Process improvement for engineering & maintenance contractors
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Chapter 1

Introduction

This thesis focuses on process improvement concepts for engineering and maintenance contractors (hereafter: EPCM contractors; for reasons which will be explained below). The aim of this thesis is to investigate several issues pertaining to the relevance and implementation of process improvement for this type of contractors. Specifically, four related themes will be emphasized: (i) frameworks that help EPCM contractors improve their processes, (ii) engineering change management, (iii) condition based maintenance and (iv) incentive contracts for process improvement. This chapter includes a motivation for the research presented in this thesis (§1.1), a general description of EPCM contractors (§1.2), a description of the industrial setting in which the research takes place (§1.3), the research aim (§1.4), the research objectives (§1.5) and the outline of this thesis (§1.6).

1.1 Motivation

The central theme of this thesis is process improvement. Process improvement entails a deliberate process change which should lead to a positive improvement in one or more of an organization’s performance criteria (e.g. Benner and Tushman, 2003; Klassen and Menor, 2007; Krishnan et al., 2000; Linderman et al., 2010; Silver, 2004). This thesis is the end result of a collaborative research project on process improvement concepts with Stork GLT, a major EPCM contractor responsible for the renovation and maintenance of industrial gas production plants. As an open and perpetually learning organization, Stork GLT feels that it could benefit from academic knowledge resulting from detailed analyses of several of their key processes. The research that is described in this thesis relates to the concerns raised by this firm, but will also aim to contribute to the academic body of knowledge. This will be further described in §1.4.
1.2 The nature of EPCM contractors

The focal firm in this thesis is the EPCM contractor. This type of firm is responsible for the engineering, construction and maintenance of large, complex, capital-intensive physical assets such as buildings and industrial plants. EPCM contractors are often key partners of asset owners such as oil and gas companies and energy companies. They manage the entire asset lifecycle which, at a general level, consists of five phases:

1. R&D and design;
2. Engineering and procurement;
3. Construction;
4. Maintenance and refurbishment;
5. End-of-life (based on Blanchard and Fabrycky, 1998; Schuman and Brent, 2005; Stavenuiter, 2002).

Note that the actual utilization (or operation) of the asset runs in parallel with the maintenance and refurbishment phase. The engineering, construction and maintenance of these assets (which are often referred to as capital goods, e.g. see Hicks et al. (2000a), or complex product systems, e.g. see Alblas (2011)) can be done in various contractual and managerial ways. Our focus lies on the contractor that is responsible for the business processes covering the entire lifecycle. We thereby restrict our attention to engineering and procurement, construction, and maintenance and refurbishment, i.e. all life cycles phases except for R&D and design, and end-of-life. We also do not directly address any aspects related to utilization/operation.

1.3 The Groningen Long Term project

The Groningen gas field is a large gas field located in the northern part of The Netherlands, exploited since its discovery in the early 1960s by NAM. In 1996 NAM invited a large number of firms to form consortia and engage in a competition for the contracts to execute renovation and maintenance of the installations in the Groningen gas field\(^1\). The GLT project entails the complete modernization and maintenance of more than 20 gas production facilities and gas transfer stations. The project scope explicitly included

\(^1\)The first part of this section is partially based on the ‘Learning Book’, which was published in 2008. This book provides a rich description of the Groningen Long Term project and its key success factors.
installation of 23 megawatt compressors and electro motors at each location, installation of a distributed control system for fully automated remote control of the plants and a new instrument protection system to safeguard the gas production process.

The consortium Stork GLT won the competition based on the quality of the project proposal and lowest total cost of ownership. Stork GLT is a consortium consisting of an engineering and procurement firm, a construction and maintenance firm, two large equipment suppliers and a firm responsible for instrumentation equipment. The design of the contractual and managerial relationship between the parties involved was considered quite unique in the industry: NAM would engage in a single contractual and managerial relationship with a consortium of different parties. The relationship between Stork GLT and NAM is governed by a project execution contract (worth approximately 2 billion US dollars) and a maintenance execution contract (worth approximately 1 billion US dollars) that included minor and major modifications to the installations. The work that is executed in the different business processes is fully reimbursable (based on at cost considerations or predefined unit rates). However, the consortium was stimulated to continuously improve based on several principles:

- Repeatability gains. Since the different locations share a great deal of technical similarities, it is expected that over the years the consortium will learn to work ‘smarter’ so that budgets will gradually reduce.

- Volume benefits. The project budget can be reduced if more than one facility is renovated at the same time. This is typically the case since the locations will be renovated in batches of 2, 3 or 4 locations.

- An incentive structure stimulating the consortium to stay within budget, procure at low cost and strive for various performance targets.

The supply chain in which Stork GLT acts is depicted in figure 1.1.

1.4 Research aim

Process improvement is a research topic that receives much attention in the academic literature. Several well-known process improvement concepts are rooted in high-volume type of industries. Lean manufacturing, for example, was first described in the automotive industry (Liker, 2004; Shah and Ward, 2004).

For an academic analysis of the control structure governing the relationship between Stork GLT and NAM, see an interesting case study by Van der Meer-Kooistra and Vosselman (2000).
2003). In the course of decades, other industries started developing process improvement frameworks that were better able to deal with industry-specific firm characteristics. In the software industry, for example, the Capability Maturity Model was developed (e.g. SEI, 2002; Harter et al., 2000; Harter and Slaughter, 2003). This model, which is also known as CMM and later CMMI, offers software engineering firms guidelines to systematically manage and improve their processes. It uses the idea of process maturity levels, which depict the path to continuous process improvement based on process standardization and process measurement. Also literature is appearing covering ideas that apply directly or indirectly to the management of EPCM processes. These concern specific topics such as learning over the asset lifecycle (Hipkin, 2001; Koochaki et al., 2008; Schuman and Brent, 2005; Venkatasubramanian, 2005), design reuse using platforms (Alblas, 2011; Muntslag, 1993), the supply chain of capital goods (Hicks et al., 2000b), business process reengineering in the capital goods industry (Cameron and Braiden, 2004) and the application of lean techniques in aerospace (Browning and Heath, 2009). However, it appears that more research on process improvement for companies that produce complex products is needed. For example, several calls for capital good process improvement literature have recently been made (e.g. Browning and Heath, 2009; Eckert et al., 2009; Gosling and Naim, 2009). In addition, it appears that within EPCM contractors such as Stork GLT knowledge exists on process improvement concepts such as lean manufacturing, but that they are in search of process improvement concepts that are capable of dealing with their specific characteristics and challenges. Although much of the literature cited above is relevant to EPCM contractors, several important questions are unanswered as we will also show in the next section. In this thesis we address several of these questions. Therefore, the research aim of this thesis is to contribute to the academic knowledge on specific process improvement
Chapter 2 provides the foundation for the thesis. In that chapter, the characteristics of EPCM contractors and suitable process improvement concepts are investigated. The chapter furthermore provides insights into some of the key issues of EPCM contractors. These insights are used to identify the research themes of this thesis. The following section describes these research themes, the related research objectives, and the details of the adopted research methodologies.

1.5 Research objectives

1.5.1 Exploration of process improvement concepts for EPCM contractors

Considering the research aim of this thesis, a necessary first step in the research project would be to investigate the characteristics of EPCM contractors in detail and to link these characteristics to existing process improvement concepts. It was expected that such a first step would lead to more insight into what specific developments are needed in the existing academic literature. Therefore the first research objective was as follows:

RO1. To explore the characteristics of EPCM contractors and to identify suitable process improvement concepts.

Chapter 2 reports on the research related to the first research objective. A literature study was conducted into existing process management practices and frameworks, the application of these practices and frameworks in the EPCM industry, and suitable process improvement concepts. An in-depth case study was undertaken at Stork GLT to describe the characteristics of EPCM contractors and to identify the way these characteristics influence the use of existing process improvement concepts. A case study approach was found relevant since the goal was to describe the ‘territory’ and map the relevant variables (Handfield and Melnyk, 1998). It was found that at a general level CMMI (see previous section) is a suitable guideline for the improvement of EPCM processes. In order to better understand how well CMMI can support EPCM process improvement and whether any amendments were considered necessary, it was decided to map the main business processes of EPCM contractors to the key process areas of CMMI. We found that CMMI is particularly strong in supporting engineering and procurement process improvement. It is less strong in supporting the improvement of downstream processes such as construction and maintenance. In addition,
several fruitful areas for future research were identified. The following research themes were found to be essential for EPCM process improvement in general and for Stork GLT in particular:

- In the project execution contract of the GLT project it is assumed that learning effects will occur so that each newly renovated location can be delivered at lower cost compared to the locations that are delivered in the previous batch (as mentioned earlier, NAM labeled this the ‘repeatability gains’). Ideally product designs and processes are highly standardized so that they can be copied from one location/batch to the other. However, due to changing regulations, supplied materials, identified improvements or problems, the firm is continuously confronted with the engineering change phenomenon. An engineering change is defined as a change to the product’s design after this design has been released to procurement and/or construction. Engineering changes can be very troublesome for firms such as Stork GLT that have repeatability at the core of its product and process designs. It was found that not much literature exists on the role of engineering change in EPCM contracting firms, especially on the question how to manage engineering change in the light of demands on stabilized (and perhaps standardized) product and process designs. Section 1.5.2 further elaborates on this theme.

- Another relevant issue relates to the maintenance phase of the asset lifecycle. Many asset owners aim at increasing installation reliability and availability. One important practice that can help them achieve this is condition based maintenance. Condition based maintenance is a predictive maintenance technique that uses condition monitoring information to diagnose and prevent failure before its occurrence. At Stork GLT, increasing amounts of data are becoming available over the years because the gas production plants are equipped with sophisticated measurement instruments. The maintenance organization has the ambition to use this data for condition based maintenance purposes. However, the circumstances under which condition based maintenance approaches may or may not be successful were not clear. For example, in an in-depth case study at Stork GLT, Pot (2007) found that even in the case of relatively simple equipment such as a heat exchanger, condition based maintenance can fail when process engineering and maintenance engineering knowledge are absent and/or insufficiently integrated. One of the conclusions that were drawn from this study is that different types of condition based maintenance may have different requirements. The question how EPCM contractors can engage
in process improvement using condition based maintenance by dealing with these requirements, appeared to be insufficiently addressed in the literature. This theme is further described in section 1.5.3.

- It was also concluded in the exploratory phase of the research project that process improvement endeavors should match company characteristics such as organization structure and culture. In the literature comparable claims are made. Carrillo and Gaimon (2002), for example, explained that process improvements could be facilitated by appropriate managerial structures such as incentive systems. The final research theme in this thesis involves a study into managerial incentives for process improvement (also see section 1.5.4).

Chapters 3-6 focus on these three research themes. The next sub-sections elaborate on these themes, specific research objectives and the methodological choices underlying the different studies that are undertaken.

### 1.5.2 EPCM product design, process design and engineering change management

The second research theme addresses the question how EPCM contractors deal with engineering change management. Researchers increasingly report on concepts that capital goods producing firms can use to stabilize product design and lifecycle process design\(^3\). Examples are design reuse (Muntslag, 1993), product platforms (Alblas, 2011), lean construction (Koskela and Ballard, 2006) and learning in complex product systems over lifecycles (Davies and Brady, 2000; Gann and Salter, 1998). However, even though many of these firms are progressing towards higher levels of stability in lifecycle processes and products, an important question remains how this can be done in environments that are characterized by variety. One important source of variety is engineering change. Engineering change management can refer to disciplines, processes and/or systems to deal with engineering changes (Huang and Mak, 1999), and is found to be a key process improvement issue that can affect the entire asset lifecycle (Eckert et al., 2009; Hicks and McGovern, 2009; Jarratt et al., 2005). The EPCM contractors we focus on in this thesis face a difficult challenge: they deliver assets that share a great

\(^3\)The definition of stability that is employed here differs from the definition provided by the Software Engineering Institute (SEI, 2002), who define a stable process as a process in which only common causes of variation of the output are present and specific causes of variation are taken out. Our definition is broader and refers to the unchanged state of the process (e.g. activities and their sequence) compared to what was originally planned. Subsequently a stable design refers to a design that remains unaltered over a period of time. Also see chapter 3.
deal of similarity (and the budgets they receive for doing so assume lifecycle learning), while at the same time they are often confronted with many engineering changes that are the result of identified product improvements, problems, changes in supplied sub-assemblies or materials or changes in legislation. They recognize that engineering changes ‘destabilize’ the asset’s design, and influence the status quo as to what constitutes the process and how processes are carried out (e.g. in the way the asset is built or how it is maintained). Thus, their challenge is to balance stability and variety in terms of process and product design. Existing literature focuses mostly on technical factors such as how change in one component cascades to other components (i.e. change propagation) (e.g. see Clarkson et al., 2001; Sosa, 2008), or on production related effects of engineering change such as longer processing times, backorders and increased capacity requirements (e.g. see Loch and Terwiesch, 1999; Balakrishnan and Chakravarty, 1996). The literature also not fully addresses the characteristics of EPCM contractors, for example the fact that they manage several asset lifecycles in parallel with potential cross-over effects of engineering change (e.g. a change initiated while building plant A may influence the design of plant B). The second research objective, therefore, is as follows:

RO2. To explore the relationship between EPCM product design, process design and engineering change management.

In chapter 3 a multiple case study is described on the engineering change management practices of Stork GLT and ASML. ASML is a large producer of lithography systems that are used in the semiconductor industry. ASML can be compared to a supplier of large equipment such as Siemens (see figure 1.1). Therefore, the two case studies represent different positions in the capital goods supply chain. In the case study the engineering change management practices of both firms are compared and mapped against the way they deal with product and process design stability and variety. Thereby special attention is paid to the role of product delivery strategies (also see Postmus, 2009). Product delivery strategies can be defined as the type of engineering work that is done independent of an order and the specification freedom the customer has in the changeable part of the design (Muntslag, 1993). Engineering changes disturb any existing balance between stability and variety, and that the severity of this disturbance depends on the positioning of the product delivery strategy.
1.5.3 Condition based maintenance process improvement

Whereas the research related to the first two research themes strongly focuses on the procedural aspects of process improvement, the third research theme emphasizes the use of technology for process improvement (e.g. see Carrillo and Gaimon, 2002, 2004; Hipkin and Lockett, 1995; Jonsson, 2000; Swanson, 1997; Upton and Kim, 1998). An important process that is somewhat underexposed in operations management literature is maintenance, which is remarkable since maintenance expenditures often exceed capital expenditures on machinery (Moubray, 1997). As many firms are increasingly looking for ways to reduce downtime, and increase utilization rate and reliability, predictive maintenance technology that is able to predict the occurrence of machine failure becomes more important (Al-Najjar, 1996; Riezebos et al., 2009; Shah and Ward, 2003; Slack et al., 2010). The third research theme focuses on a specific predictive maintenance technology: condition based maintenance. The key idea of condition based maintenance is that maintenance actions are determined based on off- and online condition monitoring information (Jardine et al., 2006). It uses several types of tools as well as input data to diagnose machine failure and predict a machine’s time-to-failure. As was mentioned above, EPCM contractors such as Stork GLT seem to struggle with successfully implementing condition based maintenance approaches, which is also addressed in the literature as an area deserving more attention (e.g. Jardine et al., 2006; Yam et al., 2001). Therefore, the third research objective is:

**RO3.** To explore and explain the relevant factors that influence the implementation of condition based maintenance technology for process improvement.

According to the research objective this part of the thesis consists of an exploratory and explanatory part. Chapter 4 describes the exploratory part. Stork GLT’s condition based maintenance practices are investigated using a single embedded case study in which a heat exchanger and an ion exchange module are investigated. Based on this investigation a typology of the various condition based maintenance approaches is developed consisting of two dimensions: (i) the method for obtaining the expected value or trend in the condition monitoring data (i.e. analytical models and statistical models) and (ii) the type of condition monitoring data used (i.e. process data and failure data). In the case study also a set of requirements was identified. For example the use of statistical models with failure data requires sufficient knowledge of the process. Since the typology is based upon empirical study, it is subsequently tested against a large sample of academic condition based
Chapter 5 describes the explanatory part. It was found that most of the literature on condition based maintenance focuses on mathematical models or on the application of a model in a single instance (e.g. the condition based maintenance of a filter system using the difference in pressure between incoming and outgoing gasses). Hardly any empirical evidence has been published so far on the managerial aspects of condition based maintenance, for instance on the program level (e.g. how to make condition based maintenance an integral part of maintenance strategy covering an entire plant), or on the obstacles companies face while implementing condition based maintenance. We were interested in how the results of the exploratory part (i.e. the typology and its requirements) and a set of related assumptions found in the literature (e.g. use of specific process engineering knowledge requires training) would hold in practice. The typology, requirements and additional assumptions were developed into 8 postulates. The postulates were structured according to a well-known conceptualization of management of technology that states that management of technology involves the technical system, the managerial system and workforce knowledge (see Carrillo and Gaimon, 2004; Gaimon, 2008; Meredith, 1987). We investigated these postulates in a multiple case study in the process industry, including Stork GLT, and found mixed results as to which postulates appear to hold true.

1.5.4 Managerial incentives for process improvement

In section 1.3 and 1.5.1 the importance of contracts to stimulate certain firm behavior was underlined. In the case of Stork GLT, the contract formalizes how the firm is paid for work that is carried out. It also stimulates process improvement (with the aim of reducing cost) due to the repeatability gains: the project budget for the renovation of a batch of production locations is lower compared to the previous batch. Another way of stimulating process improvement is through the budget incentive: when project execution cost is within budget, Stork GLT receives a certain percentage of the difference between budget and cost.

The use of contracts to stimulate firm behavior inspired us to initiate a research project on the fourth and final research theme: the use of incentive contracts for process improvement. Process improvement has been studied from operational to strategic angles. The strategic aspects of process improvement have been well-covered in the industrial organization literature (e.g. d’Aspremont and Jacquemin, 1988; Rosenkranz, 2003). However, several research issues remain somewhat underexposed. Two of these will be addressed in this thesis. Firstly, the existing body of literature is not paying much attention to the managerial systems that can be used to stimulate pro-
cess improvement undertakings (cf. Carrillo and Gaimon, 2002). Particularly the use of managerial incentives (i.e. the incentive contracts given to firm managers) as a way for firm owners to strategically commit themselves to process improvement has not received much scholarly attention. Secondly, fine-grained approaches to strategic interactions between firms are lacking. In particular, many studies assume models wherein firms are inherently equal so that the role of any relevant firm-level difference cannot be well understood. An important extension of the literature would be to study optimal process improvement decisions when differences between firms exist (for example differences in the ‘ease’ with which firms implement process improvements). Based on these considerations, the fourth and final research objective can be defined as follows:

RO4. To describe and analyze optimal managerial incentives for process improvement, considering competition between heterogeneous firms.

In order to gain a good understanding of the exact workings of managerial incentive contracts in this type of context we reside to a stylized mathematical model. This is described in chapter 6. Mathematical models in operations management are based on the assumption that objective representations can be constructed that reflect actual decision making problems faced by operations managers (Bertrand and Fransoo, 2002), and that predict what optimal decisions look like (Wacker, 1998). The focus will be on the investment decision in process improvement when a manufacturing manager faces competition with firms that have different cost structures, and on the question what the effects of certain managerial incentives are on these process improvement decisions\(^4\). When competition plays a role, a well-known approach to describing this problem is non-cooperative game theory (e.g. see Cachon and Netessine, 2005). A game-theoretic model is constructed that reflects the decision-making behavior of two owners of competing manufacturing firms and the key managers of these firms. In other words, we study the behavior of two owner-manufacturing manager pairs in competition. A firm owner offers an optimal incentive contract to his manufacturing manager, which includes a monetary reward for realized process improvements. Through such incentive contracts, a firm owner strategically commits himself to process improvement. In the competition stage that follows, both manufacturing managers make strategic decisions (i.e. production quantities supplied to the market and process improvement levels) based on the process improvement cost parameters they observe. These parameters reflect

\(^4\)In chapter 6 we describe a generic model. The applicability of the model and our findings for EPCM contractors are discussed in chapter 7.
the efficiency of process improvement investment. Since process improvement generally increases the optimal production, the process improvement incentive contract indirectly influences production quantities as well. An interesting question would be how such contracts influence the rival’s decisions in terms of incentive contracts, process improvement and production quantities. By explicitly modeling and analyzing process improvement cost differences, this research deviates from the standard economic approach to modeling these types of situations, namely where firms (and their relevant costs and decisions) are assumed to be perfectly symmetric.

1.6 Thesis outline

The chapters included in this thesis are based on journal articles that are either published, accepted for publication, or in preparation for a second-round review. The following articles are included in this thesis:


Finally, Chapter 7 includes a summary of the main findings and a discussion section.

1.7 Note on terminology in this thesis

The chapters of this thesis are written as journal articles. They are kept in their original form as much as possible, using the original terminology. This necessitates three clarifications: (i) ‘engineer-to-order firm’ (see chapter 2) and ‘EPCM contractor’: whereas EPCM-contractors naturally deliver products on an engineer-to-order basis, the reverse is not always true. Not all engineer-to-order firms control the entire asset lifecycle as EPCM-contractors do. (ii) ‘Capital goods’ (see chapter 3) can be read as ‘assets’. (iii) ‘Process innovation’ (see chapter 6) and ‘process improvement’ can also be read interchangeably.