a challenge faced by many organizations.

Before proceeding any further, it is convenient to state what is meant by quality in estimations in this document. In this study, higher quality estimations are those which lead to higher proximity between the predicted effort and the real work required to finish a project.

This chapter presents the research problem of this study, describes the context of the research and outlines the research questions. It then provides the conceptual framework and explains the relevance of the research from a management perspective.

1.1 Research Problem

The estimation and planning of projects are key processes in their lifecycle, especially in the case of large engineering projects. Low quality estimations of the resources needed for projects can have a significant negative impact in organizations (Lederer & Prasad, 1992). Underestimation may lead to cost overrun which ends up undermining the business reputation (Briand & Wieczorek, 2002, p. 2), resulting in the loss of strategic opportunities (Lederer & Prasad, 1995, p. 125), destroying the credibility of estimators and developers, and sometimes wasting valuable resources when projects are cancelled (Lederer & Prasad, 1992). On the other hand, overestimation can result in poor resource allocation and can hamper the feasibility of other projects that could have been beneficial (Heemstra, 1992; Briand & Wieczorek, 2002, p. 2; Lederer & Prasad, 1992).

With respect to the point in time when estimations are conducted, the ability of stakeholders to influence the project tends to be higher during its early phases (PMI, 2004, p. 21; Carmichael, 2006, p. 180). Unfortunately, the uncertainty of estimates is also significantly higher during this period (Boehm, 1984, p. 8; Anderson, Molenaar, & Schexnayder, 2007, pp. A-153). Estimates in the initiation phase can fall in the range of up to –50% to +100% of the real value (PMI, 2004, p. 161). This however is not an excuse to postpone important decisions because the cost of doing changes tends to increase as the project evolves due to path dependencies (see Figure 1) (PMI, 2004, p. 21; Carmichael, 2006, p. 180).

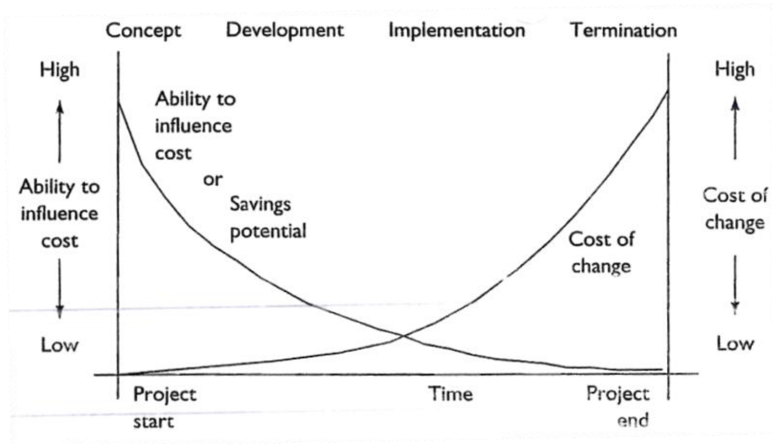

Figure 1: Anticipated cost influence and changes over a project's duration. Source: (Carmichael, 2006, p. 180)

In order to tackle these challenges within the estimations context, companies incorporate the experience gained in previous projects to enhance the front-end estimations (Jashapara, 2004). Depending on the estimation method, companies rely on tacit knowledge sources, explicit knowledge sources, or both (Armbrecht, Chapas, & et.al, 2001; Briand & Wieczorek, 2002). As a matter of fact, there are several estimation methods to choose from, ranging from methods based on models and statistics, to methods fully supported on expert knowledge.

However, in spite of the wide variety of estimation methods available, low quality estimations are believed to occur frequently. For instance, Lederer and Prasad (1992) show that nearly two-thirds of all major projects substantially overrun their estimates; and about 14% of projects are considerably over estimated. Literature shows that the effects of low quality estimates are devastating in some sectors. For instance, in the context of software development, large projects (> 60000 LOC[1]) are underestimated by anywhere from 100 to 200% and about 15% of large systems development projects never deliver anything (Jones, 1986). In 1995, American companies and government agencies spent US$81 billion for cancelled software projects (The Standish Group, 1995). Similarly, another author reports the case of an expensive disaster in the development of an information system project developed for the Dutch Police in 1989; the actual cost of the project was US$43 million instead of the estimated US$21 million (Heemstra, 1992). The same author mentions a field study conducted in 598 software development Dutch organizations which revealed that 35% of the participating organizations did not make an estimate, 50% of the responding organizations recorded no data on an ongoing project, 57% did not use cost-accounting and 80% of the projects executed by the participating organizations had overruns of budgets and duration, and the mean overruns of budgets and duration were 50% (Heemstra, 1992). It can be observed that inaccurate estimates have a significant financial impact in organizations.

[1] Lines of code

In summary "accurate estimates are crucial for better project planning, tracking, and control and pave the way for successful project delivery" (Briand & Wieczorek, 2002).

The intention of this study is to determine how the quality of front-end estimations can be improved. This will be done by exploring how estimations are currently made in the context of a specific industry, then moving onto what relevant knowledge sources they have at their disposal for enhancing project estimates. This research also aims to explore the main obstacles that hinder estimations and the recommendations found in theory and empirical data in order to overcome these obstacles. The study was conducted in a multinational company which belongs to healthcare imaging systems sector and which is headquartered in The Netherlands. The industry and the organization itself will be introduced in the next two sections.

1.2 Context of this research: The Healthcare imaging systems industry

This section describes the healthcare imaging systems industry with regards to estimations and explains how they contribute in the selection of this industry as the context of this research. The relatively high complexity of the projects, their multidisciplinary character, the high competitivity, and the continuous growth of this market make it relatively more difficult to conduct project estimations in this industry than in others. These factors constitute the main rationale to conduct this research in the context of this industry. They are explained in detail below.

First of all, projects in the healthcare imaging systems industry are relatively more complex than projects in other industries. Two things which are very unique in this industry are the strict safety standards to which medical systems need to comply and the strong governmental regulations that enforce them (Hornak, 1996, p. 4.10). Unfortunately these regulations are far from being static; on the contrary they follow the pace of technologies and they are somewhat sensitive to political influences from governments (Rozembajgier, 2011; U.S. G.A.O., 2011).

Other issues that can partially explain the complexity of projects in this industry are the complicated physical principles involved (Hendee & Morgan, 1984) and the different technologies applied in these systems (Hornak, 1996). Complexity also comes from the inherent innovation that occurs in these projects. The underling technologies behind these systems are in constant evolution. In order to keep up with the competition, an organization in this industry needs to invest significantly in R&D and this becomes part of the activities of these projects. Unfortunately, R&D projects are difficult, if not impossible, to plan in detail compared to more 'standard' -less uncertain- projects (Turner, 1999). Adding to this, the relative size of the projects and links between the different disciplines create an entangled set of activities and dependencies that require more careful planning and estimation compared to other industries where projects are more 'simple' / 'single-discipline'. Most of these complexity factors are actually recognized in the literature (Bosch-Rekveldt, Jongkind, Mooi, Bakker, & Verbraeck, 2010).

The second reason to choose this industry is the many different disciplines that are involved in the development of healthcare imaging systems products. Literature acknowledges a significant number of disciplines which dictate the considerations to be taken into account for the development and installation of these systems (Mednovus, 2008). As will be explained in the next section, there are many technical and non-technical disciplines involved in these projects. This opens the possibility to leverage the best estimation practices across these disciplines but it also means that each discipline might carry out estimations in a different way. For example, the attributes to define the size of the Information Technology (IT) part of the project might differ to those used by electrical engineers or mechanical engineering specialists because of the difference in the content and nature of their work. Also, it can be the case that non-software disciplines face more dependencies with external parties, like part suppliers or printed circuit board manufacturers. This transfers some risks to them but at the same creates more uncertainty regarding the time it takes to complete some tasks of the project. It is not possible to use a 'one-size-fits-all' approach to define a set of estimation practices that apply to all the disciplines at a specific level. This again makes project estimations in this industry substantially more difficult than in single-discipline (or at least fewer-disciplines) projects.

The third reason is more related to management. The healthcare costs are becoming unsustainable, especially in highly developed countries (Editorial NYTimes, 2007). Furthermore, the healthcare imaging systems sector is embedded in a highly competitive environment. Medical systems manufacturers often face significant time-to-market pressures, need to achieve rapid market penetration, and they often experience rapid transition from one technology to another (Walker, Mullins, & Larreche, 2008). Also, some governments are actively supporting this cause via investment and subsidies (Healthcare Economist, 2007). By improving the predictability in the estimation of the lead time and effort spent in projects, organizations can be more confident about their committed dates, financial forecasts and allocation of resources.

The fourth and final rationale has to do with the fact that the impact of budget over-run and under-run is higher in projects with high aggregated costs like those of this industry. Furthermore, the healthcare diagnostics systems market is in expansion[2]. Seeing as there is a substantial amount of capital in this growing market and taking in consideration that huge overruns resulting from inaccurate estimates are believed to occur frequently (Lederer & Prasad, 1995), it makes sense to conduct this research in the context of this industry. Improving the quality of estimations is not the only factor of success for a project-based organization, but as mentioned above, it can help them to achieve their goals.

Other high-tech sectors share some of the features displayed by this industry. For instance the aviation industry or the pharmaceutical industry also offer a R&D-intensive environment, considerable size and cost of projects, entangled involvement of different disciplines, high technical complexity, strong market pressures and strict governmental regulations among other characteristics (Iansiti & West, 1999, pp. 70-71). In this respect, the Healthcare Imaging Systems industry was deliberately chosen from the set of industries that share these characteristics.

[2] The global market for healthcare diagnostic imaging is forecast to exceed $24.4 billion by 2016 (Bharat Book Bureau, 2010).

1.3 PROFILE OF THE ORGANIZATION WHERE THE RESEARCH WAS CONDUCTED

Now that the key characteristics of this industry have been explained, some details about the company that served as case study are given. This section aims to provide these details, as well as an overview of the main properties of the projects carried out in this organization.

The organization where the research was conducted is a Business Unit (BU) that is part of the Healthcare business group a large Dutch multinational company with strong presence in the consumer electronics, healthcare and lighting sectors. The organization itself has displayed a strong presence in the healthcare imaging systems market from more than 10 years now and is among to the top 3 largest players in this market worldwide. The headquarters of this BU and their Project Management Office (PMO) are located in the Netherlands.

In 2009, the Healthcare business group accounted for nearly 33% of the company's overall sales and has approximately 34,000 employees corresponding to about 29% of the company's total workforce. This business group has sales and service support in more than 63 countries. In addition, this business group is the company's second largest contributor to sales. During that year, the company achieved €7,839 million in sales.

A typical project carried out in this organization involves the following disciplines: PMO, development (hardware engineering, software engineering, mechanical engineering, system engineering) and clinical applications. Other areas which are also involved in the project are: operations (manufacturing), marketing, supply chain management, customer service, quality and regulations and finance. This composition is depicted in Figure 2.

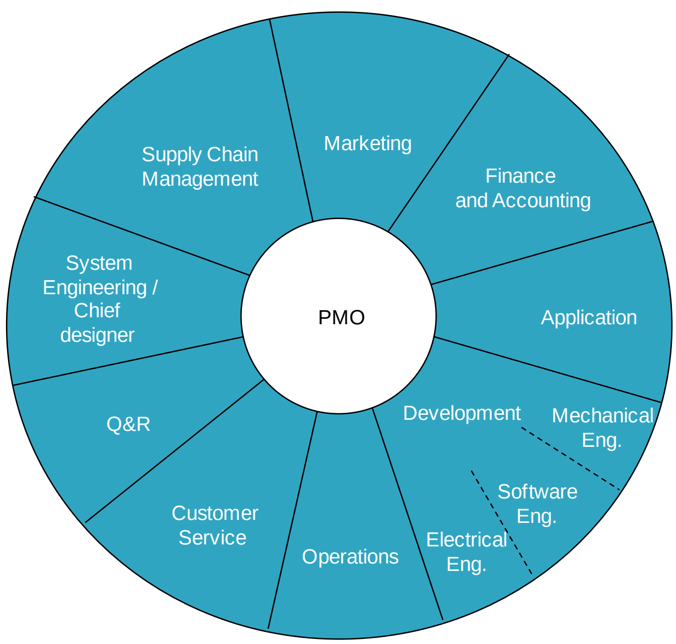

Figure 2: Core team of a typical healthcare imaging systems project
Source: Archival records of the case study organization

The typical lifetime of a project of this organization, from its conception to the point in time when it is 'delivered' for massive production, is about 1-3 years depending on the size and the typical budget allocated to a project varies between €0.5 million and €50 million depending on the size of the project and the extent of innovativeness in the technologies used. Normally this BU carries out between 5-10 projects simultaneously. A typical project involves around 1-8 employees at the PMO level and around 10-80 people counting the personnel from all the disciplines previously mentioned. Logically, a significant part of this number (and of the total effort required to bring the project to completion) is spent within the development area.

In this organization the PMO does not only monitor and control the budget and the progress of the projects but they also constitute an interface between senior directors of the organization and the development departments. One of the key responsibilities of the PMO of this BU is to assist senior directors in the realization of the organization's roadmap and to drive the estimation of projects.

In addition to the different disciplines involved in the projects, the devices developed in this BU are technologically highly complex. Even for employees with the right academic background there is a long learning curve associated with getting familiarized with the key technologies and processes behind the products of the company. Most individuals dedicated to the core activities (i.e. non-support activities) of the PMO worked in technical roles in the organization before being promoted to project managerial positions.

1.4 Research Questions

Putting aside the case study organization, academic literature shows that a relatively low percentage of projects are completed within time and budget: only 1 out of 4 projects are completed at a cost reasonably close to the initial estimate (Lederer & Prasad, 1995). It is possible to use the existing knowledge of the company as feedback to improve the estimation of projects (Briand & Wieczorek, 2002).

Literature shows that there are several project estimation methodologies (Briand & Wieczorek, 2002; Briand, Emam, Surmann, Wieczorek, & Maxwell, 1999; Henry, McCray, Purvis, & Roberts, 2007; Jørgensen, 2004; Heemstra, 1992; Hihn & Habib-agahi, 1991). There are some studies around the topic of estimations in the context of multidisciplinary projects but unfortunately these took place in sectors rather unrelated with healthcare imaging systems; such as construction projects (Liu & Zhu, 2007; Pennsylvania Department of Transportation, 2010).

Other authors provide guidelines on how to improve front-end estimates in projects which also involve the disciplines of healthcare imaging systems projects. However, these studies tend to focus on single discipline projects, the most common being software development (Lederer & Prasad, 1992; McDermid, 1991) followed far behind by estimations in (electrical engineering) hardware design (Abildgren, Diguet, & Bomel, 2008). Some authors have even explored estimations in the aviation industry –which as mentioned previously shares many of the features of the healthcare imaging systems industry when it comes to estimations– however they also focus on a single discipline (Tae-Hoon, Kyung-A, & Doo-Hwan, 2007). So far, there have not been any studies that tackle the topic of improving estimations from a general perspective instead of just a model-based approach or a technocratic approach. Also, there were not found any studies that look at the challenges faced when doing estimations for multidisciplinary projects when looking at them as a whole (in contrast to the sum of the contribution of all their disciplines).

So, all these factors, together with the already mentioned characteristics of the Healthcare Imaging Systems sector lead to the formulation of the main research question (MRQ):

MRQ: How can companies enhance the quality of their project's front-end estimations?

The broad nature of this question calls for the need to break it down into several research questions. In the first place, it is important to explore what the existing estimation methodologies are and how estimations are currently done in the context of this industry sector and by whom. This yields to formulate the first research question (RQ):

RQ1: How are the project front-end estimations currently made and by whom?

In the second place, it is expected that the different estimation methods (Briand & Wieczorek, 2002) use different knowledge sources (Chatzoglou & Macaulay, 1996). Given the time boundaries of this study, this research does not aim to go in depth on the different knowledge management practices available (Jashapara, 2004; CEA, 2009; Andriessen, 2006) and their application in the estimation processes. Instead, what is considered relevant around knowledge in this study is to determine what information sources are used when doing estimations. This leads to the next RQ:

RQ2: What knowledge sources are used in the process of estimations and to what extent?

In the process of finding out what different estimation methods are available, how the estimation is carried out and what information is used, there is chance to find some of the obstacles within project's estimation. However, getting to know the obstacles that hinder estimation and how to overcome them is the heart of the scope of this research; which is why it needs to be addressed and studied explicitly. This leads to the last RQ of this research:

RQ3: What are the main factors that make difficult the practice of front-end estimation and how can they be overcome?

An important remark about the research questions is that at first sight they seem to omit a crucial analytical aspect of this research: a contrast between what is said in the literature and what is found in reality using the healthcare imaging systems organization as a case study. This, however, is not the case. A thorough discussion is presented at the end of this document where literature and empirics are brought together and a comprehensive set of recommendations is given.

1.5 Conceptual framework

Figure 3 represents the conceptual framework for this research. Estimation is a process that requires the intervention of actors. Literature recognizes some roles involved in this process (Saunders, 1990; Heemstra, 1992). An interim objective of this research was to determine how the estimation process takes place, what methods are used and who the most influencing actors are. This corresponds to the RQ1 and is depicted as the 'Project Front-end estimation' block in Figure 3.

In addition, front-end estimations are enhanced with knowledge coming from different sources (Saunders, 1990). Literature recognizes two different types of knowledge: explicit and tacit (Dummett, 1991; Andriessen, 2006). Explicit knowledge is knowledge that has been codified in the form of drawings, manuals or specifications and can therefore easily be shared and understood. On the other hand, tacit knowledge cannot easily be transmitted or imitated as it is derived from mental models, skills, behaviors, and is largely based on experience (Andriessen, 2006). For the sake of simplicity in the diagram, both knowledge types are referred to as 'knowledge' and are represented by a block with the same name in the conceptual framework. The sources from where this knowledge comes from are determined by answering RQ2. The reader should be aware that the term 'knowledge' has been used instead of 'organizational knowledge'. This was done on purpose; as will be explained in chapters 4 and 5, knowledge can come from outside the organization as well.

By knowing what information sources are used and how the estimation process takes place, it is possible to come back to the original problem and understand the factors that hinder estimation and reflect on those so that front-end estimations can be improved. The identification of these factors and the alternatives to solve them are treated in RQ3. This research question is portrayed in the block named 'Factors that hinder estimation and strategies to overcome them'.

That being said, why is it important to have better estimates and how is this reflected in the conceptual framework? The whole point of having higher quality estimates is to have more predictability in projects, that is, greater proximity between the final effort spent and the original estimate.

While better predictability in estimations is governed not only by the quality of the estimate but also by the quality of the management of the development effort (Lederer & Prasad, 1995, p. 127; Heemstra, 1992, p. 638), having good estimates should not be undervalued. Research indicates that good predictability of a project's effort and duration is related to project success (Henry, McCray, Purvis, & Roberts, 2007). The quality of the management of the development effort and other factors that improve the project predictability are represented by the block 'Other factors that lead to project predictability' in Figure 3.

When it comes to the definition of the scope of this research, it becomes important to distinguish the difference between **knowing how to improve** estimates and **actually improving them**. The former implies knowing how the estimation processes should be, what methodologies should be applied, what the main obstacles are, possible ways to overcome these obstacles, and so on. However, **doing better estimates** implies a step further: rolling out the improved estimation process, implementing the improvement guidelines in the organization, training of personnel, among other activities.

As mentioned before, the typical lifetime of a project in this organization is about 1-3 years, meaning that if estimations are improved now, the predictability can only be assessed after the completion of the projects that were estimated using the new practices/methodologies. This would require a longitudinal study of at least 1 year (the minimum time to develop a project). This period of time does not take into account the time it takes for the organization to implement the improvements in their estimation practices. This is the main reason why the 'Project Predictibility' block is depicted out of the dotted box in Figure 3. As a matter of fact, rolling out the improved estimation process is one of the suggested ideas detailed in the section 'Further research' in the conclusions chapter.

Care must be taken when using the term 'project success', especially in the context of estimation. Many authors agree on defining project success as meeting the project cost and duration (Chatzoglou & Macaulay, 1996; Henry, McCray, Purvis, & Roberts, 2007; Jenkins, Naumann, & Wetherbe, 1984). However, project success is also defined in terms of fulfilling wider objectives of the organization (McDermid, 1991), and the degree of satisfaction of the user, the owner and the stakeholders (Jenkins, Naumann, & Wetherbe, 1984; Turner, 1999). Take for instance the Sydney Opera House construction project. The project cost was much higher than the initially budgeted amount (Seven Wonders, 2009), and still it is considered as a tremendous success. This demonstrates that project success can come from other factors besides better predictability as depicted in Figure 3. In this research, project success is understood as bringing the project to completion on time and within the budgeted cost.

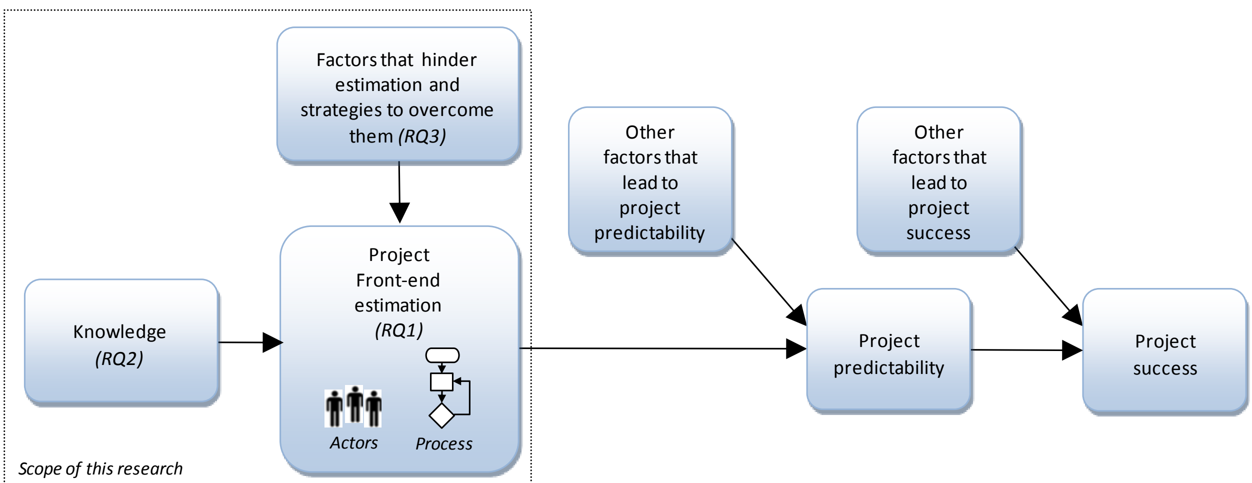

Figure 3: Conceptual framework

1.6 Relevance of the research

Literature recognizes some important benefits of having good estimation practices in place. Better estimates serve as a mechanism for comparing performance of projects, providing information on which to base the financing of a project and staffing projects properly (Saunders, 1990). Also, better estimates provide a more realistic idea of the milestones, time and resources it will take to complete a project; some of the key elements for proper control and planning of projects (Boehm, 1984, p. 19; Busby & Payne, 1999). High-quality estimates are also crucial to appropriately assess incoming, competing sub-contractor bids (Briand & Wieczorek, 2002, p. 55) and they can be a useful resource during negotiations especially in the case of fixed-price contracts (Saunders, 1990).

In addition, when the budgeted end of the project draws near, but substantial additional work remains; the tendency is to cut on the final tasks in order to complete the project at or near the budget.

Depending on the context, the last tasks can be typically testing, documentation and training (e.g. in systems development). While underestimation is not the only reason for these problems, it is clearly a contributing factor (McDermid, 1991, p. 28/3). Underestimation can impact the reliability of systems.

Another phenomenon that occurs when there is lack of realism in estimates is the extreme pressure to which staff is exposed when deadlines are approaching. This can have a long-term effect on the morale of employees (McDermid, 1991, p. 28/3; Henry, McCray, Purvis, & Roberts, 2007). Personnel are pulled from other assignments in order to 'save' the project which is in trouble, often aggravating the original problem. This high pressure and tension can lead to an increase in the staff turnover due to burnout (Brooks, 1975).

At the academic level, there seems to be a research gap in the domain of estimations. First of all, there is an abundance of references focusing on the topic of estimation but they tend to go in depth into projects involving a single discipline (e.g. software or civil engineering) rather than cross-disciplinary projects. Second of all, it is interesting to explore how to improve estimations in the context of complex projects like those of the healthcare imaging systems (whose characteristics where cited earlier in this chapter). The learnings from estimating in complex projects can be more easily ported to simpler projects rather than vice versa.

Last but not least, other theses have explored the topic of feasibility of projects (Landsbergen, 2009) –a phase where usually initial estimations are carried out. Other works have focused on the practices of inter-projects learning (De Gans, 2010) but to the knowledge of this researcher, this is the first master thesis in the faculty of Technology, Policy and Management of the University of Delft that goes in depth into the topic of improving the quality of estimations in projects. This work is also a primer in researching estimations in the context of the healthcare imaging systems industry.

Summarizing, the ultimate contribution of this research is to identify the main factors that hinder the practice of developing front-end estimations. By analyzing these issues and contrasting them with the good practices found in literature and in a complex environment like that of the Healthcare Imaging Systems sector, this study aims to shorten the research gaps mentioned above and contribute to the body of knowledge of project's estimation.

1.7 Structure of this document

This document consists of four main parts and is structured as depicted in Figure 4. The first part, Foundations, contains the first two chapters: Introduction and Research methodology. The second part provides some theoretical concepts which are relevant for all the chapters that follow. The third part elaborates on the answers of the research questions and analyzes the results found. It comprises chapters 4, 5 and 6. Finally, the conclusions, limitations and recommendations for future research are presented in the fourth part (chapter 7).

The chapters 4, 5 and 6 are structured as follows: first the theory relevant to the research question is presented at the beginning of the chapter, then the empirical data collected follows. Finally, results are discussed and empirical data are conciliated with theory. This structure is shown in chapter 4 only for simplicity purposes but it applies to the 3 research question chapters. The reader should bear in mind that due to this structure, it is not possible to discuss the validity of the theoretical findings or their applicability to the case study organization inline. Again, this is presented in a separate section at the end of each research question chapter.

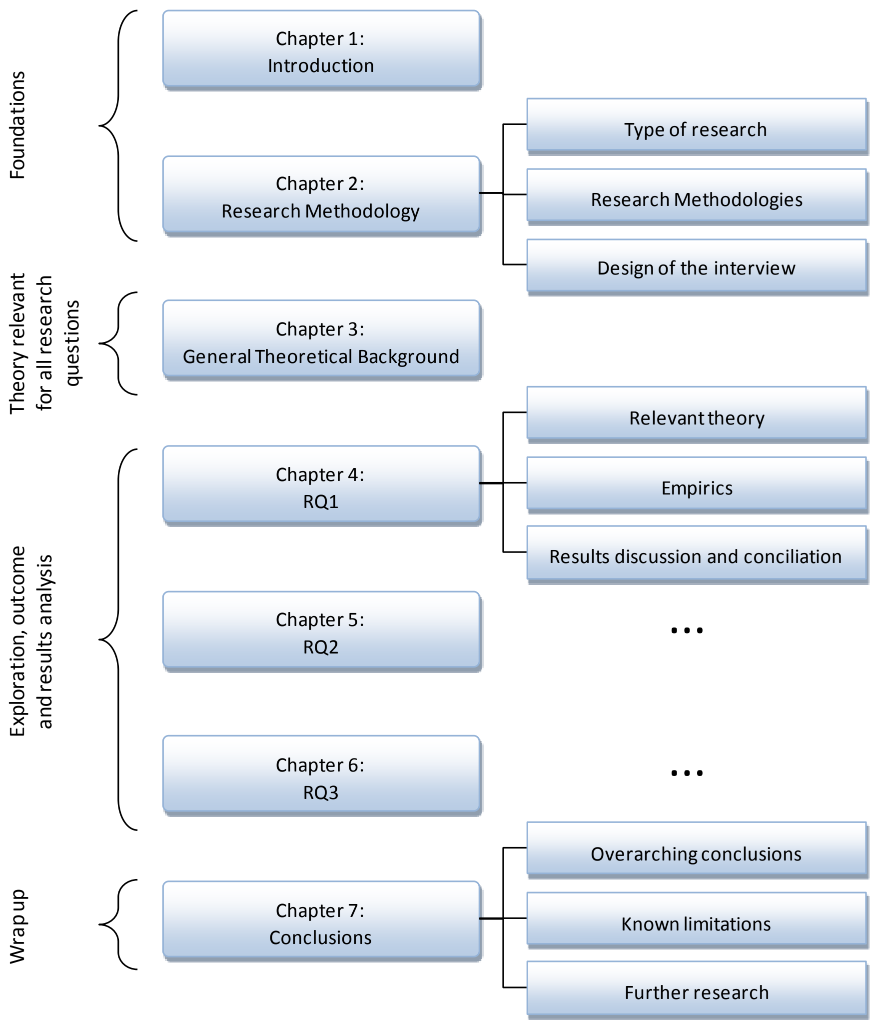

Figure 4: Layout of this document

2 Research methodology

This chapter presents the relevant aspects of the research methodology followed during this research. It starts explaining the type of research that was conducted, then it summarizes the profile of the interviewees and finally it approaches the general principles taken in consideration for designing the interviews.

2.1 Research design

The nature of the research questions formulated in this research calls for results that are not directly numerical. In other words, the nature of the research problem calls for the need of a main research question that has to be answered in terms of 'what questions' and 'how questions'. These types of questions are consistent with those of a qualitative research (Creswell, 2003, p. 106).

Furthermore, the answers to these research questions are composed of descriptions of behavior, accounts of experiences and data that must be categorized, thus owing to a qualitative research (Sekaran & Bougie, 2009, p. 369; van der Velde, Jansen, & Anderson, 2004, p. 74). Also, qualitative inquiry is highly appropriate for studying processes (Patton, 2002, p. 159). In order to identify factors that hinder front-end estimations and formulate mechanisms to improve them, estimations must be understood not only from the methodology perspective but also from the process perspective.

On the other hand, certain statistical conditions needed to be met in order to carry out a valid quantitative research around the topic of estimation, for instance, there needs to be a minimum size of the population and data needs to be chosen randomly (McClave, Benson, & Sincich, 2005). Furthermore, data is assumed to be available and to be an accurate representation of reality; however this situation is often not the case (Chatzoglou & Macaulay, 1996; McCulla, 1989; Briand & Wieczorek, 2002; Cuelenaere, van Genuchten, & Heemstra, 1987). It was not possible to assure that historical data met these conditions before starting the field research of this study.

An additional factor which also plays a significant role in the selection of the type of research was also linked to the time boundaries of this study (end of the master program). Literature mentions the fact that an estimator cannot have much experience in developing estimates, especially for large projects; "How many 'large' projects can someone manage in, for example, 10 years?" (Heemstra, 1992, p. 628). Therefore, the possibility of for instance conducting an experiment was difficult given the timeframe of this study. For all these reasons, it was decided that the approach of the research should be qualitative.

2.2 Methodology of this study

This section presents the data collection methods used to gather information to answer the research questions. Four different methods were used. The relationship between the RQs and the methods is presented below in Table 1.

Research questions (RQ)	Data collection methods			
	Literature review and analysis	Archival records[3] (Project documents and company documents gathering and reviewing)	Non-participant observations	Structured Interviews (Head of PMO (country level), Project Manager, Integration Project Leader)
1. How are the project front-end estimations currently made and by whom?	✓	✓	✓	✓
2. What knowledge sources are used in the process of estimations and to what extent?	✓		✓	✓
3. What are the main factors that make difficult the practice of front-end estimation and how can they be overcome?	✓	✓	✓	✓

Table 1: Relationship between research questions and data collection methods

All data collection methods were used for all the RQs except Archival Records. The reason behind this is that it is difficult to determine which information sources are used or not used just by looking at documents (especially when both literature and respondents reveal that estimation processes are not fully documented/standardized).

Before discussing more specific matters, it is wise to make explicit the methodology taken during this study (please refer to Figure 5). This research was divided in three chronological phases. The first phase is aimed at collecting information from 'passive' sources (literature, archival records from the organization and non-participatory observations). The intention to do this was to identify areas of strengths (richness) and weaknesses (gaps) within these sources. The second phase consisted basically in the design of the interviews and carrying out the interviews themselves. As will be explained later, structured interviews were used in this study. The third phase is comprised of the analysis of the information collected, the conclusions and the recommendations.

[3] (Yin, 2009)

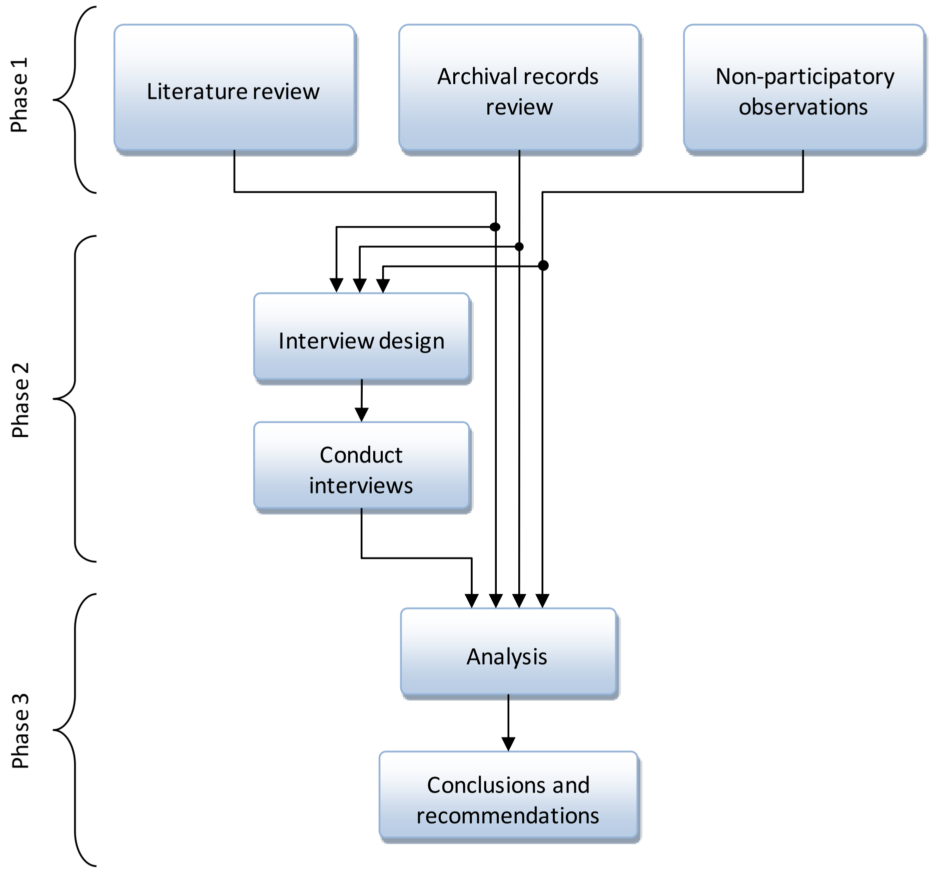

Figure 5: Methodology of this study

An important parameter when designing a research is defining the unit of analysis (Sekaran & Bougie, 2009, p. 116). In this case, the units of analysis are the estimation processes as conducted by 3 individuals at different levels within the PMO of an important BU of the company. The disciplines involved in these projects are several and involving all of them in the research would have brought breadth but not necessarily depth in the analysis of this study due to the space and timing limitations. Furthermore, all the PMO core personnel fulfilled technical positions in their past in the organization and participated in the project estimation activities during their technical and junior manager roles. The researcher relied on their familiarity of estimations even as carried out at the technical level. Due to these reasons, the PMO was chosen as the boundary of the population from which the respondents were selected. The criteria for selecting the roles of these individuals are presented later in this chapter together with their profiles.

This research also uses some mechanisms to ensure validity. 'Method triangulation' and 'Data triangulation' (Sekaran & Bougie, 2009, p. 385; Patton, 2002, p. 249) are used as can be observed in Table 1. Owing to the method triangulation principle, this research collects information using theoretical-oriented and empirical-oriented methods. From the theoretical side, an extensive literature review was conducted. On the other hand, on the more empirical side, non-participatory observations, archival records analysis and interviews were conducted. Collecting data via a multi-method approach and from multiple sources is more time consuming but adds rigor to the research (Sekaran & Bougie, 2009, pp. 216-217). As mentioned earlier, this mix enabled to do a sound comparison between the literature and a real scenario. This combination also provided useful elements for the analysis of the case study and the formulation of the recommendations.

With respect to time, this is a cross-sectional study as the data will be gathered at a single point in time (Sekaran & Bougie, 2009, p. 119).

2.3 Design of the interview

Interviews were recorded to ensure that all the information is properly captured and analyzed (Patton, 2002, p. 380). Some recommendations about tape recording in interviews were taken into account (Patton, 2002, p. 382).

The recordings were complemented with note taking as it poses some benefits (Patton, 2002, p. 383). Also, the personnel were interviewed individually and were informed about the findings only after all the interviews were concluded to avoid biasing (Sekaran & Bougie, 2009; Patton, 2002, p. 348). In this research, the role of the researcher will be non-interventionist due to the non-experimental nature of the proposed research.

Structured interviews were conducted (Patton, 2002, p. 342)[4]. This type of interview was chosen because it serves well in environments where the time of the respondents is quite limited like that of the organization where the research was conducted. Also, highly focused questions help to establish priorities for the interview, allowing the interviewee's time to be used more efficiently (Patton, 2002, p. 346). Furthermore, this type of interview makes data analysis easier because it is possible to locate each respondent's answer to the same question quickly.

An important remark about conducting structured interviews is that "the data collected are still open-ended in the sense that the respondent supplies his or her own words, thoughts and insights in answering the questions" (Patton, 2002, p. 346). This does not mean that the interview questions cannot capture what the respondents do and what they know. The researcher determines this by carefully selecting the type of interview questions. As this research is only concerned about what personnel do and what they know (instead of how they feel or how they would like things to be), only behavioral questions and knowledge questions were asked (Patton, 2002, pp. 350-351). Behavioral questions were also preferred because they encourage the interviewee to talk descriptively (Patton, 2002, p. 352).

The interview questions were carefully and fully worded before the interview, as suggested by literature (Patton, 2002, p. 344). Internal validity (Sekaran & Bougie, 2009, p. 384) was achieved by pilot testing the interview with an extra project manager. He provided feedback about the initial questions (van der Velde, Jansen, & Anderson, 2004, pp. 125, 131) and his comments were used to refine the interview

[4] This author uses the term standardized open-ended interviews for referring to structured interviews.

questions and adapt the language used to that used in the company[5]. This made it possible to build rapport more easily and achieve higher quality in the information gathered from the respondents (Patton, 2002, p. 361). Rapport was also built by highlighting the similarities between the interviewer and the interviewee (van der Velde, Jansen, & Anderson, 2004, p. 125) (e.g. both coming from a technical discipline) and by encouraging the interviewee to mention his experience and achievements within the organization at the beginning of the interview. A meeting was conducted with the three respondents after completing the interviews to validate and clarify the results obtained by observations.

Other main general guidelines that were taken in consideration were: (1) to ask singular and clear questions (Patton, 2002, p. 353), (2) to avoid 'yes/no-questions' (Patton, 2002, p. 354), (3) to provide respondents with the interview questions and information about duration of the session in advance (van der Velde, Jansen, & Anderson, 2004, pp. 125, 126) and (4) to ask for permission to tape record the interview and explain the reasons[6] for this in an informal setting beforehand (van der Velde, Jansen, & Anderson, 2004, p. 125). Also neutral questions were asked (Patton, 2002, p. 366) and the interviewer did not provide his own opinion about the topics during the interview (van der Velde, Jansen, & Anderson, 2004, p. 127). Total anonymity was assured to the respondents (both about their names, the projects discussed, the business unit and the company) to encourage them to feel safe enough to provide honest answers (van der Velde, Jansen, & Anderson, 2004, p. 136). Each interview lasted on average 1 hour and they were scheduled so that sufficient time was available after the sessions for clarification, elaboration and evaluation (Patton, 2002, p. 384).

The inquiry strategy followed during the interview is depicted below:

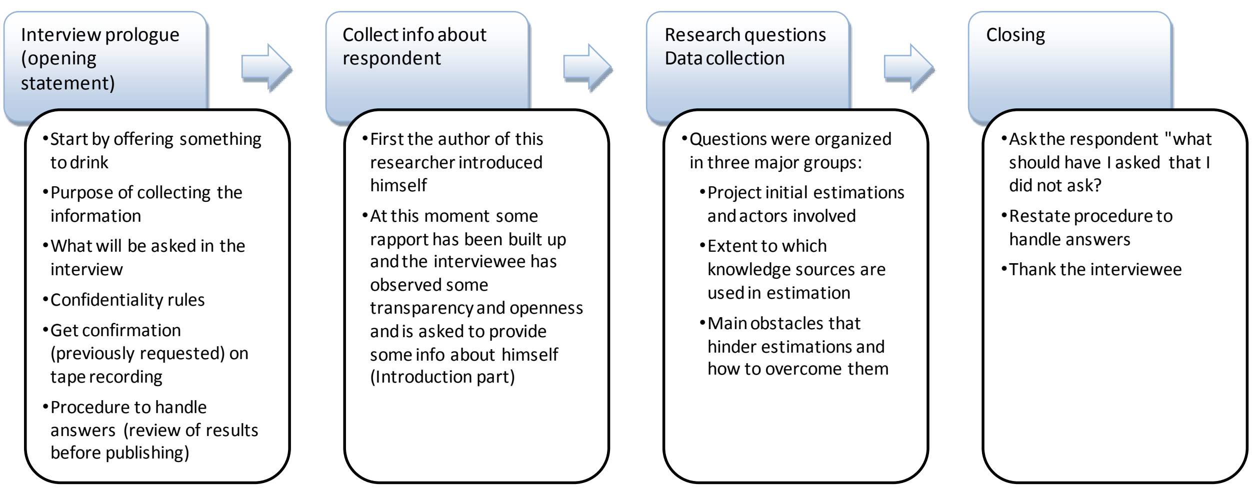

Figure 6: Inquiry strategy followed during the interviews.

[5] For instance, the term "front-end" estimations was found not to be very popular neither in academic literature (at least not in the context of estimation) nor in the corporate language of the company where the research was conducted.

[6] Avoid the risk to miss any important information or being focused on the notes instead of actually carrying out the interview (Patton, 2002, p. 381)

2.3.1 Interviewee profiles

This section discusses the selection criteria for choosing the respondents and also presents a short summary of their profiles.

An important criterion when choosing the respondents was to have individuals belonging to different levels within the PMO who had at least 10 years of experience in their roles within the organization so that they were well familiarized with the estimation and planning activities. Also, tapping at individuals from different levels allows capturing the interests of different stakeholders within the organization rather than for instance the perspective of the project managers, or the developers only. It is believed that this approach enabled a more complete view of the domain of estimations especially regarding the obstacles and the strategies to overcome them.

Following is the rationale behind the selection of the personnel who was interviewed, however before going in detail about the profile of each one of the interviewees, it is convenient to explain the rationale to limit the population of respondents to the PMO group. Most of the PMO personnel dedicated to core activities have extensive experience in one of the technical disciplines of the project (development). Additionally a significant part of the total effort required to bring a project to completion is spent within development. These two facts mean that personnel with project managerial roles have a solid understanding of the technical challenges and main activities including estimation at the activity and task-level.

An ideal scenario would have been to conduct interviews with at least 2 or 3 members of each different discipline typically involved in the project (please refer to Figure 2); but this would have exceeded the timeframe available to complete this research, not to mention the additional burden imposed to the organization. Since all core PMO personnel possess technical experience in development and estimation, one representative of each one of the top three senior roles found in this discipline were chosen. A detailed description of the rationale behind this follows below.

The first respondent was the Head of the PMO in the Netherlands (HPMO). He was chosen because he is responsible for the entire department and therefore he has an extensive overview of all the processes and activities carried at the project-level within the organization. Furthermore he plays a key role in the interface between (1) the business steering group (the group of managers who define the strategic goals of the organization) and (2) the PMO and the development department. His active involvement in the roadmap decision-making discussions adds insights from a high-level (program) management perspective. This insight is complemented further with the previous experience of this person in project leadership positions and technical development.

The second respondent was a project manager (PM). Including the perspective from someone in this role requires a short explanation. Project Managers in this organization are in charge of providing the first estimate in projects (a ‘ball-park’ estimate). They also play a key role in the process of driving the estimation discussions carried out at the front-end and consolidating estimation information provided by the project team members. Furthermore, their technical experience (both in development and detailed-level estimation) enhances the insights provided at this level.

The third interviewee was an integration project leader (IPL). This role is the highest position in PMO after project managers. This position also plays a key role in the estimation process because IPLs are in charge of developing and maintaining the integration schedule (a schedule that drives the master schedule of the project). In order to develop this schedule they actively contribute to estimations and at the same time delegate some estimation responsibilities to lower-level (more technical) positions within the project team. Similarly to the PM and the HPMO, the IPLs are individuals with previous technical experience in this organization (including doing estimations at a more technical level). Their perspective about estimations at the IPL-level is complemented with their knowledge and experience in conducting estimations at a more detailed level within projects.

The profile of each one of the interviewees is summarized in the table below.

Interviewee role	Details about the interviewee
Head of the Project Management Office (HPMO)	25+ years working in the company of which 20 years in project management. He has a background in electrical engineering but quickly moved to leadership roles. This person also worked in other BUs before joining this BU. The expertise from this individual comes from his professional experience and learning on the job. In the past, the HPMO worked as: software developer, sub system project manager, group leader, international system manager and system project manager.
Project Manager (PM)	This person has worked for about 16 years in the organization of which 2+ years have been as project manager. He has a background in software engineering and started in another BU of the same business group. 11 years ago he was transferred to this BU and approximately 7 years ago he was promoted to an IPL position. Subsequently he became a PM.
Integration Project Leader (IPL)	He has worked for 10 years in the company and has had 3+ years of experience as IPL (formerly called segment leader). He has a background in software engineering and completed 5 years of PhD work. He started working in this BU as software developer. 7 years ago he was appointed as team leader and at this point his career in leadership roles started. Before working in this organization he worked for Siemens (Vienna) in the mobile telephony domain.

2.3.2 General principles applied to the design of the interview questions

This section describes the general principles that govern the design of the interview questions. The interview questions can be found in the chapters that correspond to the research questions (chapters 4, 5 and 6).

When using structured interviews it is necessary to prepare the questions in advance so that the right information is collected (Patton, 2002, p. 344). In order to do this, it is convenient to have a thorough understanding of the topic; having studied the theory and acquired a good insight of the context where the interviews will be conducted. This is precisely the reason why the interview questions together with the process behind their formulation are presented after the theoretical and empirical findings in the chapters that follow.

Even though individuals with different roles were interviewed (HPMO, PM and IPL), the interview questions are the same. This was done on purpose and it owes to the following interview design strategy. An advantage derived from the 'standardized' nature of a fully structured interview is that it minimizes the likelihood that more information is collected from some participants than from others (Patton, 2002, p. 346). It was desirable to have less variability in the breadth of information received from interviewees and assure greater comparability of the answers. As will be seen in chapters 4, 5 and 6, the interview questions were written in such a way so that the same set of questions serves to tap at individuals with different roles and still provide useful information for this research.

The interview questions can be found in sections 4.2.3.1, 5.2.2.1 and 6.2.3.1 while the full interview protocol can be found in Appendix 1. Some answers were paraphrased because for some questions the respondent provided highly spontaneous and not so structured answers. The shorter, clearer and linear answers are quoted. All paraphrased and quoted answers are time stamped.

3 General theoretical background

The aim of this chapter is to present theoretical concepts which are relevant to more than one research question. A short definition for front-end estimations is given followed by some highlights about risk theory. Then some ways to represent estimates are introduced and finally a short summary about project planning levels is given.

3.1 Front-end estimations

Perhaps it is worth to clarify that in the literature no reference is made to this term as it is. 'Front-end estimations' are a combination of two concepts: front-end and estimations. As a whole it refers to the estimations that are carried out in the front-end phase of the project. Estimation is a wide known term that does not need further explanation, however, it is wise to provide the reader with the definition of front-end adopted in this study. Front-end is defined as the period or phase(s) of a project when resources have to be expended without any guarantee of return for the owner of the project (Morgan, 1987, p. 102; Artto, Kulvik, & et.al, 2011, p. 408). Even though the term has been used in literature for some time now, its definition has remained stable.

The front-end period is considered by some authors as a chaotic phase, however, it is also admitted that this is a phase of high opportunities in New Product Development (Verworn, 2009, p. 1571) because essential strategic decisions related to target markets, main functionalities, expected prices, costs and other important issues are taken at this stage (Artto, Kulvik, & et.al, 2011, p. 408).

3.2 Estimates and some highlights of Risk theory

Risk and uncertainty are two factors that should be incorporated in estimates (Hihn & Habib-agahi, 1991, p. 286). Also, "the accuracy of estimation is inseparable from risk management" (McDermid, 1991, p. 27/5) and when predicting project costs, the estimator considers the possible causes of variation of the cost estimates, including risks (PMI, 2004, p. 161).

The body of knowledge of risk management is quite extensive. This section aims to present only the concepts that are directly related with the scope of this research: the definition of risk and the main risk sources.

3.2.1 Risk definition

For some authors, risk is the "exposure to the chance of occurrences of events adversely or favorably affecting the project or business as a consequence of uncertainty" (Carmichael, 2006, p. 111). Others, define risk as "an uncertain event or condition that, if it occurs, has a positive or a negative effect on at least one project objective, such as time, cost, scope, or quality" (PMI, 2004, p. 238).

3.2.2 Risk sources

Risks and estimates are coupled therefore it is important that risks are considered during the estimation process. This makes them relevant to be taken in consideration in this research particularly for the discussions of chapter 6 corresponding to the RQ3. The listing below provides a summary of the main sources of risk in projects:

- The promoter/owner [S]
- The host government(s) (e.g. changes in legislation, economics, etc) [S, V]
- Financial (e.g. changes in credit system, interest rate, currency, commodity, operating, liquidity, inflation) [S,V]
- Inherited (i.e. such as from previous phases of a project) [V]
- Construction [S]
- Logistics [S]
- Estimating data (time and cost) [S]
- Acts of nature [S]
- Supply – such as availability of raw materials and resources [V]
- Business – such as change management risks, marketing, HR (human resources) risks, HSE (health, safety, environment) risks [V]
- Communication – such as lack of internal communication and communications in a crisis situation [V]
- Project management – such as poor management of the schedule, resources, costs and quality of the project [V]
- Technology – risks derived from the use of a new and unruly technology [V]

Table 2: Consolidated list of risks sources. Sources: [S] (Smith, 1995), [V] (Verbraeck, 2010)

3.3 Representation of estimates

Estimates can be represented in two ways. The first way is by using point estimates; e.g use the sample mean as a point estimate to describe a population mean. However, this representation fails to convey the sense of how accurate it is (McDermid, 1991, p. 6/7). The second method consists on using interval estimates. Interval estimates convey how accurate they are by specifying an interval within which the true value is likely to lie. The elements of this representation are two numbers that determine the limits of the range and a confidence level (McDermid, 1991, p. 6/7; Jørgensen, 2004, p. 52)[7]. These concepts are relevant during the discussions of chapters 4 and 6 corresponding to RQ1 and RQ3 respectively.

3.4 Project planning levels

Planning levels tend to be aligned with organizational levels (Carmichael, 2006, p. 140; Meredith & Mantel, 2010). For instance, senior management (or the owner) may only be interested in broad issues while middle management (engineering, construction, etc) might be interested in a bit more detail. Awareness about these levels is important because project plans of former projects can be used as an information source to estimate new projects (PMI, 2004, pp. 162, 85), and project plans can come in different levels of detail (granularity) as observed in Figure 7. Knowing the project planning levels theory enables a better understanding of chapters 4 and 5 corresponding to RQ1 and RQ2 respectively.

[7] The typical representation of an estimate using interval representation looks like "$p(a < \theta < b) = 1 - \alpha$" where a and b are two numbers that determine the limits of the interval, $1-\alpha$ indicates the confidence level and p(…) is a probabilistic function.

Level of management	**Level of information**
Customer and Senior Management	1
Project Management and management staff	2
Departments and subcontractors	3
Detailed planning and control at work package level	4

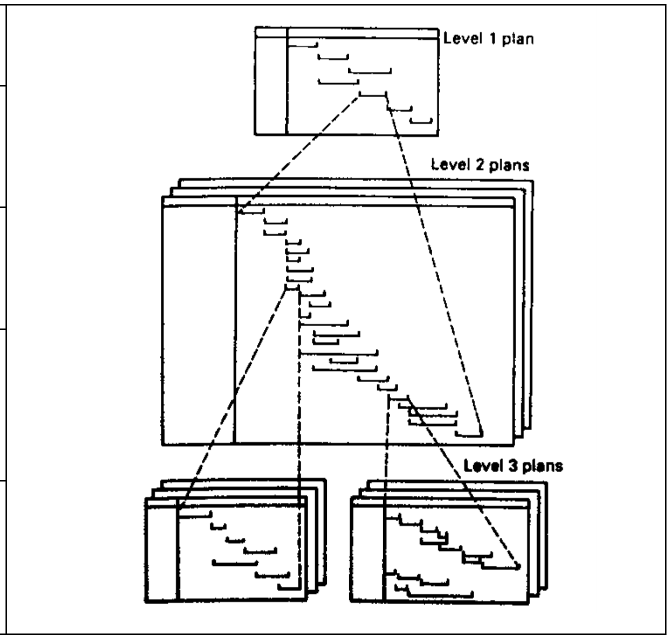

Figure 7: Link between levels of project plan and levels of management. Source: (McDermid, 1991)

4 PROJECT FRONT-END ESTIMATIONS AND ACTORS

Now that the introduction, the research methodology and the general theoretical background have been discussed, the research questions are approached.

This chapter provides an answer to the first research question: **How are the project front-end estimations currently made and by whom?** The chapter presents some relevant theory around this RQ, the empirical findings and some relevant discussion and conciliation between theory and empirics.

4.1 RELEVANT THEORY

It was found that the majority of authors in the academic literature approach the topic of estimation from the software development perspective. The main reason behind this seems to be that software resource estimation is considered to be more difficult than resource estimation in other industries. “Software organizations typically develop new products as opposed to fabricate the same product over and over again” (Briand & Wieczorek, 2002, p. 3). Another area where there is an interest in project estimation, although to a much lesser extent, is the construction sector.

Seeing as most of the studies found tend to focus on a specific industry sector, the approach taken in this literature review was to conduct an extensive search and extract the information that was general enough to be applied across different sectors, including the healthcare medical systems industry. The main theory streams covered in this section are (1) estimations over the life-cycle of projects, (2) existing criteria for classification of projects, (3) existing estimation methods, (4) type of estimates, (5) the process of estimation and (6) the main actors involved in estimations.

4.1.1 ESTIMATIONS AND THE LIFE-CYCLE OF PROJECTS

At the moment of conducting the literature search, the lifecycle for the healthcare systems development projects was not available[8]. However, the findings of the lifecycle of projects of other sectors can help to build an idea of how estimations look like in the healthcare imaging systems industry. For instance, in the construction industry, there are additional stages after the handover phase namely: (1) operation and maintenance, (2) decommission and (3) disposal (Turner, 1999, p. 11).

The Project Management Institute presents a very similar scheme with slight name variations only (PMI, 2004, p. 23). Figure 8 shows the typical phases of a project together with the estimation processes carried out in them.

[8] This document does exist within the private archive of the organization however due confidentiality issues it is not referenced or included in this report.

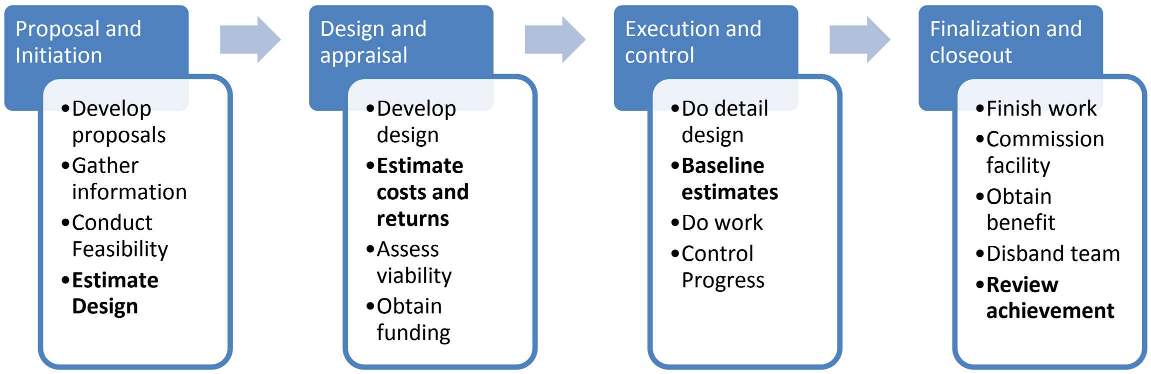

Figure 8: A project's basic four stage life cycle. Adapted from: (Turner, 1999, p. 11)

It is common that the accuracy of estimates improves during the project life-cycle because as the project progresses, more relevant information becomes available (Liu & Zhu, 2007; PMI, 2004, p. 161; Anderson, Molenaar, & Schexnayder, 2007, pp. A-153). As an example, the inaccuracies of estimates during a construction project are depicted in Figure 9. The purpose of the estimates is also indicated in each phase.

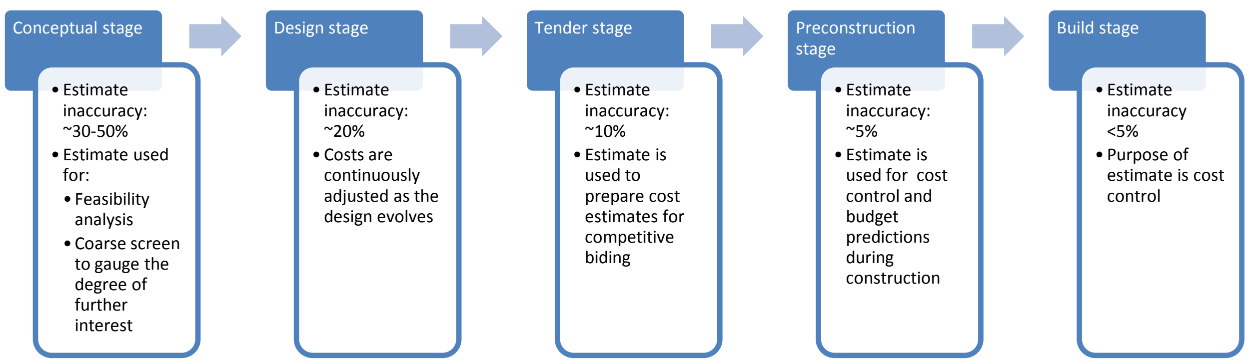

Figure 9: Accuracy and purpose of estimations in a construction project. Source: (Liu & Zhu, 2007)

4.1.2 Criteria for classification of projects

An important part of the estimation process when using historical data is to select projects which are similar to the new (to be estimated) project so that only a relevant subset of data is used as the reference framework for carrying out the estimation. This is especially critical in methods like Analogous estimating (Boehm, 1984; PMI, 2004; Chatzoglou & Macaulay, 1996). The relevance of this will become clear in the discussion of results.

Two criteria were found for grouping projects according to their similarity: by complexity and by finding common cost drivers.

4.1.2.1 Complexity

One of the dimensions in which projects can be categorized is complexity. Bosch et al (2010) conducted a study where 6 engineering projects were analyzed. They identified elements contributing to project complexity and formulated a framework for assessing the complexity of projects. The framework divides all the aspects that characterize complexity in 3 categories: Technical, Organizational or Environmental.

4.1.2.2 COST DRIVERS

There are some important factors which have an influence on the effort and duration of the project. Multiple studies have discussed these and have often denominated them 'cost drivers' (Lederer & Prasad, 1992; Heemstra, 1992, p. 628). This study uses the 5 cost-drivers categories defined by Heemstra (1992, p. 629) to structure the findings from literature (see Table 3).

The procedure that resulted in the table below started by looking at the factors mentioned by Heemstra. Then all the literature references concerning estimates were reviewed looking for any factors that could drive the effort, the cost or the lead time of projects. The factors were assigned to the category where they fitted the most based on the similarity with the cost drivers initially set by Heemstra.

What (product)	With what (means)	Who (personnel)	How (project)	For whom (user)
Size of the project [H, LE] Required quality [H] Requirements volatility [H, LE, K] (frequency or extent of potential changes) Project complexity [H, LE] Required integration with systems [LE] Level of reuse [H] Amount of documentation to be produced [H] Type of project [H]. E.g. • Advanced development • System development • Component development Clarity of owner requirements [LI] Level of detail of the scope definition [LI] Need to comply with gov. regulations [K]	Development equipment capabilities [H]. E.g. computer constraints: • Execution time • Memory capacity Use of modern development techniques [H]. E.g. • New programming languages • Techniques for faster integration of systems Availability of productivity tools [LE] (e.g. screen generators, code generators, report generators, etc) Availability of testing aids or testing facilities [LE] Availability of historical data for similar job [LI] Historical data quality [LI]	Quality of personnel [H] Quality of the management team [K] Relevant experience of personnel from previous projects [H, LE, S] • In local markets • In similar projects • In similar contract type Capabilities of team members [LE] Number of team members [LE] Quality management [H] Availability for project [H]	Project duration [H] • Compression Basis for project control [H] • Matrix organization • Project organization Development model [LE] (series or parallel) Involvement of resource (labor, cost) in preparing the estimate [LI] Formal structure to categorize and prepare project estimation and [LI, S] Experience of estimator [LO] Need of Traveling/re-hosting/multisite [BO]	Involvement of user/client [H] Number of users/customers [H] Stability of user organization (e.g. procedures, way of working, etc) [H] Experience of user with similar technologies in the past [H]

Table 3: Most important cost drivers in estimation. Adapted from: [BO] (Boehm, 1984, p. 11), [H] (Heemstra, 1992, p. 629), [K] (Koehn, Young, Kuchar, & Seling, 1978), [LE] (Lederer & Prasad, 1992),[LI] (Liu & Zhu, 2007), [LO] (Lowe & Skitmore, 1994), [S] (Shash & Al-Khaldi, 1992)

4.1.3 ESTIMATING METHODS

Before presenting the different estimation methods found in literature, it is convenient to define a grouping scheme to provide structure to this section. The estimation methods categorization scheme presented in this section incorporates some ideas from schemas found in literature however “these schemes are subjective and there is no agreement about the best one” (Briand & Wieczorek, 2002). This principle also applies to the schema defined in this document.

Unlike the existing categorization schemes, this document makes a distinction between **estimation methods** and **strategies**. A strategy only dictates the approach taken to arrive at the estimate but it is not enough by itself; in order to arrive at effort or lead time figures it needs to be combined with an estimation method. Consequently, a strategy by itself cannot be placed in a particular point in the explicit/tacit knowledge scale as this depends on the method it is paired with. This is the reason why strategies are placed below in Figure 10 covering the full spectrum of the scale. It is also important to state that one strategy can be used in conjunction with more than one method (e.g. the bottom up strategy is chosen to estimate effort and lead time at the task-level. But since not all the disciplines of have historical data at their disposal, some disciplines use the expert knowledge method while others use the standard times method). The grouping scheme and the estimating methods of each category are presented in Figure 10.

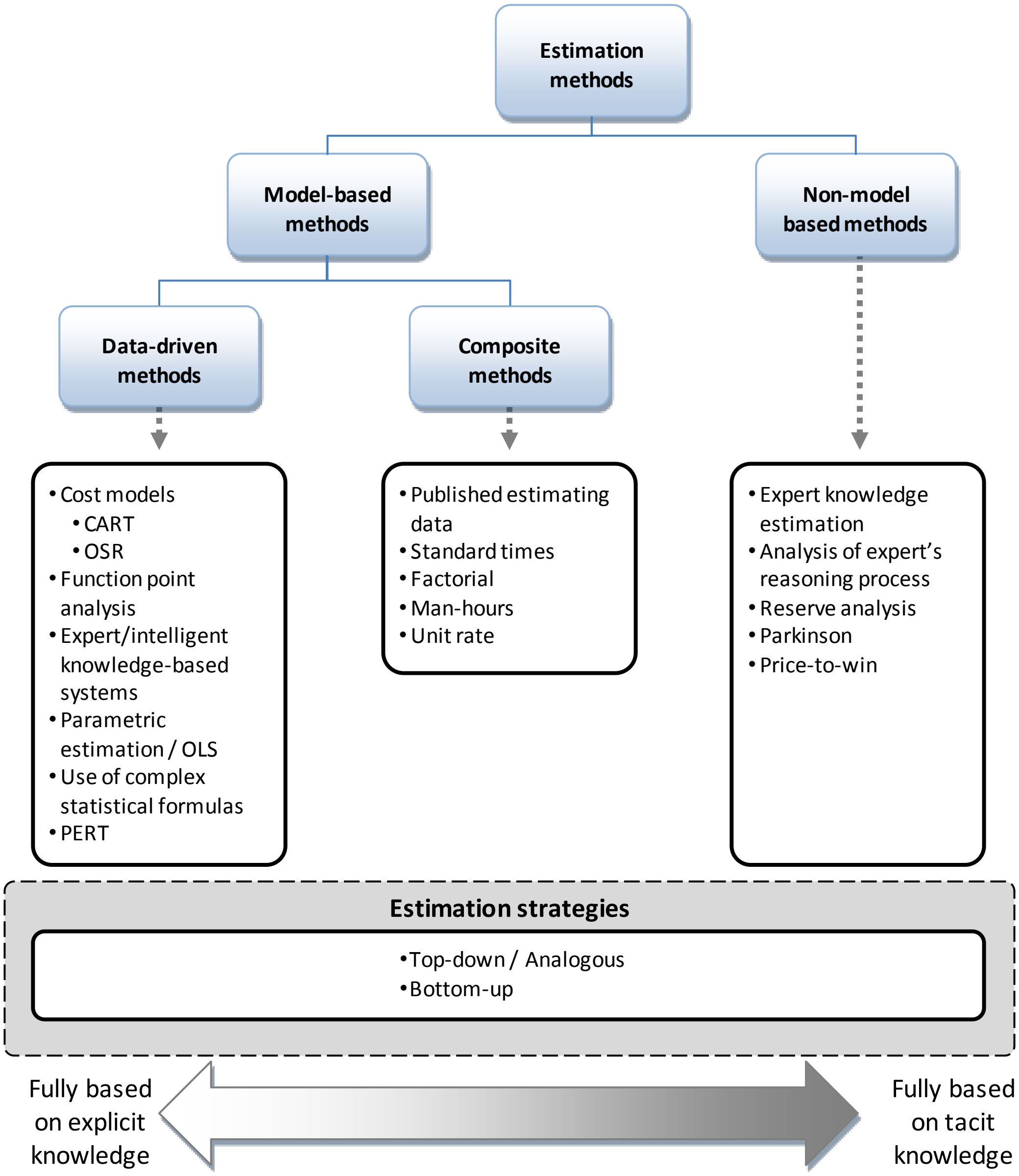

Figure 10: Classification of resource estimation methods

The classification scheme above has three major categories which are defined as follows. The Data driven methods are modeling methods purely based on historical data and its analysis. The Composite methods are methods based on combining expert opinion and data-driven modeling. Last but not least, the Non-model-based methods rely on tacit knowledge only and often involve consulting one or more experts to derive a subjective effort estimate (Briand & Wieczorek, 2002, p. 6).

The following section gives an overview of the estimation methods presented in the classification scheme above and also explains the estimation strategies.

4.1.3.1 DATA-DRIVEN METHODS

Cost models: are largely based on the productivity of developers in terms of units of work per day. Unfortunately productivity in programming depends on the programming language used (McCulla, 1989). Cost models comprise methods like CART and OSR.

CART (Classification and Regression Trees): A regression tree is a collection of rules of the form: if (condition 1 and 2 and… N) then Z where Z is a dependent variable. The objective is to build a tree in which the effort or the productivity per time of project is derived (Briand & Wieczorek, 2002; Briand, Emam, Surmann, Wieczorek, & Maxwell, 1999). Productivity figures and conditions may vary per discipline. Therefore, in multidisciplinary projects, different disciplines may have to be considered separately. An example of a CART is shown in Figure 11.

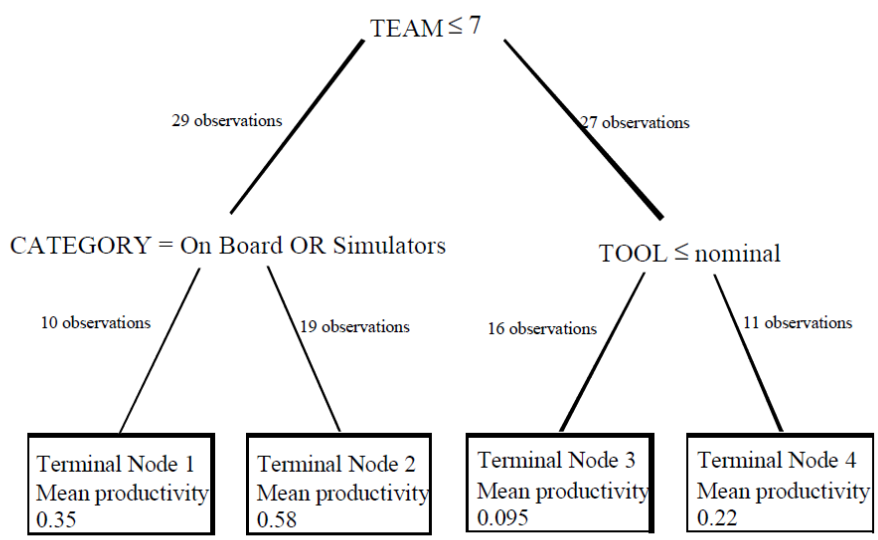

Figure 11: Example of a Categorization and regression tree. Source (Briand & Wieczorek, 2002)

OSR (Optimized Set Reduction): This method determines subsets in a historical data set that are 'optimal' for the prediction of a given new project to estimate (Briand & Wieczorek, 2002). The generated model consists of a collection of logical expressions that represent trends in a data set that are relevant to the estimation at hand (Briand & Wieczorek, 2002; Briand, Emam, Surmann, Wieczorek, & Maxwell, 1999). The outcome can be either productivity rates or project size. By combining these two, the hourly rate and size of the team, it is possible to arrive at final cost and lead time of the project. An additional remark about the output of an OSR is that in addition to a point estimate, a standard deviation can easily be estimated based on the subset of projects characterized by the rule. See Figure 12 for an example.

```
(RELIABILITY=High)
AND
(VIRTUAL_MACHINE_EXPERIENCE=High)
AND
(USE_OF_DATABASE=Low)
```

→ 299 LOC[9]/Person-Month

Figure 12: Example of rule set for an OSR. Source: (Briand & Wieczorek, 2002)

Function point analysis: The principle is to overcome the problems of cost models by measuring the functions delivered, not the lines of code. This approach is machine and language independent. The problem is that it depends on historical data and it is also perceived as a productivity measure and not only as an estimation tool (McCulla, 1989). Other authors also discuss some disadvantages of this method (Briand & Wieczorek, 2002, p. 23). It applies only to software projects.

Expert/intelligent knowledge-based systems: They have a degree of freedom in customizing the knowledge-based rules. For example, a rule could be based on the concept that each stage in a project typically takes the same percentage of the total time for the project. Thus, if the actual time for a given phase/stage is available, the time for the full project could be estimated (McCulla, 1989).

Parametric estimating / OLS (Ordinary Least Squares Regression): This technique uses a statistical relationship between historical data and other variables (e.g., square footage in construction, lines of code in software development, required labor hours, etc) to calculate an estimate for activity parameters, such as scope, cost, budget and duration (Henry, McCray, Purvis, & Roberts, 2007). A form of relationship between the dependent and independent variables (e.g. linear, quadratic, log-linear, etc) needs to be specified. Unfortunately, this method is difficult to use for most engineers and managers and requires extensive training and experience (Briand & Wieczorek, 2002). Another drawback of this method is that it does not account for the detailed individual components and the workflow in the system (Doloi, 2010, p. 1).

Use of complex statistical formulas: Some authors reported the use of methods like multiple regression, differential equations, and so forth to support project estimations (Lederer & Prasad, 1992, p. 57). One of the methods that fall into this category, OLS, was explained above already. Some authors refer to this method as 'formulae' (Chatzoglou & Macaulay, 1996).

PERT (Program Evaluation and Review Technique): Consists on modeling a collection of activities either as a sequence, in parallel, or as combination of both. The outcome of this modeling is a network in which the arcs represent activities and the nodes represent the events or milestones during the project.

This method does not provide a direct cost estimate, however by combining hourly rates and expected times of activities, it is possible to arrive at an aggregated cost of the project and find out its lead time (Turner, 1999; Meredith & Mantel, 2010). PERT deals with uncertainty in activity completion times and the equations used to model the effort spent in each task can be found in Appendix 4.

[9] LOC: Lines of code

4.1.3.2 Composite methods

Estimate based on Published Estimating Data: Includes production rates and unit costs of resources for an extensive array of labor trades, material, and equipment for different countries and geographical locations within countries (PMI, 2004, p. 137).

Estimate based on standard times: Consists on analyzing many previous projects times so that a standard time is calculated (e.g: the duration of task A is about 50-60% of task B with a determined level of significance α) (Chatzoglou & Macaulay, 1996).

Factorial: Is a method used widely on process plants where key components are identified and priced and all other works can be calculated as factors of these components (Smith, 1995, pp. 9, 18).

Man-hours: This method is most suitable for labor-intensive operations (e.g. maintenance or mechanical erection). Work is estimated in total man-hours and costs are determined in conjunction with plant and material costs (Smith, 1995, pp. 9, 19).

Unit rate: This method estimates the quantities of work based on the Bill of materials (BOM). It must not be assumed that previous work was similar and carried out in identical conditions or in the same duration. It is not very accurate during the initial phase as a detailed BOM is not available (Smith, 1995, pp. 9, 20).

4.1.3.3 Non model-based methods

Expert knowledge estimation: Some authors report different variations of this method, for instance intuition, guessing and comparison to similar past projects based on personal memory (Lederer & Prasad, 1992). This method is also known as informal analogy and it has the disadvantage of relying on the accuracy of the estimator's memory (Hihn & Habib-agahi, 1991, p. 281). Some authors refer to this as "professional judgment" (Chatzoglou & Macaulay, 1996) or "expert judgment" (PMI, 2004).

When more than one expert is involved it becomes "Collective estimation" (Briand & Wieczorek, 2002; PMI, 2004; Boehm, 1984). When done collectively, this method poses some advantages seeing as the enthusiasm of some individuals may be counterbalanced by the caution of others. However, this also implies that stronger personalities may dominate. To reduce these risks and to avoid biasing of individual experts, the adoption of the Delphi technique is suggested. Several iterations may be necessary (Boehm, 1984; Briand & Wieczorek, 2002).

Analysis of experts' reasoning process: Use tape-recorded verbal protocols to analyze the behavior of experts during the estimation process (Vicinanza, Mukhopadhyay, & Prietula, 1991).

Reserve Analysis: Consists in adding an extra cost contingency budget (in terms of lead time or money). When is time-related is also called "protection time-buffer" (PMI, 2004, p. 142).

Parkinson: The Parkinson's Law or Einstein expansion is extended to the Project Management domain as "a work project expands to fill the space available" (Carmichael, 2006, p. 76). The cost estimate is equated to the available resources. This method is not considered an acceptable estimation method (Briand & Wieczorek, 2002, p. 20; Boehm, 1984, p. 7).

Price-to-win: The cost estimate is matched to the price believed to win the job. Also, the schedule can be ‘forced’ to be the first in the market with a new product (Boehm, 1984, p. 7). This method is not considered an acceptable estimation method (Briand & Wieczorek, 2002, p. 20; Boehm, 1984, p. 7). However, it is worth to say that “that the estimates of organizations which use Price-to-Win are no less accurate than organizations which use other methods” (Heemstra, 1992).

4.1.3.4 Estimation strategies

As mentioned before, this section presents the two strategies given in the classification scheme above: town-down and bottom-up.

Top-down (also known as analogous estimating): An overall cost estimate for the project is derived from global properties of the final product/service to be developed. The total cost is then divided between the various components. (Briand & Wieczorek, 2002; Boehm, 1984, p. 7; McDermid, 1991; Doloi, 2010; Henry, McCray, Purvis, & Roberts, 2007; Jørgensen, 2004). This strategy is used when there is limited amount of information about the project. It uses the values of parameters such as scope, cost, budget, and duration, complexity from a previous similar activity as the basis for estimating the same parameter or measure for a future activity (Henry, McCray, Purvis, & Roberts, 2007).

Bottom-up: Involves effort estimates for each activity separately and the total effort is an aggregation of the individual estimates, possibly involving an additional overhead (Briand & Wieczorek, 2002; Boehm, 1984; McDermid, 1991; Doloi, 2010; Henry, McCray, Purvis, & Roberts, 2007; Jørgensen, 2004). This strategy is used when a schedule activity cannot be estimated with a reasonable degree of confidence by itself and it needs further decomposition (PMI, 2004).

4.1.4 Types of estimates

The main estimates in the context of project management are activity resource estimate, activity duration estimate and cost estimate (PMI, 2004). The three types are briefly explained below.

Activity Resource Estimate: This involves determining **the resources that will be required for the project (people, equipment or raw materials) and their quantities** (PMI, 2004, p. 137).

Activity Duration Estimate: This is about estimating the **number of work periods that will be needed to complete individual schedule activities** (PMI, 2004, p. 139). Most project management software for scheduling handles this by using a project calendar together with availability resource calendars. The duration estimate can be assumed to be progressively more accurate as more detailed and precise data becomes available.

Cost Estimate: This involves developing an approximation of the **costs of the resources needed to complete the scheduled activities**. Possible causes of variation are considered, including risks. The main resources considered within the estimates are depicted in Figure 13.

Figure 13: Types of resources taken in consideration when making cost estimates. Source: (PMI, 2004, p. 161)

Other authors also refer to another cost category which also has to be estimated, the so called 'indirect costs'. These are one-off costs which have to be paid whether or not the project is done (e.g. salaries of project administrative staff, hire of accommodation, insurance, etc) (Carmichael, 2006, p. 63).

4.1.5 Estimation process

The cost estimation practice and cost estimation management processes can be framed in four steps (Anderson, Molenaar, & Schexnayder, 2007). Estimation is carried out during each phase of the project however the manner in which these steps are implemented depends on the phase. The four steps and the activities carried out in them are depicted in Figure 14.

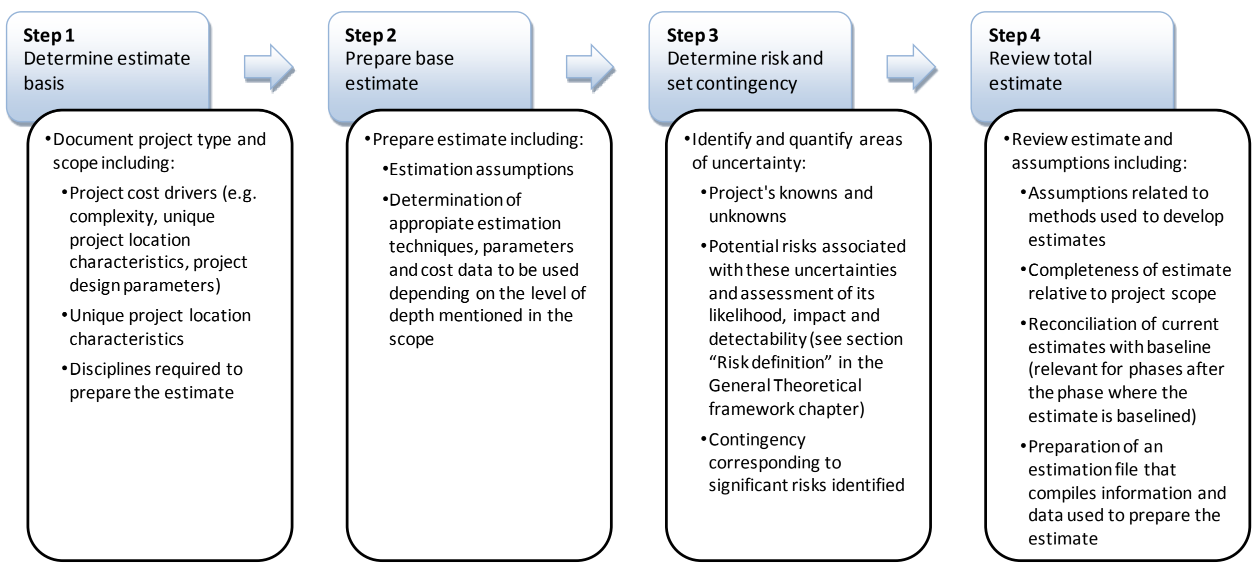

Figure 14: Cost estimation process. Adapted from: (Anderson, Molenaar, & Schexnayder, 2007, p. 11)

4.1.6 Estimations in similar industries or in related single-discipline projects

After having introduced estimation as a process in the previous section, this section aims to present the main estimation methods reported by studies carried out in the context of similar industries or in single discipline projects. Seeing as all the projects use expert knowledge at some extent to carry out estimations, only the other methods used in these projects are presented in this section. All the methods mentioned in this section were already explained before.

For instance in the military avionics industry, a study determined that there is a gap in the software maintenance project management and developed a probabilistic effort estimation model (Tae-Hoon, Kyung-A, & Doo-Hwan, 2007). The model was built taking into account the **structural characteristics of the software** and data collected from 76 software maintenance projects.

In the digital hardware design domain, a group of researchers developed a model for estimating implementation effort. The inputs for their model are the **complexity of the hardware** to be designed and the **experience of the developer**. The predictions obtained using their model fell inside a 95% confidence interval of the real data (Abildgren, Diguet, & Bomel, 2008). Another study conducted in this area used **statistic regression analysis and the least squares** to develop a model to explain the effort spent by hardware board designers based on historical data (Xing-hui, Qi-yong, & Jian-guo, 2007). The difference between the actual effort and the effort estimated with their model is about 7.2%.

In software projects, it is preferable to size projects using **function points** rather than **LOC** (Lines of code). The reason for this is that there is not an accepted standard definition for LOC, LOC depend on the programming language used and the individual programming style among other reasons (Briand & Wieczorek, 2002, p. 22; Abildgren, Diguet, & Bomel, 2008, p. 3). When data is available, metrics-based cost models are used, for instance the **CART** method is commercially used (Salford Systems). Another cost model that can be applied is **OSR** (Briand & Wieczorek, 2002). However, in spite of the benefits claimed by the creator of this method, no commercial applications of it were found for OSR.

4.1.7 Stakeholders involved in the front-end estimation process

The following table summarizes the actors that are involved in the estimation of projects according to literature:

Category	Actors

Project members	• Cost engineer [S]
	• Project engineer [S]
	• Design engineer [S]
	• Project manager [S, P, D, HM]
	  ○ Responsible for building a staffing profile for their projects. (A staffing profile is a skill-based layout of project demand).
	  ○ The staffing profile should have some element of time phasing, so the duration of resource commitment can be determined.
	• Team members [HM, L]

Managers	• Functional Managers [P]
	  ○ They own the actual people who deliver the work.
	  ○ They are responsible for the effort forecasting (i.e. validating the staffing profile with respect to areas they manage, and assigning people to deliver the work in these areas)
	• Business development team [D]
	• Development department management [L]

External personnel	• Consultant (optional. Depends on the situation) [S, D, C] • Contractors and subcontractors who have critical roles in the project (Construction projects) [D] • Customers [D] • Users (mostly in software projects) [L]

Category	Actors
Internal personnel	• Financiers [D] • System analysts (only in software projects) [L]
Other	• There is no fixed set of disciplines involved in the estimation process. These are determined in one of the first steps of the estimation process (see Figure 14) [A]. • The estimate itself depends on the perspective one takes and the interests the actor has in the estimating process [B]. For instance: ○ People in planning support functions had the goal of demonstrating that they had learned from past projects, and could identify material risks: they therefore preferred top-down strategies that drew heavily on past outcomes, especially numerical data [B]. ○ People in senior, operational roles typically had the immediate goal of winning a contract, and the longer-term goal of increasing productivity. Both goals were served by their strategy of estimating top-down with target costs as an anchor [B, HM, L]. • People in more junior, operational roles often preferred bottom-up strategies because other people wanted them to justify their estimates by breaking them down into detail [B].

Table 4: Different actors that should be involved in the estimation process.
Sources: [A] (Anderson, Molenaar, & Schexnayder, 2007), [B] (Busby & Payne, 1999, p. 297), [C] (Chatzoglou & Macaulay, 1996) [D] (Doloi, 2010), [H] (Heemstra, 1992, p. 638), [HM] (Henry, McCray, Purvis, & Roberts, 2007), [L] (Lederer & Prasad, 1995),[P] (Portfolio Decisionware, 2009), [S] (Saunders, 1990)

Some authors indicate that estimates are carried out in several phases of the project (Turner, 1999, p. 11; Doloi, 2010) and also that the actors involved depend on the phase itself (Doloi, 2010).

It can be seen that the roles mentioned in Table 4 are a subset of the main project stakeholders (PMI, 2008, pp. 213-215).

4.2 EMPIRICS

The methods for collecting empirical data for the research question of this chapter were to look in archival records of the company, conduct non-participatory observations and to carry out structured interviews to relevant personnel. The information collected is summarized in this section.

4.2.1 ARCHIVAL RECORDS ANALYSIS

This data collection method revealed two important concepts. The first finding corresponds to the estimation process as documented in the internal quality management system of the organization (see Figure 15). This process diagram depicts the major steps carried out when doing estimations in this organization. It also indicates the actors involved and where in the process they intervene. The analysis of this finding is presented at the end of this chapter.

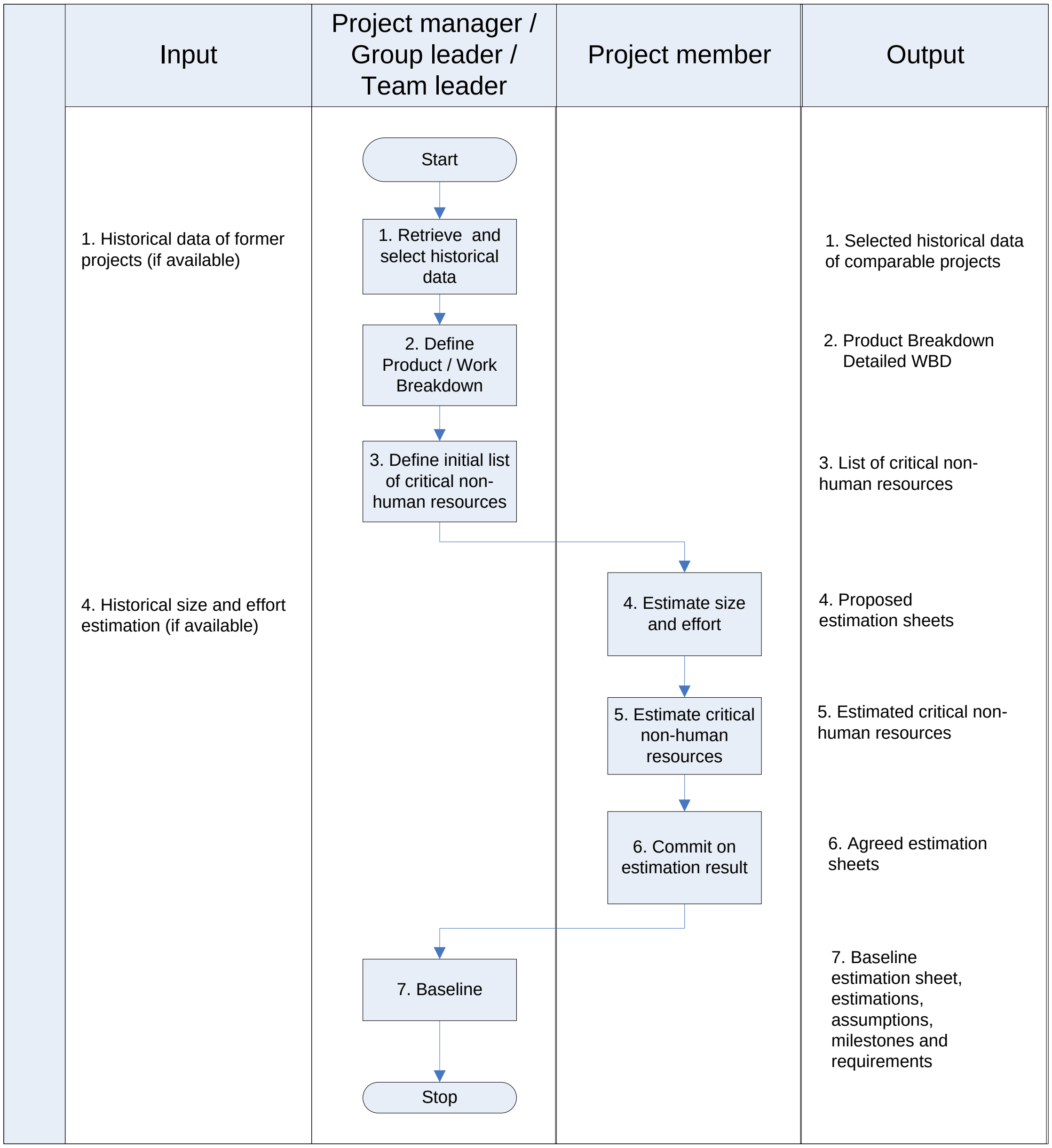

Figure 15: Estimation process of the organization according to archival records.
Source: Archival records of the case study organization

The second major finding from the archival records analysis is the way in which the estimates are represented in reports. Estimates at PMO-level reports are expressed in terms of a point estimate with a variance percentage (e.g. "Project A will take 5.1 man-years + 10%"), however the variance is defined using expert knowledge rather than a quantitative analysis.

4.2.2 Summary from non-participatory observations

Observations did not take place during the workshops or the discussion meetings where the estimation processes were carried out in the case study organization. However, during the time spent carrying out the research, it was observed that project managers tend to focus on the similarities in the scope of the projects rather than in the project type itself. They also do not look for similar projects in terms of complexity without regarding their content. The similarities in the scope are used by PMs for determining a set of completed projects that can be used as meaningful reference when a new project is estimated.

4.2.3 Interviews

Before discussing the results obtained from the interviews, it is convenient to make explicit how the theoretical findings, the archival analysis and the non-participatory observations motivated the interview questions that were asked to answer the research question of this chapter: **How are the project front-end estimations currently made and by whom?** This was already depicted in the Methodology process of Figure 5.

This section presents the design process behind the interview questions pertaining to this chapter together with a summary of the findings obtained after the interviews.

4.2.3.1 Design of interview questions

It is convenient to recall the rationale behind RQ1 so that the purpose of the interview questions related to this RQ become immediately clear. RQ1 aims to explore how estimations are currently done, **the estimation methods that are used** and **the actors** involved and when in the process they participate. The first interview question aims to determine which of the estimation methods presented in section 4.1.3 are used in reality and also see how the estimation process described in literature (section 4.1.5) links to the case study organization when looking at it from different levels. This interview question also aims to determine which of the actors found in literature (section 4.1.6) are the most active and where in the estimation process do they participate. By looking at these aspects in a real scenario, it becomes possible to (1) make a comparison between the theoretical and the empirical findings and start building some arguments for (2) answering the MRQ (how to improve the quality of estimations) and RQ3 (what obstacles are there and how to overcome them).

It is wise to clarify something about the style of the first interview question. At first sight, the reader may be tempted to think this is a hypothetical question and not a behavioral question; however this is not the case. When the respondent is asked to answer this question as if he had to tell it to a colleague coming from another BU, he is being provided a context from which to answer the question. Literature suggests that "providing a context […] can help the interviewee hone in on relevant responses. A helpful context provides cues about the level at which a response is expected" (Patton, 2002, p. 367). When asked to answer the question from this perspective, it is expected that the respondent will provide extra insights (than he normally would) as he has to make sure someone coming from another BU in the organization would understand his answer.

Aside from the process and the actors involved, it is also interesting to identify what tangible means are used to support the estimation activities and when they are used in the process. This leads to the second interview question. Although there is some relationship between this interview question and the RQ2 (knowledge sources used) this interview question is presented here so that the tangible means that support estimation can be linked to the step of the process where they are used. Needless to say, the findings from this question are also discussed in chapter 5 (RQ2).

Moving onto another aspect of estimation, literature suggests that there can be some reconciliation between the estimates and the baseline (see step 4 in Figure 14, section 4.1.5); meaning that estimations can occur at different points in time during the project. Developing some understanding on the frequency and the similarity of the (potential different) estimations yields to the interview questions 3 and 4.

The following table summarizes the interview questions and the rationale discussed above.

Research question	Interview questions	Rationale behind the question
How are the project front-end estimations currently made and by whom?	1. If you had to explain it to a fellow project manager of another division of the Imaging Systems business unit, how would you describe the project estimation process at the level of PMO? That is, could you draw a flow chart and highlight the main actors involved in each step and briefly point out their responsibilities?	Identify the estimation process and its steps from a practical perspective in the context of a healthcare imaging systems organization
	2. Are there any tools, (excel) forms, etc that you use during this process? If so, could you indicate roughly, how are these tools used in the process of estimation?	Identify what tangible means are used to support this process
	3. Is estimation a one-shot procedure during the project life cycle and why? (i.e. is estimation only carried out at the beginning of the project?). 4. Can you indicate the main differences between the project initial estimation and other subsequent estimations carried out during the project life cycle, if any?	Determine the frequency of estimations and the similarities/differences of the different estimations carried out at different points in time during the lifetime of a project

Table 5: Interview questions related to RQ1

4.2.3.2 Summary of Interview with Head of the PMO in The Netherlands

Now the first interview is presented. In the next two sections, the thoughts of the Project Manager and the Integration Project Leader are introduced.

The estimation process from the perspective of the HPMO is depicted in Figure 16. According to this respondent, the time between step 1 and the completion of step 4 can be up to 2 months.

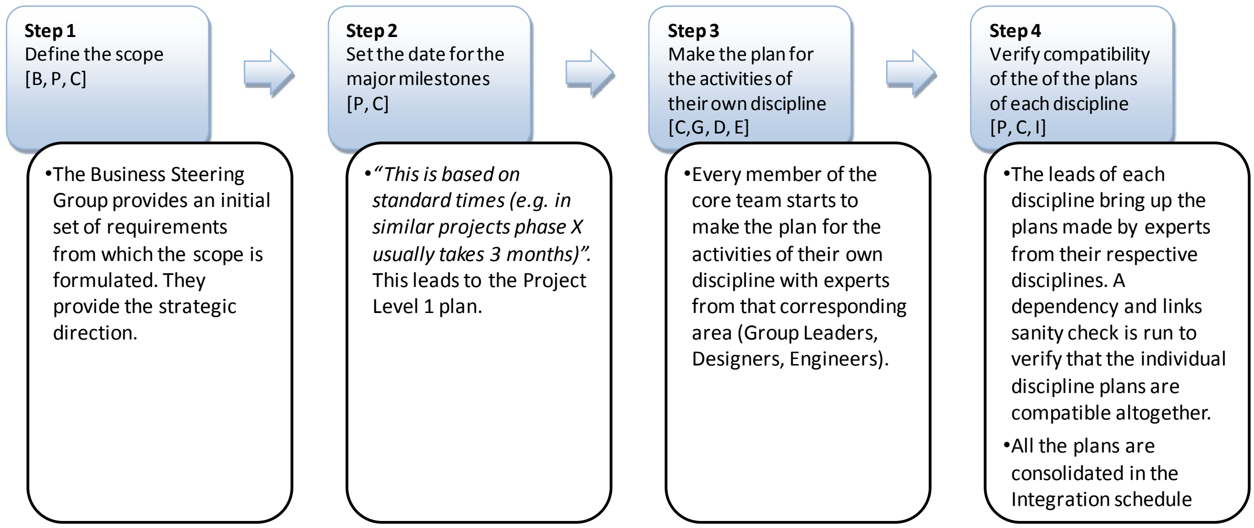

Figure 16: Front-estimation steps and actors involved according to the Head of the PMO of the organization in The Netherlands. Actors: B: Business Steering Group, C: Core Team members, D: Designers, E: Engineers, G: Group Leaders, I: Integration Project Leader, P: Project Manager

The view of this respondent is more focused on the processes that occur at the PMO level. This respondent indicated that *"the 'leads' of each discipline bring up the plans made by staff from their disciplines to verify that it is feasible as a whole for all the different groups".*

In the step 2, the Project level-1 plan (master plan) is elaborated. The Integration schedule on the contrary is build up at the end of step 4. According to the HPMO, the integration plan is *"where the heart of the development activity is planned"*. Moreover *"[the integration plan] drives the master schedule of the project"*. The respondent stated that the integration schedule is maintained by the Integration Project Leaders.

The WBS (Work Breakdown Structure) is also elaborated within the activities of the step 3. The respondent pointed out that *"re-estimation is a bit situational; it occurs on a need basis depending on the amount of deviation between the actual and the last estimate"*. He also mentioned that *"the [project] 'actual' is cross checked with the last estimates on a weekly basis"*. According to the HPMO *"the Estimation and re-estimation processes are basically the same"*.

4.2.3.3 Summary of Interview with Project Manager

The second person interviewed was the Project Manager (PM). His view about the estimation process is portrayed in Figure 17.

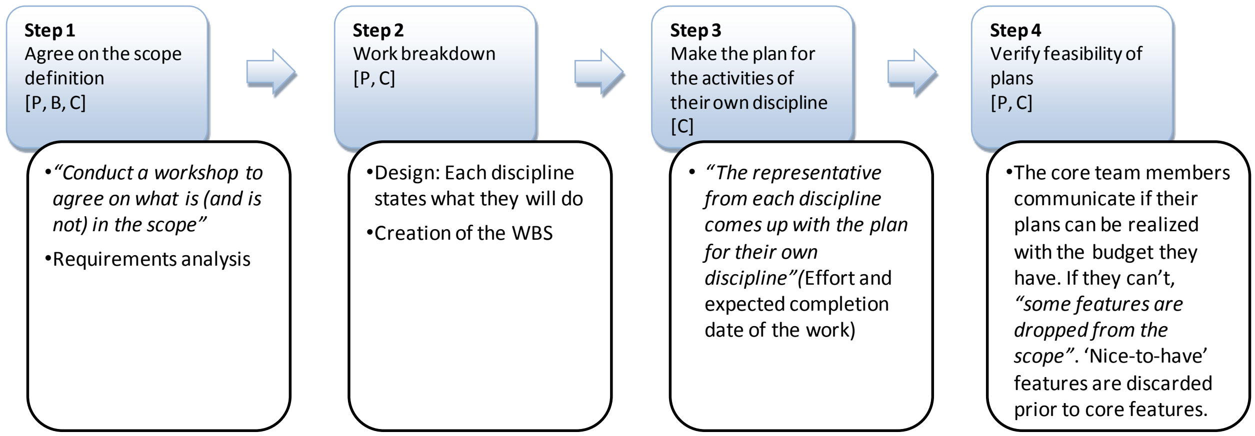

Figure 17: Front-estimation steps and actors involved according to one of the Project Managers of the BU. Actors: B: Business Steering Group, C: Core Team members, D: Designers, E: Engineers, G: Group Leaders, I: Integration Project Leader, P: Project Manager

According to the PM, the estimation and planning process are fed with two main inputs: *"The list of deliverables that need to be created"* and *"the content of the project itself"*. The content (scope) of the project is used to make a list of previous projects which are similar to the new project to be estimated.

The PM indicated that *"The tasks' size, category (e.g. documentation, development, etc) are captured in the WBS form"*.

The respondent mentioned that the estimation process is iterative at this level. He also mentioned that the front-end estimation and subsequent estimations *"there is not a real difference. What is a little bit different is that as the project evolves, you have more information for your estimates… but process-wise is sort of the same"*.

4.2.3.4 Summary of Interview with Integration Project Leader

Finally, the perspective of the Integration Project Leader regarding RQ1 is presented. His view of the estimation process carried out in the organization at his level is represented in Figure 18.

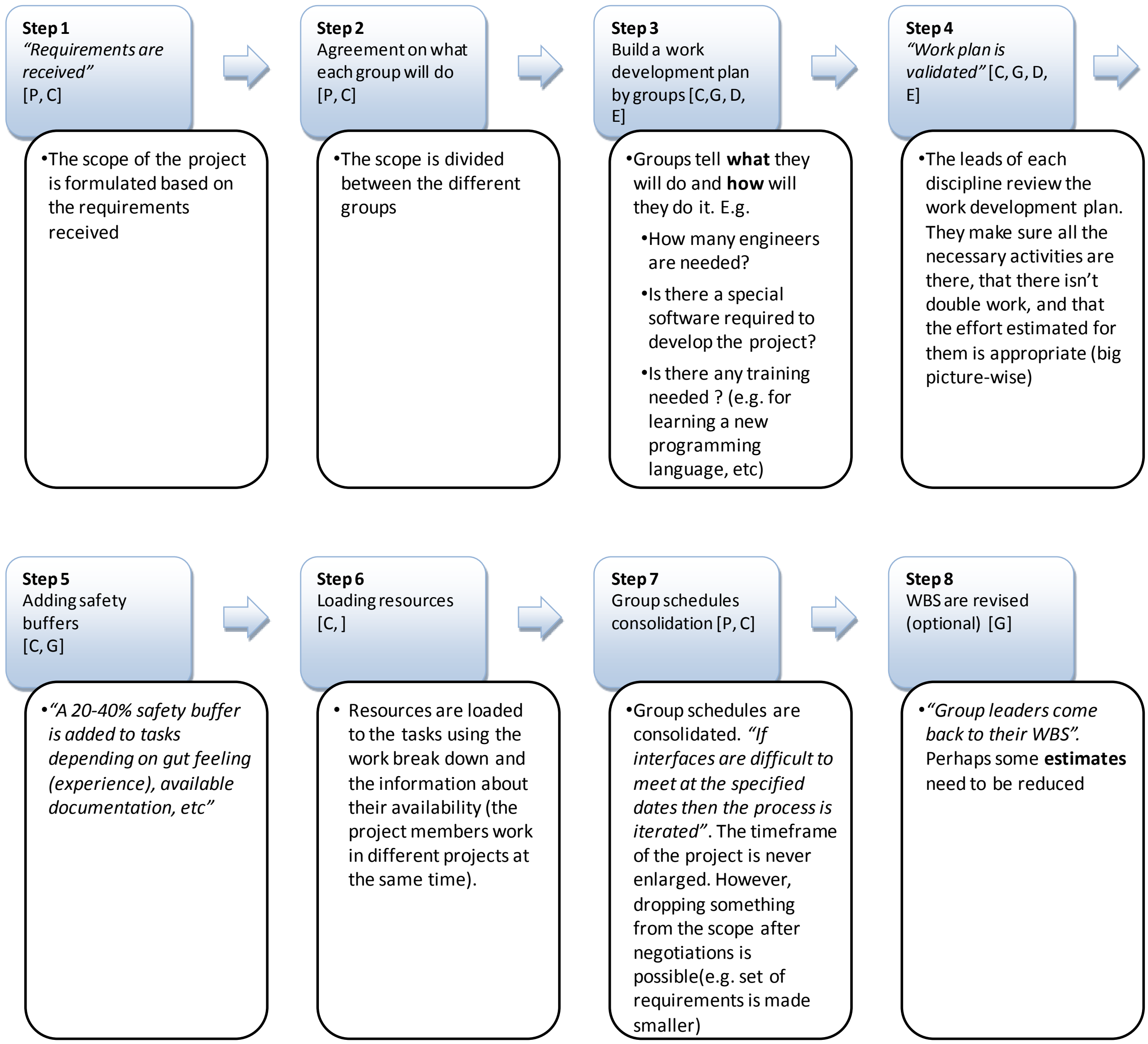

Figure 18: Front-estimation steps and actors involved according to one of the Integration Project Leaders of the BU. Actors: B: Business Steering Group, C: Core Team members, D: Designers, E: Engineers, G: Group Leaders, I: Integration Project Leader, P: Project Manager

The groups that work on the project carry out their estimates and then this information is reported back to the project core team. At this level, effort (and not cost) is estimated. Development and integration effort are estimated and planned within groups. Effort is translated to cost when the estimates reach a higher organizational level (e.g. Project Manager).

Due to the amount of activities that occur in step 3, it is worth looking at it more in detail. The work is broken down in this step and the WBS forms are used to capture the corresponding information. The respondent mentioned that *"[…] ideally they should be updated as the project progresses, but that is not the case"*. The IPL mentioned that estimations are done by *"involving experts in estimation"*. They are asked to *"[…] to provide estimates for the tasks in the WBS"* based on their experience. There are two ways to do this: have group discussions and then reach a collective agreement or ask them to do it *"in isolation and then average [their estimates] out"*. Once this is done, experts are challenged to review each other's estimates paying special attention to those tasks where there are large discrepancies in the effort estimated.

After step 8, the project is ready to pass the milestone where the estimates are committed and base lined.

The respondent mentioned that *"from the development part, during execution we don't look anymore at our development estimates"*, that is, estimation is a one-off process at this level.

4.3 Results discussion and conciliation with theory

Due to time restrictions only three people were interviewed, the internal validity is limited and results can hardly be generalized. Still the results provide interesting insights as explained below.

Having complex estimation methods in place is not a precondition for achieving estimations. From the interviews it can be seen that only a few estimation methods are used in the context of the case study organization and yet the company has a demonstrable track of successful[10] projects.

From the interviews, it was observed that both estimation strategies are used in estimations: top-down and bottom-up. When the scope and the budget are split between the groups involved in the project, a top-down approach is used. Then each group carries out bottom-up estimations separately and uses them to build their work plan. At the end some conciliation occurs when the group schedules are consolidated. This finding is also consistent with the findings presented in Table 4 about the preferred methods of personnel in planning support functions, senior roles and junior roles. At junior (development) roles, bottom-up estimation is used because they need to justify the estimates to senior managers while at senior roles and planning roles, a top-down approach is preferred.

Concerning the estimation process itself, it is interesting to see how the findings from the interviews fit into the general process outlined in the literature (section 4.1.5). When looking at empirical results, the reader might be inclined to think that there are discrepancies between the three different processes described by the interviewees, but instead, it was observed that the lower level estimations (IPL-level) fill in the 'placeholders' mentioned at a higher level (HPMO): *"the leads of each discipline bring up the plans made by staff from their disciplines to verify that it is feasible as a whole for all the different groups"*. They are not opposing views but complementary perspectives of the same process looked from different levels. This is aligned with the project planning levels concept presented in section 3.4 and furthermore it makes clear the direct link that exists between estimations and planning.

According to the interviews one estimation method used extensively is expert knowledge estimation. Another estimation method found in practice is estimation based on standard times. The HPMO mentioned that milestones targets were set based on standard times: *"e.g. for similar projects phase X*

[10] Success as defined in the conceptual framework section.

usually takes 3 months…", however he also acknowledges that *"historical data is not used quantitatively"*.

When looking at the major differences between the cost estimation process of Figure 14 and the findings obtained during the interviews, it can be seen that in the context of this industry, there is not an explicit relationship between risk quantification and estimation. None of the respondents mentioned anything about risks during this part of the interview.

Concerning the frequency of estimations, at the HPMO and PM level, re-estimation occurs when the variance between the actual and the baseline exceeds a given threshold. However, from the interviews it was noticed that re-estimations do not occur at all levels in the case study organization. This is further analyzed in the conclusions.

Regarding the representation of estimates, an attempt to use interval estimates was observed from the archival records analysis. However, although estimates are expressed in terms of ranges, the confidence level is omitted. Apparently the amount of effort required to express the estimates using the interval estimate representation surpasses the benefits obtained from doing so. It can also be observed that the data necessary to express estimates in this format are not available or that the required processes to do so are not yet in place.

With respect to the stakeholders involved, the observations did not add any further information to the findings collected via the archival records analysis and the interviews. The estimation process of the case study organization (Figure 15) defines the actors involved in the process; however this definition can be more precise. This is further elaborated in the conclusions at the end of the document.

Something important to mention about the estimation process found in the archival records of the organization is that the retrieval and selection of historical data needs to be defined further (see step 1, Figure 15). For instance, the document does not give any guidelines about the information sources that should be looked at; the metrics that should be extracted from these information sources; the frequency to update this information; or the specific person responsible for this. Other documents from the organization do define some metrics (like milestone slippage, or early supply involvement, among others) but unfortunately these metrics are not directly correlated with effort or lead time of projects.

Another important element which is discussed in literature to some extent but is not defined in the estimation process of the organization (see step 1, Figure 15) is the criteria to select historical data of former (similar) projects. Observations revealed that the project type and the project scope are two of the most important aspects that Project Managers look at when determining which previous projects to use as a basis to estimate a new project. This finding was confirmed during the interview with the PM. Some methods like CART and OSR account for filtering data according to certain rules. These methods are used in software projects mostly; however the same principle could be applied to data retrieved by other disciplines. For instance, hardware designers might have a rule that filters data according to the number of layers of a printed circuit board, or according to the type of signals routed in the board (analog/digital), or according to the number of nodes or number of connectors in a board, etc. At the project level, the rules for selecting similar projects can be based on the functionalities defined in the scope of the projects. For example, a rule could be the project type (advanced development / normal development), another rule could be the power of the radiation/signals produced by the device (high / medium / low), other rule could be type of signals captured (digital / analog), etc. The discipline-level rules and the project-level rules should be defined taking in consideration the input of at least the actors involved in estimations (i.e. those mentioned in the process diagram of Figure 15).

It was found that the project cost-drivers defined in literature (section 4.1.2.2) are too general for being of practical use when it comes to filtering projects for estimation purposes according to their similarity. The set of cost drivers is comprehensive but it is very high-level. The projects in the healthcare imaging systems industry are far too complex and involve the participation of many different disciplines and more discipline-specific set of rules (like those mentioned as example in the paragraph above) are advised.

Nevertheless, refining the processes for retrieving and selecting historical data is only part of the improvement opportunities found in the case study organization. The core of the process of Figure 15 occurs in step 4 – 'Estimate size and effort'. The process does not define which estimation methods to use neither at the project level nor at the discipline level or at the task level. If historical data had been available and the process/rules for filtering it had been defined (see step 1, Figure 15), then historical data could have been used to cross check the estimates based on effort knowledge.

If historical data was readily available at the PMO level, a top-down strategy in combination with estimation based on standard times could be used. The ratio between the effort spent by phase and during the whole project can be calculated. Depending on the amount of data available, an interval estimate for the effort and lead time per phase and per project could be calculated using descriptive statistics (e.g. the mean and the standard deviation). The data obtained via this approach would help to cross check the project's 'ball-park' estimate obtained through expert knowledge.

Now, if historical data, sizing attributes and filtering rules were available for every discipline, a different approach should be taken. Taking into consideration the information obtained from the interviews and the estimations in similar industries and single-discipline projects (section 4.1.6), a combination of a bottom-up strategy together with statistical regression analysis is suggested. For the software projects in particular, function point analysis can be used if the software development team standardizes the functional features seen by the user and the timesheet system is modified so that the hours spent in software development/testing/integration can be traced back to the functional feature they correspond. An alternative would be to size the software effort based on LOC, however the organization should take into account the language and version of the language used, the expertise of the person who wrote the software (perhaps by defining an experts classification scheme) and defining what is considered as an LOC and sticking to this definition for all the statistical analysis.

The two approaches to use historical data (at the PMO-level and at the discipline-level) proposed above are not mutually exclusive. On the contrary, the case study organization is encouraged to use them in a complementary manner to support the estimates developed using expert knowledge.

5 Knowledge sources used and not used in estimation

This chapter provides an answer to the second research question: **What knowledge sources can be used in the process of estimations?** The chapter presents some relevant theory around this RQ, followed by the empirical findings and some relevant discussion and conciliation between theory and empirics.

5.1 Relevant Theory

The theory relevant to the discussions of this chapter is limited only to the sources of information used when doing front-end estimations.

The organizational information sources found in literature were grouped in 6 categories. The categories were defined by the author of this document based on the four sources reviewed. The categories and the knowledge sources are listed in the Table 6.

Category	Details / Information sources
Project files	• Scope, cost, schedule, and quality baselines [P] • Work breakdown structure (WBS) [SA] • Performance measurement baselines [P] • Project calendars [P] • Project schedule [P] • Network diagrams [P] • Risk registers [P] • Planned response actions [P] • Timesheets (a.k.a. labor hours) [P] • Design information [SA]
Issue and defect management database	• Issue and defect status [P] • Control information [P] • Issue and defect resolution [P] • Action item results [P]
Configuration management knowledge base	Contains the versions and baselines of all official company standards, policies, procedures, and any project documents [P]
Financial database	Contains information such as: • Budgets [P] • Any project cost overruns [P] • Inflation indices [S] • General inflation forecasts [S] • Recent quotes for main plant items [S] • Hourly rates [S] • Productivity rates [S] • Overheads [S] • Material costs [S]
Market factors	• Market trends (e.g. competition for resources, new technologies that may impact unit costs) [S]

Category	Details / Information sources
Others	• Historical unit rates for similar work items [S] • Expert's knowledge. E.g. ▪ Input from different project disciplines (e.g. planners, roadway, structures, right-of-way, real estate utilities, environment and construction) [A] ▪ Input from external parties (Metropolitan Planning Organizations, environmental organization, local agencies, the public) [A]

Table 6: Summary of information sources for estimations. Sources: [P] (PMI, 2008, p. 33), [S](Smith, 1995), [SA] (Saunders, 1990), [A] (Anderson, Molenaar, & Schexnayder, 2007)

Some mention the use of explicit knowledge sources in estimations however they do not specify in detail what particular reports/documents can be used. Saunders stated that cost estimates come from parameters such as: The Work Breakdown Structure of the project (WBS), Design information and Historical models (Saunders, 1990). Historical models take many forms, for instance mathematical equations such as regression or isoquants (equal cost and benefit lines).

Estimators are encouraged to use several information sources whenever possible and estimates should be obtained using more than one method and then cross-checked (Saunders, 1990, p. 47; McDermid, 1991, pp. 27-5; Jørgensen, 2004, p. 51).

5.2 Empirics

The methods for collecting empirical data for the research question of this chapter were to conduct non-participatory observations and to carry out structured interviews to relevant personnel. The information collected is summarized in this section.

5.2.1 Summary from non-participatory observations

From the observations it was seen that timesheet reports and project monthly reports are commonly used to develop a 'ball-park figure' of the effort and lead time associated to a new project. The author of this research had the opportunity to accompany one of the project managers while he was developing the estimations for a new project. This person used the project monthly reports to extract information about the milestone dates and determine the total lead time. He also used the milestone dates to determine how the effort spent in the project was split between the project phases.

In addition to this, it was noticed that even within the same organization, **there are different ways to document processes and codify information**. For example, even though there is a standardized way to break down the work of a project, it is up to the group leaders to define the task-level structure used to book time to the project. Different levels of granularity were observed at this level in the project plans. Another example is the different standard used to report old projects and new projects. Some new milestone names appeared, others changed names and the meaning of some of them also changed. Backwards compatibility to compare the projects was not easily attainable.

5.2.2 Interviews

Similarly to how it was done in chapter 4, this section presents the rationale behind the interview questions that correspond to the research question developed in this chapter: **What knowledge sources are used in the process of estimations and to what extent?** After the interview questions are introduced, the results obtained from the interviews are summarized.

5.2.2.1 DESIGN OF INTERVIEW QUESTIONS

From the literature (section 5.1) it was seen that many different information sources can be used when doing estimation and planning. Getting to know which of these information sources are used in a real scenario can provide some indications as to which information sources are the most valuable and why and at the same time which ones are not used. It is also interesting to see how often are these information sources updated to determine the relative effort required to keep them up to date. This yields to interview questions 5, 6 and 7.

By discussing some of the information sources that could be used but are not currently used, it is expected to identify and overcome some roadblocks in the path of estimations and therefore achieve more improvements. This leads to questions 8 and 9.

Finally, it is also interesting to determine the awareness of the interviewees regarding the information sources available at their disposal. Question 10 (unlike question 8) aims to do this by asking the respondents which sources they would use not only based on their memory but when shown the list of Table 6.

The following table presents the interview questions that correspond to the discussion above together with a summary of the rationale behind them.

Research question	Interview questions	Rationale behind the question
What knowledge sources can be used in the process of estimations and to what extent?	5. What specific knowledge sources are used in project estimations? (hint: you may think on historical data sources (i.e. what specific documents) and also on people's knowledge (i.e. what particular knowledge exactly and from whom)). 6. Which ones are the 3 more important knowledge sources for estimations and why is this so? 7. For the items mentioned in the question below, how often are they updated?	Identify the (primary) knowledge sources that are used in the estimation process and the frequency to which they are updated. Identify potential difficulties in estimation due to information sources that become out of date relatively fast or due to other reasons.
	8. Could you identify some knowledge sources that are not used during the initial estimations and briefly indicate the reason of this?	Determine what other knowledge sources are good candidates for being used in the process of estimation
	9. What has to be done to use them?	Identify potential difficulties in estimation due to obstacles associated to the use of information sources

Research question	Interview questions	Rationale behind the question
	10. Take a look at the Table 6 (provided to the interviewee during the interview only) and name 3 other knowledge sources which you would use and please explain why.	Determine what other information sources could be used for estimations besides those used in the organization and those remembered by the interviewee.

Table 7: Interview questions related to RQ2

For each respondent, first the information sources that are used are mentioned, then the information sources that are available but are not used follow. Finally, the information sources that the respondents would like to use after being shown Table 6 are presented.

5.2.2.2 Summary of Interview with Head of the PMO in The Netherlands

As in the previous chapter, the first view that is presented is the one provided by the HPMO followed by the perspective of the PM and the IPL in the next two sections. The HPMO indicated that two major sources are used for estimation, namely (1) expert's knowledge from comparable projects and (2) WBS' from previous similar projects. At this organizational level it is not known how often these sources are updated.

The respondent mentioned that there are two concepts within the knowledge from experts which are particularly important when doing estimations: (1) how complex the current (new) project is compared to those done in the past? and (2) *"who did it before and who is going to do it this time?"* (in terms of relative level of experience).

The most useful information from the WBS is the size estimates from previous projects. Each discipline has a specific set of attributes they use for describing the size of their part of the project (e.g. # of hours, # of pages, # of LOC, # of components, etc). When these figures are not available then this is done in a brainstorm session with several experts.

The respondent also mentioned some sources which do exist at the moment but that are not being used for estimations. He indicated that ***"historical data is not used quantitatively"*** (except for example for estimating the average time it takes to solve a problem). The HPMO also mentioned that ***"External knowledge*** *[…] is not used either"* because there is a belief that the work within the BU is unique.

After being showed the Table 6 during the interview, the respondent mentioned that it would be potentially beneficial to use **performance measurements baselines** because *"it lets you know how relatively good you are doing what you are doing"*. He would also like to use the **risk registers** because there is a tendency to be relatively optimistic in projects and sometimes risks are underestimated or not taken into account. He pointed out that risk registers could be useful for identifying technical risks mostly. This person would also like to use **historical data coming from previous WBS** more intensively.

5.2.2.3 Summary of Interview with Project Manager

The next interviewee after the HPMO was the PM. This person indicated that four information sources are used mainly: (1) the WBS forms from previous projects, (2) expert knowledge, (3) project schedules from previous projects and (4) scope of similar projects. In the view of this person *"around 80% of the information comes from people's expertise and only in 20% of cases people look at historical data"*. Project schedules from previous projects and scope of similar projects are used to a lesser extent.

On the contrary, timesheets information and evaluation reports from previous projects could be used but are not currently used. This person mentioned that in order to use them, three things need to occur. First, it is necessary *"[…] to accept that there is a similarity between the current project and others done in the past"*. Second, *"data [should be kept] […] at a central place and [be] maintained by someone"*. Last but not least, it is necessary for the organization to *"recognize that it takes time to work on proper estimates"*.

When this respondent was shown Table 6, he said that he would like to use **risk registers**, **timesheets** *"but on a deeper level of detail"* and information about *"how much budget has been set for each individual phase of previous similar projects"*.

5.2.2.4 Summary of Interview with Integration Project Leader

Finally, the response to the interview questions related to RQ2 as expressed by the IPL is presented. The IPL mentioned that **expert knowledge** coming mainly from senior designers and engineers is used for estimations. He pointed out that *"at the PMO level, general historical data is useful [e.g. effort per phase] but for estimating at the group level more specific data is needed"*.

On the other hand, **productivity figures,** a form of historical data, could be used but are not used. For instance, the average time needed per LOC, solving a problem request, or conducting a given test could be useful. This respondent also mentioned that there is room for improving estimation practices by **learning from other BUs** but this is not done at the moment.

After observing the Table 6, the respondent pointed out that **risk registers** could be used**.** The IPL mentioned that this would enable to *"learn from the likelihood and impact (cost) of risks of previous projects"*. Doing so is difficult at the moment because the location of the documents where they are captured is not widely known within the organization. This person also indicated that he would like to use the **timesheets** of the personnel involved in the projects. Doing so is difficult because the task structure depends on the particular project manager or groups involved in the project.

5.3 Results discussion and conciliation with theory

In the opinion of the author of this research, there is a tendency to over-abuse of the term 'historical data' in literature. Many authors and experts use it, but actually they do not go in detail regarding what sort of historical data they mean exactly. The reason behind this might be that there is limited consistency in the ways to document processes and codify information as observed within the case study organization. Each organization might do this in a different way too which makes it difficult to define this term in detail.

Concerning the empirics, Table 8 summarizes the answers from the respondents. Results can hardly be generalized but still they provide interesting insights. Expert knowledge is the heart of information sources used for estimations. There are some issues regarding the WBS but these are left for the analysis in the next chapter as this information source is mentioned very often in the empirics of that chapter.

The results also show that there are some missed opportunities in the case study organization regarding the use of information sources. All the respondents stated that they would like to take into consideration the risk registers from previous projects. However, it stands out that the respondents only mentioned the risk registers after being showed the entire list (Table 6) in question 10 and not before. From this it can be said that risk registers do exist but the difficult access to them affects the awareness about their potential value among estimators in the case study organization. This also confirms the 'overoptimistic' behavior in estimations in the case study organization mentioned by HPMO.

A final conclusion obtained from the findings of this chapter is that overall, personnel in the organization do have an idea of the missed opportunities. For instance they all mentioned that they would like to use historical data (timesheets, risk registers, etc) but the organization have not done it yet. There is one or more roadblocks keeping the organization away from doing this. This is discussed in detail in the analysis at the end of the next chapter.

	Head of PMO	Project Manager	Integration project leader
Information sources used	• Expert knowledge • WBS	• Expert knowledge • WBS • Project schedules • Scope of similar projects	• Expert knowledge
Information sources available but not used	• Historical data • External knowledge	• Timesheets information • Evaluation reports from previous projects	• Productivity figures • External knowledge (Input from external parties e.g. other BUs)
Information sources that the respondent would like to use (after being showed Table 6)	• Performance measurements baselines • Risk registers • Use more historical data from previous WBS	• Risk registers • Timesheets (but in a more detailed level) • Historical data (total effort and budget per discipline and per phase)	• Risk registers • Timesheets

Table 8: Summary of information sources that can be used for estimations. Source: Interviews

6 MAIN OBSTACLES THAT HINDER ESTIMATIONS AND ALTERNATIVES TO SOLVE THEM

This chapter presents the relevant theory, empirical data and results discussion for the third and last research question: **What are the main factors that make difficult the practice of front-end estimation and how can they be overcome?** The chapter presents some relevant theory around this RQ, followed by the empirical findings and some relevant discussion and conciliation between theory and empirics.

6.1 RELEVANT THEORY

This section presents the following topics: factors that hinder high quality estimations, guidelines to improve the quality of estimations and some methodologies to improve organizational processes which can be applied to estimation processes.

6.1.1 OBSTACLES FOR GOOD ESTIMATIONS

This section presents the factors that impede good estimations according to literature. A large number of obstacles were found and it was necessary to categorize them to facilitate its analysis. Two categorization schemes where taken in consideration for grouping these obstacles (Lederer & Prasad, 1995, p. 131; Doloi, 2010, p. 10). The first one proposes 4 main categories: methodology, politics, user communication and management control. The second one brings forward a 5-category scheme: economic, political, financial, technical and attitudinal concerns. The categorization scheme proposed in this study takes elements from both. It is not meant to be universally comprehensive but it helps to structure the discussions that follow.

As a first approach, the obstacles can be divided between internal and external (with respect to the organization). Several sub-categories can be found within the internal sub group. Even with this classification scheme, a large number of obstacles fell into the methodological category. It was necessary to create a further classification within this group. The entire scheme is shown in Figure 19.

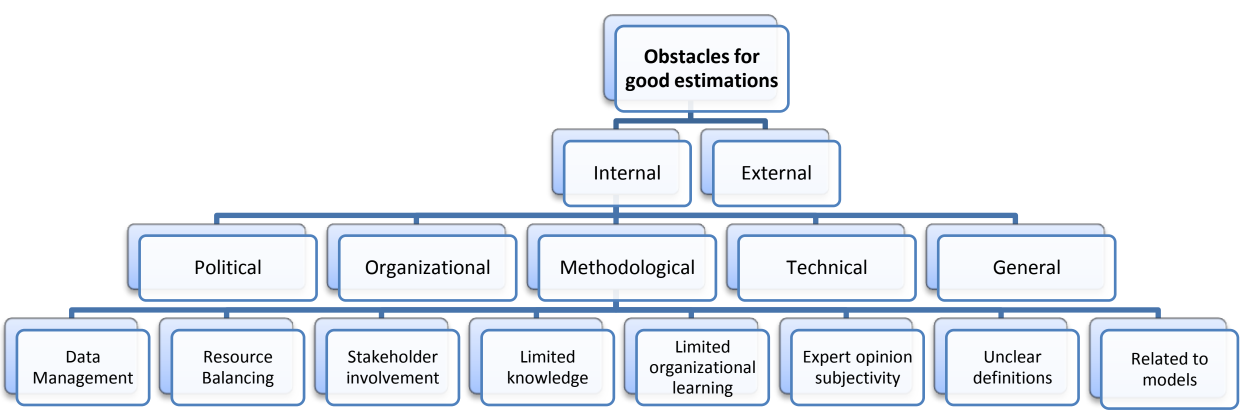

Figure 19: Categorization scheme for discussing the obstacles for good estimations

The following tables in this section present the most relevant obstacles found. The selection was made based on the applicability to the case study organization according to the information obtained through the empirics. The full-detail list of obstacles can be found in the Appendix 2. Table 9 presents the (summarized) difficulties that fall into the political and organizational categories.

Category	Obstacles
Political	• Project managers are asked to make early estimates without knowing the detailed requirements [C, MD p. 28/5] • Effort required to do credible estimates is underestimated. [A, D p. 1, H p.628, SO, MD p. 28/5]. • Pressures from managers, users or others to increase or reduce the estimate [L, H p. 628, LP p. 131]. Even when the cost estimate is done correctly, the senior management may determine that the costs are too high resulting in cost reductions without a corresponding reduction of the project scope [D p. 1, MD p. 28/5]
Organizational	• The project team members and their abilities may also be unknown [C, L] • Validity of data: Organizations, their processes, and their products may change over time [B p. 54, CU p.558] • Staff members do not comply with the estimating/tracking process due to lack of executive mandate [P] • Project customers do not understand their own requirements [D p. 13, L, LP p. 131] • Staff turnover, changes in the project team composition [L] • Once a project is finished, the group of people working together is dissolved and the project knowledge is fragmented [LI]

Table 9: Summary political and organization obstacles found when doing project estimation. Sources: [A] (Akintoye & Fitzgerald, 2000), [B] (Briand & Wieczorek, 2002, pp. 4, 32, 56-58), [BP] (Busby & Payne, 1999), [C] (Chatzoglou & Macaulay, 1996, pp. 175-177), [CA] (Carmichael, 2006),[CU] (Cuelenaere, van Genuchten, & Heemstra, 1987), [D] (Doloi, 2010), [H] (Heemstra, 1992), [HH] (Hihn & Habib-agahi, 1991), [J] (Jørgensen, 2004), [LI] (Lindner & Wald, 2010), [M] (McCulla, 1989), [MD] (McDermid, 1991), [SO] (Sonje, 2008), [L] (Lederer & Prasad, 1992, p. 54), [LI] (Liu & Zhu, 2007) , [LP] (Lederer & Prasad, 1995), [P] (PMI, 2008), [S] (Smith, 1995)

Now that the political and organizational problems were mentioned, the next table presents the difficulties concerning the methodology of estimations. The impediments found through the empirics only fell in 7 of the 8 subcategories depicted in Figure 19. The missing sub-category is 'Related to models'. The reason for this is that during the evolution of this research, the case study organization was still not using model-based methods or historical data to do their estimations.

Sub-Category	Methodological Obstacles
Data Management	• Very few companies have bothered to store previous project data in a way that can be used later [A, C, M, SO, L, CU, LI]. (See Appendix for details) • By definition, every project is unique [P p. 4, CA p. 97] • Data for estimation is captured in desktop spreadsheets or may exist in different information systems and is difficult to consolidate and analyze [P].
Resource Balancing	• Human resources availability during the project lifecycle is not taken in consideration [C]
Stakeholder involvement	• Lack of careful examination of the estimate by management [LP p. 131]
Limited knowledge	• Lack of knowledge on how to estimate and estimation techniques [B, SO, LI, H, A, J p. 40]. (See Appendix for details) • The estimator ignores the fact that a lot of work will be done by less experienced people, and junior staff with a lower productivity rate [H p. 628, MD p. 28/5] • Miss-representation of estimates: Though the output of resource models is often a single value, this is misleading as it falsely conveys an impression of high accuracy [H p. 637]. Point estimates

Sub-Category	Methodological Obstacles
	do not allow for proper risk management [B p. 56]
Limited organizational learning	• Estimators prefer not to compare outcomes with estimates because their estimating assumptions had been violated during the project. This prevents to learn from the outcome [BP p. 296] • Inability to tell where the previous estimates failed [L, LP p. 131]
Expert opinion subjectivity	• Individual expert's opinions can be biased by several factors [B p. 21]. (See Appendix for details) • Techniques based on expert opinion tend to be less repeatable [B p.32]
Unclear definitions	• Different definitions on measurement [S p. 17]

Table 10: Summary methodological obstacles found when doing project estimation. Sources: please refer to Table 9

Finally, the barriers found in the remaining categories (technical, communications, external and general) are presented in Table 11 below.

Category	Obstacles
Technical	• Productivity rates may increase over time due to learning from previous experience (learning curve). This can make historical data obsolete [CA, pp. 70-72]. • In software projects, the language in which the code is written is not taken into account [C]
General	• Poor or imprecise problem definition [L, LP p. 131]
External	• Variability in the time it takes to get approvals from third parties (e.g. government) [D p. 13] • Broad variability of sub-contractors / suppliers prices [A]

Table 11: Summary of technical, general and external obstacles found when doing project estimation. Sources: please refer to Table 9

6.1.2 Guidelines to improve the quality of estimations

Literature provides recommendations for overcoming the obstacles that make difficult to produce high quality estimations. A relationship between the recommendations and the categories outlined in section 6.1.1 was made. This provides some structure to present the large number of suggestions found in literature. The structure of this table is slightly different than those of section 6.1.1 because some recommendations apply to more than one category. Due to the large number of solutions, only a subset of them is presented in the body of this document. The criteria for filtering them were to maximize the number of categories to which they apply, the applicability to the case study organization based on the empirical findings, and include some guidelines which could be refuted.

The summarized list is presented in Table 12. For the extended list, please refer to Appendix 3. This section only presents the guidelines as the corresponding analysis about the applicability of these suggestions to the organization is located at the end of this chapter. The obstacles found in the case study organization are contrasted with literature and a link with the solutions (both theoretical and empirical) was made.

Recommendations to improve the quality of estimations according to literature	Political	Organizational	Methodological	Methodological*	Technical	Communication	External	General
‡ Separate the estimating function from the rest of development activities. This allows: (1) to shield the estimating function from potential political interference, (2) Specialize the role of the estimator, who then concentrates on building expertise in this area and (3) to gain consistency on subjective assessments [C p. 177, M p. 38].	x	x	x					
When groups are dispersed after a project and knowledge is not socialized/transferred, some mechanisms for knowledge capturing, storage and distribution could be put in place [LI]. Conduct workshops to share techniques between managers and estimators [HH p. 287].		x	x					
Adopt project postmortems as a practice (i.e. feedback on the estimates at the end of the project). They provide insights into managerial practices [HH p. 287, J p. 54]. Feedback should be provided comparing the estimates with the actual values and reasons for deviations should be analyzed [B p. 58]. Document the experience gained in the estimation of projects properly [D p. 2]		x	x	x				
Institutionalize a culture to educate project teams about estimation (techniques/tools) [SO p. 1-2]. Train your estimators [J p. 55]		x	x	x				
Once estimation is done, it should not be considered as sacrosanct. There should be provision to revise it if the circumstances under which it was prepared for the first time change. Estimate and re-estimate after every phase of the project life cycle (if necessary) [SO p. 1-2]	x		x					
Use historical data for estimations: Leverage lessons learned / best practices from documented engagements executed in the past [SO p. 1-2]. Build a databank with old project data to offer relevant information on old and comparable projects [CU p. 558]. Define metrics, collect them and develop databases [HH p. 287]. The use of documented data helps to overcome the problem of reliance on 'personal memory' [J p. 48]			x	x				
Assign the initial estimating task to the final developers [L p. 53]	x	x	x					
Management demonstrates commitment to meeting estimates. This signalizes to estimators that senior managers are concerned about creating an accurate estimate and meeting it [L p. 57]	x		x					
Management should **carefully** study and approve the cost estimate: Results support the belief that computing management approval increases estimating accuracy [L p. 58]	x		x					
Generate estimates using a triangulation of different methods [MD p. 27/5, BP p. 295, HH p. 287, J p. 49]. Estimates should be carried out using more than one technique and being cross-checked [S, p. 47]			x					
Develop, accept and use a uniform set of definitions and standards [H p. 638]. Define more formalized cost estimation processes [HH p. 287]. Use of estimation checklists [J p. 52]			x					
‡ High cost of data collection could be overcome by collaboration of organizations to form multi-organizational data sets [B p. 4]			x	x				
Consult people with broad (repeated) experience [BP p. 295]			x					
Using cost models as aide memoires, not as replacements for judgment [BP p. 295]			x	x				
Document the assumptions under which estimates are made [HH p. 287]			x					
Incorporate risk and uncertainty into the estimates [HH p. 287]			x					

Table 12: Summarized list of solutions to overcome obstacles in estimations.

Sources: [B] (Briand & Wieczorek, 2002), [BP] (Busby & Payne, 1999), [C] (Chatzoglou & Macaulay, 1996),[CU] (Cuelenaere, van Genuchten, & Heemstra, 1987), [D] (Doloi, 2010), [H] (Heemstra, 1992), [HH] (Hihn & Habib-agahi, 1991), [J] (Jørgensen, 2004), [L] (Lederer & Prasad, 1992),[LI] (Lindner & Wald, 2010), [M] (McCulla, 1989), [MD] (McDermid, 1991), [S] (Saunders, 1990), [SO] (Sonje, 2008). * = Methodology recommendations for model-based estimation methods

‡ = Not applicable to the case study organization (please refer to the conclusions for discussion)

Remark about Table 12: Please note that the relationship between the recommendations listed above and the obstacle category they contribute to (political, organizational, methodological, etc) is only a representation from the self-understanding of the author of this research based on the different grouping schemes found in literature (Lederer & Prasad, 1995, p. 131; Doloi, 2010, p. 10). Except for these two publications, the literature found does not provide a categorization scheme to divide the obstacles nor a classification of the recommendations in any categorization scheme.

6.1.3 Standardization and process improvement methodologies

Section 6.1.2 mentions the use of standards as an alternative to improve the quality of estimations. It is relevant then to mention some of the process improvement frameworks currently available and list a few examples of success in organizations where they have been used.

Typical examples of these frameworks are for instance the ISO 9000 (Requirements for Quality management systems) (International Organization for Standardization, 2000) or process improvement models such as the CMMI (Capability Maturity Model Integration) (Carnegie Mellon University).

Recent studies have concluded that the implementation of these methodologies has a positive effect in the firm's performance (Koc, 2007; Beattie & Sohal, 2009). For instance the implementation of the CMMI model brought significant benefits across companies from different sectors such as Accenture, Boeing Australia, Lockheed Martin, among others (Goldenson & Gibson, 2003). These are just two examples that show the benefits of the implementation of these methodologies in the industry.

6.2 Empirics

Now that the theoretical findings were presented, the empirical findings follow. The data corresponding to the research question of this chapter was collected by means of Archival records analysis, non-participatory observations and interviews. These findings are summarized in the sections below.

6.2.1 Archival records analysis

The author of this research had access to two explicit information sources in the case study organization: timesheet reports and project monthly reports.

In general, a main obstacle comes from the fact that some information with high potential to improve estimations resides in different documents and often comes in different formats. This poses two main difficulties. First, in order to extract the full value from it, information needs to be processed and re-combined and this takes a significant amount of effort. In second place, there are slight inconsistencies across different documents as they are maintained by different people (e.g. slight variance in the dates of milestones, some hours booked before the project has started and after the project was delivered).

Concerning the timesheets, these documents are often generated in a yearly basis, and it is necessary to combine the data from several years to extract the information corresponding to a single project. Also, departments and projects are often represented by codes instead of names. This information is sometimes spread across the organization making the processing of this data a time-consuming process.

With respect to the project's monthly reports, some difficulties were found as well. Organizational changes render data out of date. For instance, it was found that the meaning and the naming standard of the milestones were recently changed. There were some differences between the information coming from documents from old projects (previous standard) and those from newer projects. This issue needs to be managed in order to use the existing data.

However, from the findings above, it can also be seen that the organization has recorded information with significant potential to improve the quality of estimations such as project schedules (containing milestone dates), timesheet reports and project monthly reports over a significant period of time (about 5-6 years). Even the fact that there are different standards for defining the milestones means that still internal procedures to ensure the consistency of data across projects were in place; this is positive and enables the extraction of valuable information to improve estimations even if some data re-conversion is needed.

6.2.2 Summary from non-participatory observations

One of the obstacles observed is the fact that estimating is difficult because the scope of the projects can be sensitive to external unexpected events. For example, new governmental regulations appear suddenly and mandate changes in the scope of the project to comply with the new regulations. Another common cause for changes in the scope is unexpected moves from competitors (e.g. releasing a competing product earlier than previously announced). The likelihood that these events occur while a project is in progress is high as the length of the project life-cycle in this specific industry is typically 2+ years.

Another obstacle which poses considerable difficulty, especially when estimating based on historical data, are projects that are 'stopped' and are 'absorbed' by a bigger one. The milestones take a different meaning in this context and the effort spent in the absorbed and the merged project should be analyzed with extra care.

An additional factor that hinders estimation is related to the fact that input is needed from experts and they have limited availability. Even when historical data exists, some advice is needed from experts to decide how to process this data and make it readily usable (e.g. defining what sort of reports would be useful to generate and what their content should be). Even when there is someone fully dedicated to do the time-intensive tasks, the input from these individuals is also needed and by definition their time is significantly limited.

During this research, the organization appointed a team to drive the improvements of estimation practices in the BU. At the moment of concluding the observations of this study, the team was still in an early phase of their endeavor, however it was observed that a significant amount of effort was required to locate, process and transform historical data into useful and ready-to-use information for estimations. It was also observed that this effort is often underestimated both by senior managers and by the members of the team itself. As a first approach, this team proposed to the organization that estimation processes should be standardized but suggested that every discipline involved in the projects should have the authority to define the processes to select the data to be recorded and maintain it as well as deciding how often the data should be updated. The rationale behind it is that when estimation is done at the discipline level, the knowledge to estimate usually resides within the experts belonging to that discipline and not in a coordinating/monitoring discipline like PMO. As a matter of fact, the team was composed by a representative from each one of the different disciplines involved in the projects of this organization.

6.2.3 Interviews

Again, before discussing the results obtained from the interviews, it is convenient to make explicit how the theoretical findings, the archival analysis and the non-participatory observations motivated the interview questions that were asked to answer the research question of this chapter (RQ3): **What are the main factors that make difficult the practice of front-end estimation and how can they be overcome?** This flow of information is depicted in the Methodology process of Figure 5.

This section presents the design process behind the interview questions related to the RQ of this chapter together with a summary of the findings obtained after the interviews.

6.2.3.1 Design of interview questions

Even though the RQ of this chapter is more directly connected to the main research question than the other RQs, the other two were necessary to build up some context and background that allowed a deeper understanding and analysis.

From the literature, a long set of obstacles was found (see section 6.1.1). The list was broken down in several major categories and sub-categories (please refer to Figure 19). From the observations related to RQ2 (section 5.2.1), some methodological difficulties were perceived (e.g. limited knowledge of how to handle the historical data of projects that are stopped and absorbed by a bigger one, or managing the backward compatibility of information when new standards redefine for instance the meaning and naming of milestones). Also some organizational barriers were noticed (e.g. difficult access to experts). It made sense to use the opinion from the interviewees to validate these observations. This is why the interviewees were asked to provide the most important obstacles in estimations according to their experience leading to interview question 11. It must be pointed out that this question was partially answered via the answers of the interview questions corresponding to RQ1 and RQ2.

Something similar occurred with the strategies to overcome estimation obstacles. The interviewees were given freedom to provide spontaneous solutions instead of leading the answer and asking them for strategies that would fall in particular categories. This is crystallized in question 12.

The following table summarizes the interview questions introduced above together with the rationale behind them.

Research question	Interview questions	Rationale behind the question
What are the main factors that make difficult the practice of front-end estimation and how can they be overcome?	11. From your experience, what are the most important factors that hinder the initial estimation process? (please state the 5 most important ones)	Determine what are the most important factors that hinder the estimation process
	12. What are your strategies to deal with these difficulties? (for the 5 obstacles that you identified and if possible for the others too)	Identify potential strategies to cope with the factors that add difficulty to estimations.

Table 13: Interview questions related to RQ3

6.2.3.2 Summary of Interview with Head of the PMO in The Netherlands

Continuing with the same line of discussion, the response of the HPMO to the RQ3 is presented first, then the views of the PM and the IPL follow.

Concerning obstacles when doing estimations, the HPMO mentioned that *"it is difficult to come up with meaningful size attributes to estimate the effort spent in a specific activity"*. He argues that some attributes like number of lines of code are not a 100% accurate as they not always drive the effort required to write software. He also indicated that *"[the] amount of effort depends on who actually carries out the task"*. He stated that the expertise of the person has a direct impact on the time it takes to complete an activity.

This person revealed that there are also some factors that make it difficult to learn from other Business Units in the company. He said that *"Inter BUs learning is difficult because they sometimes come up with templates or procedures that are very specific to what they do and cannot be easily mapped to what we do"*.

On the other hand, there are some difficulties from the risk management perspective too. This person mentioned that *"people tend to be overoptimistic […]"* and also that *"they don't take the proper risks into account"*.

The HPMO acknowledged the fact that there are multiple factors next to the technical difficulty; unfortunately, he did not mention them explicitly during the interview. The last barrier he mentioned is that effort for some standard units of work is not really standard. For instance, the effort it takes to solve a problem report is not standard but still in some estimations it is accounted as if it was.

Moving onto the solutions proposed by the HPMO to improve estimations, he mentioned that it would help to have a checklist to verify estimations. He also recognized the value to document the aspects on which plans are based. He also suggested that peer reviews could improve estimations, he said that employees should ask others *"[…] what their basis for their estimations are"* and to *"reflect on them"*. Finally he suggested that an opportunity to improve also lays in *"[estimating] based on factual data"* as the organization fully relies on expert knowledge estimation at the moment.

6.2.3.3 Summary of Interview with Project Manager

The second perspective which is presented is the one of the PM. According to this respondent, one of the main obstacles when doing estimations is the fact that the *"initial project scope is extended during the project life-cycle"* after carrying out the front-end estimations. He also mentioned that *"timesheets cannot be used easily because the tasks against which time is booked are created and thought out by the project manager or group leaders"*. He explained that there is not a standard for this and it makes difficult to compare data of different projects at the task level.

Concerning the personnel turn over in the organization, the PM, said that the fact that *"the time people stay in a given role is limited (e.g. every 2-3 years group leader roles are switched)"* combined with a limited 'knowledge handover' process between the predecessor and the successor adds to the difficulty of estimations. This respondent mentioned that a possible solution for this would be to *"agree on general definitions so that when people switches positions there is a standard set of estimation procedures they can adopt"*.

The PM also acknowledged the fact that estimations are somewhat unlinked to the expertise and the productivity of individuals. In connection to this he indicated that the *"estimator has greater experience than [the] implementer, but his estimate is based on his personal productivity figures"*. He also mentioned that there is an unrealistic feeling about the effective working capacity of individuals as sometimes the amount of time needed for meetings, helping others, answering emails and so on is neglected when calculating the effective working capacity of individuals.

In relation to the use of historical data, the PM pointed out that *"estimations are 'out of the heart' and are not deduced*". This links to what he mentioned in a question from the previous chapter about the ratio between information that comes from people's expertise vs. information coming from historical data repositories. In connection with this, the PM suggested to *"build up own historical database"* and as a first approach at the PMO level to *"break down the effort of previous similar projects per phase and per discipline to give an indication of how much the current project could cost"*.

Similarly to the HPMO, this respondent also mentioned that *"there isn't enough room to discuss or review estimates with others"*.

6.2.3.4 Summary of Interview with Integration Project Leader

After introducing the view of the HPMO and the PM, the perception of the IPL is presented. This respondent gave several comments concerning the use of historical data to do or to improve estimations. He indicated that the *"organization is very good at producing data but not very good at doing something with it"*. In this respect, he says that there is a lot of potential in this stored information but the processes for processing this data and improving estimations with it are not in place yet. The IPL also pointed out that in some disciplines the historical data available is limited. He stated that even though there is some historical data already, *"the historical data has not been stored for long enough time"*. The limitedness of historical data makes it difficult for instance to determine how big the safety buffers for tasks should be.

From the IPL it was known also that there is limited awareness within the organization whether or not certain data exists or where it resides. For instance, *"risk registers exist but their location are unknown"*.

This person confirmed that in some instances there is limited consistency in the production of historical data. For example, *"[the] use of WBS templates is up to the group leaders. At the end is the problem of the group leader how does he/she does the estimation"*. Also, he indicated that some information sources are not updated after the front-end estimations are concluded, for instance the WBS templates are not updated during the progress of the project after the estimation has been base-lined. In addition to this, the structure of the time booking system is not standard across projects and it changes every year. Furthermore, he also points out how the effects of personnel turnover add extra difficulty. He said that *"group leaders are in that position only for a few years"* and *"if there are no standard procedures or templates, it becomes very difficult to use existing historical data"*. All this contributes to the difficulty to predict the effort at the task level and doing an evaluation of projects afterwards.

The interview with the IPL also identified impediments in other areas. For instance, *"the organization does not encourage doing estimation based on historical data"*. This respondent mentioned that *"doing good estimates and updating the data to do them takes time but there is significant time pressure and insufficient time to do this"*. This lack of time also prevents individuals to learn from others. At the end *"carrying out the project itself has higher priority"*.

The IPL brings forward some managerial obstacles too. For instance, he mentions that *"managers do not accept realistic estimates"*. This person indicated that when an estimate shows that resources are not enough to complete the project with the resources available and by the finish date required, then *"management transfers back this problem to the group leader and asks him to fix the estimates in any way he can"*.

When it comes to solutions, the IPL suggests to *"do post mortem evaluation of projects and [to] make time for them"*. He points out that *"everyone knows when the project is delayed informally but it would be nice if this could be supported by numbers"*. In this respect he proposes to *"add to the monthly reports the original estimates […] at a mid-level of detail"*. The current data only allows tracking slippage at the milestone level, but not at the activity level or at the task level.

The IPL also proposes to *"establish some standards for collecting data (for instance a uniform timesheet format) to ensure historical data is more consistently structured"*. He said that that *"even if the standard is not the optimal, as long as there is some consistency, then data could be potentially used for estimation"*.

The IPL brings forward an idea related to the project portfolio management domain. He suggests to *"decrease the number of projects that are done simultaneously"*. He also pointed out that management needs to acknowledge that good project estimations take time and more commitment is needed from them. He proposes for instance to *"allocate more time or resources to maintain schedules and historical data so that it is useful and easier to find"*. He believes that good estimations should be considered as a project deliverable as well.

The IPL recognizes that all these improvements require a significant amount of effort. He proposes to start simple. As a first step make the right data available, then see if there is a chance to do correlations.

Finally, the IPL believes in the opportunities to learn from other BUs. He thinks it is possible to learn *"[…] what sort of historical data they capture, how often do they do it, how do they capture it, how do they use it, etc and incorporate other's best practices into the BU"*.

6.3 Results discussion and conciliation with theory

This section discusses the findings concerning the RQ3. Due to the overarching nature of this question it was decided to incorporate the findings from the previous two chapters as well. Seeing as the roadblocks and the solutions found in literature are not paired, this section aims to bring them together and contrast them with the empirical findings.

The table below summarizes the main obstacles found in the case study organization together with the solutions to overcome them. The author of this document would like to make explicit that even though a table is not the most reader friendly way to portray this information, it helps significantly to compare and connect problems and solutions from the literature and the empirics.

Every entry in the table is comprised of 3 columns. The left-most column is the category of the obstacle. The categories were defined back in section 6.1.1. The middle column is the obstacle found in the literature which applies to the case study organization. The third and final column provides information in triplets. The first element of the triplet is the obstacle as found in the empirics (interview, archival record analysis or observation). The second element of the triplet is the solution to the obstacle. The third element of the triplet is the comments of the author of this study about the obstacle and the solutions. Sometimes no solution was found. In those cases, the author of this document proposed a solution in the comments field.

Category	Obstacle found in literature	Obstacle found in the case study organization / Solution(s) / Comments
Political	Effort required to do credible estimates is underestimated. [A, D p. 1, H p.628, SO, MD p. 28/5].	PM: *"There isn't enough room to discuss or review estimates with others"* IPL: *"There is no time to do post mortem evaluation of projects"*
		Literature: Management demonstrates commitment to meeting estimates. This signalizes to estimators that senior managers are concerned about creating an accurate estimate and meeting it [L p. 57] IPL: Having more commitment from management (e.g. for leveraging estimation knowledge across different BUs or for encouraging *"doing estimation based on historical data"*)
		Management needs to provide more resources for instance for maintaining the sources of information up to date, carrying out post mortem evaluations and carrying out the estimations and the estimation improvements themselves.
Political	Pressures from managers, users or others to increase or reduce the estimate. [L, H p. 628, LP p. 131]. Even when the cost estimate is done correctly, the senior management may determine that the costs are too high resulting in cost reductions without a corresponding reduction of the project scope [D p. 1, MD p. 28/5]	IPL: *"Managers do not accept realistic estimates (e.g. we cannot finish this project by the finish date you want with the current resources that we have). Management transfers back this problem to the group leader and asks him to fix the estimates in any way he can. This undervalues good estimates"*
		Literature: Management demonstrates commitment to meeting estimates. This signalizes to estimators that senior managers are concerned about creating an accurate estimate and meeting it [L p. 57]
		Management needs to acknowledge the benefits of having better estimates (see introduction chapter)
Organizational	Validity of data: Organizations, their processes, and their products may change over time [B p. 54, CU p.558]	Observations: Changes in the internal standards (meaning and naming of phases) has an impact in the backward compatibility of data
		Literature: N/A
		A recommendation for the organization would be to create a Change Control Board (CCB) and ask them to ensure that the new internal standards are backwards compatible when it comes to historical data.
Organizational	Individual expert's opinions can be biased by several factors (please refer to Appendix 2 for details) [B p. 21]	HPMO: *"People tend to be overoptimistic. They don't take the proper risks into account"*, *"People underestimate the risks"*
		Literature: Incorporate risk and uncertainty into the estimates [HH p. 287]. Institutionalize a culture to educate project teams about estimation (techniques/tools) [SO p. 1-2]. Train your estimators [J p. 55] Generate estimates using a triangulation of different methods (e.g. top-down, expert knowledge estimation) [MD p. 27/5, BP p. 295, HH p. 287, J p. 49]. Estimates should be carried out using more than one technique and being

Category	Obstacle found in literature	Obstacle found in the case study organization / Solution(s) / Comments
		cross-checked [S, p. 47] HPMO: *"Challenge each other more. Ask them what their bases for their estimations are. To reflect on them"*
		Estimators can to be trained to learn how to use the risk registers from previous projects in their estimations.
Organizational	Staff turnover, changes in the project team composition [L]	PM: *"The time people stays in a given role is limited (e.g. every 2-3 years group leader roles are switched)"* IPL: *"Processes are not clear and are changed very often"*. *"The structure of the timesheet (time booking system) changes every year"*, *"It is also not prescribed and every group leader does it in its own way"*, *"This makes impossible to look at historical data at a detailed level"* PM: *"Timesheets cannot be used easily because the tasks against which time is booked are created and thought out by the project manager or group leaders (and there is no standard)"* IPL: *"Use of WBS templates is up to the group leaders […]"*
		Literature: Develop, accept and use a uniform set of definitions and standards [H p. 638]. Define more formalized cost estimation processes [HH p. 287]. Use of estimation checklists [J p. 52] When groups are dispersed after a project and knowledge is not socialized/transferred, some mechanisms for knowledge capturing, storage and distribution could be put in place [LI]. Conduct workshops to share techniques between managers and estimators [HH p. 287]. HPMO: *"An alternative could be to have a checklist to verify your estimations and on what aspects are plans based"* PM: *"Agree on general definitions so that when people switches positions there is a standard set of estimation procedures they can adopt"* IPL: *"Establish some standards for collecting data"*
		The procedure to define the WBS structure at the task-level needs to be standardized further. Otherwise, historical data will not be useful at the task-level because it will depend at on the criteria of the group leader mostly.
Methodological	The estimator ignores the fact that a lot of work will be done by less experienced people, and junior staff with a lower productivity rate [H p. 628, MD p. 28/5]	HPMO: *"Amount of effort depends on who actually carries out the task"* PM: *"Estimations are done without looking at productivity rates"*, *"Estimator has greater experience than implementer, but his estimate is based on his personal productivity figures"*
		Literature: N/A
		Modify the time booking system so that the expertise of the person carrying out a task is tracked. This will ensure that in the future, historical data does account for the productivity according to the experience of the implementer

Category	Obstacle found in literature	Obstacle found in the case study organization / Solution(s) / Comments
Methodological	By definition, every project is unique [P p. 4, CA p. 97]	HPMO: *"Inter BUs learning is difficult because they sometimes come up with templates or procedures that are very specific to what they do and cannot be easily mapped to what we do"*
		Literature: N/A IPL: learn from other BUs PM: it is necessary *"[…] to accept that there is a similarity between the current project and others done in the past"*
		The projects need to be looked at a more abstract level. Revise the size attributes or the cost drivers of the projects. As a suggestion, the organization could use those provided in section 4.1.2.2.
Methodological	Techniques based on expert opinion tend to be less repeatable [B p.32]	PM: *"Estimations are 'out of the heart' and are not deduced"*
		Literature: Generate estimates using a triangulation of different methods [MD p. 27/5, BP p. 295, HH p. 287, J p. 49]. Using cost models as aide memoires, not as replacements for judgment [BP p. 295] HPMO: *"Estimate based on factual data"* PM: *"Build up own historical database"* IPL: Create a team with the responsibility to process and maintain historical data
		Expert opinion should still be the primary source for estimations, although it should not be the only one. Expert opinion can be biased by several factors (See Appendix 2) for details.
Methodological	Data for estimation is captured in desktop spreadsheets or may exist in different information systems and is difficult to consolidate and analyze [P].	IPL: *"Historical data does exist but it is not readily available at the moment of doing estimations […] or it is difficult to find […] or is not accessible "*, *"It is not clear if data exists or not"*, *"Risk registers exist but their location are unknown"*
		Literature: Use historical data for estimations - Build a databank with old project data to offer relevant information on old and comparable projects [CU p. 558].
		The organization should ensure that the information sources for estimations are easily accessible and should increase the awareness of their existence among these experts.
Methodological	Lack of knowledge on how to estimate and estimation techniques [B, SO, LI, H, A, J p. 40].	HPMO: *"It is difficult to come up with meaningful size attributes to estimate the effort spent in a specific activity"*.
		Literature: Consult people with broad (repeated) experience [BP p. 295]
		The projects need to be looked at from a more abstract level. Revise the size attributes or the cost drivers of the projects. As a suggestion, the organization could use those provided in section 4.1.2.2. The organization should encourage each discipline to come up with their own set of cost drivers / attributes. They are the more knowledgeable persons in the organization to do so.
External	N/A	Observations: External unexpected events with significant impact occur during a project (e.g. new governmental

Category	Obstacle found in literature	Obstacle found in the case study organization / Solution(s) / Comments
		regulations are enacted)
		N/A
		The organization should allow room for a safety buffer for contingencies. The buffer should protect the project both in terms of lead time and in budget and initially it could be based on the slippage due to previous similar events. The organization should start documenting these events together with the impact in terms of time and delay so that in the future these decisions can be supported on historical data in addition to expert knowledge.

Table 14: Summary of obstacles and solutions and relationship between theory and empirics.

Sources: [A] (Akintoye & Fitzgerald, 2000), [B] (Briand & Wieczorek, 2002, pp. 4, 32, 56-58), [BP] (Busby & Payne, 1999), [C] (Chatzoglou & Macaulay, 1996, pp. 175-177), [CA] (Carmichael, 2006),[CU] (Cuelenaere, van Genuchten, & Heemstra, 1987), [D] (Doloi, 2010), [H] (Heemstra, 1992), [HH] (Hihn & Habib-agahi, 1991), [J] (Jørgensen, 2004), [LI] (Lindner & Wald, 2010), [M] (McCulla, 1989), [MD] (McDermid, 1991), [SO] (Sonje, 2008), [L] (Lederer & Prasad, 1992, p. 54), [LI] (Liu & Zhu, 2007) , [LP] (Lederer & Prasad, 1995), [P] (PMI, 2008), [S] (Smith, 1995)

7 Conclusions

This chapter presents the main conclusions obtained after completing this study. Next, it discusses the known limitations of this work. At the end some suggestions for further research are given.

7.1 Overarching conclusions

Estimations in the context of the healthcare imaging systems are the joined effort of several disciplines. When aiming to improve estimations, all the disciplines involved should participate. The approach taken in this research focused on improving the quality of estimations by collecting empirical information within the PMO department. This enabled to have a wider view of the problem than adopting a more technocratic view by focusing too closely on estimations at the discipline level. The objective of identifying the non-technical difficulties around estimations was achieved.

With respect to the estimation process of the case study organization, there is a formal process defined, however in some steps it has a very high level approach and there is room for improving it. In particular two steps need to be defined in more detail, namely the 'Retrieval and selection of historical data' step and the 'Estimate size and effort' step. As discussed, healthcare imaging systems are the joined effort of several subjects and these steps should be clearly defined at the discipline level for each one of them. There is some room for improvement concerning the definition of actors too. For instance the role of 'Project Member' portrayed in the estimation process of the organization is far too general. This term is rather broad as it can refer to (senior) engineers, (senior) designers, support employees or all the above.

When it comes to estimation based on historical data, literature focuses simply on using historical data to improve estimates but it does not approach the topic of processing the data or maintaining it. In the case of the case study organization, some disciplines have recorded data but it is not readily usable. Regarding the existing historical data available at the organization, there is limited consistency in the ways to codify information which impedes the proper re-use of the existing historical data. This was confirmed through observations and findings from the interviews. One of the respondents suggested *"[establishing] some standards for collecting data (e.g. a uniform timesheet format) to ensure historical data is more consistently structured"*.

In spite of all the estimation methods and all the information sources available in literature, the empirics showed that this organization only relies on expert knowledge estimation at the moment. From some case studies in the literature, it was found that the CART and the OSR estimation methods could be used for the software and hardware disciplines in the projects of this organization. It should be made explicit though, that at first the organization needs to define the size attributes or cost drivers at the discipline level and also ensure they have enough data to make inferences. Looking at the guidelines for improving obstacles from chapter 6, it is also wise to point out the fact that there is much more to do for improving estimations than just the application of estimation methods.

Concerning the frequency of estimates, it was found in the empirics that re-estimations do not occur at all levels in the organization. Personnel at high level (HPMO and PM) stated that it does occur, but according to personnel more directly involved with developers (IPL), re-estimation does not really occur and there is insufficient time to document the outcome from them in the supporting documents. This indicates that at some point the flow of information between high-level estimations and the task-level estimations is interrupted. It was also noticed that some information sources like the WBS are used in estimations but there is limited awareness about the fact that some of them are outdated.

Unlike the estimation process found in literature, in the case study organization there is not an explicit relationship between risk quantification and estimations. There is a tendency of estimators to be optimistic. There is no allowance for contingencies in the estimation process as it is currently defined in the case study organization. Two strategies are advised to overcome this. The first guideline comes from literature and suggests training personnel about the usage of this information source. The second one comes from the analysis of the researcher; the organization should ensure that the information sources for estimations are easily accessible and should increase the awareness of their existence among these experts.

A major conclusion deduced from this study is that obstacles and solutions to improve the quality of estimates do not come from a single category (e.g. only methodological). The theoretical and empirical findings show that improving estimations is a challenge that needs to be tackled from many different perspectives: political, organizational and technical, among others.

Regarding the roadblocks found in estimations, it was noticed that there is a significantly higher amount of methodological obstacles in contrast to other categories. The case study organization should start gradually and invest effort in a limited set of problems in order to see visible results, and then move on to approach another set of problems. A qualitative cost-benefit analysis should be carried out to determine which obstacles to tackle first.

Personnel in the organization is aware of the additional information sources that could be used to improve estimations, however, these improvement opportunities still exist. The impediment is not the lack of knowledge about the sources that could be used but the decision-making process to actually make it happen. As found in literature and also as pointed out by representatives from the organization, more commitment from management is needed. More resources are required for instance for maintaining the sources of information up to date, for carrying out the estimations and the estimation improvements themselves and for carrying out post mortem evaluations. These evaluations are highly important as they allow to cross-check the end cost of the project against the initial estimate and document the rationale behind the discrepancies. It is also recommended that management stimulates the development of higher-quality estimations and becomes more actively involved in the process of estimations.

It is worth to make explicit some observations about the applicability of some of the theoretical findings to reality. Not all the guidelines found in literature are universal. The context of each organization needs to be analyzed carefully. For instance, some authors suggest separating the estimating function from the rest of development activities in order to reduce the political interference in estimations. This makes sense in a purely academic world however it does not hold in reality. In a real work environment, the task-level estimators are expert developers whose expertise in estimation comes precisely from their involvement in technical activities. In addition, it is not possible to isolate estimators from management because at the end the directors of the company are those who control the approval of resource spending.

Another suggestion from literature which does not really hold in practice is motivated from the high cost of data collection. An author suggested that organizations can collaborate to form multi-organizational data sets. This may happen within the same company, but it will hardly occur in the real world. One of the reasons for this is that historical data provide clues about confidential information as they can signalize problems in the organization as well as recent improvements in performance. Both occurrences are not wise to share with competitors for obvious reasons.

The high granularity and variety of the obstacles and solutions found in literature and in the empirics makes them quite precise, recognizable and addressable in the case study organization. However, this also comes with a downside; it makes it difficult to consolidate them without losing valuable details. This constituted an obstacle for the formulation of the conclusions of this study. There is a lot more to be said about improving the quality of estimations than can be read in these conclusions.

7.2 Known limitations

External validity (Sekaran & Bougie, 2009, p. 384), was intended by choosing the respondents randomly however due to time boundaries and space constraints only 3 respondents were interviewed. In practice, the external validity is partially limited because even though the personnel at the organization was very diligent and willing to help, the occupation level of the population to be interviewed was not homogeneous and therefore this influenced the selection of the respondents. This has a slight impact in the validity of the study (Sekaran & Bougie, 2009, p. 240). In spite of these limitations, the findings from the interviews provide interesting results as was observed in the results discussions and at the concluding remarks.

7.3 Further research

The external validity of this study is also partially constrained due to the fact that this research was conducted in the context of a specific industry rather than for large engineering R&D projects in general. However, it is the belief of the author, that a specific context is necessary for having concrete discussions during the analysis of the results. This study can be seen as the starting point (and perhaps as the framework) for exploring how to improve the quality of estimates in other industries. An ultimate study could be conducted highlighting the differences and similarities in the ways to improve estimations across different industries.

Another interesting possibility for future research could be to assess the impact of the recommendations for overcoming the obstacles in estimations through a transversal study. This study could tackle principles of organizational change management by setting the guidelines to adopt the estimation practices/recommendations provided in this study. The transversal study would consist on the definition and collection of some key performance indicators before and after applying the recommendations in the organization. This sort of study could potentially identify the most effective recommendations and help organizations in choosing how to focus their improvement efforts towards better estimates.

A third potential idea for further research could be to analyze the impact of having higher-quality estimates in employees at different levels within the organization. This could provide interesting findings about the relationship between having high-quality estimates and certain aspects of the behavior of employees across different departments and hierarchical levels.

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APPENDIXES

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APPENDIX 1
INTERVIEW PROTOCOL WITH ANSWERS

Interview Prologue

The purpose of this interview is to find out the opinions of PMO members regarding how project's initial estimations can be improved in the context of developing Healthcare medical systems. The outcome of the information from these interviews will be used to elaborate a set of recommendations for the company and also partially as an information source for my thesis report. The questions of the interview have been grouped in 4 categories:

- Introduction
- Project initial estimations and actors involved
- Extent to which knowledge sources are used in estimation
- Main obstacles that hinder estimations and how to overcome them

All the references to the name of the company, the business unit, project names and names of project managers will be made anonymous in the questions and the answers.

It would be convenient to tape record the interview so that I do not miss something or inadvertently change your words somehow. So, if you do not mind, I'd very much like to use the recorder. If at any time during the interview you would like to turn the tape recorder off, please feel free to let me know.

I will combine and consolidate the answers of the respondents and send them to you for review and approval before they are incorporated in the PMO Cycle Time and Effort Estimation deliverables and in my thesis report.

Interview questions

I. Introduction
   A. Please provide some background information about your self
      - Time working in the company?
      - How much time being a project manager?
      - What technical background do you come from (electrical, mechanical, etc)?
      - Your experience comes from your role in this company (or other BU)?
      - In how many companies/BUs have you worked in a PM-related position before working in this BU?

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Respondent	Answer
Integration Project Leader	10 years in the company. Started as an engineer. Studied Computer Science (Graduated in 1995). Did 5 years of PhD work. Worked for Siemens (Vienna) – Mobile Telephony 2002 Started working in the BU within software development. He has more a coordinator role rather than developer role 7 years as team leader (growing in team size and importance) 2007 Appointed as segment leader (aka Project Manager of software). He did this in a project predecessor to Project_X (the biggest project of the BU within the last 6 years) 2008 (Reorganization occurred) – Became group leader March 2011: He became segment leader again (Integration project leader) **4 years of project managerial experience**
Head of PMO at the Country-level	25+ years working in the company of which 20 years in project management. Background in electrical engineering but quickly moved to leadership roles. He also worked in another BUs (X-ray, cardio systems, others). Expertise come from experience and learning on the job. Positions he occupied: - Software development - Sub system project manager - Group leader - International system manager - System project manager
Project Manager	Started in Philips in 1995 in x-Ray Moved to the BU in 2000 2004 became a segment leader (or nowadays an IPL) – function: reviewing other's WBSs 2009 promoted to Project Manager (mostly software projects)

II. Project initial estimations and actors involved

1. If you had to explain it to a fellow project manager of another division of Imaging Systems, how would you describe the project estimation process at the level of PMO?. That is, could you draw a flow chart and highlight the main actors involved in each step and briefly point out their responsibilities?.

<table>
<tr><td>Respondent</td><td>Answer</td></tr>
<tr><td>Integration Project Leader</td><td>Bottom up: Estimation is done by the groups that work in the project and this info is reported back to the core team.

How is estimation done? (40m 30s)
“Involving experts in estimation. Asking them to provide estimates for the tasks in the WBS”. “Another option is to ask experts in isolation and then average out” (46m 52s).
Challenging experts:
WHO is involved: Designers, engineers
Discuss together about the estimates
Special attention is paid to those estimates where there are large discrepancies between the answers (48m 40s)

Development effort is planned within the groups.

Integration effort is done by the groups.

At the group level they do effort estimation and not cost estimation per se. Effort estimation is translated to some sort of cost (1h 02m 30s)

In his view the steps to do estimation at the group leader level (not the PMO level) are:

Steps (26:09):
“Requirements are received”
“As a group you need to know what to do… to divide the entire scope between the different groups”
Do a work development plan: “Tell what the group will do and how do you want to do it” (e.g. how many engineers, special software required to</td></tr>
</table>

	develop it, training or courses needed (e.g. it is necessary to learn a new programming language) 4. "Work plan is validated" 5. "A 20-40% safety buffer is added to tasks depending on gut feeling (experience), available documentation, etc". (32m 00s) 6. Resources are loaded to the tasks using the work break down and the information about their availability (the project members work in different projects at the same time). 7. Group schedules are consolidated. "If interfaces are difficult to meet at the specified dates then the process is iterated". The timeframe of the project is never enlarged. "What can happen is that something is dropped from the scope after negotiations" (e.g. set of requirements is made smaller) 8. "Group leaders come back to their WBS". Perhaps some estimates need to be reduced. 9. Then the project is ready to go through the plan commitment milestone
Head of PMO at the Country-level	"This process can take up to 2 months". These are the steps when looking at the PMO level: 1. Define the scope 2. Target setting of the major milestones (when should they occur). "This is based on standard times (e.g. for similar projects phase X usually takes 3 months…)". This ends up in the L1 project plan. 3. "Every member of the core team starts to make the plan for the activities of their own discipline". 4. "The leads of each discipline bring up the plans made by staff from their disciplines to verify that it is feasible as a whole for all the different groups" (dependency and links sanity check). They justify the estimation based on the attributes and the size. [The fine detail about how estimations are done at the task level is abstracted at the PMO-level. This is up to each discipline to do] Actors: PM, Core Team members (composed by one expert of each discipline involved in the project)
Project Manager	At the PMO level: They use two things as inputs: 1. "The set of deliverables that need to be created" 2. "The content of the project itself" Steps: 1. Requirements analysis

	2. Design (each discipline says what they will do) 3. Creation of the WBS Steps for estimating: 1. "Conduct a workshop to agree on what is (and is not) in the scope" 2. "The representative from each discipline comes up with the plan for their own discipline" (Effort and finish date of tasks) 3. The core team members communicate if their plans can be realized with the budget they have. If they cannot, "some features are dropped from the scope" (basically distinguishing between core requirements and nice-to-have features). Actors: Project Manager, Core Team members

2. Are there any tools, (excel) forms, etc that you use during this process?. If so, could you indicate roughly, how are these tools used in the process of estimation?.

Respondent	Answer
Integration Project Leader	"The WBS forms are used during the Work Breakdown. Ideally they should be updated as the project progresses, but that is not the case".
Head of PMO at the Country-level	• L1 plan (a powerpoint slide or an excel spreadsheet) • L2 plan: "This is where the deliverables of all the groups come together". • Integration schedule: "This is where the heart of the development activity is planned". "This schedule drives the master schedule of the project". "This schedule is maintained by the Integration Project Leaders". • WBS templates from previous projects (basically attributes that describe the size of the project)
Project Manager	"The tasks' size, category (e.g. documentation, development, etc) are captured in the WBS form".

3. Is estimation a one-shot procedure during the project life cycle and why? (i.e., is estimation only carried out at the beginning of the project?).

Respondent	Answer
Integration Project Leader	"From the development part, during execution we don't look anymore at our development estimates".
Head of PMO at the Country-level	No. It is done continuously. Estimation is done at the beginning but re-estimation can occur. "Re-estimation is a bit situational; it occurs on a need basis depending on the amount of deviation between the actual and the last estimate". "The actual is cross checked with the last estimates on a weekly basis".

Project Manager	No. It is iterative.

4. Can you indicate the main differences between the project initial estimation and other subsequent estimations carried out during the project life cycle, if any?

Respondent	Answer
Integration Project Leader	Not applicable
Head of PMO at the Country-level	"The Estimation and re-estimation processes are basically the same".
Project Manager	"There is not a real difference. What is a little bit different is that as the project evolves, you have more information for your estimates… but process-wise is sort of the same".

III. <u>Extent to which knowledge sources are used in estimation</u>

5. What specific knowledge sources are used in project estimations? (hint: you may think on historical data sources (i.e. what specific documents) and also on people's knowledge (what particular knowledge exactly and from whom)).

Respondent	Answer
Integration Project Leader	Expert knowledge (Senior designers (51m 50s), Engineers (52m 30s)) "At the PMO level, general historical data is useful, but for estimating at the group levels more specific data is needed" (59m 40s)
Head of PMO at the Country-level	(1) Historical knowledge of comparable projects (collective experience from the core team) but not on factual data (9m 18s). "There are two important aspects which are important for us here: • How complex the project is? • Who did it before and who is going to do it this time? (relative level of experience)" (2) Previous WBS: Specifically the size estimates of previous projects (e.g. # of hours, # of pages, # of LOC, # of components, etc). Each discipline has a specific set of attributes they use for describing the size of their share of the project. "When these figures are not available then this is done in a brainstorm session with several experts".
Project Manager	(1) Filling-in the WBS form is an experience-based (gut-feeling) process: It makes estimates a little bit more fact-based and it allows discussion about more specific task durations

	(2) Expert knowledge (3) Project schedules from previous projects (only remembered after seeing the list) (4) Look at the scope of similar previous projects (only remembered after seeing the list)

6. From the previous list, which ones are the 3 most important knowledge sources for estimations and why is this so?

Respondent	Answer
Integration Project Leader	N/A
Head of PMO at the Country-level	N/A
Project Manager	"Around 80% people's expertise and in 20% of cases people look at historical data for discussions".

7. How often are these knowledge sources updated?

Respondent	Answer
Integration Project Leader	Not applicable
Project Manager	Making the WBS is a one-time activity. It doesn't get updated during the project.
Head of PMO at the Country-level	Not applicable

8. From your experience, what are the main knowledge sources that are <u>not</u> used during the initial estimates and what is the reason for this?

Respondent	Answer
Integration Project Leader	Historical data: Productivity figures (e.g. average time per LOC, average time per PR) (1h 01m 35s) "Knowledge from other BUs" (50m 00s).
Head of PMO at the Country-level	"Historical data is not used quantitatively" (e.g except for estimating the average time per PR) (37m 00s) "External knowledge (i.e. how others do it or how fast do they work) is not used

	either [...] we believe projects are unique" (38m 00s)
Project Manager	Use timesheets information (time booked to the tasks of projects on a weekly basis). Evaluation reports from previous projects.

9. What needs to be done to use them?

Respondent	Answer
Integration Project Leader	[No explicit answer given. But it is possible to infer it based on the obstacles listed in answer 15.]
Head of PMO at the Country-level	[No answer]
Project Manager	"We need to accept that there is similarity between the current project and others done in the past" (43m 30s) "Data is kept at a central place and maintained by someone" (44m 05s) "Recognize that it takes time to work on proper estimates"

10. Take a look at the table (this will be provided during the interview) and name 3 other knowledge sources which you would use and please explain why.

Respondent	Answer
Integration Project Leader	"Risk registers… they exist but their location is unknown" (57m 30s). "Learn from the likelihood and impact (cost) of risks of previous projects" (58m 02s). What was done (and not) done in the past? (58m 12s) Time sheets
Head of PMO at the Country-level	"The performance measurements baselines: Because it lets you know how relatively good are you doing what you are doing" (41m 00s) Risk registers: Especially useful for technical risk identification. "We are fairly too optimistic. Some risks are not identified and therefore are not taken into account" (41m 00s) Historical data (42m 10s): e.g. use the WBS as a starting point to do the estimations.
Project Manager	Risk registers "Timesheets but on a deeper level of detail" "How much budget has been set for each individual phase of previous similar

	projects" (53m 51s)

IV. Main obstacles that hinder estimations and how to overcome them.

11. From your experience, what are the most important factors that hinder the initial estimation process and how would you fit them in these categories? (please state the 5 most important ones)

Respondent	Answer
Integration Project Leader	"Organization is very good at producing data but not very good at doing something with it… There are a lot of missed opportunities there" (10m 18s) "The historical data has not been stored for long enough time" (23m 00s) (e.g. the historical data contained in WBS forms) "There is no time for doing post mortem evaluation of projects". The data for post mortem evaluation is available, even some group leaders want to do it, but there isn't time allocated for this. Management is not interested in meeting accurate estimates. "Use of WBS templates is up to the group leaders. At the end is the problem of the group leader how does he/she does the estimation… no matter how they estimate they still have to deliver in time" (38m 40s). "Being unfamiliar with the type of project to be realized" (42m 30s) There is no historical database to determine how much effort should be put to the tasks or how big the safety buffers should be (42m 50s) "Historical data does exist but it is not readily available at the moment of doing estimations" (44m 52s). "or it is difficult to find" (54m 40s). "or is not accessible" (56m 12s). "It is not clear if data exists or not" (56m 20s) Estimation knowledge is not leveraged across different BUs (50m 00s). The WBS templates are not updated during the progress of the project (after estimation has been baselined… leading to no historical data (54m 00s) "The structure of the timesheet (time booking system) changes every year" (58m 40s). "It is also not prescribed and every group leader does it in its own way" (58m 45s). "This makes impossible to look at historical data at a detailed level" (59m 20s) Group leaders are in that position only for a few years or the organization structure changes. If there are no standard procedures or templates, it becomes very

	difficult to use existing historical data (58m 45s) "The organization does not encourage doing estimation based on historical data" (1h 01m 00s). Doing good estimates and updating the data to do them takes time but there is significant time pressure and insufficient time to do this. (1h 03m 45s), (1h 07m 20s). People are forced to a situation where they cannot maintain their schedules, they have to improvise and you cannot do an evaluation afterwards (1h 09m 26s). "Processes are not clear and are changed very often" (1h 04m 40s) The time span of a project is some times larger than the time people stay there (1h 06m 35s) "Every group leader carries out estimates in their own way and there is no time to learn from others... carrying out the project itself has higher priority" (1h 10m 50s) "Managers do not accept realistic estimates (e.g. we cannot finish this project by the finish date you want with the current resources that we have). Management transfers back this problem to the group leader and asks him to fix the estimates in any way he can. **This undervalues good estimates"** (1h 12m 50s) Effort per PRs is not standard… they vary! "Risk registers exist but their location are unknown" (57m 30s)
Head of PMO at the Country-level	To get the estimation quantified and not only qualified (because we fully rely on expert knowledge estimation) (42m 50s) • "It is difficult to come up with meaningful size attributes to estimate the effort spent in a specific activity" (e.g. # LOC is not a 100% accurate). [By meaningful he means that they really drive the effort of your project] • "[the] amount of effort depends on who actually carries out the task" (44m 40s). "Inter BUs learning is difficult because they sometimes come up with templates or procedures that are very specific to what they do and cannot be easily mapped to what we do" (46m 05s) "People tend to be overoptimistic. They don't take the proper risks into account" (49m 50s). "People underestimate the risks" (50m 00s) "There are multiple factors next to the technical difficulty" (50m 05s) [**But the respondent did not mentioned which**] "Effort per PRs is not standard… they vary"
Project Manager	"Initial project scope is extended during the project life-cycle".

	“Timesheets cannot be used easily because the tasks against which time is booked are created and thought out by the project manager or group leaders (and there is no standard)” (41m 25s) “The time people stay in a given role is limited (e.g. every 2-3 years group leader roles are switched)”. There isn’t a “knowledge handover” process between the predecessor and the successor (44m 40s) “Estimations are done without looking at productivity rates” (54m 18s) “Estimations are ‘out of the heart’ and are not deduced” (57m 10s) “ Estimation knowledge is not leveraged across different BUs” (58m 40s) “Estimator has greater experience than implementer, but his estimate is based on his personal productivity figures” (1h 00m 50s). “There isn’t enough room to discuss or review estimates with others” (1h 02m 25s) There is an unrealistic feeling about the effective working capacity of individuals (e.g. about 30 or 40% of that amount goes to meetings, helping others, answering emails, etc)

12. What are your strategies to deal with these difficulties?

Respondent	Answer
Integration Project Leader	Create a team to make easier to extract and use historical data to do estimations. “Do post mortem evaluation of projects and make time for them” (1h 14m 30s). “Add to the monthly reports the original estimates and current progress compared to that (at a mid level of detail. Current level is just the project milestones but not the tasks themselves)”. “Everyone knows when the project is delayed informally but it would be nice if this could be supported by numbers”. “Establish some standards for collecting data (for instance a uniform timesheet format) to ensure historical data is more consistently structured. Even if the standard is not the optimal, as long as there is some consistency, then data could be potentially used for estimation” (1h 05m 20s) Allocate more time or resources to maintain schedules and historical data so that it is useful and easier to find (1h 10m 00s, 1h 15m 10s). “Decrease the number of projects that are done simultaneously” (1h 10m 00s) Management needs to acknowledge that good project estimations take time. As a matter of fact, good estimations should be considered as a deliverable as well (1h 14m 15s). Management should encourage the elaboration of good estimates (1h 18m 10s). More commitment is needed from top management (e.g. enforce and encourage

	project managers to do project estimates post mortem evaluation) Management could invest in having better estimates (1h 16m 20s). Don't leave it just to the group leaders… but also provide the tools (1h 16m 30s). Assign more (perhaps dedicated) resources like in other departments (1h 17m 00s). Start simple. As a first step make the right data available (1h 15m 40s), then see if there is a chance to do correlations (1h 15m 50s) "Encourage cross BUs learning (see what sort of historical data they capture, how often do they do it, how do they capture it, how do they use it, etc) and incorporate other's best practices into the BU" (1h 17m 00s)
Head of PMO at the Country-level	"An alternative could be to have a checklist to verify your estimations and on what aspects are plans based" (i.e. make sure x,y,z where taken in consideration) (49m 20s) "Challenge each others more. Ask them what their basis for their estimations are. To reflect on them" (51m 15s) "Estimate based on factual data" (9m 18s)
Project Manager	"Agree on general definitions so that when people switches positions there is a standard set of estimation procedures they can adopt" (45m 50s) "Break down the effort of previous similar projects per phase and per discipline to give an indication of how much the current project could cost" (56m 12s) "Build up own historical database" (59m 10s)

13. (Optional) From your understanding, how do other actors cope with these obstacles?

Appendix 2
Detailed list of obstacles that hinder good estimations

The following table presents the extended list of obstacles found in estimations. As mentioned in the body of the document, a significant amount of them fall in the methodological category. For this reason, the first table presents the obstacles for all categories (excluding methodological obstacles) and a second table presents the subcategorized set of methodological obstacles.

Category	Obstacles
Political	• † Project managers are asked to make early estimates without knowing the detailed requirements [C, MD p. 28/5] • "When there is strong motivation to accept the work, the job is accepted under the assumption that any inconsistencies between requirements, cost and schedule will be resolved while the task is under development" [HH p. 279] • † Effort required to do credible estimates is underestimated. [A, D p. 1, H p.628, SO, MD p. 28/5]. • † Pressures from managers, users or others to increase or reduce the estimate [L, H p. 628, LP p. 131]. Even when the cost estimate is done correctly, the senior management may determine that the costs are too high resulting in cost reductions without a corresponding reduction of the project scope [D p. 1, MD p. 28/5] • The different project stakeholders (project manager, customer, developer, user, etc.)often have their own hidden agendas and goals conflicting with each other [H p. 636, BP p. 296]. For instance: ▪ Minimization of the costs, maximization of the quality, minimization of the duration, optimal use of employees, etc [H p. 636]. ▪ People downstream (like sales managers) would cut estimates to win contracts [BP p. 296] ▪ The estimator's job is threatened if the contract was not won because the price was too high[BP p. 296]
Organizational	• † The project team members and their abilities may also be unknown [C, L] • Difficult access to experts: Certain estimation methods are based fully or partially on some expert elicitation process. Experts are, by definition, extremely busy people [B, p. 54] • † Validity of data: Organizations, their processes, and their products may change over time [B p. 54, CU p.558] • † Staff members do not comply with the estimating/tracking process due to lack of executive mandate [P] • Unexpected changes in the scope [L, H p. 628, D p. 1] • † Project customers do not understand their own requirements [D p. 13, L, LP p. 131] • † Staff turnover, changes in the project team composition [L] • Performance reviews do not consider whether estimates were met [L, LP p. 131] • Lack of coordination of the different disciplines involved in the project during its development [LP p. 131] • † Once a project is finished, the group of people working together is dissolved and the project knowledge is fragmented [LI]
Technical	• Emergence of new techniques and tools that may influence unit costs and render historical data obsolete [C, H p. 628, BP p. 293]. • † Productivity rates may increase over time due to learning from previous experience (learning curve). This can make historical data obsolete [CA, pp. 70-72]. • † In software projects, the language in which the code is written is not taken into account [C] • Required expertise may not exist if the organization is new or if the projects to estimate belong to a new line of product, based on entirely new technology [B p. 54]
Communication	• Insufficient user-analyst communication and understanding [L]

General	• Initial misunderstandings of the scope of the project [MD p. 28/3] • † Poor or imprecise problem definition [L, LP p. 131] • Information about the project itself is limited at an early stage of the project [LI]
External	• † Variability in the time it takes to get approvals from third parties (e.g. government) [D p. 13] • † Broad variability of sub-contractors / suppliers prices [A] • Inflation [S p. 17]

Table 15: Extended summary of obstacles when doing project estimation (all categories).Sources: [A] (Akintoye & Fitzgerald, 2000), [B] (Briand & Wieczorek, 2002, pp. 4, 32, 56-58), [BP] (Busby & Payne, 1999), [C] (Chatzoglou & Macaulay, 1996, pp. 175-177), [CA] (Carmichael, 2006), [CU] (Cuelenaere, van Genuchten, & Heemstra, 1987), [D] (Doloi, 2010), [H] (Heemstra, 1992), [HH] (Hihn & Habib-agahi, 1991), [J] (Jørgensen, 2004), [LI] (Lindner & Wald, 2010), [M] (McCulla, 1989), [MD] (McDermid, 1991), [SO] (Sonje, 2008), [L] (Lederer & Prasad, 1992, p. 54), [LI] (Liu & Zhu, 2007) , [LP] (Lederer & Prasad, 1995), [P] (PMI, 2008), [S] (Smith, 1995). †: Discussed in the body of the document

Sub-Category	Methodological Obstacles
Data Management	• † Very few companies have bothered to store previous project data in a way that can be used later [A, C, M, SO, L, CU, LI]. E.g. ▪ Lack of cost and resource data collected from past projects [H p. 631, D p. 1] ▪ Lack of data with which to check new estimates, therefore estimators often start by doing a bad job and never get any better [MD p. 28/5] ▪ Data collection is an expensive, time-consuming process for individual organizations [B p. 4] ▪ A large amount of data is required and this is rarely available in organizations [B p.54] ▪ Inconsistencies in existing data [B p.54] ▪ † By definition, every project is unique [P p. 4, CA p. 97] and every project has a set of elements which are new. “No database will ever be sufficient” and some guessing will occur to estimate the unknown (new) items [HH p. 286]. • † Data for estimation is captured in desktop spreadsheets or may exist in different information systems and is difficult to consolidate and analyze [P]. • Timesheet actuals are frequently captured at the task/activity level, and tend to be too detailed to maintain accurately overtime [P].
Resource Balancing	• † Human resources availability during the project lifecycle is not taken in consideration [C]
Stakeholder involvement	• † Lack of careful examination of the estimate by management [LP p. 131] • Lack of participation in estimating by the developers [L]
Limited knowledge	• † Lack of knowledge on how to estimate and estimation techniques [B, SO, LI, H, A, J p. 40]. ▪ Overwhelming amount of estimation methods and lack of knowledge about which one to choose [B] ▪ Adoption of inappropriate estimation methodologies [SO] ▪ Characteristics of product make estimating difficult (e.g. the level of abstraction, complexity, measurability of product and process, innovative aspects, etc)[H p. 628] ▪ Difficulties around cost drivers of the project [H p. 628]: 1. Definition: Lack of clear and accepted definitions for drivers. For instance in software projects the use of LOC measures has some limitations [B p. 22]: • No accepted standard definition exists for Lines of code (LOC) • LOC depends on the programming language used and the individual programming style • LOC emphasizes coding effort, which is only one part of the implementation phase in a software project 2. Quantification: Majority of the cost drivers are hard to quantify. 3. Objectivity. What may be complex for developer A is not complex for developer B.

	4. A change in the value driver A may have consequences in the values of several other cost drivers. 5. Relationship between driver and effort: It is sometimes fuzzy or hard to determine. 6. Calibration: There is no single "most important set of drivers". It differs from situation to situation. 7. Human factors: Some factors like experience and quality of the personnel influence the cost drivers. 8. Reuse factor: It can be difficult to estimate the reuse factor of components/modules within the project. ▪ No clear picture as to how to tackle project sizing [B p. 56] ▪ Ignoring the non-linear aspects of software development, for example coordination and management [H p. 628, MD p. 28/5]. ▪ Miss-assumption of a linear relation between the required capacity per unit of time and the available time [H p. 628]. ▪ † Over-emphasizing uniqueness of tasks (estimating at the wrong level of abstraction) [BP p. 295] ▪ "Estimators know that factors like risk and uncertainty should be incorporated but they don't know how to do it" [HH p. 281] ▪ Difference between wishful thinking and realism: People get over-optimistic when predicting their own performance because of the "I am above the average" feeling and because the Level of over-optimism increases with the level of control [J p. 46] ▪ Estimators do not have much experience developing estimates [MD p. 28/5] or cannot have much experience in developing estimates, especially for large projects (e.g. How many 'large' (long) projects can someone manage in, for example, 10 years?) [H p. 628] ▪ The estimator ignores the fact that a lot of work will be done by less experienced people, and junior staff with a lower productivity rate [H p. 628, MD p. 28/5] • Costs were collected at a different level of aggregation from estimates [BP p. 295] • Miss-diagnosis of unusual events: ▪ Misinterpretation of available historical information [SO]. ▪ Sometimes new projects are estimated by adjusting the recorded costs from a **single past** project of a similar kind. But there is no allowance for the fact that the past project's outcome was one sample of all possible outcomes [BP p. 295]. ▪ When, as an individual, one has had experience only of a few projects one cannot know the statistical properties of this kind of event(e.g. people would plan to avoid or cope with the specific disaster they had recently experienced, and ignore all the other events of roughly equal scale and probability that could have occurred but, by chance, did not) [BP p. 296] ▪ People in organizations seem to be tolerant of single errors, but not of repeated ones. This means that you are likely to want to demonstrate how you have learned from the last project by planning to avoid or cope with exactly those specific events that occurred, not all the other equally likely events that by chance did not occur[BP p. 296]. • † Miss-representation of estimates: Though the output of resource models is often a single value, this is misleading as it falsely conveys an impression of high accuracy [H p. 637]. Point estimates do not allow for proper risk management [B p. 56] • Data driven techniques based on statistics are usually difficult to handle by most practitioners. Their results are difficult to interpret, thus forcing the estimator to rely on prediction results as a black box [B]
Limited organizational learning	• † Estimators prefer not to compare outcomes with estimates because their estimating assumptions had been violated during the project. This prevents to learn from the outcome [BP p. 296] • † Inability to tell where the previous estimates failed [L, LP p. 131]
Expert opinion subjectivity	• † Individual expert's opinions can be biased by several factors [B p. 21]: ▪ Pessimistic / optimistic opinion ▪ Uncertainty of judgments ▪ Role of memory in complex problem solving

	▪ Involvement of the estimator in the development ▪ The predictability of the environment • † Techniques based on expert opinion tend to be less repeatable [B p.32]
Unclear definitions	• Different definitions on the costs that are included in the estimate [S p. 17] • † Different definitions on measurement [S p. 17] • Not comparing like with like [S p. 17]
Related to models	• Calibration is omitted when working with models [CU p. 559]. Models are not calibrated to the organization [J p. 40]. An incorrect calibration has a negative effect on the quality of the subsequent estimates made with the model [CU p. 558] • Majority of models do not support calibration [H p. 628] • When performing the calibration the user is often meeting the model for the first time, whereas experience is needed in using the model to be able to calibrate properly [CU p.559] • Input values for the model are difficult to define [CU p. 560]. • In methods were productivity is taken into account, actual productivity figures vary over a wide range due to differences in projects that are assumed to be similar [HH p. 281]

Extended set of methodological obstacles when doing project estimation. Sources: please refer to Table 15

Appendix 3
Extended list of recommendations to improve the quality of estimations

Recommendations to improve the quality of estimations according to literature	Political	Organizational	Methodological	Methodological*	Technical	Communication	External	General
† Separate the estimating function from the rest of development activities. This allows: (1) to shield the estimating function from potential political interference, (2) Specialize the role of the estimator, who then concentrates on building expertise in this area and (3) to gain consistency on subjective assessments [C p. 177, M p. 38].	x	x	x					
Avoid the use of imprecise inputs and subjective assessment of cost drivers [C p. 177]			x					
† When groups are dispersed after a project and knowledge is not socialized/transferred, some mechanisms for knowledge capturing, storage and distribution could be put in place [LI]. Conduct workshops to share techniques between managers and estimators [HH p. 287].		x	x					
Calibrate existing models to the characteristics of the particular organization or develop organization-specific models [C p. 177]				x				
Use different estimation models at different stages in the life-cycle [C p. 177, SO p. 1-2]				x				
Utilizing errors: A record of errors allows assessment of methods of estimating, helping to ensure the use of the best method in the future [S p. 50]. Also applies for expert estimates [B p. 21]			x					
† Adopt project postmortems as a practice (i.e. feedback on the estimates at the end of the project). They provide insights into managerial practices [HH p. 287, J p. 54]. Feedback should be provided comparing the estimates with the actual values and reasons for deviations should be analyzed [B p. 58]. Document the experience gained in the estimation of projects properly [D p. 2]		x	x	x				
† Institutionalize a culture to educate project teams about estimation (techniques/tools) [SO p. 1-2]. Train your estimators [J p. 55]		x	x	x				
Clearly defined guidelines for creating estimate baselines should be in place [SO p. 1-2]			x					
Every change request should be documented and estimated [SO p. 1-2]			x					
† Once estimation is done, it should not be considered as sacrosanct. There should be provision to revise it if the circumstances under which it was prepared for the first time change. Estimate and re-estimate after every phase of the project life cycle (if necessary) [SO p. 1-2]	x		x					
Project needs and requirements should be clearly defined. The clearer the input, the better the estimate can be [SO p. 1-2]			x					
† Use historical data for estimations: Leverage lessons learned / best practices from documented engagements executed in the past [SO p. 1-2]. Build a databank with old project data to offer relevant information on old and comparable projects [CU p. 558]. Define metrics, collect them and develop databases [HH p. 287]. The use of documented data helps to overcome the problem of reliance on "personal memory" [J p. 48]			x	x				
Propagate the culture to define work packages and track time against them diligently. Project management tools should be provided to do so [SO p. 1-2]			x	x				
† Assign the initial estimating task to the final developers [L p. 53]	x	x	x					
Delay finalizing the initial estimate until the end of a thorough study [L p. 53]	x		x					
Anticipate and control user (and customer) changes [L p. 55]		x						
Monitor the progress of the proposed project: This may be important to developers because they feel forced to complete their project within the estimate [L p. 56].			x					
Evaluate proposed project progress by using independent auditors [L p. 56-57]. Use the knowledge from external consultants keeping in mind however that they are less familiar with in-house practices, so their estimates may require some adjustments [C p. 176]			x					
† Management demonstrates commitment to meeting estimates. This signalizes to estimators that	x		x					

Recommendations to improve the quality of estimations according to literature	Political	Organizational	Methodological	Methodological*	Technical	Communication	External	General
senior managers are concerned about creating an accurate estimate and meeting it [L p. 57]								
Use the estimate to evaluate project personnel [L p. 58]		x						
† Management should **carefully** study and approve the cost estimate: Results support the belief that computing management approval increases estimating accuracy [L p. 58]	x		x					
Rely on documented facts, standards, and simple arithmetic formulas rather than guessing, intuition, personal memory and complex formulas: There is no proved correlation (nor positive nor negative) between the use of memory to estimate and more accurate estimates [L p. 58]			x					
Do not rely on cost estimating software for an accurate estimate: Research shows that software packages will not likely have major, favorable effects on the accuracy of an organization's cost estimates [L p. 58]			x					
When making the calibration, the estimator should be supported by expertise from an experienced model user [CU p. 558]				x				
Estimation models should be calibrated for specific development environments [CU p. 558]				x				
Calibration is not a one-off activity but must be repeated periodically [CU p. 560]				x				
† Generate estimates using a triangulation of different methods [MD p. 27/5, BP p. 295, HH p. 287, J p. 49]. Estimates should be carried out using more than one technique and being cross-checked [S, p. 47]			x					
† Develop, accept and use a uniform set of definitions and standards [H p. 638]. Define more formalized cost estimation processes [HH p. 287]. Use of estimation checklists [J p. 52]			x					
Use historical data from the same organization (and not from others) [H p. 638]			x	x				
† High cost of data collection could be overcome by collaboration of organizations to form multi-organizational data sets [B p. 4]			x	x				
Do not confront developers/engineers with a plan without any consultation [H p. 638]	x		x					
† Consult people with broad (repeated) experience [BP p. 295]			x					
† Using cost models as aide memoires, not as replacements for judgment [BP p. 295]			x	x				
Adopting a project-based organization where project managers have primary authority over staff. The reasons behind this are [BP p. 298]: (1) It helps ensure that a project's full complement of staff is available when the project starts (2) It helps a project retain its staff throughout a project, and (3) It helps resolve function-project conflicts in favor of the project.	x	x						
Reduce the cost engineering skill turnover [D p. 2]		x						
Incorporating market behavior into estimates [D p. 2]					x		x	
† Document the assumptions under which estimates are made [HH p. 287]			x					
† Incorporate risk and uncertainty into the estimates [HH p. 287]			x					
Do not appoint estimators with relatively strong interest in the outcome [J p. 46]	x							
Assess the uncertainty of the estimate by representing it with a prediction interval (i.e. a range and a probability) [J p. 52]. When the available data does not allow providing point estimates, there is no point in doing so [H p. 628]. A better approach is to provide Project Management with a number of scenarios from which alternatives can be chosen [H p. 628]			x					

Table 16: Extended list of Solutions to overcome obstacles in estimation found in literature.
Sources: [B] (Briand & Wieczorek, 2002), [BP] (Busby & Payne, 1999), [C] (Chatzoglou & Macaulay, 1996),[CU] (Cuelenaere, van Genuchten, & Heemstra, 1987), [D] (Doloi, 2010), [H] (Heemstra, 1992), [HH] (Hihn & Habib-agahi, 1991), [J] (Jørgensen, 2004), [L] (Lederer & Prasad, 1992), [LI] (Lindner & Wald, 2010), [M] (McCulla, 1989), [MD] (McDermid, 1991), [S] (Saunders, 1990), [SO] (Sonje, 2008)
***: Methodology recommendations for model-based estimation methods. †: Discussed in the body of the document**

APPENDIX 4
ESTIMATING EFFORT OF TASKS USING THE PERT METHOD

PERT planning involves the following steps:

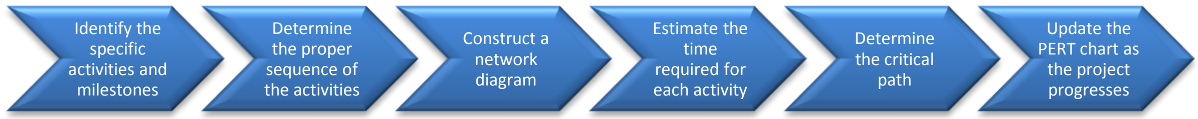

Figure 20: Steps of the PERT method. Source: (Turner, 1999; Meredith & Mantel, 2010).

It is interesting to look into the fourth step of this method in detail. PERT deals with uncertainty in activity completion times. Three different values are used to represent each activity of the project:

- *Optimistic time*: Namely the shortest time in which the activity can be completed. A common practice is to specify optimistic times to be three standard deviations from the mean so that there is approximately a 1% chance that the activity will be completed within the optimistic time.
- *Most likely time*: The completion time having the highest probability. It is important to mention that this time is different from the *expected time*.
- *Pessimistic time*: This is the longest time that an activity might require. Three standard deviations from the mean is commonly used for the pessimistic time.

PERT assumes a beta probability distribution for the time estimates so the expected time for each activity can be approximated using the following weighted average:

Expected time = (Optimistic + 4 x Most likely + Pessimistic) / 6

To calculate the variance for each activity completion time, if three standard deviation times were selected for the optimistic and pessimistic times, then there are six standard deviations between them, so the variance is given by:

Variance of expected time = [(Pessimistic - Optimistic) / 6]