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A Framework for Analysing Contracting Strategies: Studies on Maximising Paper Production Line Life Cycle Profits

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Abstract

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Keywords: Profitability, Cost and performance, Modelling, Contracting, Product life cycle

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Increasing market competition forces firms to improve profitability, and outsourcing and partnership contracts are some of the essential means of pursuing cost efficiency. Comparing the profitability of alternative contracting strategies, however, is a difficult managerial decision-making problem.

The primary aim of the study is to develop a framework for analysing the total profitability of alternative contracting strategies. This framework attempts to capture the relationship between the costs and performance of alternative contracting strategies as well as to provide normative results to support managerial decision-making.

The thesis is based on three main elements. First, an extensive literature study is made of measuring cost structures and performance in the paper industry, followed by a discussion of paper industry development trends and the resulting effects on contracting strategies. On the basis of this study, a framework to model costs and performance of alternative contracting strategies is constructed. Second, the accuracy and reliability of the developed framework is validated with empirical data of Finnish paper companies. Third, the usefulness of the model is tested by means of an imagined, real-like managerial decision-making process in which the profitability of three different contracting strategies to implement paper production is compared.

The contribution of the thesis can be divided into two elements. First, the constructed modelling framework reveals the effects of the performance and costs of production inputs on total profitability in alternative contracting strategies. Second, the results of the thesis challenge practitioners and scholars to work towards unification of predominant theories regarding the measuring of *total profitability* instead of fine-tuning only parts of the measuring process. These two elements might also imply new business opportunities for able firms.

On the basis of the discussion in this work, a few potential research questions can be formulated for future studies. First, developing the introduced model further and unifying central microeconomic theories with it remains as the main direction for future research. Second, the modelling framework should be further tested in real-world decision-making situations as the empirical validation results suggest that the model gives quite realistic results.

Preface

To be educated, a person doesn't have to know much or be informed, but he or she does have to have been exposed vulnerably to the transformative events of an engaged human life.

- Thomas More

Intellectual curiosity has spurred me on my whole life. I owe gratitude for this mindset to my mother Marja-Liisa and my late father Reino as they have supported and encouraged me to pursue in life whatever I consider worthwhile.

I feel privileged for being involved with so many different projects and firms during my career. These appointments have guided me during my career by offering new challenges, thus inspiring me to carry on with my studies in new disciplines and to look at the world from different viewpoints.

Uncountable number of people has given their contribution to this research. I would like to express my gratitude to my supervisor Professor Erkki Uusi-Rauva, Dr. Petri Suomala, and everyone at Department of Industrial Management for their guidance and support on the path of management research. I am indebted to Jari Vähäpesola, Senior Vice President of Metso Paper for letting me prepare this thesis among other duties. I also wish to express my gratitude to Jari Hangasluoma of UPM-Kymmene Corporation, Ilkka Lumme and Esko Vörgren of M-real Corporation and Dr. Christian Behnke of Myllykoski Continental for their valuable comments and time in discussing paper industry practices and model validation tests with me. Without Your involvement this work could not have been built on as solid basis as it is now.

The pre-examiners of the work, Docent, Dr. Jyrki Ahola (Senior Advisor (ret.), UPM-Kymmene GHO Finance) and Docent, Dr. Kari Komonen (Chief Research Scientist, VTT Technical Research Center of Finland) have helped me significantly in developing the manuscript with their valuable comments. I am thankful for their involvement and helpful advice.

Listing of all the people who contributed to this work would be impossible. All of my former colleagues at Metso Paper have given me support by sparring me during the writing process, but my closest colleagues and friends Marko Kinnunen, Vesa Kuusio, Mika Uusitalo and Timo Vuorimies made this quest enjoyable and even fun.

Finally; Tuuli – thank you for everything.

Järvenpää, Finland
August 8, 2008

Juha-Pekka Koskinen

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1. Introduction

Can you measure it? Can you express it in figures? Can you make a model of it? If not, your theory is apt to be based more upon imagination than upon knowledge.

- Lord Kelvin

Recent development in the paper industry[1] can be interpreted as a signal of the industry reaching a declining phase in some market areas (Pöyry FIC 2006). This development has also endangered some of the core assets of paper machine technology suppliers, namely the product and process knowledge accumulated during their operating years. Furthermore, the markets for new paper machine installations are also decreasing, thus challenging paper machine technology suppliers to find new business opportunities built on utilising their protected assets and core competencies. Paper machine maintenance contracts (Kuusisto et al. 2005, p. 47) and asset (or *Installed Base*) management services serve as good examples of such business opportunities, to name only a few.

One might ask if the roles of paper companies and technology suppliers need to change. This is one of the fundamental questions of this research along with the additional question of *how* contracting between them should be implemented. The fundamental paper-making activities and decision-making accounting settings combined with the resource-based approach (Day 1994) provide a solid basis for delving into the topic. Increasing market competition has caused a demand for higher Installed Base availability, and a demand for *availability guarantees* for the machines has gained emphasis in new machinery investments. All contracting parties, however, need to control the risks associated with these ventures in the competitive environment. Williamson (1985, pp. 47-48) brings up the problem of self-interested behaviour between contracting parties. Examples of such behaviour are easily found in the insurance business, where the insurer may be exposed to lack of adequate information on a candidate's true risk likelihood *ex ante*, or where the insured acts incautiously, leading to unnecessary claims *ex post*. Thomas and Rao (1999) mention controlling the process of maintaining service costs to cover warranties (i.e. insurance) over time as the most vital risk for the insurer.

Quite clearly paper machine technology suppliers have an incentive to integrate forward to position themselves as suppliers of paper *production* functions instead of just physical and intellectual assets and, respectively, provide new possibilities for paper companies to focus on in developing *their* core competencies. However, comparing the profitability of managing mill functions with alternative contracting strategies is a difficult managerial decision-making problem. Developing a framework to analyse the profitability of alternative contracting strategies will hence be the central question addressed in this thesis.

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[1] The term *paper industry* refers hereafter to pulp, paper and board industries unless otherwise mentioned

1.1. Fundamental Processes and Machines in Paper-making

Paper production requires a wide spectrum of activities (Britt 1964), as Figure 1-1 illustrates. Forest management constitutes the basis for all forestry end products, such as paper and cardboard. Geographic limitations strongly affect the supply of raw material and thus have a direct effect on the end product costs. Further on, harvesters are needed to collect the wood from the forest and the delivery of raw materials for further processing is accomplished using logistics services. Further processing of raw materials utilises specialised machinery to produce products such as pulp and timber, which are further used as inputs for other products with higher added value. Pulp, chemicals and water are the main inputs for paper, cardboard and board production.

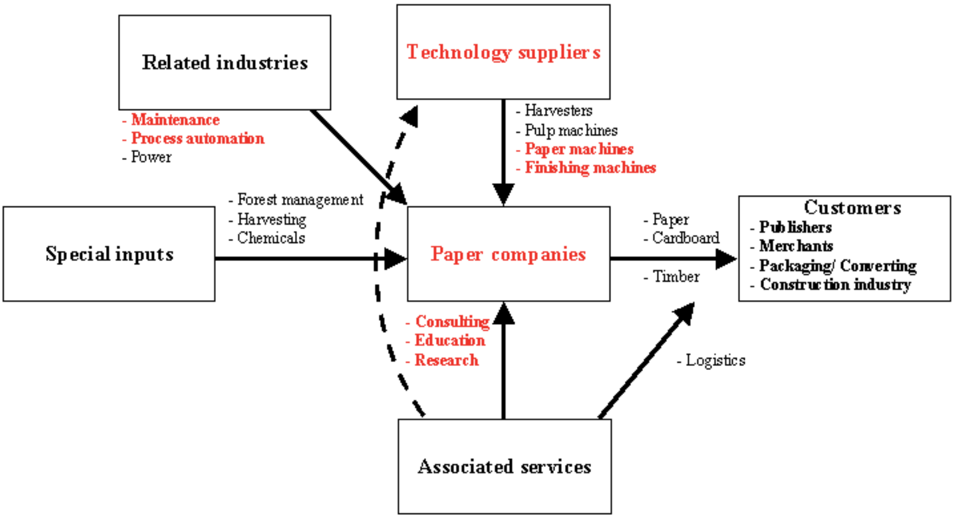

Figure 1-1. Chart of forest cluster products, assets, activities and firms. Functions coloured in red are discussed in more detail in the thesis.

Paper production is a delicate business. Despite the seemingly straightforward processes and machines, it takes several years of experience to manage the necessary functions in order to set up a *single production line* efficiently. Quite extensive infrastructure, such as waste management, factory buildings and roads, are needed to facilitate paper production at the paper mill. Figure 1-2 illustrates practically all paper-making related machines, including *wood handling, chemical and mechanical pulping*, *stock preparation*, *recycled fibre*, *paper/ board/ tissue machines* and *finishing machines*.

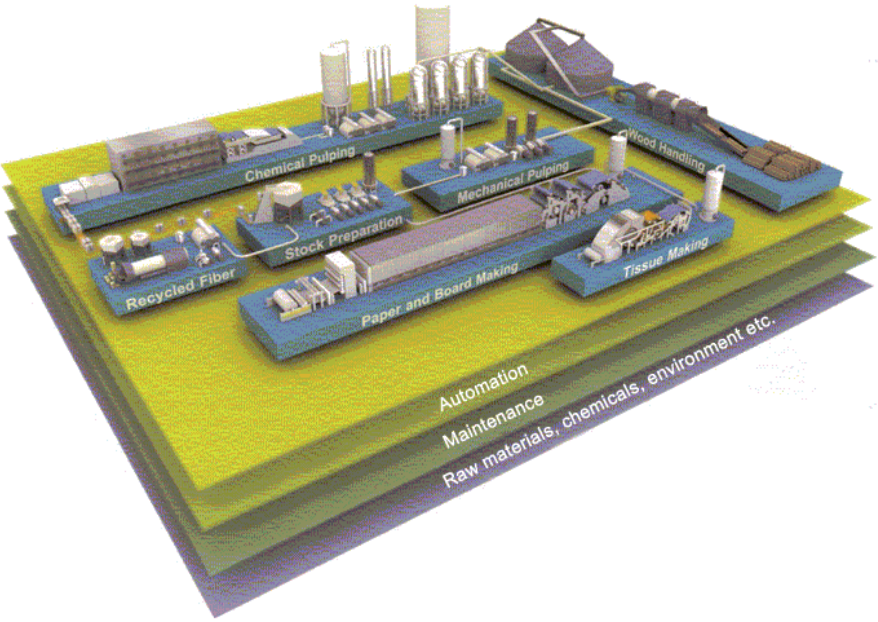

Figure 1-2. Characterisation of a paper mill (KnowPap 8.0 2006).

Pulp, chemicals and other raw materials play an essential role in the paper-making process. Deviations in the quality of these production inputs have a strong impact on the paper quality as well as on paper production line runnability and maintainability. The actual paper-making process at the paper mill begins with stock preparation and ends at the finishing section, as Figure 1-3 illustrates.

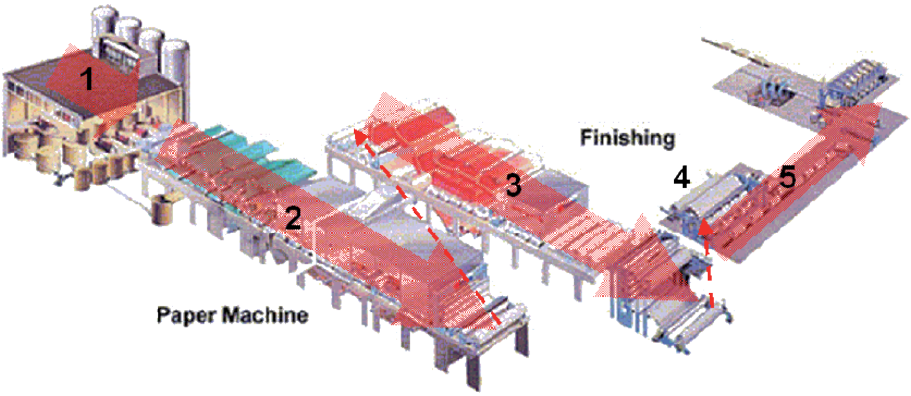

Figure 1-3. Paper-making main process (KnowPap 8.0 2006). The red arrows indicate the direction of the paper-making main process: stock preparation, water systems and broke collection (1), paper machine (2), finishing section (Off-line concept) (3), winder (4) and roll handling (5). Dashed arrows indicate conveyer systems, which carry the paper rolls from one section to another.

Stock preparation, *water systems* and *broke collection* are used for processing raw materials, e.g. pulp, wood, chemicals, etc., into the proper form for the paper machine. The purpose of broke collection is to collect redundant process waste (i.e. "leftover paper") from the production line and re-use it in the process. The structure of stock preparation, water systems and broke collection depend on the pulp delivery concept, the produced paper grade and the maturity of the technology. *Paper machine* mainly processes a liquid mixture of water, fibres (from pulp) and chemicals into dry form, i.e. paper, by extracting water from the mixture during the paper-making process. This *dewatering process* consumes a lot of energy. The structure of the *finishing section* varies for different paper grades. For coated paper grades, the finishing section includes machines that apply a coating (chemicals) to the base paper coming from the paper machine. This improves some preferred characteristics of the paper, such as printing quality or stiffness. This so-called *coating section* can be either an *On-line concept* where the coating machines are interleaved with the paper machine or an *Off-line concept* where the coating machines are independent of the paper machine (as in Figure 1-3). Especially in the case of an off-line coating concept, *reels* are needed to reel the paper from the paper machine onto rolls, which are then delivered to the off-line coating section (step 2 to 3 in Figure 1-3). Other finishing machines, *winders* and *roll handling*, are needed to prepare the paper for delivery to paper wholesale companies and other customers. All the above-mentioned machines comprise the *machine automation* for controlling the overall process and individual machine functions. Modern paper production lines incorporate extensive automation, which sets high demands regarding the mill crew's technical expertise. Even though the definition of paper production line varies in the literature (Britt 1964; MacDonald and Franklin 1970), the term *paper production line* is defined in this thesis to cover only paper and finishing machines, including the machine sections between headbox and winder.

1.2. Organisational Models for Managing Paper Mill Activities

A firm has the freedom to choose the appropriate organisation for its purposes. In the case of a paper company, the firm must in any case ensure that the machines introduced above, i.e. the *Installed Base*[2], are run efficiently at the mill and that the mill is capable of satisfying market demands (Bleuel and Patton 1986, pp. 92-116; Kelly 1984; Komonen 1998, pp. 17-19). Usually these tasks require organisational models at both corporate and mill-level. Figure 1-4 illustrates the main functions at paper mill-level.

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[2] *Asennettu laitekanta* in Finnish

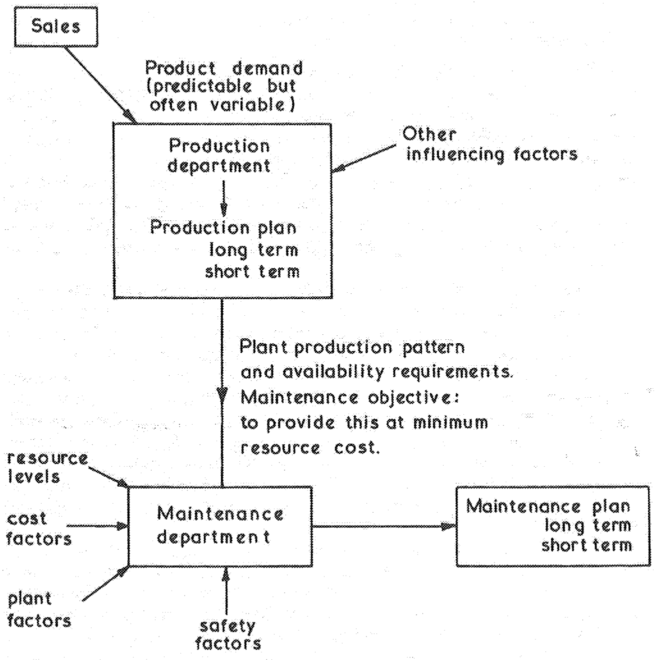

Figure 1-4. Characterisation of paper mill organisation and its functions (Kelly 1984, p. 18).

The term *sales* is ambiguous. Sales may refer to corporate-level sales as well as to mill-level sales, depending on the applied corporate organisation model. However, regardless of the organisation model, the purpose of sales is to bring money to the mill (and corporation) in order to generate profits and to provide capital to cover the mill's operating costs. On mill-level sales function can practically adjusts only two variables, namely paper grade and annual production plan, given that *technology*, i.e. machine design at a specific mill, makes it possible to produce several grades. The change of paper grade is also reflected in operating costs as it involves a change in the used raw materials. Hence, producing the same amount of paper using different paper production lines (or mills) incorporating different production technology may involve unequal production costs and thus unequal profit.

The *production department* manages the mill's production functions. In brief, the production department is in charge of keeping the production line(s) running in such a way that the amount and quality of paper sold to customers is available for customer delivery. This task requires the production line to be in effective production with a planned production capacity for a planned production time. The capacity of the production line depends directly on the machine design, while the actual throughput, i.e. produced tonnes of paper, depends mostly on the expertise of the production department personnel, i.e. *mill crew*. The role of the mill crew is to control the paper-making process and to adjust the different process parameters to ensure optimal production and quality of paper. In fact, the mill operating conditions are in continuous change as the quality of produced paper depends on the quality of the process inputs, e.g. chemicals, water, pulp, etc. Furthermore, it may be commercially reasonable also to change paper grades over time, which puts pressure on the mill crew expertise.

The mill's *maintenance department* manages cleaning, maintenance development, mill shutdown planning and implementation, daily maintenance, spare part operations and document management of the mill's Installed Base. Mill maintenance functions also include investment and planning of (minor) machinery rebuilds. These functions make it possible for the production department to guarantee planned production capacity with minimal costs.

Spare part functions are needed in the maintenance department to secure delivery of proper Installed Base parts to the production line. Additional resources worth noting are *training*, including updated *operating* and *service instructions* (Kelly 1984, pp. 170-184; Juva and Gustavson 1996, p. 12), and technology suppliers' *technical backup* in securing optimal paper production operations.

Paper companies develop their organisation to suit their purposes. Hence, the actual organisation varies considerably between different mills. Four basic types of maintenance management organisation, discussed for example in (Juva and Gustavson 1996, p. 45), are illustrated in Figure 1-5.

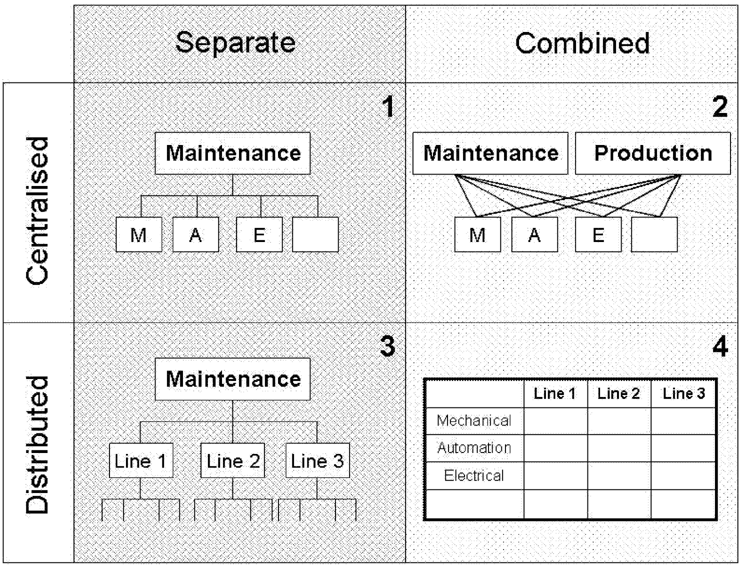

Figure 1-5. Typical basic types of mill maintenance management organisation (adapted from Juva and Gustavson 1996, p. 45).

Although the maintenance cost share of paper companies' annual net sales is only c. 6 % (Komonen 2002, p. 3), the manner in which maintenance is managed has a strong impact on the mill's organisational structure. The maintenance department can either be combined with the production department (cases 2 and 4 in Figure 1-5), or they can be separate departments (cases 1 and 3 in Figure 1-5). In the case of combined maintenance and production departments, the organisation may be managed under *centralised management* (case 2 in Figure 1-5) or by a *matrix organisation* (case 4 in Figure 1-5). When maintenance and production departments are separate, they may be managed as *functional organisations* (case 1 in Figure 1-5) or as *distributed organisations* (case 3 in Figure 1-5). All of these models have advantages and drawbacks, and the essential difference between these models is whether production and maintenance are taken as separate or combined functions.

1.3. Research Goals and Scope

Several paper companies have recently been outsourcing some of their paper mill functions. Most of the outsourced functions can hardly be considered as paper companies' core business and must hence be interpreted as a means of reducing overhead costs and increasing short-term profitability. This evidence supports Toivanen's (2005) remark that the paper industry is becoming more and more competitive, and it also supports the strategic management options for declining industries suggested by Porter (1998b, pp. 267-271). On the other hand, this development is not new, as several well-known paper companies have regularly developed themselves by integrating functions, or by divesting of these, to achieve higher profitability (Komonen 1998; Lamberg et al. 2006; Ojala et al. 2006). Although several real-world attempts have been made to improve profitability in the paper industry by means of contracts between firms, few or no studies have been published which describe how the parties in question co-operate in joint decision-making. Lamberg et al. (2006) discuss the strategic reasons for forest industry evolution and approach contract issues by means of the theory of games (Lamberg et al. 2006, pp. 225-256). However, they fail to describe the decision-making setting leading to an actual decision whether to co-operate or compete. A more pragmatic study by Koskinen (2004) on improving maintenance and spare part functions suggested that some regularity exists in the spare part order backlog of paper machine technology supplier. These results also implied that there are new business opportunities in outsourcing the spare part functions of paper mills, but the financial significance of such services to the paper mills could not be assessed. Instead, Komonen (1998, p. 170) presents several interesting scenarios where outsourcing is attractive in terms of maintenance profitability. Komonen (1998, p. 171) also points out future research topics, one being assessing the total profitability of different outsourcing strategies.

Hence, the aim of this thesis is to develop a mathematical modelling framework for analysing different contracting strategies from the point of view of life cycle profits (LCP) for use in the managerial decision-making process.

No studies have yet been published which asses the total effects of alternative contracting strategies at the paper production line level. A few concepts and theories are also addressed in this thesis to justify the development of the modelling framework. These include

- *Introducing the business field of study,*
- *Reviewing performance indicators in the business field,*
- *Identifying relationship between utilisation of a firm's assets and its financial performance and*
- *Identifying the effects of industry development trends on market competition.*

In order to characterise strategic decision-making situations in the management of paper production line life cycle, a mathematical modelling framework will be developed. The modelling methodology utilises *transaction cost economics*, a methodology developed by Coase (1937) and later refined by Williamson (1985), who studied the significance of different contracting models for transaction costs during inter-organisational transactions. Transaction costs may be taken as an economics counterpart of *friction* in the physical sciences. Harrigan (1988) suggested that the forms of co-operation between industries and firms are dictated by prevailing situations in them, and hence this thesis combines elements from transaction cost literature, strategy and tacit knowledge of the Finnish paper industry. The modelling methodology could be used in analysing contracting strategies in other industries as well, even though the model itself should be developed case-specifically. Furthermore, this thesis addresses the identification of the circumstances under which the analysis model can be utilised in practice, and discusses the drivers of the paper industry's global business development.

The developed model is validated with real-world data from several paper production lines. The validated model is then used in analysing an imagined, real-like decision-making situation concerning choosing a contracting strategy which maximises the life cycle profits of a paper production line. Results from this imagined, real-like analysis are then used to describe the effects of contracting on paper companies and paper machine technology suppliers[3].

1.4. Field of Research and Research Paradigms

This thesis seeks to develop a methodology to analyse the profitability of different contracting strategies in delivering paper industry core activities with a view to increasing profitability in the industry. This target positions the research in the field of industrial management. Especially in management sciences where the research problem contexts are typically wide, it is more common to utilise a mixture of *research paradigms* than to use merely one paradigm (Olkkonen 1994, pp. 80-81).

There are several research paradigms available for studying the problem at hand. The selection (or better still, *emphasis*) of research paradigms depends greatly on the data available on the problem, knowledge of the problem and expectations

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[3] *Paper machine technology supplier* refers to an actor specialised to manufacture of paper and finishing machinery, not to a supplier of separate components or systems.

regarding the research results (Olkkonen 1994, p. 64). Olkkonen (1994, pp. 65-81) categorises research paradigms into *concept-analytical*[4], *nomotetic*[5], *decision-making methodological*[6] and *action-analytical*[7] *paradigms*. The purpose of the concept-analytical paradigm is to conceptualise an ambiguous research problem, yielding as an output a descriptive, theoretical model of the problem. Validation of the model is generally achieved by evaluating the model in numerous cases in the field of application, thus seeking to find empirical evidence of the model's validity for real-world problems. The nomotetic research paradigm seeks to discover causality or correlation between parameters in empirical data and as a result present a model to characterise these dependencies. Validation of the model is generally achieved by applying statistical methods to the empirical data. The decision-making methodological paradigm is generally used in developing mathematical methods to support managerial decision-making. The output of the paradigm is generally a normative model to support decision-making or a model which can be used in evaluating the effects of some managerial decision(s). Furthermore, the research paradigm is used to refine earlier knowledge on the research problem in a more exact form, thus attempting to theoretically generalise the earlier views on the problem. The scientific contribution of the model is usually evaluated in terms of the model's usability, i.e. whether it is more reliable, faster, or more elegant solution to the problem than earlier solutions. Finally, the action-analytical paradigm is often applied in problems where objectively measurable data on the problem are not available, and where the researcher's experience of the problem plays an essential role in interpreting data. The output of the action-analytical paradigm can be a hypothesis, a theory, or even a normative instruction. Validation of the research results is empirical, and eventually the contribution of the research appears *ex post* upon discovery of possible practical benefits of the research results. In addition to Olkkonen's (1994) classification, other classifications of research paradigms have been made as well (Neilimo and Näsi 1980; Kasanen et al. 1991). The *constructive research paradigm*[8] (Kasanen et al. 1991) is a significant paradigm in management research and it pursues the development of decision-making methods in the case of management problems. The constructive research paradigm sets out from the research problem and seeks to either solve or develop methods for solving the original problem. The proposed solution and its generality are then validated empirically.

The expected main results of this research is a general mathematical modelling framework to support the managerial decision-making process when choosing the "best" contracting strategy for a specific real-world managerial problem. Development of the modelling framework was inspired by current managerial topics in the paper industry and hence the practical implications of the theories are emphasised in this work. Ijiri (1965, p. 52) mentions that the model should be useful to its (intended) users, and Ijiri and Jaedicke (1966, p. 483) emphasise *finding the correct balance between objectivity (reliability) and usefulness of the model*. Olkkonen (1994, pp. 51-52) points out that the testing of theoretically

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[4] *Käsiteanalyyttinen tutkimusote* in Finnish
[5] *Nomoteettinen tutkimusote* in Finnish
[6] *Päätöksentekometodologinen tutkimusote* in Finnish
[7] *Toiminta-analyyttinen tutkimusote* in Finnish
[8] *Konstruktiivinen tutkimusote* in Finnish

derived models using empirical examples is common in management sciences. Balancing between objectivity and usefulness is strongly present in this research, too, and hence this research combines empirical data and assumptions with theory, as Figure 1-6 illustrates.

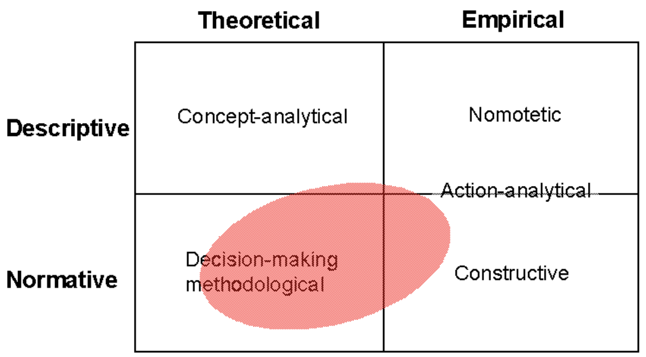

Figure 1-6. Different research paradigms and positioning of the research (red figure).

The decision-making methodological paradigm is mainly utilised in this work, and the desired output result is a normative model. However, lack of objective measurements of the research problem hinders the use of the decision-making methodological paradigm and therefore other paradigms are needed to define an exact model of the problem with the aid of earlier empirical research as well as subjective knowledge. Furthermore, the developed modelling framework is tested with available empirical data and its usefulness is also tested with imagined, real-like decision-making scenarios from the paper industry. The attempt to clarify the research problem from the pragmatic point of view adds something of the action-analytical and concept-analytical paradigms, while constructing the model using empirical knowledge of paper production is really an example of the nomotetic and constructive research paradigms. However, the lack of reliable empirical data limits the use of these research paradigms.

1.5. Research Structure

Since this research attempts to follow closely the decision-making methodological paradigm, the structure of the thesis follows the typical structure of a research on decision-making methodology (Olkkonen 1994, pp. 70-71). Figure 1-7 presents the structure of the research as well as the balance between theory and practice in the different chapters.

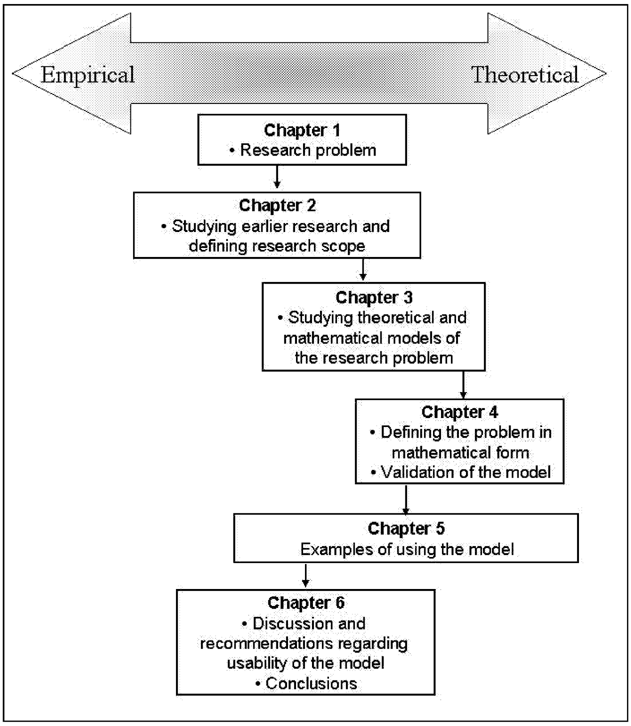

Figure 1-7. Research structure.

Chapter 1 introduces the research problem, the goals and scope of the research and its structure. Chapter 2 reviews earlier research on the evolution of the paper industry and its core functions to provide a basis for developing the modelling framework. The paper industry's main actors from the point of view of the scope of the thesis and a summary of the development of the world paper market are also presented in chapter 2. Chapter 3 introduces different mathematical modelling options for studying and comparing alternative business strategies and thus provides the basis for using mathematical modelling tools appropriately. Accordingly, the modelling methodology is developed in chapter 4 and the reliability (or *objectivity*, or *accuracy*) and sensitivity of the mathematical modelling framework is then validated with empirical data. The usability of the model is then tested with three examples by applying it in an imagined, real-like paper production line decision-making process in chapter 5.

Chapter 6 presents conclusions and recommendations derived from the main results and discusses the empirical benefits of these results. Chapter 6 also discusses the positioning of the thesis and its relevance to the research field.

2. Core Functions, Actors and Development Trends in the Paper Industry

This chapter introduces the background and development trends of the studied business field – paper industry. Maintenance models and managerial paper production organisation models are introduced first. Dominant performance measurement concepts are introduced next, followed by a review of the industry's main actors. The rest of this chapter focuses on analysing development trends in the paper industry and their impact on the main actors of the field.

2.1. Maintenance Models and Trends

Maintenance plays a central role in paper production line management and it could be defined as a mixture of actions needed to help a mechanical device to carry out or even cultivate its original function. There are several ways to conduct maintenance. One way is to divide it into improvements and into preventive and corrective maintenance (Bleuel and Patton 1986, p. 128). Komonen (1998, p. 13) further divides *preventive maintenance* into *predictive*[9] and *proactive maintenance*[10]. Figure 2-1 illustrates the relationships between the different maintenance models.

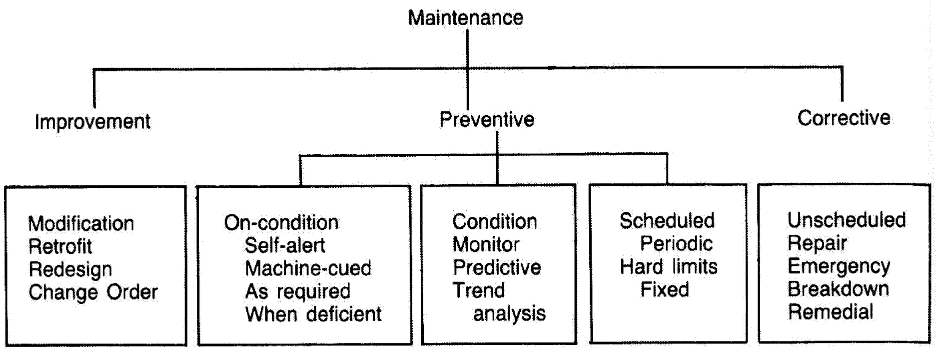

Figure 2-1. Maintenance relationships (Bleuel and Patton 1986, p. 128).

In practice, mill maintenance is managed with long- and short-term maintenance plans that consist of a balanced mixture of improvements and of preventive and corrective maintenance applied to a specific production line. The long-term planning is more strategy-driven and is generally governed by the investment return expectations. In a case where the investment returns are expected with a short time interval, the machines may be exploited to yield maximum tonnes within the short time interval. In such a case there might be no incentive to make further investments in the production line and increase the *replacement value*[11] of

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[9] *Ennustava kunnossapito* in Finnish (Komonen 1998, p. 13)

[10] *Ennakoiva kunnossapito* in Finnish (Komonen 1998, p. 13)

[11] *Jälleenhankinta-arvo* in Finnish

the production line Installed Base. Under such circumstances the long-term maintenance plan would most likely favour corrective maintenance, e.g. the repairing of only emergency faults, in order to keep the production line as efficient as possible while emphasising minimal cost level. Preventive maintenance seeks to predict machine failures by monitoring and analysing different machine parameters, resulting in a better understanding of risks that might jeopardise productive use of the production line. The increased awareness of risks improves resource management and maintenance planning at the maintenance department. Finally, improvements aim to solve production bottlenecks at the production line. An example might be substitution of a constantly breaking machine component that cuts down production time of the line and increases maintenance costs with a new machine component.

There are several ways to detect or anticipate machine failures. Bleuel and Patton (1986, pp. 131-134) divide maintenance detection methods into *manual, semi-automatic, automatic* and *integrated* methods. These methods mainly differ in labour intensity and the need of presence at the production line. Figure 2-2 shows the costs associated with these methods.

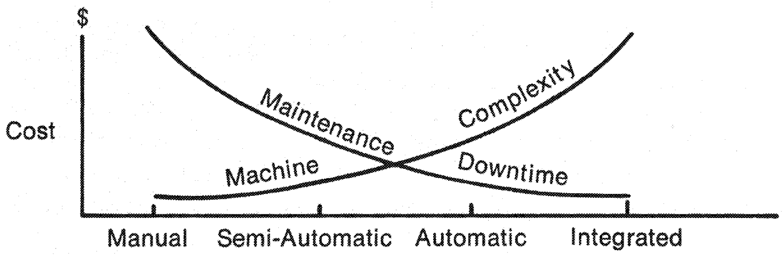

Figure 2-2. Cost relationships of different maintenance detection methods (Bleuel and Patton 1986, p. 132).

As shown in Figure 2-2, the unit cost of maintenance downtime decreases as production line complexity and predictive fault detection capabilities increase, but the unit cost of technology increases. However, it should be kept in mind that equal Installed Base efficacy might be attained with any of the above methods. Nevertheless, organisational and cost structures may still vary significantly, depending on several factors. The question asked by firms' management regarding the unit costs of assets could be phrased as follows: "What are the correct actions to make most profit with the current or available assets in a given time interval?"

Ensuring paper mill production requires a wide range of expertise and sharing of knowledge between different experts, including those in the field of finance and various areas of engineering. Today, most paper mills have been organised according to Figure 2-1 on page 12, and production and maintenance departments are managed either separately or combined (as seen in Figure 1-5 on page 6). No department or function alone, however, is capable of managing all mill activities independently. *Terotechnology*[12] (Kelly 1984, pp. 4-13; Komonen 1998, p. 15; Sherwin 1999) was adopted as a term to describe the (research field of) management of financial, engineering and other functions in the pursuit of economical life cycle costs of physical assets. Terotechnology thus encompasses management of all paper mill activities. Two common terms related to the concept of terotechnology are *Reliability Centred Maintenance*[13] *(RCM)* and *Total Productive Maintenance*[14] *(TPM)*. All of these concepts combine maintenance models of Figure 1-5 earlier on page 6 to improve the efficacy of maintenance in terms of cost efficiency and technical reliability. Beehler (1997, p. 1023) defines reliability as "*the probability that a system will perform a given function satisfactorily for a specified time under specified operating conditions*". System reliability must of course be balanced vis-à-vis quality and maintenance costs. Beehler (1997, p. 1023) specifies the fundamental and quite ambiguous goal of the RCM concept (Sherwin 1999), which is to "*preserve the function or operation of a system*", also *cost efficiently* (Sherwin 1999, p. 238), one might add. The four fundamental principles of RCM (Beehler 1997, pp. 1023-1024) are:

- Preserving system function,
- Identifying specific failure modes to define loss of function or functional failure,
- Prioritising the importance of the failure modes,
- Identifying effective and applicable preventive maintenance tasks.

RCM utilises Installed Base condition monitoring, data analysis and optimisation methods for identifying and predicting failures as well as achieving effective maintenance planning. Unlike Reder and Flaten (2000), Sherwin (1999, p. 238) criticises RCM for being a technical concept, as the criterion of RCM is the reliability of a paper production line's (or any system's) function rather than its economic efficacy. Sherwin (1999, p. 241) emphasises the role of maintenance as an economic issue and hence argues that good co-operation between technology suppliers and machine operators is an important factor in ensuring maximal *life cycle profit* (LCP) for the Installed Base. Furthermore, Sherwin (1999, pp. 243-244) suggests using the term terotechnology instead of RCM to signify maintenance management driven by *economic reliability*.

As discussed earlier, organisational structures (or boundaries) prevent the transfer of required skills and knowledge between organisations. Maggard et al. (1989, p. 13) define TPM as a "*conscientious, systematic, data based approach to skills transfer*". The original footing of TPM is in Japanese industry (Kelly 1984, pp. 303-306; Juva and Gustavson 1996, pp. 84-115, p. 164) and it seeks to bring different organisational structures closer to each other, for example the production and maintenance departments of a paper production line and to improve knowledge transfer between them. Secondly, TPM is an organisational change in which individual workers' expertise and personal commitment to the Installed Base are emphasised, as Figure 2-3 shows.

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[12] Based on the Greek word "terein" – *to guard or look after* (Kelly 1984, p. 5)

[13] *Luotettavuuskeskeinen kunnossapito* (Järviö 2000) in Finnish

[14] *Tuottava kunnossapito* (Juva and Gustavson 1996) in Finnish

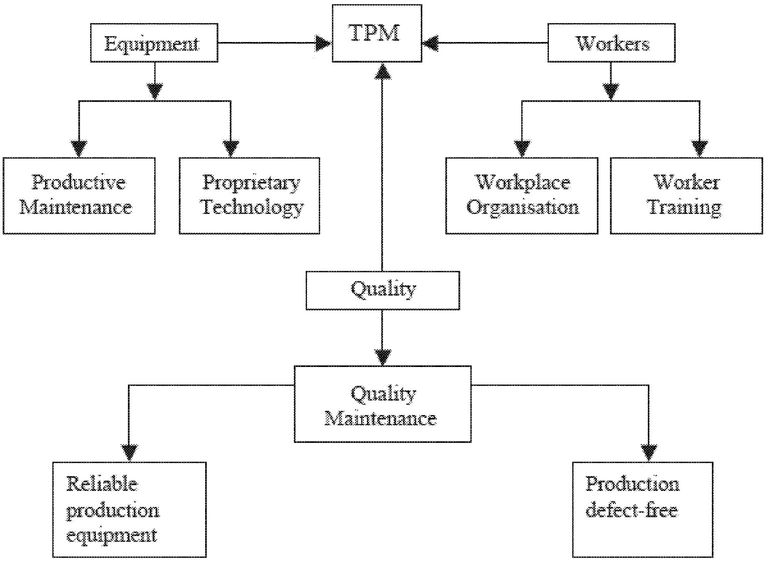

Figure 2-3. Key supporting elements of TPM (Chan et al. 2003, p. 74).

The three pillars of TPM, shown in Figure 2-3, are *quality, workers* and *equipment*. Quality incorporates the measurement of personnel expertise and equipment reliability, while equipment covers top design resulting in productive maintenance. The organisation of workers and their training can be optimised and standardised for similar machines throughout the firm. According to Chan et al. (2003, p. 72), the word *total* is used in referring to three things:

1. *Total effectiveness*, indicating the pursuit of economic efficiency and profitability with TPM,
2. *Total maintenance system* aiming at a '"maintenance-free"' design through the incorporation of reliability, maintainability and supportability characteristics into the design of equipment,
3. *Total participation of all employees* by accomplishing maintenance through a 'team' effort, with the operator being held responsible for the ultimate care of his/her equipment.

The first one refers to quality, the second to equipment and the third to workers in Figure 2-3. The above philosophy aims at maximising the overall efficiency of the Installed Base machinery, thus establishing a thorough system of preventive maintenance (PM) for the equipment's entire life span. Implementation of TPM straddles various departments in a company, involving all employees from top management to workers on the shop floor. The idea of TPM is to implement the preventive maintenance of a paper production line through ''motivation management'' in small groups who care for *their* production line. TPM also enables further optimisation and streamlining of processes (White et al. 2003). Komonen (2005) mentions that the significance of RCM and TPM is increasing in Finnish paper companies.

To summarise the contribution of chapter 2.1, some essential core functions of the studied business field were introduced and the relationship of alternative maintenance models with respect to Installed Base availability were also addressed. This suggests that a firm's strategy for managing physical and intellectual assets has an effect on its financial performance, too.

2.2. Indicators of Paper Production Line Performance

Paper companies as well as paper machine technology suppliers wish to measure the performance of a paper production line for financial, technological and referential reasons. The focus of this research is studying the production line level and hence the studied indicators are selected from this viewpoint. Generally speaking, the concepts of financial and physical indicators are quite often confused and the difference between these is described next.

Profitability[15], as defined by Uusi-Rauva (1997, p. 19), is the indicator of the financial efficiency of the firm. Profitability is, put most simply, the margin between a firm's income and expenses. In contrast, *productivity*[16] characterises the efficiency of the physical or real process. Productivity can be defined as the outcome of the process, such as annually produced tonnes of paper, with respect to given inputs[17]. Paper production, like other businesses, comprises both financial and real processes. Figure 2-4 shows the *financial purpose* for which paper is produced at the mill, more operative *targets* of paper production and finally both financial and physical *indicators* that are used in mill management to steer activities towards reaching the targets. *Customer satisfaction* is an important target in pursuing long-term profit, although measuring it analytically is difficult. However, measurable (physical) indicators of performance, reliability and maintainability should directly lead to repeated positive interaction between buyer and seller.

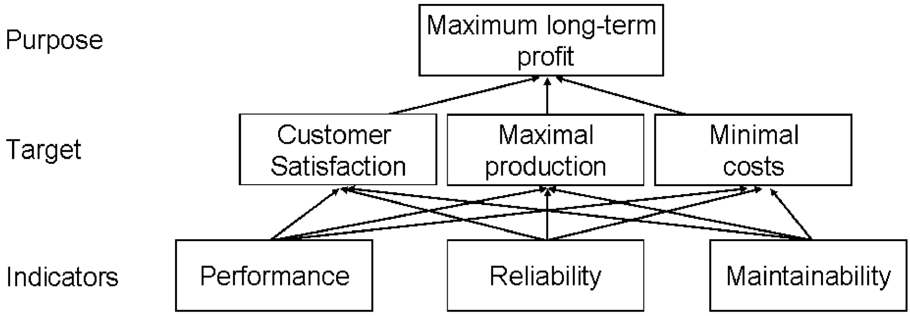

Figure 2-4. Financial objective in paper production, operative-level targets and indicators to measure achievement of the operative targets.

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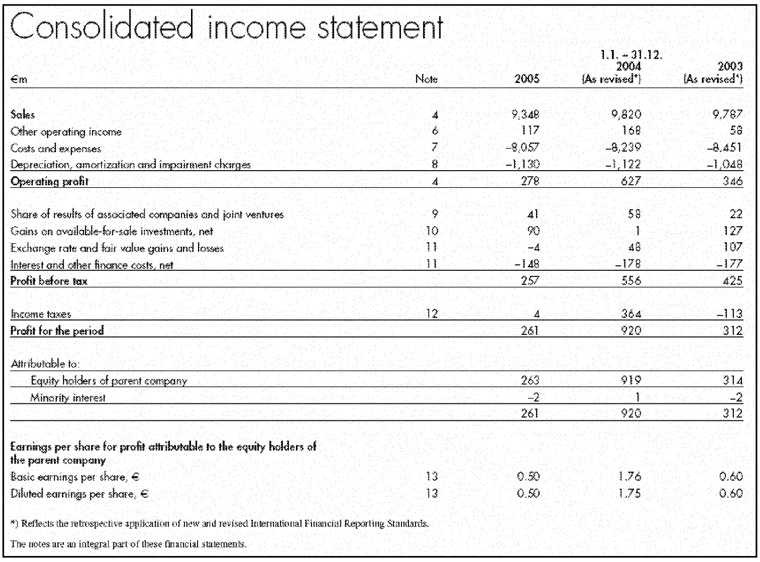
[15] *Kannattavuus* in Finnish
[16] *Tuottavuus* in Finnish
[17] *Panokset* in Finnish

A firm's *income statement*[18] mainly considers *financial performance indicators*. Income statements are usually reported in annual reports and they are typically *consolidated income statements*, such as the one in Figure 2-5, which cover *corporate-level* financial indicators of several individual mills and production lines instead of one. The purpose of an income statement is to provide reliable and comparable indicators of the firm's economic efficiency to the firm's owners, public authorities and investors. In accordance with the globalisation of business life, firms' income statements need to be globally comparable. This is pursued by means of accounting practice standardisation (Räty and Virkkunen 2004, pp. 23-26). UPM-Kymmene Corporation, for example, prepares its consolidated financial statements in accordance with *International Financial Reporting Standards* (*IFRS*) (UPM-Kymmene Annual report 2005, p. 66).



Consolidated income statement

€m	Note	2005	1.1. – 31.12. 2004 (As revised*)	2003 (As revised*)
Sales	4	9,348	9,820	9,787
Other operating income	6	117	168	58
Costs and expenses	7	–8,057	–8,239	–8,451
Depreciation, amortization and impairment charges	8	–1,130	–1,122	–1,048
Operating profit	4	278	627	346
Share of results of associated companies and joint ventures	9	41	58	22
Gains on available-for-sale investments, net	10	90	1	127
Exchange rate and fair value gains and losses	11	–4	48	107
Interest and other finance costs, net	11	–148	–178	–177
Profit before tax		257	556	425
Income taxes	12	4	364	–113
Profit for the period		261	920	312
Attributable to:				
Equity holders of parent company		263	919	314
Minority interest		–2	1	–2
		261	920	312
Earnings per share for profit attributable to the equity holders of the parent company				
Basic earnings per share, €	13	0.50	1.76	0.60
Diluted earnings per share, €	13	0.50	1.75	0.60

*) Reflects the retrospective application of new and revised International Financial Reporting Standards.

The notes are an integral part of these financial statements.

Figure 2-5. Consolidated income statement in UPM-Kymmene Corporation's Annual Report 2005 (UPM-Kymmene Annual report 2005, p. 62).

As Figure 2-5 shows, an income statement basically sums all of a firm's income and then subtracts expenses from it, thus yielding positive or negative profit for the considered period (one year, for example). The above income statement has three indicators of economic efficiency, and each represents the firm's profitability under different conditions. *Operating profit*[19] (*OP*) represents profitability, i.e. the economic efficiency of the firm's *core business*. The operating profit is the sum of *Sales*, *Other operating income*, *Costs and expenses* and *Depreciation, amortisation and impairment charges*, as Figure 2-6 illustrates.

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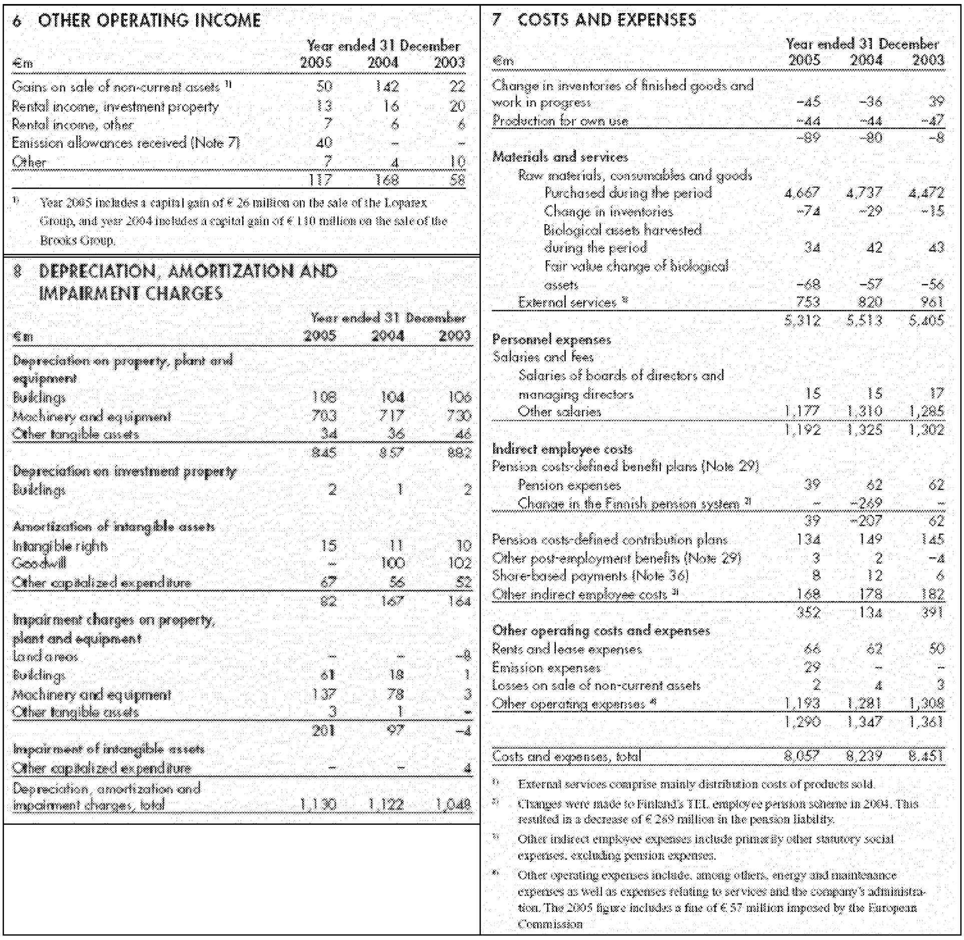
[18] *Tuloslaskelma* in Finnish

[19] *Liikevoitto* in Finnish



6 OTHER OPERATING INCOME

€m	Year ended 31 December 2005	2004	2003
Gains on sale of non-current assets [1]	50	142	22
Rental income, investment property	13	16	20
Rental income, other	7	6	6
Emission allowances received (Note 7)	40	–	–
Other	7	4	10
	117	168	58

[1] Year 2005 includes a capital gain of € 26 million on the sale of the Loparex Group, and year 2004 includes a capital gain of € 110 million on the sale of the Brooks Group.

8 DEPRECIATION, AMORTIZATION AND IMPAIRMENT CHARGES

€m	Year ended 31 December 2005	2004	2003
Depreciation on property, plant and equipment			
Buildings	108	104	106
Machinery and equipment	703	717	730
Other tangible assets	34	36	46
	845	857	882
Depreciation on investment property			
Buildings	2	1	2
Amortization of intangible assets			
Intangible rights	15	11	10
Goodwill	–	100	102
Other capitalized expenditure	67	56	52
	82	167	164
Impairment charges on property, plant and equipment			
Land areas	–	–	–8
Buildings	61	18	1
Machinery and equipment	137	78	3
Other tangible assets	3	1	–
	201	97	–4
Impairment of intangible assets			
Other capitalized expenditure	–	–	4
Depreciation, amortization and impairment charges, total	1,130	1,122	1,048

7 COSTS AND EXPENSES

€m	Year ended 31 December 2005	2004	2003
Change in inventories of finished goods and work in progress	–45	–36	39
Production for own use	–44	–44	–47
	–89	–80	–8
Materials and services			
Raw materials, consumables and goods			
Purchased during the period	4,667	4,737	4,472
Change in inventories	–74	–29	–15
Biological assets harvested during the period	34	42	43
Fair value change of biological assets	–68	–57	–56
External services [1]	753	820	961
	5,312	5,513	5,405
Personnel expenses			
Salaries and fees			
Salaries of boards of directors and managing directors	15	15	17
Other salaries	1,177	1,310	1,285
	1,192	1,325	1,302
Indirect employee costs			
Pension costs-defined benefit plans (Note 29)			
Pension expenses	39	62	62
Change in the Finnish pension system [2]	–	–269	–
	39	–207	62
Pension costs-defined contribution plans	134	149	145
Other post-employment benefits (Note 29)	3	2	–4
Shore-based payments (Note 36)	8	12	6
Other indirect employee costs [3]	168	178	182
	352	134	391
Other operating costs and expenses			
Rents and lease expenses	66	62	50
Emission expenses	29	–	–
Losses on sale of non-current assets	2	4	3
Other operating expenses [4]	1,193	1,281	1,308
	1,290	1,347	1,361
Costs and expenses, total	8,057	8,239	8,451

[1] External services comprise mainly distribution costs of products sold.

[2] Changes were made to Finland's TEL employee pension scheme in 2004. This resulted in a decrease of € 269 million in the pension liability.

[3] Other indirect employee expenses include primarily other statutory social expenses, excluding pension expenses.

[4] Other operating expenses include, among others, energy and maintenance expenses as well as expenses relating to services and the company's administration. The 2005 figure includes a fine of € 57 million imposed by the European Commission

Figure 2-6. Additional notes for calculating operating profit related to UPM-Kymmene Corporation's income statement shown in Figure 2-10 (UPM-Kymmene Annual report 2005, pp. 79-80).

Although the income statement above covers all business areas of the corporation, the operating profit can be calculated at a paper production line level, too. At this level it indicates the profitability of the paper production line under the examined period of time. The operating profit considers the value of capital in the physical assets of the firm, such as a paper machine, taking into account depreciation, amortisation and impairment charges (see Figure 2-6, note 8). The income statement, however, does not show a direct dependency between the paper production line's economic and physical efficacy.

The other two indicators of a firm's economic efficiency are *profit before tax* and *profit for the period*. Profit before tax characterises a firm's (or corporation's) overall financial strength as it indicates the economic conditions under which the firm operates. Two similar firms having the same OP, for example, might have unequal profits before tax; one firm might need loan capital to run its business, while the other one might receive additional income from having properly invested capital. Profit for the period, instead, links the firm to the society in which it resides. To give an example, two firms having equal profits before tax might yield different annual profits if the firms operate in different countries. In the context of this thesis, the interest is on the factors that affect the operating profit. Other economic indicators mentioned above are not discussed in more detail later on.

Productivity indicators encompass performance measurements of real processes and resources. In other words, productivity indicators attempt to measure the relationship between inputs and outputs of the production at the physical level. First of all, paper companies need reliable performance indicators at the production line level for efficient production planning. Mardon et al. (1991, p. 90) suggests that *maintenance*, *mill crew*[20] *capability and knowledge*, *technical backup*, and *process engineering and machine design* constitute a significant part of a paper production line's productivity. Several attempts to measure paper production line productivity have been made, and few of them have been adapted to use. Mardon et al. (1991) suggest that *absolute efficiency* outperforms *time-* and *operational efficiency* as a measure of a paper production line's productivity. The former signifies the total tonnes of paper shipped from the mill as a percentage of the mill's theoretical operating hours, while the latter two focus on the percentage of the total available machine operation time and the percentage of hypothetical production and tonnes of paper actually produced. The view presented by Mardon et al. (1991) reflects paper companies' worldview, but it fails to provide an objective indication of the efficacy of maintenance or spare part operation inputs with respect to a paper production line's total productivity. Measurement of these inputs and their significance for productivity is important in a case where an outside firm delivers these functions. Lost production (time) can, in fact, be due to several causes, but the external service provider might only have control over a few of these causes. To overcome this problem, an objective indicator to measure efficacy of maintenance, spare part and other operations directly affecting the technical *availability*[21] of the production line is needed.

Several indicators to measure the technical efficiency of a paper production line have been developed (Kelly 1984; Bleuel and Patton 1986; Mardon et al. 1991; Komonen 2002b; Airola et al. 2005). The most common of these are presented next, although their definitions seem to vary depending on the reference used.

Availability (A) is given by equation Eq. 2-1:

$$A = \frac{t_{production}}{t_{production} + t_{MB}}, \qquad \text{(Eq. 2-1)}$$

where $t_{production}$ equals the time a paper production line is expected to produce paper according to an annual production plan, and t_{MB} equals the total time used for maintenance breaks, *including planned and unplanned breaks* (Kelly 1984, p. 64; Airola et al. 2005, p. 14). Komonen (2002b) mentions that availability is

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[20] By *mill crew* Mardon et al. obviously mean all personnel working at the paper mill, e.g. both production and maintenance departments' personnel

[21] *Käytettävyys* in Finnish (Juva and Gustavson 1996, p. 27)

reported by 74 % of Finnish paper companies as (one of) their efficiency indicator(s). Availability (Eq. 2-1) makes a good indicator when the worldview of the paper companies is considered. This is quite reasonable as the indicator measures exactly how much the production line is unavailable because of *technical maintenance issues*, regardless of the actors (i.e. firms) performing them. Furthermore, the significance of "lost" production time is directly reflected to the number of produced tonnes.

Another indicator, *Overall Equipment Effectiveness (OEE)*, has recently become popular in Finnish paper companies (Komonen 2002b; Komonen 2002b; Airola et al 2005) with a report activity of 35 %. OEE is a product of machine *availability*, *speed* and *quality*, as Eq. 2-2 shows:

$$OEE = A \cdot S \cdot Q, \qquad \text{(Eq. 2-2)}$$

where A is availability, S machine speed and Q quality factor. OEE, as well as S and Q, are valued in an interval between (0,1).

In addition to the machine efficiency indicators presented above, *capacity utilisation rate*[22] (*CUR*) is also used. CUR indicates the paper production line's operating efficiency and is given by Eq. 2-3:

$$CUR = \frac{t_{running}}{t_{calender}}, \qquad \text{(Eq. 2-3)}$$

where $t_{running}$ is the production line's actual *running time*, excluding all maintenance breaks, and $t_{calender}$ is normally one calender year, i.e. 8760 hours. However, capacity utilisation rate is subject to *production cutbacks* and other downtime factors, which are not necessarily caused by *technical unavailability* of the Installed Base, and hence CUR is a poor measure for maintenance activity as well as machine technology and design efficiency. Similarly, the definition for availability in Eq. 2-1 fails to directly measure the goodness of *planned maintenance* as availability according to Eq. 2-1 does not specify *how* the value of parameter t_{MB} is obtained. Juva and Gustavson (1996, p. 162), for example, present some illustrative examples of such pitfalls in measuring machine efficiency.

Another definition of availability was introduced by Kelly (1984, p. 19) and an even more convenient one by Bleuel and Patton (1986, p. 127):

$$A_0 = \frac{MTBM}{MTBM + MDT}, \qquad \text{(Eq. 2-4)}$$

where *MTBM* stands for *mean time between maintenance* and *MDT* for *mean downtime*. MTBM includes two indicators of equipment reliability, called *MTBF* (*mean time between failure*) and *PM* (*preventive maintenance*), while MDT includes administrative and logistics supply times. Compared with the definition

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[22] *Käyntiaste*, in Finnish

of Eq. 2-1, Eq. 2-4 indicates the goodness of maintenance planning as it divides machine downtime between maintenance and logistics-related problems. Furthermore, MTBM consists of two indicators, MTBF and PM, which are expected to influence one another. For example, if the planned preventive maintenance actions are carried out correctly, the amount of corrective maintenance is expected to decrease. Hence, increasing the PM value should also increase the MTBF value and in addition decrease the value of MDT as resources can be planned better for anticipated maintenance breaks. Financially speaking, preventive maintenance should cost less than corrective maintenance (Bleuel and Patton 1986, p. 198) although the effects of these might be equal. Chan et al. (2003, p. 72) remark that the cost of repairing the same problem in corrective maintenance is about three times higher than in preventive maintenance. Given this situation, the management in firms should obviously promote preventive maintenance in any circumstances, but sometimes this is not the case.

The most common efficiency indicator with 93 % reporting rate in the Finnish paper industry (Komonen 2002b) is the *utilisation rate*[23], given by

$$UR = \frac{t_{operating}}{t_{calender}}, \qquad \text{(Eq. 2-5)}$$

where $t_{operating}$ is the production line's operating time, *including all maintenance breaks*, and $t_{calender}$ is normally one calender year, i.e. 8760 hours. The utilisation rate excludes raw material supply problems and other machine-unrelated causes of production loss.

Airola et al. (2005, pp. 13-14) point out that the term *capacity utilisation rate* in the paper industry is quite often closer to the definition of *utilisation rate* given above in Eq. 2-5 than to the definition of Eq. 2-3, thus causing confusion. Also Komonen (2006) mentions the problem of unestablished and ambiguous definitions of availability and OEE. Komonen (2005) also points out that the development of maintenance indicators has been active in Finland during the 21st century. Regardless of the development trends, the total number of tonnes of paper produced, with respect to the Installed Base capacity, of course still seems to be the most significant and meaningful efficiency indicator, as Mardon et al. (1991) suggested.

In conclusion, the division into economic and physical performance indicators is quite natural. People in different roles within an organisation seldom work with both types of indicators directly. Technical and production management are generally more concerned about productivity indicators, while mill and corporate management are mainly concerned about profitability. Of course these two types of indicators are linked and the ability to understand and furthermore control the dependencies between productivity inputs and profitability might be defined as the core competence of paper firms. In addition to the technical and financial measurements and indicators, some attempts have been made to measure and modell their dependencies (Harjunkoski 1997; Fogelholm 2000). Even though these studies have even led to releasing commercial IT products and to some

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[23] *Käyttöaste* in Finnish

business implementations, the greatest achievement in those studied has been the positive change in the willingness to challenge measurement practices against earlier knowledge. After all, the data has in reality been available much longer.

Performance indicators were discussed in chapter 2.2. Clearly much development work with performance indicators has been carried out in the past, but these indicators have been developed to express either financial or production efficacy – not the relationship of these. Recent discussions regarding outsourcing certain paper mill functions in the changing business field have called for better indicators which would allow management in firms to evaluate the efficacy and costs of these functions in alternative contracting strategies.

2.3. Paper Production Line Life Cycle Costs and Profits

Paper mills, paper production lines and individual machines all have a life span, i.e. a life cycle. *Product life cycle* (PLC) was originally introduced in marketing literature (Cox 1967; Kotler 1976, pp. 230-246) and four life cycle states (originally *stages*) were defined for every product (Cox 1967, p. 375; Prasad 1997; Magnan et al. 1999; Massey 1999): *Introduction, Growth, Maturity* and *Decline*. As the original footing of PLC dates back to *product* marketing management, product life cycle can be seen as a generalised model that describes *the sales trend of a narrowly defined product*. However, this definition is neither sufficient nor unambiguous: Porter (1998b, p. 157) applied the PLC definition to whole industries instead of to a single product, and generally the definition of a PLC can vary significantly, depending on the firm defining it, as Suomala (2004, pp. 26-28) points out. Rink (1999) suggests that a *five-state PLC concept – Pioneering, Introduction, Growth, Maturity* and *Decline* - could be a useful tool in product financial management and planning, but it fails to recognise the operation (or production) state of the product at the users' side. Kääriäinen et al. (2000) define PLC according to Figure 2-7.

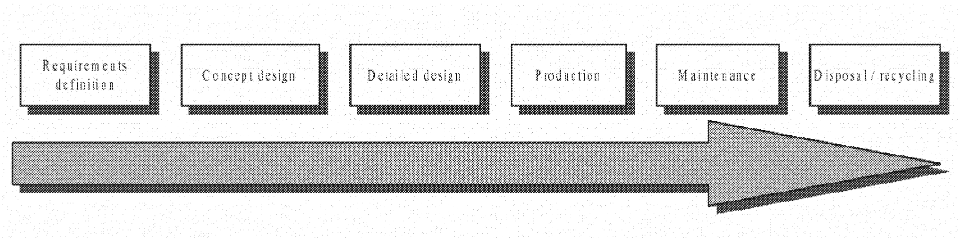

Figure 2-7. Product Life Cycle. (Kääriäinen et al. 2000)

Compared with earlier definitions, Kääriäinen et al. (2000) made important additions to the definition of PLC - production and maintenance states - which actually overlap in real life. Hence, also their definition fails to depict the viewpoints of different firms concerning concurrent life cycle states. For example, a paper machine technology supplier may consider *its* old product concepts obsolete, while at the same time some paper companies might consider the same products *reliable and thus favourable*. Prasad (1997, p. 95) remarks that successful firms wish to maximise the life cycle value of their products and this policy does not always best serve the users of these products.

Kelly (1984) defines *plant life cycle* and associated life cycle costs in a meaningful and pragmatic manner, as shown in Figure 2-8.

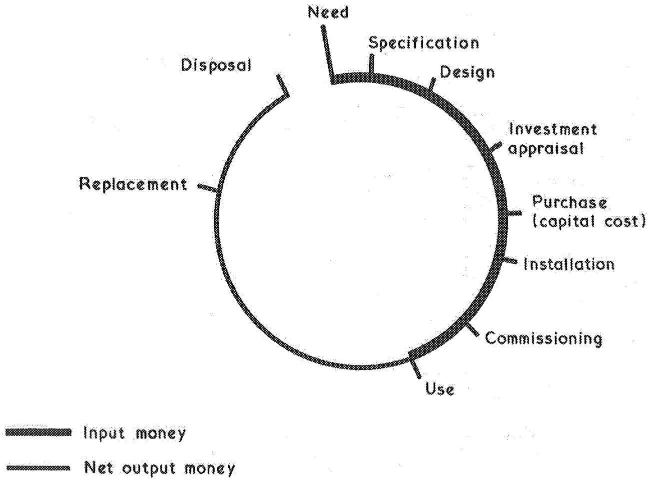

Figure 2-8. Plant Life Cycle and Costs (Kelly 1984, p.1).

Figure 2-8 shows that the starting point of a mill or of a production line life cycle is the business need for a green-field investment. Accumulation of costs will also begin at this point, but it may still be unclear how many new products are needed to fulfil the fundamental need initiating the life cycle process. From the user's, e.g. in this case the paper company's point of view, the total life cycle costs of a production line consist of

1. Capital costs,
2. Operational costs,
3. Maintenance costs, and
4. Production and quality losses caused by *unavailability* of Installed Base, insufficient raw materials or inadequate resources.

The above-mentioned costs are generated by various factors, such as technical design (i.e. technology), organisational structures, logistics structures and their interaction. Capital costs are influenced by firms' financial solidity and firms' need for loan capital. Loan capital, on the other hand, exposes firms to interest rate changes, which might yield either positive or negative effects, depending on the interval of loan payback and the direction of rate changes. Other costs, namely operational and paper production line availability costs, can be linked more easily with the productivity and profitability indicators. Figure 2-9 illustrates cost structures from paper producers' worldview.

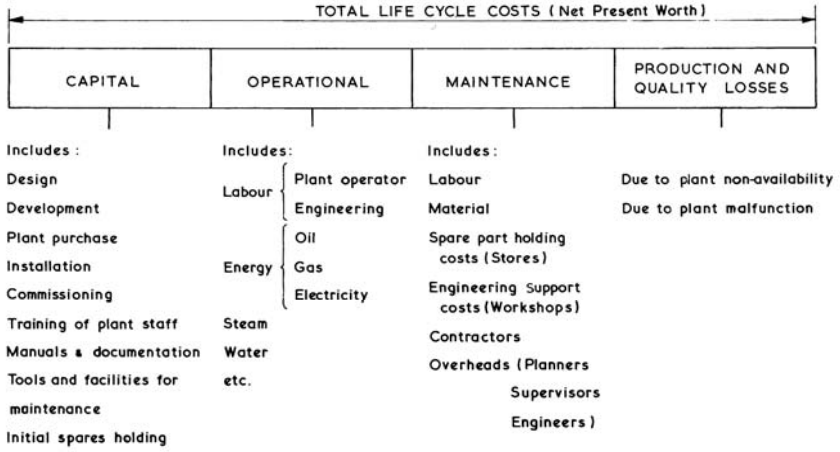

Figure 2-9. Factors and area considered for building up costs over a mill's or a machine's life cycle (Kelly 1984, p. 3).

The level of a paper production line's technology, especially automation, directly affects the number of required production and maintenance personnel as well as the production line's energy consumption. Figure 2-10 shows paper production cost structures in Finland in years 1990 and 2003 according to the Finnish Paper Industry (2006, adapted from Table 6.2, p. 40) report.

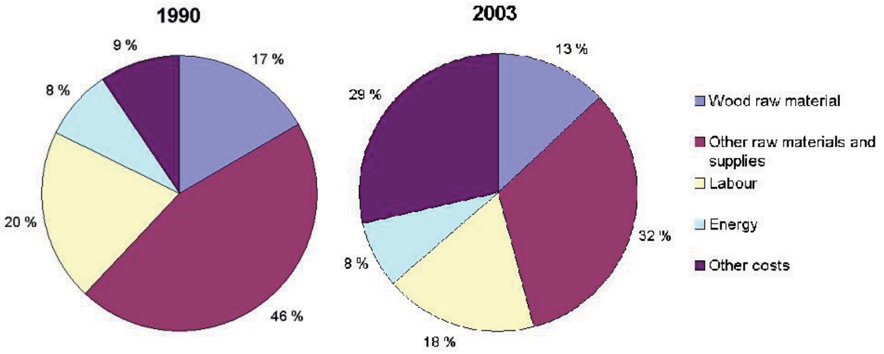

Figure 2-10. Paper production cost structures (adapted from the Finnish Paper Industry 2006, p. 40).

Despite what is claimed elsewhere (The Finnish Paper Industry 2006, p. 38), these figures are not exactly comparable due to differences in accounting practices, paper companies' internal reporting principles or human factors. More recent data would be welcome, but unfortunately this data is practically the only data publicly available. Still, these figures give some indication of the cost structures in the industry and they also indicate the development trend in the field. Table 2-1 shows the exact figures adapted from the Finnish Paper Industry (2006, p. 40), with the exception of the corrections made to figures. Original statistics in (The Finnish Paper Industry 2006, Table 6.2, p. 40) show total labour costs (including *Salaries, Wages, Social security costs, Social security costs for salaries, Social security costs for wages*) to be 83 EUR/ tonne in 1990 and 74 EUR/ tonne in 2003, but the sum of the respective sub-costs (shown in Table 2-1) yields 102 EUR/ tonne and 90 EUR/ tonne, respectively. Energy and other costs contain some minor errors, too, and the total costs of a produced paper tonne was actually (in the light of the figures of Table 2-1) 508 EUR/ tonne in 1990 and 505 EUR/ tonne in 2003. The cost structure shown earlier in Figure 2-10 is based on the combined costs (shown in bold) of Table 2-1.

Table 2-1. Paper industry cost structures in the years 1990 and 2003 (adapted from The Finnish Paper Industry 2006, Table 6.2, p. 40).

COST STRUCTURE (ANNUAL COSTS IN EUR/ TONNE)	**1990**	**2003**
Wood raw material	85	66
Stumpage costs	44	21
Harvesting	6	5
Transport of domestic and imported wood in Finland	11	7
Imported wood at the border	10	14
Domestic and imported chips and sawdust	14	19
Other raw materials and supplies	230	165
Minerals and chemicals	44	54
Other than minerals and chemicals (pulp, etc.)	186	111
Labour	102	90
Salaries	21	18
Wages	45	39
Social security costs	18	17
Social security costs for salaries	6	5
Social security costs for wages	12	11
Energy	43	40
Fuel	3	8
Electricity	24	23
Heating	16	9
Other costs	48	144
Purchased services (e.g. transporting and marketing)	21	98
Purchased industrial services (e.g. repairs and installation work)	14	22
Merchandise	4	20
Rents	9	4
TOTAL COSTS	**508**	**505**

Table 2-1 indicates that the costs of paper producers' mill activities are decreasing while external costs, such as minerals, chemicals and purchased services, are increasing when cost levels between years 1990 and 2003 are compared. In the context of this research, it is interesting to notice that the share of purchased (outsourced) services has increased by as much as 75 %. Hence, technology can only improve the profitability of the paper production process with respect to improved technical efficiency, e.g. indirectly through reduced consumption of raw materials and energy or through less need for external maintenance and repair services. Table 2-1 seems to consider only operative costs, and the cost of technology is not calculated in the total costs although it is typically considered in a firm's income statement under depreciation.

Energy costs have recently been given special attention, and for example Kilponen (2002), Maarni (2004) and Sivill (2004) have studied how the energy management of the paper production process could be improved. Figure 2-11 illustrates the dependency between paper production and energy consumption at the paper mill.

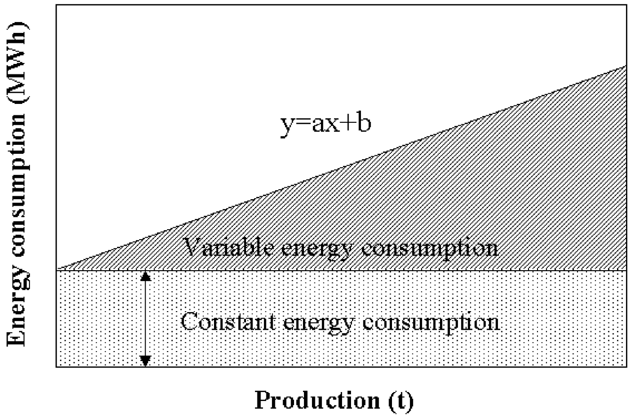

Figure 2-11. Relationship of paper production and energy consumption (Sivill 2004).

However, the total cost of energy is not linear because paper firms are able to negotiate an annual energy contract based on the planned production. As Sivill concludes (2004), the significance of energy consumption for paper production profitability strongly depends on the energy price. The level of technology plays an essential role in improving the paper production line’s energy efficiency and use of raw materials but also efficient use of the machinery is required. Komonen (1998, p. 168) finds evidence of decreasing maintenance costs when invested capital increases, e.g. when a more sophisticated Installed Base is used. Komonen also mentions that preventive maintenance activities increase in the process industry (in paper production, for example) along with the increase in invested capital. An issue worth noticing is the strong influence of technology design on later life cycle states (Mardon et al. 1991, p. 90). In other words, limited technology might lower the initial capital costs, but might also increase operational and maintenance costs as well as production and quality losses during a production line’s life cycle. Figure 2-12 illustrates the dependencies between various factors generating cost during the production line’s life cycle.

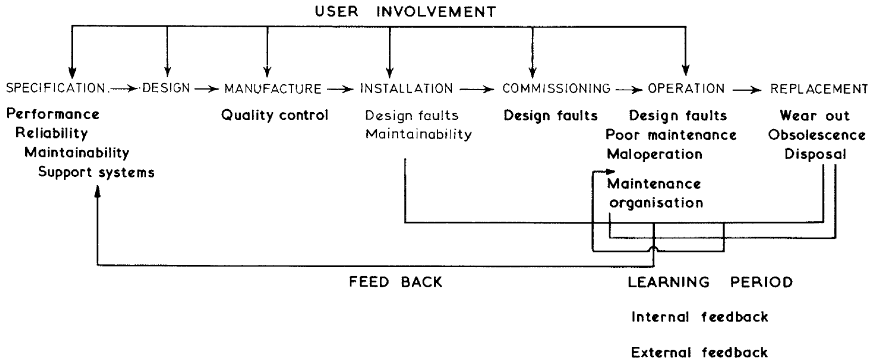

Figure 2-12. Factors influencing maintenance costs over life cycle (Kelly 1984, p. 6).

Recapturing Bleuel and Patton's (1986, p. 132) concept of the cost relationships between machine complexity and maintenance downtime (represented earlier in Figure 2-2), a high technology machine, too, increases costs in comparison with a lower technology machine having higher maintenance costs. Järviö (2000, p. 188) presents an *iceberg theory of production costs* which claims that as much as 80-90 % of paper production costs are *indirect costs* that are difficult to measure. Järviö (2000) adds that these indirect cost drivers *can* be measured with some extra effort. Despite extensive harmonisation of accounting practices, objective measurement of costs is difficult and current standards, such as OEE, only provide comparable indicators of a paper production lines' *technical efficiency*.

Even though the pressure to understand the "true" cost generation mechanism and the respective performance indicators is high, in practice there are several alternative ways to achieve a *sufficient* level of paper production capacity from the paper mills' business perspective. Unfortunately, the different alternatives cannot co-exist at one specific mill, thus leaving room for speculation, as Porter (1991, pp. 98-99) remarks, and the significance of direct costs becomes ultimately emphasised. Figure 2-13 shows that *too active* as well as *inadequate* maintenance schemes tend to increase maintenance costs and thus decrease a paper production line's profit.

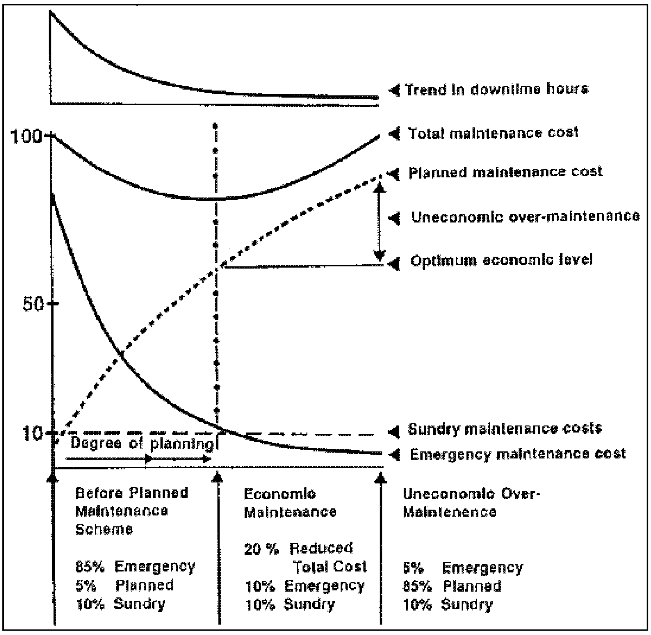

Figure 2-13. Maintenance cost – downtime relationship chart (Mardon et al. 1991, p. 96).

Although maintenance costs do not constitute a major share of paper companies' net sales, as Figure 2-14 shows (Komonen 2002, p. 3), lack of effective maintenance activities would most likely increase the total production costs (Mardon et al. 1991; Järviö 2000, p. 186). Instead, the LCP concept considers maintenance as an investment rather than a cost (Sherwin 1999, p. 242).

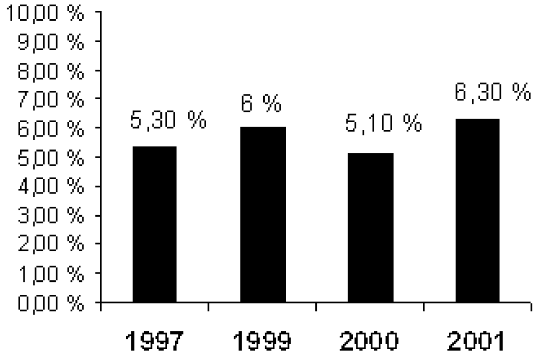

Figure 2-14. Share of maintenance costs of paper companies' annual net sales, based on questionnaire results in (Komonen 2002, p. 3).

It may be noticed that the share of maintenance costs is approximately 5…6 % of paper companies' annual net sales. Reinhold and Kraft (2004, p. 42) estimate the total maintenance costs to be between 19,40…32,70 EUR/ tonne, depending on the paper grade and the technology concept.

The terotechnology philosophy introduced earlier, together with remarks by Mardon et al. (1991, p. 90), Sherwin (1999, pp. 241-242) and Chan et al. (2003, p. 72), suggest that the pursuit of paper production line economic efficiency and profitability suppresses technical and operational cost factors *per se*. In other words, making profit counts much more than reducing costs. This rationale may easily be noticed in Figure 2-15, which shows that a 10 % increase in production brings much more profit than a 10 % reduction in operating costs.

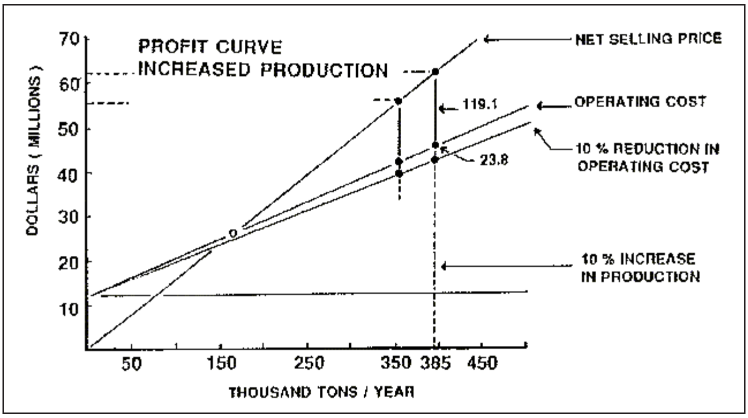

Figure 2-15. Cost reduction versus efficiency improvement profit curves (Mardon et al. 1991, p. 87).

Mardon et al. (1991, p. 91) argue that consultants and paper machine technology suppliers do not share enough information with the mill crew and that engineering design is sometimes inadequate for its purpose. Chan et al. (2003, p. 72) support this statement by mentioning blind acceptance of technology suppliers' inputs as one cause of maintenance problems. Coincidentally, after sales activities provide a good feedback channel to technology suppliers and allow them to learn about their products. As feedback information plays an important role in directing paper machine technology development as well as delivering paper machine maintenance contracts, obtaining and the ownership of such feedback information becomes an important issue.

Chapter 2.3 has indicated some of the apparent difficulties in analysing paper production line profitability from the point of view of different firms. Clearly, the inherent life cycles of paper producers and technology suppliers are different as the incentives of these firms are also different, but their contracting roles repeatedly place them in the same decision-making situation. Hence, a tool is needed to examine the *decision-making accounting setting*[24] with empirical data, which is *temporarily* significant for both parties. In this way both firms would be able to grasp the total relationship between a supplier's assets and its potential effect on a buyer's profitability.

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[24] *Laskentatilanne* in Finnish

2.4. Main Actors in Paper Industry

The need to produce paper for the market has been the driving force in paper production technology development. In the past, paper companies developed internally the technology they needed for paper production and hence technology was considered much more as a core competence of paper companies, as illustrated in Figure 2-16. Some firms may still deliver and manage the paper-making activities introduced earlier even if nowadays the core competencies seem to have become specialized.

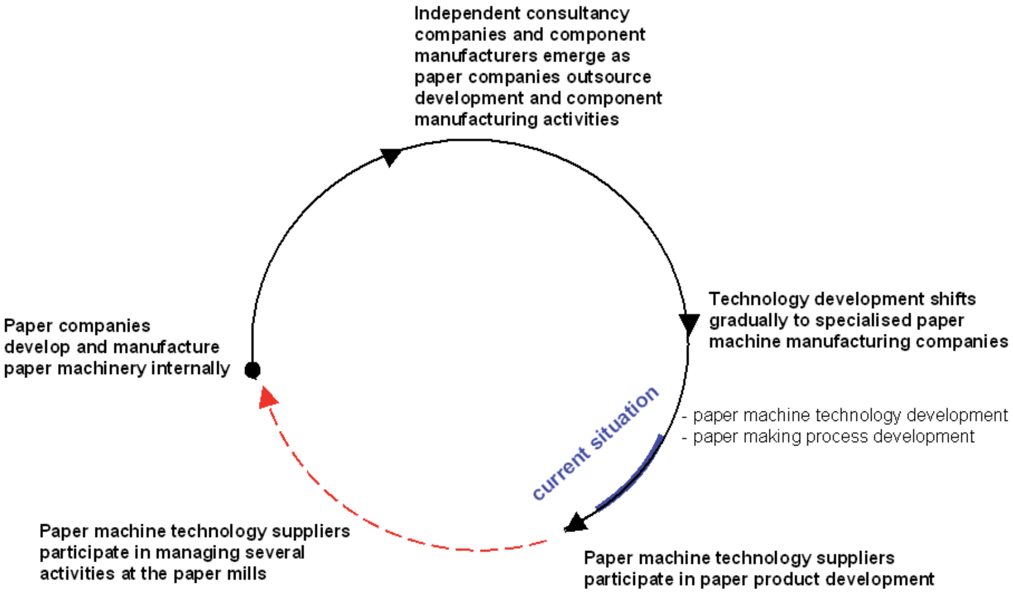

Figure 2-16. Change in ownership of paper industry activities. The blue curve depicts the current situation while the red, dashed arrow suggests one possible future alternative.

Toivanen (2005, pp. 90-116) outlines the history of several firms in the paper industry. The Finnish paper company *Yhtyneet Paperitehtaat Oy*, for example, founded *Jylhävaara Works* in the year 1940 to focus on the manufacturing of stock preparation equipment. *Jylhävaara Works* was acquired by Swedish tissue producer *SCA* (2006) in 1987, but it eventually became part of *Metso Corporation* in the merger of *Valmet* and *Rauma-Repola* in the late 1990's (Toivanen 2006, p. 100). *Ahlström* (2006), a global manufacturer of filters, wipes, flooring, labels and tapes, developed and manufactured its production machinery until competition drove *Ahlström* to outsource some of its functions. *Ahlström's Karhula Works* merged with *Valmet* in 1987 (Toivanen 2006, p. 93). Toivanen (2006, p. 92) also mentions a joint venture pilot paper machine between *Valmet* and *Enso-Gutzeit* in the 1970's. German family-owned Voith (2006), now one of the top paper machine technology suppliers, acted in the role of technology supplier as early as 1848 in a joint venture with a paper company in building the first wood milling machine. Voith has since been acting in this technology supplier role although its product mandate has since broadened. Paper machine technology development also underwent a change as parts of it became outsourced to engineering consultancy companies like *Jaakko Pöyry*. *Jaakko Pöyry* was founded in 1958 to handle the engineering work for a major pulp mill project in Finland, and the company soon won several major engineering contracts with European pulp and paper clients (Jaakko Pöyry 2006).

Ojala et al. (2006) discuss the drivers of the strategic choices, organisational structures and performance of several well-known paper companies. Ojala et al. (2006, pp. 274-276) also mention paper companies' divestments of horizontal and vertical functions, such as technology development and manufacturing or the production of some paper grades, as a means of playing against their competitors, thus focusing on their core functions. In line with this, Porter (1998b, pp. 4, 49-67, 108-125) discusses analysing industry competitors in terms of the rivalry between competing firms, potential entrants, the bargaining power of buyers and suppliers and substitute products, as Figure 2-17 illustrates. This might also be interpreted as a process of developing the most economical way to operate. After all, firms seem to act upon their nature, as Coase (1937) put it, instead of directly responding to market development.

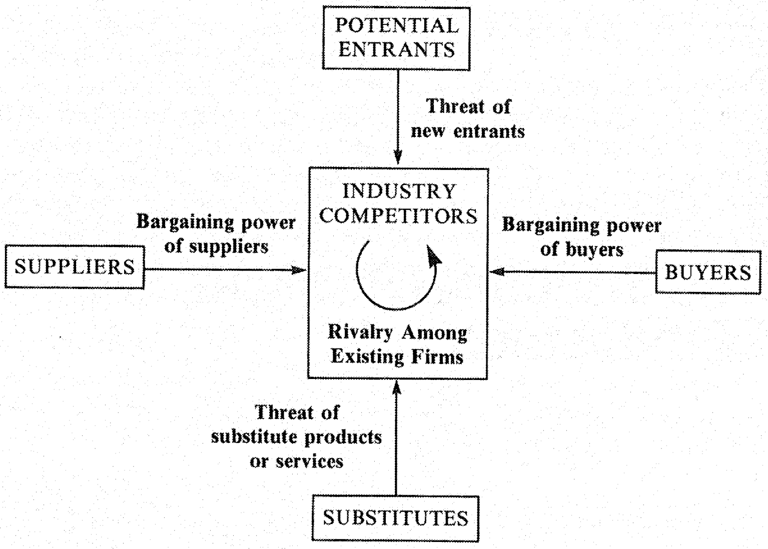

Figure 2-17. Forces driving industry competition (Porter 1998b, p. 4).

Porter (1998b, pp. 108-125), although emphasising only competitive forces, is in agreement with Coase's (1937) idea regarding firms' seeking the most economical way to operate. In addition, Porter points out evident reasons for firms to evolve, such as integrating forward to gain more profit through increased added value in its products or services. Toivanen (2005, pp. 72-73) indicates some technology-related explanations to the evolution of Figure 2-16. The most important of these explanations seems to be the need to share knowledge-intensive functions as paper machines become more sophisticated, especially since paper machine manufacturers have assumed a stronger role in paper machine RTD. Success in the competition to win a share of the market depends not only on the ability of firms to manage with suppliers, new entrants, buyers and substituting products. Also political, economical, social and technical (PEST, for short) aspects have great significance, as Cummings and Wilson (2003, p. 29) point out. Yet, companies who have managed to stay in the game must have succeeded well in responding to market requirements and anticipating changing conditions. Day (1994, p. 37) suggests that such *market-driven organisations* will enjoy a competitive advantage and superior profitability in the long run.

At the end, chapter 2.4 suggests that firms' competitive competencies could be divided roughly between technology and paper production activities, i.e. process control. Furthermore, resulting from advances in technology and the need among technology suppliers and production organisations to analyse machine data, these two core functions have moved closer to each other. A strong trend of development from product supplier towards "solution supplier" seems to be under way, meaning that paper companies wish to obtain solutions rather than products from their vendors. Hence, one potential development scenario might be consolidation of technology ownership at the main suppliers, namely Voith and Metso, while smaller technology suppliers might be merged or develop alliances with these bigger "integrator" firms. Accordingly, paper companies would have to choose one firm as their main technology provider. Hence, one way of looking at this potential development trend would be to say that the circle in Figure 2-16 is closing. On the other hand, such development would inevitably pose new challenges in the market in terms of paper companies' weakening bargaining power and also limit the possibility of new rivals entering the business. Such development would emphasise objective measures even more during investment decisions as traditional competitive bidding would lose its importance.

2.5. Paper Industry Development Trends

Demographic and geographic differences between main market areas, encompassing Europe, Asia Pacific, North America and South America seem to be increasing. Based on a market analysis (Pöyry FIC 2006), paper consumption is expected to grow at an average annual growth rate of 2.1% until the year 2020. This conditional forecast makes assumptions about the world population reaching 7.6 billion by the year 2020, population growth being fastest in Africa, Asia (excluding Japan and China) and Latin America. Furthermore, the forecast relies on ageing of the world's population, which has a number of implications for the paper industry, such as increased demand for packaging and educational materials as well as consumer hygiene products. Substitute products are also affecting the paper industry (Porter 1998b, pp. 108-125) as paper-based advertising media, including newspapers, magazines, direct mail and directories, have been losing their market share in competition against electronic media. Internet advertising expenditure has recently grown annually by 15…40%, depending on the country and market area, while newspaper/magazine advertising has grown slowly, at a 2…3% annual average rate. Analysis (Pöyry FIC 2006) expects the competition between paper-based and on-line media to lead eventually to fairly modest growth rates or a decline in the case of some graphic papers by the end of the current decade.

A 3% growth in the world economy is expected through 2020, with an estimated annual growth in North America and Western Europe of 2.7% and 2.2%, respectively. China, Asia (excluding Japan) and Eastern Europe are expected to grow annually by 5…7%. Li et al. (2006) provide supporting evidence of an increase in paper demand in China, resulting from increasing income. According to Pöyry's report (Pöyry FIC 2006), there is a clear correlation between GDP and paper consumption per capita, as Figure 2-18 illustrates. The relationship between GDP and paper consumption per capita is valid between countries and with respect to time. Low- and medium-income market areas with vast populations, such as Asia-Pacific and Latin America, posses the biggest potential for long-term growth in the paper industry.

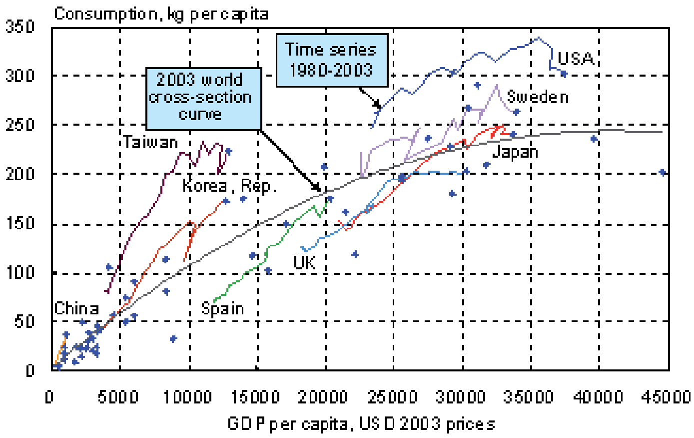

Figure 2-18. Paper consumption and GDP per capita (Pöyry FIC 2006).

High transportation costs, for example, encourage firms to plan paper production near the main consumer markets, and this seems to be one of the reasons for the gradual shift in production to outside the traditional supply areas, e.g. North America and Europe. The growth in Europe's paper industry has been taking place in both Eastern and Western Europe, implying heavy structural changes in the European industry. Eastern Europe's growth in production is expected to depend partly on the Western European paper industry's investment policy and capacity management, while the production share of North America and Western Europe is expected to decline from the current 55…56% to 44% by 2020. China, the Middle East and the rest of Asia will be responsible for over 60% of global incremental production during 2004-2020. Figure 2-19 illustrates the above forecasts.

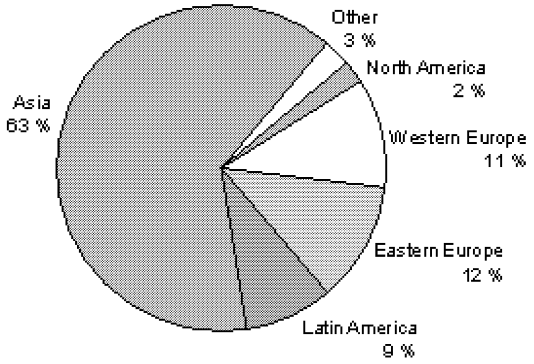

Figure 2-19. Total incremental production during 2004-2020 135 million tonnes (Pöyry FIC 2006).

Evidently the paper industry is undergoing a transition period, and paper companies are currently looking for ways to make their business more profitable. The overall paper consumption is expected to grow conservatively up to year 2020, but the growth seems to be polarised between the market areas. Growing market areas, such as Asia and particularly China, seem to enjoy continuing good growth as meanwhile traditional market head towards maturity.

The different market areas have diverse advantages as well as disadvantages in terms of paper industry profitability, mainly related to the differences in the significance of capital, productivity and unit (or operating) costs. In the growing market areas, lower labour costs have a strong, positive effect on operating costs (Häggblom 2006, p. 21). Forest management has also a positive influence on the profitability of paper production, resulting from strengthening supply of pulp due to fast-growing wood species. However, pulp price is subject to market demand and this causes variations in price development. Capital costs are not a central factor in different market areas as the Installed Base machines are practically the same everywhere. However, construction of infrastructure is less expensive in some market areas, mainly because of lower labour costs. In order to achieve good paper production line productivity, there must be an effective technology concept as well as a good supply of raw materials, but the resources of human expertise are also crucial. In the past, expertise has been the most important factor in the traditional market areas, but the gap between traditional and growing markets has recently diminished. McGahan (McGahan 2004, p. 90) gives four trajectories for evolution in the industry, as Figure 2-20 illustrates.

Core Assets	Core Activities: Threatened	Core Activities: Not Threatened
Threatened	***Radical Change*** Everything is up in the air. Examples; makers of landline telephone handsets, overnight letter-delivery carriers, and travel agencies.	***Creative Change*** The industry is constantly redeveloping assets and resources. Examples; the motion picture industry, sports team ownership, and investment banking.
Not Threatened	***Intermediating Change*** Relationships are fragile. Examples; automobile dealerships, investment brokerages, and auction houses.	***Progressive Change*** Companies implement incremental testing and adapt to feedback. Examples; online auctions, commercial airlines, and long-haul trucking.

Figure 2-20. Four trajectories of industry change (McGahan 2004, p. 90).

The definitions in Figure 2-20 indicate that the paper industry is going through change, but this change is not really radical, except perhaps in the case of paper producers. Instead, the industry change can rather be seen as intermediating, creative and progressive. The true globalisation of competition in paper production has locally lead to radical consequences. Looking at the paper industry's development from a distance, the competitive forces in local markets seem to exist also globally. Porter (1998b, p. 18) suggests that the slow industry growth in the maturing markets to turn competition into a market share game and is obliging firms to seek expansion possibilities.

While paper companies might be even undergoing a radical change, paper machine technology suppliers are definitely going through an intermediating change in terms of the definitions in Figure 2-20. The core assets of paper machine technology suppliers, namely the product and process knowledge which they have accumulated during their operating years, are well protected by secrecy and patents[25]. Their traditional core activities are threatened, however, as the markets for new paper machine installations are decreasing. Hence, the challenge for the paper machine technology suppliers is to find new business activities built on utilisation of their protected assets and core competencies. Paper machine maintenance contracts (Kuusisto et al. 2005, p. 47) and asset (or Installed Base) management services serve as good examples of such business activities. Considering the trajectories of change in these two adjacent fields, there is a quite clearly in the interest of the technology suppliers to integrate forward to position themselves as suppliers of paper production core activities and provide new possibilities for the paper companies to focus on in developing their core competencies. Recent paper mill maintenance outsourcing contracts provide evidence of such tendency, and naturally technology suppliers wish to gain their market power in spare part and other after sales functions by taking over

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[25] Two of the largest paper machine technology suppliers had applied 185 (*Metso Paper*) and 318 (*Voith Paper*) patents in 2003 (Derwent World Patent Index 2006). *Metso Corporation* was the biggest patent applicant, with 125 patent applications in year 2005 (PRH 2006).

functions at the paper mills. The role of these primary as well as other firms, such as component suppliers, service companies, etc., is currently not quite clear. Hence, there exists a fear of diffusion of proprietary knowledge, and the business field's main actors should (re-) position themselves in the field to establish and protect their positions in the evolving industry. Intellectual property rights (IPR) management will thus be emphasised in the future, too.

Kuusisto et al. (2005) discuss the advent of knowledge-intensive service activities (KISA) and knowledge-intensive business services (KIBS) in the Finnish forest cluster. Lindström et al. (2004, pp. 7-14) point out that it is quite difficult to give a clear definition of KIBS services, but earlier studies have identified transfer and logistics, maintenance, engineering design and consultancy and information services as common KISA or KIBS services in the forest cluster. A lot of knowledge-intensive work has gone to implementing standards for product data exchange in order to streamline transfer and logistics operations (papiNet 2006). Furthermore, research and technology development (RTD), a highly knowledge-intensive activity, plays an important role in renewing the industry. Paper machine technology suppliers' RTD activities are, in fact, a strong source of technological innovations for the paper industry (Lindström et al. 2004, p. 16). As knowledge-intensive services typically seem to act in close relationship with various actors, the role of co-operation[26] agreements, or partnerships even, is becoming more important in the paper industry, thus shifting also the more knowledge-intensive services from paper companies possibly to other parties. Vikman suggests (Vikman 2005, pp. 8-9) that several services will be centralised to obtain competitive advantage in the industry. This centralisation (or *decentralisation* when looked at from the individual paper mill's perspective) of services sets high demands for information management, but also necessitates the use of new analysis and optimisation tools, such as remote monitoring of industrial processes (Jämsä-Jounela 2005), spare part consumption estimation and inventory optimisation (Koskinen 2004). The effects of such knowledge-intensive services should be realised in terms of increased productivity as well as better utilisation of invested capital.

The paper production process and related activities are very similar in all significant producer countries. This is explained by the technologically homogeneous production machinery, i.e. Installed Base, which requires similar expertise in managing the production processes. The deviations in productivity seem to be caused mainly by differences in work contribution, varying working hour arrangements and the length of working hours in the different producer countries (The Finnish Paper Industry 2006, pp. 59-63). The Finnish forest industry, for example, is undergoing difficult times as production capacity is growing slowly and is under-utilised. Hence, the profitability of the industry has been poor in recent years and an oversupply of many paper grades dominates the traditionally important market areas - a situation not completely explained by the normal business cycle. As growth in the traditional paper industry is inevitably decreasing, the labour unions have expressed their concern about the future of the paper industry, production levels and employment opportunities in Finland. Although the cost-effectiveness of the Finnish paper industry is high, as Figure 2-

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[26] *Co-operation* and *partnership* can be taken to mean the same at this point. Partnership will be defined more specifically later.

21 shows, the work contribution has decreased and continues to do so. This means that the volume of labour will decrease, and productivity as well as profitability can be improved by measuring production cost structures objectively and managing them more effectively by exploiting IT and optimisation models (Söderman 2005) and by the formation of new co-operation agreements. The paper industry has conventionally tried to avoid forceful actions in decreasing the volume of labour, which may be an unavoidable option in the current economic situation.

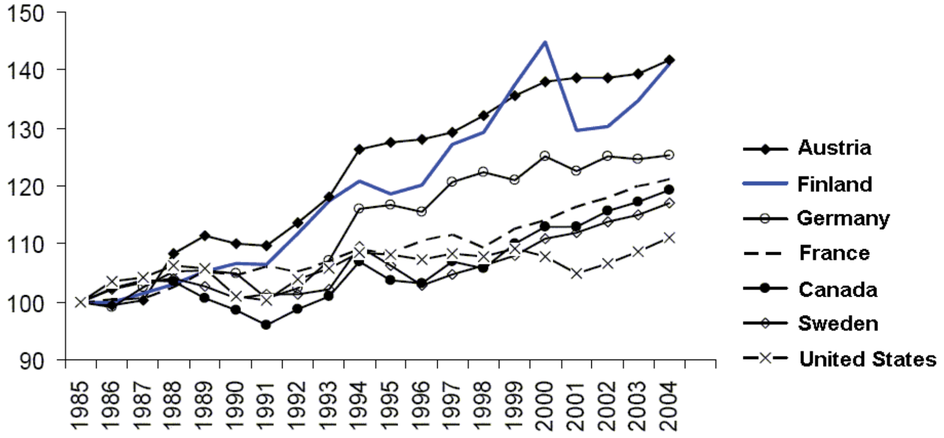

Figure 2-21. Annual total productivity of paper industry by country (Index 1985 = 100, branch 211, i.e. pulp, paper and carton production). (The Finnish Paper Industry 2006, p. 51)

The development of new business opportunities and technological innovations are seen as crucially important in the field. These require investing in research and technology development (RTD) in several sectors (Brunila 2006). The paper industry should also develop new products with higher added value (The Finnish Paper Industry 2006, pp. 87-92). Tissue business, a specialised part of the paper industry, adapted very well to this philosophy at an early phase. For example, Finland-based *Metsä Tissue* is dynamically developing consumer goods for households and industrial, institutional and commercial consumers. One of their brands, *Katrin* (2006), offers several services to make the everyday live of private and industrial consumers easier. Hence, *Metsä Tissue* seems to be positioning itself as a provider of hygiene solutions rather than as a producer of tissue paper.

Market development in the paper industry was discussed in chapter 2.5. The development seems to be segmented as the emerging markets in Asia are growing fast while Europe and North America are maturing. This is forcing both paper companies and technology suppliers to decide where and how they will operate. The issues discussed in this chapter are not in the main focus of this thesis, but as long as anywhere in the world there is contracting over paper production process inputs, there will be a need to measure the relationship between investments and profits.

2.6. Financial Planning and Investment Decisions in the Paper Industry

A paper mill is an extensive, strategic investment[27]. Planning and implementing such investments requires both strategic-level *cost accounting* and implementation-focused *cost engineering*, as defined by Kärri and Uusi-Rauva (2003, p. 1). Paper mill investment planning activities are addressed at both of these levels in this thesis.

Strategically important investments are generally driven by market demands, investment decisions are based on a *capital investment decision-making* (*CIDM*) *process* (Brien 1997, p. 173) and the decision-makers are confronted with a *decision-making accounting setting*[28]. Uusi-Rauva et al. (1994, p. 5) define a decision-making accounting setting as a decision-making situation where a management decision is to be based on accounting information. The decision-making accounting setting should be carefully identified (Kärri and Uusi-Rauva 2003, pp. 12-14) before planning an investment decision. The decision-making accounting setting practically yields a model for estimating the amount and time horizon of investment returns. Brien (1997, pp. 174-176, p. 184) suggests that *investments whose expected returns or profits are the best* are generally favoured. As future events are uncertain, investments providing most profits within a short time horizon tend to be most favoured by investors. The investment decision-makers thus seem to ignore any potential investment returns beyond the selected *planning horizon* (Hanssmann 1968, p. 30), which characterises the importance of the time horizon in the investment decision.

The life cycle concept introduced earlier has been adapted to the paper industry, too. In order to clarify the life cycle concept and facilitate consideration of decision-making accounting settings from several firms' viewpoints, the following life cycle definitions are given in the context of this research:

1. *Paper mill life cycle,*
2. *Paper mill Installed Base life cycle and*
3. *Installed Base product life cycle.*

Paper mill life cycle encompasses all major events in a specific paper mill's history. These events may be broken down to technical, political and social activities as the paper mill's state affects its surroundings in several ways.

In contrast, *paper mill Installed Base life cycle* characterises the technical level of the mill in terms of the "average technical age" of the individual machines in the production line. For example, rebuilding certain machine sections might reduce the gap between an obsolete and new production line significantly even though most machine sections in the old production line remain unchanged. The remaining technological gap between a new and rebuilt production line is

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[27] For example, the value of the order of a complete production line for LWC paper to *Jiangxi Chenming Paper Co., Ltd.* in China was approximately EUR 100 million (covering stock preparation, paper machine, finishing section, and roll handling) and annual production capacity 350 tonnes/ a. (Metso 2006, Metso Paper 2006).

[28] *Laskentatilanne* in Finnish

typically production line speed. Still, usually the financial justification for such machine rebuilds involves a grade change to some special product, and typically the special grades cannot be produced with high-speed machines.

Finally, *Installed Base product life cycle* specifies the technical and the operational level of an individual machine in the paper mill's Installed Base. This research focuses mainly on analysing activities at these two levels, but their implications for a paper mill life cycle are discussed as well. Each of the above life cycles has four possible states:

1. *Planning,*
2. *Roll-out,*
3. *Operation and*
4. *Disposal/ Closure.*

The life cycle states are defined at a general level to provide an adequate financial planning horizon to serve the goals of this research. Next, the above life cycle definitions are linked with investment planning activities, decision-making accounting settings and related investment return calculations.

The green-field paper mill investment project mainly addresses planning, roll-out, and (ensuring) operation of the above life cycle states. For simplicity, a green-field investment track is assumed, which allows more options for the investment decision-making process. The following list depicts the main activities during and after an investment decision-making process from paper companies' viewpoint, and the activities as well as their significance for this particular study are explained in more detail.

The investment decision-making process generally accrues from paper companies' (continuous) business development process. An unsatisfied or gradual shift of demand for some paper grade or, alternatively, a high cost structure in the current producer countries, or some other changes in the markets might be the initial drivers for the investment planning process. As these business drivers practically dictate the market area where the new paper mill will be situated, some of the attributes of investment return calculation become bounded. External consultant reports are often used in evaluating the business environment. Paper market study is followed by an assessment of technology concepts. The purpose of the assessment is to identify available technology concepts that satisfy the demands coming from the paper market study as well as to develop a *bonitary interpretation* (see Uusi-Rauva et al. 1994, p. 3) for the available technologies to be used during investment return calculations. Available technology concepts also narrow down the range of attribute values in investment return calculations. Once the technology concepts have been evaluated, the decision-making process proceeds to investment planning. Investment planning considers both financial and technological issues and acknowledges risks related to these. This activity has the most influence on the selection of attributes in the investment return calculation, and attributes that have the most emphasis in the calculation are most likely to have the most emphasis in the risk assessment, too (Woodward 1995, p. 239). The outcome of the investment planning activity is a finalised investment return calculation, which will be used as a reference during supplier selections. It should be noticed that once the investment return calculation is fixed, the investment process becomes more implementation- than strategy-driven. Hence, financial planning focuses on cost engineering (Kärri and Uusi-Rauva 2003, p. 1), i.e. on reaching project outcomes within an agreed budget.

Generally speaking, investors expect the investment, e.g. the selected technology and mill crew, to start producing sellable goods as soon as possible to respond to market demands. Hence, new installation projects are implementation-oriented and consequently track budget development. The faster the project is able to deliver a production line to produce the desired tonnage of desired paper, the faster are the investment returns, as Figure 2-15 on page 29 illustrates. Figure 2-22 shows the significance of the production line production curve. The production curve has low productivity at first, because the Installed Base is adjusted within project management activities. The first two-year period of the production curve is called a *start-up curve*[29]. The first two-year period is commonly also a warranty[30] period for the technology, and technology design is usually validated with the start-up curve. In practice, the annual paper tonnage, grade and quality demanded by the investor during the investment process are momentarily[31] to be verified by the technology supplier. This verification may be achieved along with the normal production process without any specific actions from the technology supplier. Needless to say, reaching the investment targets within the project strongly influences the technology supplier's reference management.

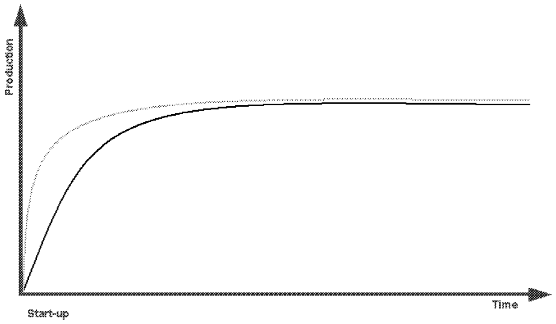

Figure 2-22. Development of paper production line production curve from start-up to normal production. The grey curve is preferred over the black one as the production line reaches full capacity at an earlier stage.

Once the production line is running and the technology design has been validated, the mill crew take full responsibility for production activities. It is worth noticing that the production capacity is limited by the production line's design speed, and increase in production requires machinery rebuilds to upgrade the production

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[29] *Starttikäyrä* in Finnish

[30] *Warranty* usually covers factory defects but *not* availability of the production line or design speed (i.e. expected production). Productivity guarantees are avoided mainly because each project is practically an expedition with unique, new design and involving machines with high costs.

[31] Usually there are a few agreed checkpoints in the start-up curve where the production line needs to produce designed production in a 24-hour time frame, for example.

technology. Still, usually the annual production levels are slightly lower than the maximum design speed.

There are several ways to manage paper production line investment projects. The paper company can either outsource the whole project to one contractor (the *TurnKey*[32] approach) or divide the project into smaller work breakdown structures and manage each sub-project separately (*EPCM*[33] and *EPC*[34] approaches) (Kärri and Uusi-Rauva 2003, p. 7). A case study by Blommegård and Mannila (2002) concluded that the TurnKey project approach could be utilised more extensively in the paper industry. Blommegård and Mannila (2002) as well as Talvitie (2005) find EPC, EPCM and TurnKey approaches to be the most interesting and suitable project-contracting strategies for operative use in the present business environment.

Advancement of the above contracting models naturally brings up the question: "Why do the technology suppliers not have to ensure optimal production levels at the paper production line for a longer period of time?" Such contracts are rarely found, and the main reason for lack of them seems to be the unclear ownership of process- and technology-related intellectual property rights. Since the paper industry development is demographically unequal, as discussed above in chapter 2.5, paper companies are facing several different types of investment and disinvestment decisions. Chapter 2.4 discussed the worldviews of paper companies and technology suppliers and emphasised the need to have mutually important measures to evaluate investment plans. The focus was deepened in chapter 2.6 to illustrate the length of the conventional contracting window between these firms and to indicate the importance of the start-up curve and guarantee period.

2.7. RTD Intensity, Product Commercialisation and Ownership of Intellectual Property Rights – Drivers of Co-operation or Competition?

Investing in research and technology development (RTD) in several sectors is seen as an important source of technological innovations for the paper industry (Brunila 2006; Lindström et al. 2004) since RTD plays an important role in renewing the industry. Lin et al. (2006) suggest that firms need to continuously create innovations to gain competitive advantage, and they find a link between commercialisation orientation, RTD intensity and a firm's performance. Kotler (1976, p. 198) suggests that a lack of major innovations leads to economic stagnation. Still, innovations do not necessarily need to be technological, as the firms' ultimate objective should be to satisfy market and customer demands. Hence, market-driven organisations that have the capabilities to satisfy and foresee market and customer demands have the competitive advantage in the long run. The link between market shares and technological innovations or patents seems to have less significance in creating competitive advantage for market-

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[32] "*Avaimet käteen*" in Finnish

[33] *Engineering, Procurement and Construction Management*

[34] *Engineering, Procurement and Construction*

driven firms than the firms' ability to use the innovations and patents in satisfying customer demands (Olsen 1988; Teece et al. 1997, p. 522; Teece 1996). Furthermore, turning innovations and patents into profits is a big challenge, as Quinn and Mueller (1991) point out. The single firm's innovation and RTD activities seem, in fact, to be mostly driven by the particular firm's ethos and organisation structure (Brown 1991) rather than by the rivalry for market shares, as Figure 2-23 illustrates. Furthermore, O'Brien (2003, p. 419) asserts that large expenditures on RTD do not guarantee that a firm will be an effective innovator.

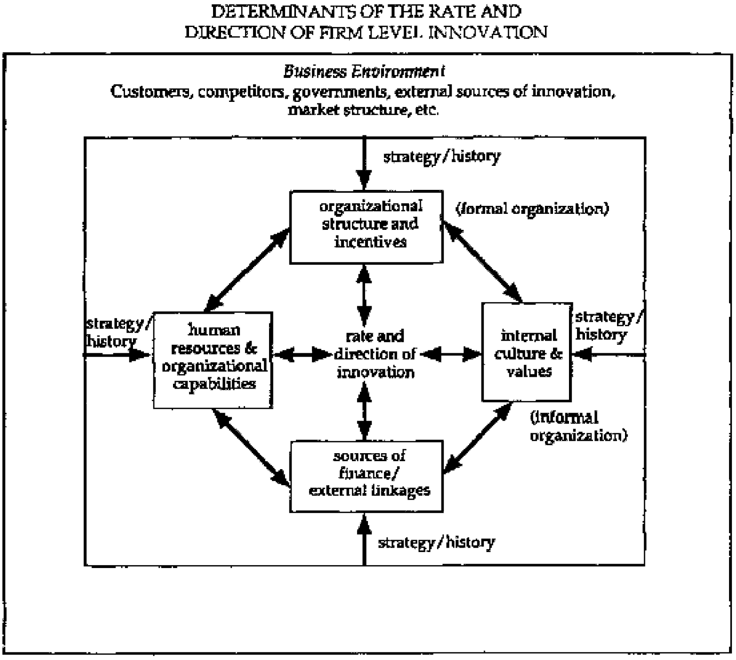

Figure 2-23. Determinants of rate and direction of firm-level innovation (Teece 1996, p. 208).

Dominant paradigms of the strategic management field, e.g. entry deterrence and Porter's (1991; 1998b) competitive forces approach (Teece et al. 1997), emphasise product market position and firms' ability to "outplay" their competitors in the respective market segment to gain profits. This competitive setting requires a system which protects against imitation and duplication as the firms' core assets are embodied in their products. The role of intellectual property rights (IPR) management is to protect firms' inventions, i.e. intellectual properties, from their competitors, and the best known instrument of IPR is called a *patent*. Although the importance of IPR is increasing, firms competing with product technology are confronted with the unfortunate circumstance of exposing what they have developed in order to profit from the technology. Profits can be gained either directly through sales volume or indirectly via patent royalties. Table 2-2 shows selected firms' paper industry related patent applications in the year 2003 (Derwent World Patent Index 2006). Title *Paper industry related patents* in Table 2-2 is composed of several IPC (International Patent

Classification system) classification domains which are related to paper-making, while *paper machine technology patents* is a further division of them which includes only paper machine technology domains of the IPC classification.

Table 2-2. Paper industry related patent applications of selected firms in the year 2003. The division between paper machine technology related and other patents is based on the International Patent Classification (IPC) system. (Derwent World Patent Index 2006)

FIRM'S FIELD	FIRM	# OF PAPER MACHINE TECHNOLOGY PATENTS Y2003	# OF OTHER PAPER INDUSTRY RELATED PATENTS Y2003
Technology supplier	Metso Paper	185	0
Technology supplier	Voith Paper	318	0
Technology supplier	Mitsubishi Heavy Industry	52	0
Technology supplier	Andritz & Küsters	50	0
Technology supplier	Kvaerner Pulping and Power[35]	14	0
Tissue producer	SCA	0	179
Tissue producer	Kimberly-Clark	0	518
Tissue producer	Procter & Gamble	0	868
Tissue producer	Georgia Pacific	2	46
Paper and Carton producer	International Paper	6	57
Paper and Carton producer	UPM-Kymmene Corporation	0	14
Paper and Carton producer	StoraEnso	3	13
Paper and Carton producer	M-Real	0	16

Although Table 2-2 illustrates patent activities of the selected firms for only one year, it gives evidence of the core businesses of these: technology suppliers' patents mainly concern patent classification domains related to paper machine technology, such as *D21G001 (Calenders), D21H023 & B05B,C,D (Coating of paper), D21F001 (Paper machines wet end), F16C013 (Rolls), D21F007 (Other details in paper machines), D21F003 (Paper machines press section), D21D005 (Stock preparation), B65H019 (Changing the web roll), B65H018 (Winding webs), D21F005 & F26B013 (Paper machines drying section)* (IPC), while paper and carton as well as tissue producers' patents mostly concern[36] domains like *B32B003 (Layered products comprising a layer with discontinuities), B65D005 (Containers of polygonal cross-section, D21H027 (Special paper made by multi-step processes), D21H021 (Non-fibrous material added to the pulp), D21H019 (Coated paper)* and *B65D085 (Containers, packaging elements or packages)*

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[35] *Kvaerner Pulping and Power* was acquired by *Metso Corporation* in 2006

[36] It is common knowledge in the paper industry that the tissue producers in Table 2-2 possess quite extensive patent portfolios the covering paper machine technology of specialised tissue paper machines.

(IPC), to name a few. This setting also enables speculating with the competitive forces approach as a paper company can gain competitive advantage against its competitors by patenting some critical paper machine technology products or processes. In turn, short-sightedly and self-centredly applied patent protection limits the technology suppliers' ability to use the respective technology in other customers' machines even when these customers do not compete in the same market segment.

McKenna (1991, p. 65) suggests that marketing will move in the knowledge- and customer-driven direction. One point of view on the matter is that the fundamental drivers behind a firm's actions are the *beliefs* according to which the firm maximises its shareholder returns. If new business opportunities are looked at from the marketing perspective, the future innovative ventures might be priceless. These elements are part of *value-based marketing* (VBM), in which the place of marketing is to increase the shareholder value (SHV) (Doyle 2003, pp. 335-336). Following the discussion of Rotemberg and Saloner (1995), the profitability of new innovations depends on a firm's ability to manage the old and new businesses. The *capabilities approach* addressed by Day (1994) suggests different ways to achieve superior financial performance than the competitive paradigms of the strategic management field, such as entry deterrence and Porter's (1998) competitive forces approach (Teece et al. 1997). While the competitive paradigms focus on controlling competitors, the capabilities or *resource-based* approach attains competitive advantage from the company's distinctive assets and activities which can only be duplicated with difficulty and which have been cultivated slowly over time along the path that the company has evolved on (Teece et al. 1997, pp. 513-524). Incidentally, an entry barrier is also set up when firms learn how to reduce manufacturing costs over time and keep this experience as proprietary knowledge (Porter 1998b, p. 12). On the other hand, distinctive assets which give a firm competitive advantage also limit the firm's ability to adapt to changes (Day 1994, p. 38).

In conclusion, RTD intensity and IPR management do not seem to have any effect on firms' co-operation strategies. Instead, firms set their business strategies beyond external technological drivers such as innovations or RTD activity, and the competitive advantage of the firm seems to require both good self-positioning in the market as well as the ability to respond to customers' demands. A firm's business success, in turn, seems to depend on its management's ability to determine how to improve and exploit the firm's resources to serve its customers in the best way. In contrast to the conclusions of chapter 2.6, the lack of maintenance outsourcing contracts does not seem to depend on unclear ownership of process- and technology-related intellectual property rights in the light of technology patents. Moreover, the problem is more related to evaluating the quality of inputs and their costs.

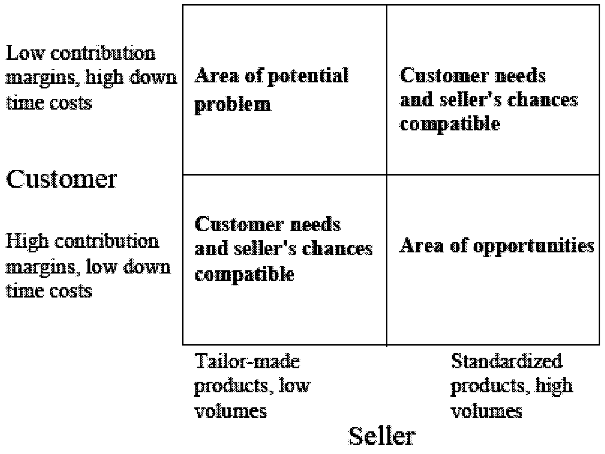
2.8. Re-Thinking Contracting in the Paper Industry

Komonen et al. (2006) suggest that green-field investments are based on assumptions concerning longer-term demand, competition, interest rate, technology development and cost level development. The pressure to measure a firm's performance in the longer run has also emphasised accounting concepts such as Life Cycle Costing (LCC) (Suomala 2004, p. 119; Sherwin 1999; Juva and Gustavson 1996, p. 17, pp. 184-209) and *Activity-Based Costing (ABC)* (Cooper and Kaplan 1988; Kaplan 1990; Uusi-Rauva et al. 1994; Seppänen 2001). ABC focuses on *identifying cost drivers that measure the particular activities causing costs to arise* (Kaplan 1990, p. 270), while the LCC concept can be used for defining *necessary activities* (or functions) for attaining a targeted life cycle so that the number of activities which cause costs is minimised. Proper use of ABC and LCC should result in optimised *total costs* during the targeted (product's) life cycle.

A paper production line's life cycle costs comprise of capital costs, operational costs, maintenance costs and production or quality losses caused by unavailability of Installed Base or poor raw materials or resources, as Figure 2-9 on page 24 shows. Several of these life cycle activities could be managed using the ABC concept, but these tasks are seldom identified in the operative environment, as emphasised by Kulmala (2003). LCC analysis can be applied in the investment decision-making process by taking into account specified performance, safety, reliability, maintainability and environmental requirements of the production line. In addition, LCC analysis can be used in supplier and product selection. Unfortunately, the business environment is constantly changing and changes may occur in all the factors which the investment calculations have been based on. This uncertainty raises the essential question of how to sustain or improve the life cycle profits of the original investment. This is the core issue in *asset management* (Komonen et al. 2006).

Brennan and Stracener (1992, p. 50) argue that decisions which commit a large percentage of products' life cycle costs are often fixed at an early development stage. Furthermore, they remark that reliability, maintainability and supportability (RMS) are the drivers for product effectiveness, availability and LCC. An availability guarantee (Komonen 2006) is (just) one of the tools which enable a buyer to control risk, while adding to the risks of the supplier. Yet, availability requirements appear to depend on companies' business situation. Bhat (2000, p. 107) mentions that the age of mill Installed Base, buildings and company size and return on assets significantly influence a firm's maintenance expenditures. Even though the slow growth of maturing paper industry markets increases the pressure on firms to strive for efficiency, some highly differentiated firms can place limits on their size and efficiency demands (Porter 1998b, p. 199). Hence, appropriate product and market differentiation provides these firms with an umbrella under which general industry laws can be ignored and thus also implicates less significance for new technology investments.

A necessary condition for a successful business relationship is a balanced interest between paper companies and paper machine technology suppliers. Comments supporting this view have also been presented by Kortekangas and Spolander (2001) and Porter (1990). Otherwise, the risk inherent in self-interested behaviour becomes apparent, as Figure 2-24 illustrates.



Customer	Tailor-made products, low volumes	Standardized products, high volumes
Low contribution margins, high down time costs	**Area of potential problem**	**Customer needs and seller's chances compatible**
High contribution margins, low down time costs	**Customer needs and seller's chances compatible**	**Area of opportunities**

Figure 2-24. Relationships of customer needs and sellers' possibilities in delivering availability of production equipment (Komonen 2006).

Both lower left-hand and upper right-hand boxes represent balanced business interests. The upper left-hand box represents a situation where customers call for high availability of the production line, but the technology suppliers have weak chances of collecting feedback information from the Installed Base to steer their technology development. There is a potential problem in this situation since natural balance between customer needs and supplier capabilities is not supported here, and hence the risks of the seller are not balanced with the possible returns from the risky investment. In contrast, the lower right-hand box characterises a situation where customer demand for high Installed Base availability is relatively lower, and the supplier is able to utilise long-term availability improvement. Still, the paper production process is strongly affected by a mill's environmental factors, and most paper production lines are hence tailored to meet specific customer demands. Williamson (1985, pp. 32-35) shows a relationship between special-purpose technology and contracting, as illustrated in Figure 2-25.

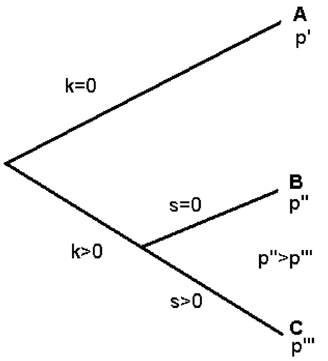


Figure 2-25. Simple contracting schema (Williamson 1985, p. 33).

Following Williamson's idea (1985, pp. 32-35), a product or service may be attained with either a general- or special-purpose technology. The special-purpose technology requires a larger investment, but it is also more productive in servicing steady state demands. Symbol *k* of Figure 2-25 acts as a measure of transaction-specific assets, and *k=0* represents situations where general-purpose technology is used. In contrast, condition *k>0* characterises the use of special-purpose technology. The better *p* represents the *break-even price* of delivering a product or service at each node (*A, B* and *C*) and *s* represents *safeguards* that may be used to protect a contracting scheme. The two special-purpose technology branches in Figure 2-25 show that the break-even price can be lower (*p'''<p''*) when a safeguard is used, because the supplier has a smaller risk regarding breaking even. Today, the field's main actors have self-positioned themselves poorly in the changing industry. For example, many technology sub-contractors participate in machine component development and manufacturing (Herbig and O'Hara 1994), and a similar contracting model between paper companies and technology suppliers might not only facilitate more efficient delivery of operations but also provide new means to improve the total cost structure in the network of firms by enabling use of innovative knowledge management services, as shown by Koskinen (2004).

The general problems in the maturing capital-intensive paper industry appear to be excess production capacity and low investment returns. The means for increasing investment returns are quite simple:

1. Increasing productivity,
2. Decreasing operating costs and
3. Developing new products.

Komonen et al. (2006) suggest that these requirements are best met by means of dynamic and continuing life cycle management, optimal capacity development, higher overall equipment effectiveness, higher reliability and flexibility of physical assets and lower maintenance costs of production equipment. The sharing of several functions from paper mill investment planning to a mill's closure seems to have both rational and financial justification. Industry evolution explains the transfer of product development and manufacturing functions from paper companies to firms specialized in paper machine technology development. Harrigan (1988) also supports the idea of firms selecting co-operation strategies according to current industry traits. Development of paper companies' financial planning principles and organisational structures affect to management of a paper mill's activities even though practically the same resources are needed to deliver them regardless of the actor. Also, recent rivalry for market shares has driven paper companies to refine their organisations and rationalise their cost structures. Especially the significance of making costs directly measurable has increased, which might be one driver in firms outsourcing larger work packages. Furthermore, focusing on core functions and sharing them in a network of appropriate partners allows firms to narrow internal objectives (Rotemberg and Saloner 1995;Saloner and Shepard 1995), which seems to promote co-ordination (Rotemberg and Saloner 1995, p. 1331) and thus improve efficiency. Hence, paper companies seek partners and contractors who can deliver services of appropriate scope and at measurable costs. Figure 2-26 illustrates a potential business model for achieving delivery of the fundamental activities of a paper mill with a network of vertically and laterally separate firms (Kuusisto et al. 2005, p. 54).

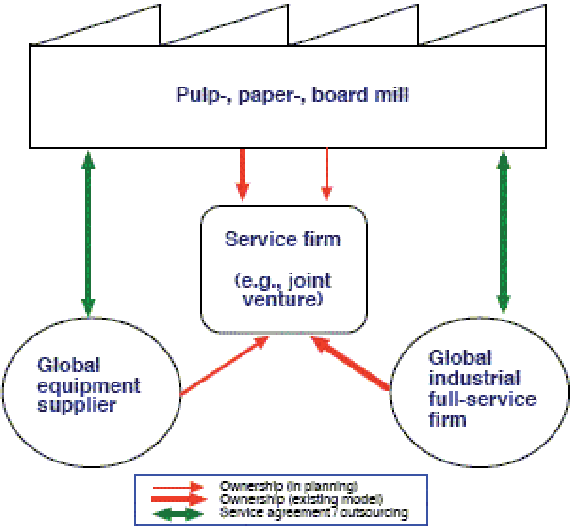


Figure 2-26. New business models in mill service and maintenance (Kuusisto et al. 2005, p. 54). Both actors, *Global equipment supplier* (e.g. paper machine technology supplier) and *Global industrial full-service firm* can co-exist and compete in the same markets.

The concept in Figure 2-26 seems to make good sense, given the earlier requirements for managing paper mill main activities and the core assets of firms (Hart and Moore 1990, pp. 1141-1150). Managing paper industry activities calls for a global (Kandampully 2003, p. 443) and wide-ranging knowledge of the local production processes of paper mills, knowledge of their maintenance activities and knowledge of suitable machine components for them, thus limiting the number of firms capable of offering such services. The needed activities mainly concern

- **Paper mill production and operation**
- **After sales activities**
  - Maintenance
  - Spare parts operations
  - Roll service
  - Process improvements

Production activities are truly the core assets of paper companies. Firms capable of providing the remaining services are paper machine technology suppliers (spare parts, roll service and process improvements) together with their contractor networks (Herbig and O’Hara 1994) and multi-discipline service firms (maintenance), both competing in the same markets with quite different core assets. The technology suppliers' assets are embodied in their products and they are threatened if these are accessible to competitors. On the other hand, the development of technology concepts has generated distinctive assets the technology suppliers which are difficult to duplicate. Swanson (1997, p. 201) finds technical complexity to be associated with more decentralised maintenance, more extensive training, greater use of professional staff and lower operator involvement. However, no associations have been found to be involved in the whole variety of technology and maintenance practices. Swanson (2001, pp. 237, 243) also finds a link between aggressive maintenance strategy and technology development and suggests that total productive maintenance (TPM) has a positive effect on equipment availability.

The changing environment thus generates new demands as well as new business opportunities for firms in the industry. Maintenance, in turn, is labour-intensive and requires several workers for carrying out the activities needed at the paper mill (Davis 1999). This requirement is not supported by the organisational structures of the technology suppliers, as they are mostly knowledge-intensive firms with fewer employees. Timonen et al. (2005, p. 27) suggest that the paper industry might consider these services only if they are delivered by a few well-established companies. All in all, the firms are expected to commit themselves to long-term contracts to make the joint venture profitable. Otherwise, the firms are in a constant bargaining situation (Muthoo 2000) and prepared to protect their core assets. Accordingly, if the firms have a conflict of interests over the co-operation details, they might refrain from profitable co-operation and thereby reduce their own profits (Muthoo 2000). Indeed, it would be unusual for a firm to guarantee definite and predefined outcomes to another firm while withholding the power to direct the other firm's actions (Coase 1937, p. 400). Such a setting is called *the hold up problem* (Klein et al. 1978). Hart and Moore (1988) study in their seminal paper how long-term commitment between firms leads to *incomplete contracts* (Tirole 1999) as the events during a long co-operation period are difficult to anticipate and thus to specify, *ex ante*. Related studies (Hart and Moore 1988; Nöldeke and Schmidt 1995) also suggest that objective verifiability of the contract, i.e. showing whether or not the original contract terms are met at all times, plays an essential role in evaluating the success of a contract. Figure 2-27 illustrates the key elements of partnership (Lambert et al. 2004) and also provides simple answers to the questions *why, when* and *how* to share the needed activities with several partners.

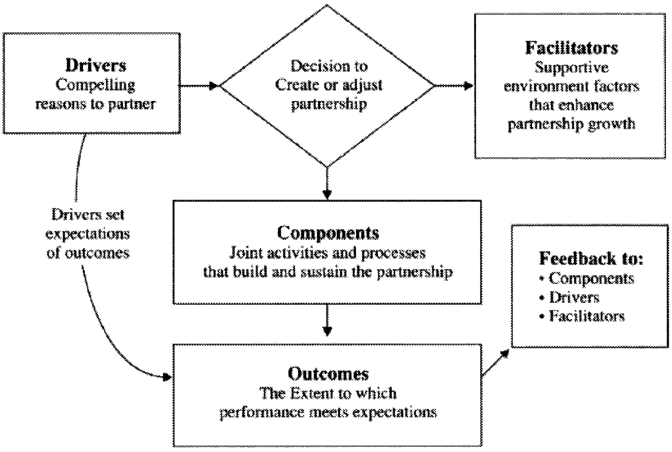


Figure 2-27. The partnership model (Lambert et al. 2004, p. 23). The key elements of a partnership are *drivers* (financial, technological, etc.), *facilitators* (appropriate supply and demand, for example), *components* (partners' core competencies) and *outcomes* (win-win).

As Coase (1937, p. 396) put it, a firm does not benefit from taking over another firm's functions unless they can be produced with fewer costs than buying these functions from the open market. The contrary applies in considering an outsourcing decision; it is not reasonable to outsource a function if its price in the open markets is higher than producing the function internally. Kanter (1991) supports Brown's (1991) and McKenna's (1991) ideas of developing communication between customer and contractor at all organisational levels. Porter (1998) also emphasises the importance of locality as a motivator of good co-operation. Humphreys et al. (2003, pp. 175-177) conclude that partnering, the highest form of co-operation, can only be achieved when the firms go through all the steps from adversarial contracting to collaboration, and finally to partnering. Kulmala (2003) supports this suggestion, too. Williamson (2002) agrees that organisational structures and human relations play an essential role in co-operation, and Madhok (2002, pp. 535-536, 539-543) presents strong arguments supporting transaction cost economising by means of the efficient allocation of resources. Control over the tangible and intangible assets has an important role in partnering (Hart and Moore 1990). Ownership of control dictates *who*, in practice, has the final say in the investment decisions during the paper mill's life cycle and who has access to the return on investments (Farrel and Scotchmer 1988; Fieseler et al. 2003; Hauswald and Hege 2003). Grossman and Hart (1986) suggest that specific and residual (ownership) rights would provide a natural way to contractually define ownership of mutual assets, thus eliminating the possibility of an incomplete contract. Specific rights are those specified in the contract, while residual rights include everything else. Hence, the *possibility of controlling the other partner's outcomes* with either specific or residual rights might encourage the parties to work most efficiently in a long-term contracting scheme.

In practice, long-term contracts *are* difficult to define and thus long-term co-operation between firms is quite often composed of contiguous, short-term contracts which are renegotiated at the time of their renewal. Rey and Salanie (1990) discuss the settings under which long-term contracting would directly yield optimal outcomes to the firms involved, and in which cases the contiguous, renegotiated, short-term contracts eventually lead to a long-term optimum. Generally, problems arise if the parties cannot objectively verify that the *ex post* surplus from their initial investments is divided appropriately *ex ante* (Klein et al. 1978; Rogerson 1992; Ellingsen and Robles 2002).

To summarise the contribution of chapter 2.8, a firm is expected to take over another firm's functions if and only if these needed functions can be produced with lower costs than buying the same functions from the open market (Coase 1937, p. 396). Despite the theoretical and empirical clutter of chapter 2.8, the main message is still clear: decision-makers need to evaluate which of the available options is (financially) most tractable.

2.9. Summary

Paper industry background and development trends were introduced in chapter 2. The significance of the essential mill functions was discussed and reasons for industry development were presented. Although the main driver of industry development seems to be increased focus on growing market areas, other drivers in the changing business environment exist, too. The most important of them appears to be emphasising the measuring of direct costs as a tool of strategic decision-making. Paper companies have been struggling with excess capacity problems in traditional market areas, and they have been closing down less productive, *yet profitable*, production lines. This trend has also favoured the development of technically new Installed Base in the pursuit of better productivity, thus giving technology suppliers an opportunity to sell modernisation and expert service projects. Following McGahan's (2004, p.90) definitions (shown in Figure 2-20 on page 35), a few recent examples of progressive change can be found in the field - outsourcing maintenance functions to technology suppliers, for example - which coincide with the concept discussed by Kuusisto et al. (2005, p. 54). However, feedback from these implementations cannot be expected in a few years. Later on it will be possible to estimate whether a successful business relationship with a balanced interest between paper companies and paper machine technology suppliers has been found.

3. Models for Comparing Alternative Contracting Strategies

> *Remember that all models are wrong; the practical question is how wrong they have to be to not be useful. Essentially, all models are wrong, but some are useful.*
>
> ***- Box and Draper (1987,** pp. 74, 424)*

Chapter 3 presents alternative modelling frameworks and theories for analysing contracting strategies and focuses on their theoretical foundations as well as their suitability for the research problem studied. Presented modelling frameworks include models of *control theory*, *statistical signal processing* and *microeconomic theory* - such as production theory and game theory (von Neumann and Morgenstern 1967; Brandenburger and Nalebuff 1995; Mas-Colell et al. 1995, pp. 217-305; Renault 2001; Wong 2005).

3.1. Problem Boundaries and Mathematical Models

The available empirical data on the problem, model validation possibilities, and the intended use for the analysis results strongly influence the choice of modelling methodology. Hence, the best measure of model goodness is simply its ability to answer the research objectives, as noted by Box and Draper (1987, p. 6).

The time dimension has been widely used as a reference for observations in the physical sciences, engineering (Ohanian 1988, pp. 379–402; Boas 1983, p. 297) and economics (Box et al. 1994; Hamilton 1994; Nason and Sachs 2000). Time series data basically characterise the evolution of some process over time, and observations of the process are usually measured at equal time intervals. *Time series analysis* (*TSA*) methods are generally applied for studying *long-term* or *trend movements*, *cyclic movements*, *seasonal movements* and *irregular* (or *random*) *movements* (Box et al. 1994; Han and Kamber 2001, pp. 418-427). Different applications have also been developed for (*partial*) *periodicity analysis* for performing a similarity search for time series data (Agrawal and Srikant 1995; Han et al. 1999; Caraça-Valente et al. 2000). If a lot of measured data on current paper companies' Installed Base efficiency were publicly available, it might be interesting to study whether some recurrences could be discovered in this data. Koskinen (2004) made such an attempt in predicting spare part consumption at paper mills, with some promising results. In the absence of such empirical data the time series approach becomes useless. Furthermore, since the main goal of the study is to make this multifaceted problem more concrete, staring at past realisations does not necessarily help to meet this challenge.

Sometimes it is useful to express the research problem as a *black box system* to be studied in terms of its responses, i.e. *outputs* to given *inputs*, as Figure 3-1 shows. This modelling approach is called *control theory* (Speedy et al. 1970) and it has commonly been used for examining how the input parameters of a system being studied can be manipulated so as to make the system to produce a desired or optimal output. When control theory is applied for building a model of the system studied, it falls under the heading of *system identification*. Also *cybernetics* (Ashby 1956) studies such input-output models in a wider context, and Fogelholm (2000) emphasised cybernetics in developing cost function modelling. Similar methodology can be used also as a tool for prediction and classification problems. Prediction and classification approaches are widely used in statistics, engineering and signal processing, especially in *pattern recognition* (Bishop 2003; Devijver and Kittler 1982; Duda et al. 2000; Haykin 1999; Kohonen 1997; Koskinen et al. 2004; Koskinen 2004). In these cases the purpose might not be to discover the "true" process or system, but rather to develop an efficient computational model which *imitates* the behaviour of the real system and can further be utilised in different real-world problems. Searching for such an "optimal" model (Akaike 1974) is quite a difficult task, and different methods strive towards reduced computational complexity at the cost of oversimplified assumptions of the reality (Johnstone 2000). A quite common example of such assumptions is to assume the data to consist of two parts: the "real data" and (additive) noise. However, distinguishing the "real data" from the noise requires subjective measures, such as *Bayesian priors* (Silverman 2000). Actually, only few methods treat the data objectively, and one of them is the *Minimum Description Principle* (*MDL*) (Rissanen 1978), which defines the incompressible part of the data as "noise" while the compressible part is considered as "information". The fundamental problems concerning prediction, estimation and compression are discussed in (Rissanen 1984), providing a quite informative insight into the question. The search for a model often incorporates *optimisation methods* (Fox 1971; Fletcher 1986; Miettinen 1999) or recursive estimators, such as the *Kalman filter* (Kalman 1960; Maybeck 1979). Kalman filters have been used for aircraft flight path tracking (Wong and Blair 2000), extracting cycles and trends in economic time series (Harvey and Trimbur 2003) and numerous tracking problems in several other fields of application (Welch and Bishop 1997; Cemgil et al. 2001; Cemgil and Kappen 2003).

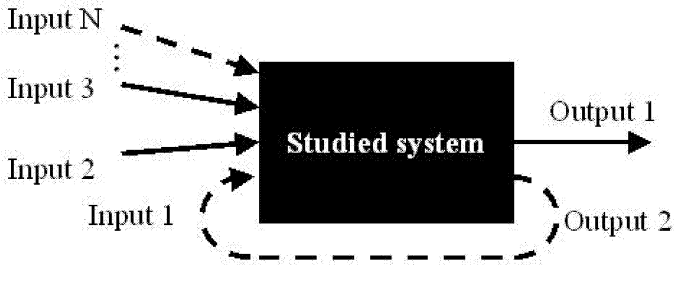


Figure 3-1. Illustration of control theory *Black box* approach.

Ijiri and Thompson (1970), Wall and Westcott (1974) and Chow (1974) studied the applicability of control theory to econometric problems and found it useful, provided that the structure of the system studied is defined at some level – *a black box approach is not sufficient*. Furthermore, defining an *optimal output* for the research problem studied is difficult because it is impossible to know the maximum numerical value of a paper production line's LCP (*ex ante*, at least).

However, an adjacent methodology, *operations* (or *operational*) *research* (*OR*) (Hanssmann 1968; Shamblin and Stevens 1974; Gass 1983) offers several useful approaches for modelling the problem at hand. OR is an interdisciplinary science which deploys scientific methods such as mathematical modelling, statistics and algorithms to real-world decision-making problems. The fundamental aim in OR is to find the best possible scientific solution to a real-world problem although the responsibility for the decision made will still rest with managers. Hence, the *output of OR is not decisions but information to support decision-making*, as Hanssmann (1968, p. 13) put it. In fact, the degree of responsibility left delegated to managers in decision-making and the resulting social impact of OR have emphasised its place in a management science (Drucker 1955; Drucker 1959), thus favouring the adaptation of the term *Operations research/ Management science* (*OR/ MS*) (Brans and Gallo 2004) over plain OR. This thesis unquestionably follows OR/ MS methodology and Hanssmann's (1968) example of the use of OR in investment decision planning, following the ideology of Figure 3-1, is utilised quite straightforward in this study. All in all, it is of great interest to verify whether some *generic* input combinations have positive or negative effects on the output of the system, e.g. LCP. Also, it is important to identify which input and output parameters are appropriate and inappropriate for the system (Hanssmann 1968, pp. 29-36), the time dependence of these parameters and their meaningful combinations. In order to do so, the OR approach needs to be supplemented by economic models related to the problem. Some of the central problems concerned are contracting, production and profit maximisation - all studied extensively by microeconomics.

3.2. Microeconomic Models of Production

Microeconomic theory provides several useful ways to model production, contracting and profit maximisation. The control theory input-output model introduced in Figure 3-2 above resembles closely a *production set* concept in microeconomic theory (Mas-Colell et al. 1995, p. 127). Moreover, production is one of the core activities of a paper production line, as discussed in chapters 2.1, 2.2 and 2.5. Furthermore, a firm's production capabilities give rise to well-known production optimisation problems, such as profit maximisation and cost minimisation problems (i.e. PMP and CMP, respectively) (Mas-Colell et al. 1995, pp. 135-143). Hence, the production modelling offers useful approaches for modelling the profit maximisation problem in the paper production line life cycle.

A production vector[37], as defined in microeconomic theory (Mas-Colell et al. 1995, p. 128), is a vector

$$y = (y_1, \ldots, y_L) \in \mathrm{R}^{\mathrm{L}}. \qquad \text{(Eq. 3-1)}$$

Vector y describes L commodities that a firm's production process (the "black box") contains. By agreement, negative elements of y represent production vector inputs and positive elements represent its outputs. In other words, commodities

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[37] Also known as an *input-output* or *netput vector*, or as a *production plan* (Mas-Colell et al. 1995, p. 128).

y<0 are consumed in the process while all *y>0* are produced. For completeness, products *y=0* are neither consumed nor produced.

A firm's *production technology* depends on available resources (including technology) and its own expertise. Hence, not all production vectors are feasible for a specific firm and the set of feasible production vectors, also known as *production set*, is denoted by

$$Y \subset \mathrm{R}^{\mathrm{L}} . \qquad \text{(Eq. 3-2)}$$

Any $y \in Y$ is a possible production vector, while any production vector $y \notin Y$ is not. Many actual production processes, including the one being studied, concern distinct inputs and outputs, which encourages the use of a notation that distinguishes a system's inputs from its outputs. For example, the production levels of a firm's *M* outputs (products) can be denoted by

$$q = \{q_1, \ldots, q_M\} \geq 0 . \qquad \text{(Eq. 3-3)}$$

Respectively, the amount of a firm's *L-M* inputs can be denoted by

$$z = \{z_1, \ldots, z_{L-M}\} \geq 0 , \qquad \text{(Eq. 3-4)}$$

where variables z_l are *nonnegative* numbers.

In a case where the firm (or process) produces a single output, the production set is commonly described with a *production function f (z)*, which gives the maximum output *q* in response to input $z = (z_1, \ldots, z_{L-1}) \geq 0$ (Mas-Colell et al. 1995, p. 129). As an example, for (a no-cost disposable) output product *L* the production function *f (·)* gives rise to a production set

$$Y = \{(-z_1, \ldots, -z_{L-1}, q) : q - f(z_1, \ldots, z_{L-1}) \leq 0 \text{ and } (z_1, \ldots, z_{L-1}) \geq 0\} . \qquad \text{(Eq. 3-5)}$$

Marginal rate of technical substitution (*MRTS*) can be defined by keeping the output level fixed and letting the inputs vary. More specifically,

$$MRTS_{lk}(\bar{z}) = \frac{\partial f(\bar{z}) / \partial z_l}{\partial f(\bar{z}) / \partial z_k} . \qquad \text{(Eq. 3-6)}$$

In words, MRTS measures the needed amount of additional input *k* to keep output at level $\hat{q} = f(\bar{z})$ when the amount of input *l* is marginally decreased. MRTS seems practical in studying the effects of different contracting models as they most likely affect the paper production inputs (and maybe outputs, too). MRTS can, for example, be applied to evaluate how much a machinery rebuild (increasing *k* characterises investment capital) must reduce labour costs (*l* decreases) to justify the change in production process.

Microeconomic models of production provide a few useful assumptions and tools to be adopted in studying the main research problem of this thesis. The idea of marginal rate of technical substitution is practical and relevant in analysing the effects of changing paper production inputs in alternative contracting strategies. Similarly, some of the general assumptions concerning production set Y properties are useful to be adapted to the modelling framework, especially *constant returns to scale* (*CRS*) assumption. A production set Y exhibits constant returns to scale if $y \in Y$: $\alpha y \in Y$ for all scalars $\alpha \geq 0$, and when CRS holds economies of scale are not available. The definition of production function also gives rise to profit maximisation (PMP) and cost minimisation (CMP) problems (Mas-Colell et al. 1995, pp. 135-143), which have a central place in this thesis. However, the assumptions needed to justify the use of microeconomic theory might not hold in reality, and validating these assumptions could be difficult in practice.

3.3. Profit Maximisation and Cost Minimisation

The profit maximisation problem stems from the assumption that a firm's objective is to maximise its profit. This assumption is a central accepted element in this research, and a methodology for finding a profit maximising contracting strategy is accordingly developed.

Given a *price vector*

$$p = (p_1, \ldots, p_L) >> 0 \qquad \text{(Eq. 3-7)}$$

for commodities L, it is also assumed that the prices p_L are controlled by market competition and hence they are independent of a firm's production plans. This assumption is known as the *price-taking assumption* (Mas-Colell et al. 1995, p. 20). Given a price vector $p >> 0$ and a production vector $y \in \mathrm{R}^L$, a firm generates profit

$$p \cdot y = \sum_{l=1}^{L} p_l y_l \qquad \text{(Eq. 3-8)}$$

by implementing production plan y. A firm's production plans are further limited by technological constraints, represented by production set Y. Hence the profit maximisation problem (PMP) has the form

$$\underset{y}{Max}\, p \cdot y, \text{ s.t. } y \in Y^{38}, \text{ or using the transformation function notation,}$$

$$\underset{y}{Max}\, p \cdot y, \text{ s.t. } F(y) \leq 0\,. \qquad \text{(Eq. 3-9)}$$

For a given production set Y, the firm's *profit function*

$$\pi(p) = Max\,\{p \cdot y : y \in Y\} \qquad \text{(Eq. 3-10)}$$

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[38] s.t. refers to *subject to* in optimisation constraints.

associates the value $\pi(p)$ - the value of the PMP problem's solution - to every price vector p. In the same way, a firm's *supply correspondence* at p, denoted $y(p)$, is defined as the set of profit-maximising vectors

$$y(p) = \{y \in Y : p \cdot y = \pi(p)\} \ . \qquad \text{(Eq. 3-11)}$$

Generally speaking, $y(p)$ may be a set of vectors instead of a single vector. It may also be possible that a profit-maximising production plan y does not exist. This occurs, for example, if the price system is not bounded from above, thus allowing profits to grow infinitely, i.e. letting $\pi(p) = +\infty$.

Given a production set Y for a single output technology with differentiable production function $f(z)$, the firm's production decision can be seen as a choice over input levels z. In the following, scalar p denotes the price of the firm's output product and vector $w >> 0$ input prices. Then, the input vector z^* maximises firm's profit with respect to (p, w) if z^* solves

$$\operatorname*{Max}_{z \geq 0} \ pf(z) - w \cdot z \ . \qquad \text{(Eq. 3-12)}$$

If z^* really is optimal, then the following first-order conditions must be satisfied for $l=1,\ldots, L-1$:

$$p\frac{\partial f(z^*)}{\partial z_l} \leq w_l, \text{ equality holds if } z_l^* > 0. \qquad \text{(Eq. 3-13)}$$

Hence, the *marginal product* of every input l actually used (i.e. $z_l^* > 0$) must equal its price w_l in terms of output p, namely w_l / p. Another point worth noting is that for any two inputs l and k with $(z_l^*, z_k^*) >> 0$, the condition of Eq. 3-13 implies that the marginal rate of technical substitution between the two inputs is equal to their price ratio, the economic rate of substitution between them. More succinctly,

$$\frac{p_l}{p_k} = \frac{w_l}{w_k} = MRTS \ . \qquad \text{(Eq. 3-14)}$$

When a firm chooses a profit-maximising production plan y, it has discovered that producing the same amounts of output at a lower input cost is not possible.

The focus is next on cost minimisation. Since cost minimisation is a necessary precondition to profit maximisation, it becomes important to study the cost minimisation problem (CMP). CMP is interesting as it leads to a number of technically useful results and constructions: when a firm is not a *price-taker* in its output market (i.e. the market selling price of commodities produced by the firm depends on its production plan), the profit function can no longer be used for analysis. Yet, when a firm *is* a price-taker in its input market, the results following from cost minimisation continue to be valid.

First, the analysis will focus on the single-output case. As before, z is nonnegative vector of inputs, $f(z)$ production function, q the amounts of output and $w >> 0$ vector of input prices. Then the cost minimisation problem (CMP) takes the form

$$\underset{z \geq 0}{Min}\, w \cdot z, \text{ s.t. } f(\mathrm{z}) \geq q. \qquad \text{(Eq. 3-15)}$$

Hence CMP minimises the second term of the PMP of (Eq. 3-12). The optimised value of CMP is given by the *cost function c(w,q)*, and the corresponding set of input (or *factor*) choices that yields the optimum, denoted by $z(w,q)$, is known as the *conditional factor demand correspondence*. The term *conditional* signifies that these factor demands are conditional on the requirement that q amounts of output should be produced. Assuming that z^* is optimal and production function $f(\cdot)$ is differentiable, the following first-order conditions must hold for some $\lambda \geq 0$ and for every input $l=1,\ldots, L-1$:

$$w_l \geq \lambda \frac{\partial f(z^*)}{\partial z_l} \leq w_l, \text{ with equality if } z_l^* > 0. \qquad \text{(Eq. 3-16)}$$

As with the PMP, for a convex production set Y the condition of (Eq. 3-16) is not only a necessary but also a sufficient condition for z^* to be an optimum in the CMP. In accordance with condition (Eq. 3-14) for the PMP, the condition of (Eq. 3-16) implies that any two inputs l and k with $(z_l, z_k) >> 0$ yield

$$\frac{w_l}{w_k} = MRTS_{lk}. \qquad \text{(Eq. 3-17)}$$

This correspondence can be expected since profit maximisation implies that input choices are cost-minimising for the chosen output level q. The Lagrange multiplier λ can be interpreted as the marginal value of relaxing the constraint $f(z^*) \geq q$. Hence,

$$\lambda = \frac{\partial c(w,q)}{\partial q} \qquad \text{(Eq. 3-18)}$$

is the *marginal cost of production.* The cost function may be particularly useful when Y exhibits constant returns to scale. In the CRS case $y(\cdot)$ is not single-valued for any price vector, thus allowing nonzero production. Using the cost function $c(\cdot)$, a firm's problem in determining the profit-maximising production level can be restated as

$$\underset{\mathrm{q} \geq 0}{\mathrm{Max}}\, pq - c(w,q). \qquad \text{(Eq. 3-19)}$$

This ends the discussion of profit maximisation and cost minimisation. Despite the fact that both CMP and PMP are central issues in this thesis, they focus more on characterising firms' actions in responding to market development than on inter-firm transactions. In the real-world, paper production lines are quite often specialised to producing only certain paper grade(s) and hence the paper company does not usually have an option to change its output products. Also, the paper sales price is not usually directly determined by markets but rather negotiated annually between the paper company and its customer(s). Because of these factors, CMP and PMP fail to provide a convenient way to characterise differences in production inputs and associated costs in different contracting strategies. This fact is further evidence of the necessity of this research.

3.4. Competition, Power and Equilibrium in Markets

Although the effects of market competition are not at the focal point of the modelling framework, this chapter justifies its place in the thesis by introducing common theories used to model *market competition* discussed above in chapter 2.8. *Market economy*, i.e. *private ownership* of firms, is assumed to be as the institutional arrangement throughout this thesis. Firms, ultimately owned by individual consumers, decide on their production plans to obtain a desired position in the markets. *Market equilibrium* exists when each firm is doing as well as possible given the actions of other firms. Here the focus is on pointing out how the different contractual management options affect a firm's position in the markets. In competitive market economies all firms in the economy seek to perform as well as possible. Later on in this thesis, this tendency is called *self-interested behaviour*. In reality, as in the application field of this research, there might only be a few firms (*oligopoly*), or possibly just one (*monopoly*) firm acting as a buyer or a seller in the market. In such case this firm would possess *market power*, i.e. the ability to abolish competitive price levels. Hence the pricing behaviour of a *profit-maximising monopolist* (i.e. of a firm which is the only producer of some good in the market) and of an *oligopolist* are studied next (Mas-Colell et al. 1995, pp. 383-427).

A continuous and strictly decreasing function $x(p)$ characterises the demand for some good at price p. It is also assumed that a price $\overline{p} < \infty$ exists such that $x(p) = 0$ for all $p \geq \overline{p}$. Furthermore, the monopolist is assumed to know the demand function for its product and to be able to produce output level q at cost $c(q)$. Then the monopolist's decision problem concerns setting the price p to maximise its profits, or more succinctly, solving

$$\underset{p}{\text{Max}}\; px(p) - c(x(p)) . \qquad \text{(Eq. 3-20)}$$

A more common situation in real markets is where there is more than one, but still very few firms on one side of the market. This situation is called an oligopoly. Competition between firms in an oligopolistic market involves strategic interaction, which has traditionally been studied using *game theory* (von Neumann and Morgenstern 1967; Mas-Colell et al. 1995, pp. 217-305). *Static* oligopoly models consider only a single period of competitive action and are discussed first together with an introduction to the application of game theory. Two well-known models of economic theory, i.e. *Bertrand* and *Cournot* models, are also introduced. Importantly, this analysis should also reveal how the game-theoretic approach affects firms in choosing their strategies and payoff functions.

A Bertrand duopoly characterises competition between two profit-maximising firms 1 and 2 in a market whose demand function is $x(p)$. Both firms have CRS technologies with equal costs $c>0$ per unit produced. It is also assumed that $x(c) \in (0,\infty)$, implying that the optimal output level in this market is strictly positive and finite. The circumstances defined above only leave room for price competition. Hence, the firms set their prices p_1 and p_2, and sales for the firm j are given by

$$x_j(p_j,p_k) = \begin{cases} x(p_j) & \text{if } p_j < p_k \\ \frac{1}{2}x(p_j) & \text{if } p_j = p_k \\ 0 & \text{if } p_j > p_k \end{cases} . \qquad \text{(Eq. 3-21)}$$

The firms produce to order, and production costs are thus generated only for an output level that equals their actual sales. Given prices p_j and p_k, the profits of firm j are therefore $(p_j - c)x_j(p_j,p_k)$. In fact, the Bertrand duopoly constitutes a *simultaneous-move game* in which *Nash equilibrium* (Mas-Colell et al. 1995, pp. 246-253, 388-389) can be clearly seen to operate. Bertrand duopoly model has a unique Nash equilibrium (p_1^*, p_2^*) in which both firms set their prices to equal costs: $p_1^* = p_2^* = c$[39]. The Bertrand duopoly model thus suggests that distortions arising from firms exercising market power are limited solely to the case of a monopoly. The Bertrand duopoly model does not, however, represent the competition in real markets very realistically and hence some important related theories are discussed next.

Let us assume that the two competing firms *simultaneously* decide on their production levels q_1 and q_2. At these production levels the price should adjust to a level which clears the market, that is $p(q_1 + q_2)$, where $p(\cdot) = x^{-1}(\cdot)$ is the inverse demand function. This model is known as the *Cournot duopoly model*. Function $p(\cdot)$ is assumed differentiable with $p'(q) < 0$ for all $q \geq 0$. As with the Bertrand model above, both firms are expected to have equal production costs $c>0$ per unit produced. It is additionally assumed that $p(0)>c$ and that there exists a unique output level $q^\circ \in (0,\infty)$ with $p(q^\circ) = c$, implying that the quantity q° is the optimal (competitive) output level in this market. In order to find a (pure strategy) Nash equilibrium of the Cournot duopoly model, firm j's maximisation problem is considered when firm k's ($k \neq j$) output level $\overline{q}_k$ is known, i.e.

$$\underset{q_j \geq 0}{\text{Max}}\ p(q_j + \overline{q}_k)q_j - cq_j . \qquad \text{(Eq. 3-22)}$$

In conclusion, in any Nash equilibrium of the Cournot duopoly model with cost $c>0$ per unit produced by the two firms and an inverse demand function $p(\cdot)$ satisfying $p'(q) < 0$ for all $q \geq 0$ and $p(0) > c$, the market price is greater than c (the competitive price) and less than the monopoly price.[40]

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[39] Proof presented in (Mas-Colell et al. 1995, pp. 388-389).

[40] Proof given in (Mas-Colell et al. 1995, p. 391).

Competition in real markets is not as straightforward as indicated by the Bertrand and Cournot models, because *capacity constraints* and *product differentiation* are usually present. Capacity constraints characterise the situation where a firm's commitment to deliver any quantity at a given price is no longer reasonable because orders larger than capacity would imply infinite costs. Hence, the Bertrand model needs to be adjusted to assume firms only committing themselves to deliveries up to their capacities, which are assumed publicly known. This complements the theory of competition when firms' production capacity is assumed exogenous. However, firms are typically considered to *choose* their capacity levels, thus raising the question of a model's outcome where firms first choose their capacity levels and only after that engage in price competition. A re-interpretation of the Cournot model (Mas-Colell et al. 1995, p. 395) suggests that the Cournot quantity competition captures long-run competition through capacity choice and price competition occurring in the short-run, given the chosen levels of quantity. Product differentiation, on the other hand, signifies that the buyers in the market to perceive differences in the firms' products. This allows each firm to gain some degree of market power and this softens the competitive result of the Bertrand model.

The last implications of market competition involve *repeated interaction*, *market entry* and *strategic precommitments* of firms. The models discussed above assumed unrealistically that transactions between firms are one-shot in nature, and these models are next complemented to cover transactions of dynamic nature. An important feature in many *oligopolistic settings* is firms' attempt to make strategic precommitments to alter future competition so that it becomes more favourable to them. Mas-Colell et al. (1995, p. 395) mention that investments in cost reduction, capacity and new product development (NPD) all lead to long-lasting changes which affect the nature of future competition. Some of the general features of such strategic precommitments are illustrated by the following simple two-stage duopoly model:

> *Stage 1: Firm 1 has the option to make a strategic investment, the level of which is denoted by* $k \in \mathrm{R}$.
> *Stage 2: Firms 1 and 2 play some oligopoly game by choosing strategies* $s_1 \in S_1 \subset \mathrm{R}$ *and* $s_2 \in S_2 \subset \mathrm{R}$. *Given an investment level k and strategy choices* (s_1, s_2), *profits for firms 1 and 2 are given by profit functions* $\pi_1(s_1, s_2, k)$ *and* $\pi_2(s_1, s_2, k)$.

An example case might be one in which the marginal production cost of firm 1 can be reduced by an investment *k*, where the stage 2 game is a Cournot competition (i.e. firm *j*'s quantity choice is $s_j = q_j$). Such strategic precommitments can also be used for *entry deterrence* as the rivals have difficulties to play against a firm which has altered competitive settings in its favour in advance. Even though the theory of firms' market competition does not play a central role in developing the modelling framework, the implications of the results of this thesis for market competition are of great interest and hence substantiate the necessity of this study. In operative real-world environment analysis of inter-firm competition, power and market equilibrium are often connected with *business intelligence* (BI) and *customer relationship management* (CRM) functions.

3.5. Optimal Contracts and Asymmetrical Information

The concepts of microeconomic theory introduced earlier have assumed that all firms in the market are capable of observing market transactions and related parameters, such as production levels and prices. Quite often the situation in real markets differs from this and firms have unique knowledge concerning market transactions, as originally discussed by Akerlof (1970). The concept of *information asymmetries* and their use by firms to compete in the markets are discussed next. The discussion will also introduce the central theorem of this thesis - the concept of an *optimal contract*.

Information asymmetries and adverse selection characterise how quality and uncertainty in the markets relate to one another, and original examples are given from labour and insurance markets (Akerlof 1970; Rothschild and Stiglitz 1976; Stiglitz 1987). It is useful to fit these concepts into the scope of this research. The following discussion (Mas-Colell et al. 1995, pp. 437-450) assumes several identical firms with single-input CRS technologies potentially investing in input resources (which might be labour, for example). Each firm is risk neutral, seeks to maximise its profit, acts as price-taker and produces the same output for the market. In this thesis, paper companies can be assumed to operate in such a setting. In addition, the price of firms' output is taken to equal 1 (in units of a numeraire[41] good). Now, the available resources in the markets (inputs) *differ* as regards the units of output they produce when acquired by a firm, and the level of resource productivity is denoted by θ. The proportion of resources with a productivity of θ or less is given by distribution function $F(\theta)$, and $F(\cdot)$ is assumed nondegenerate, i.e. to contain at least two different types of resources θ. This is also the case with paper production inputs, such as maintenance or spare parts. It is also reasonable to assume that the providers of resources (such as paper machine technology suppliers) wish to maximise their profits (or some other utility). The provider of a type θ resource then receives a payoff $r(\theta)$. Furthermore, this *opportunity cost* $r(\theta)$ is also the limit which determines the contracting scenario; the provider of resource θ is willing to change the existing contracting schema *if and only if* a higher payoff is available.

When productivity levels θ of the different resource types are *publicly observable* to all firms, there exists a distinct equilibrium price $r^*(\theta)$ for each distinct resource type θ. The situation is quite different when the productivity levels θ of the different resources are *unobservable* in the markets by the firms. In such a case, firms have to pay an average price, say $r'(\theta)$, of the resources due to firms' inability to distinguish more productive resources from the less productive ones and the average price is based on an average productivity level $\overline{\theta}$. However, the resource providers know *their* productivity levels and can thus decide *self-interestedly* which contracting model is best for them. More precisely, a resource

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[41] *Numeraire* can be interpreted as "reference".

(provider) θ is willing to alter an existing contract if and only if the payoff received from the new contract $r_{new}(\theta)$ is greater than the average payoff in the markets, i.e. $r_{new}(\theta) \geq r^{'}(\theta)$. Correspondingly, only resource providers with a productivity *below* average, i.e. $\theta \leq \overline{\theta}$, are willing to accept contracts at payoff $r^{'}(\theta)$. This phenomenon is known as *adverse selection*. In contrast, firms anticipate average productivity levels of the resource providers and expect the selected providers to meet them. Naturally, firms do not appreciate resource providers whose productivity is below the "average productivity", while resource providers above average wish to receive a payoff *greater* than $r^{'}(\theta)$. Resulting from this, the type of equilibrium to occur depends on the distribution *F(·)*; if the number of above-average resource providers dominate the markets, firms wish to acquire (all) resources[42] at the *lowest acceptable price*. In contrast, if the below-average resource providers dominate the markets, firms are reluctant to acquire them for an acceptable price, namely $r^{'}(\theta)$. To sum up, a Pareto optimal competitive allocation of resource providers does not exist in markets when there are information asymmetries.

Contracting when there is asymmetric information complicates the decision-making situations of all participants. Spence (1973; 1976) discussed how the sellers of above-average products or services could *signal* their level of competence to the buyers in the market and thus try to distinguish themselves from the less-productive resource providers. This is called *signalling*, and in its simplest form requires resource providers to take a test to reveal what type the resource provider is. Spence (1976, p. 592) asserts that the signalling test is significant only if the negative outcome of the test can mean loss of business to the seller. An example of a signalling test is product guarantees. A relatively straightforward conjecture is to assume all sellers with productivity $\theta \geq \overline{\theta}$ to be willing to take (and pass) such a test (an example of implementing such a test might be granting a lifetime guarantee for the firm's product), while sellers with productivity below average productivity $\overline{\theta}$ would not engage in this test. Buyers can take a similar action, too. This action is a direct counterpart of signalling and it is known as *screening* (Spence 1976; Rothschild and Stiglitz 1976). Screening takes place contractually when firms invite several offers simultaneously in the hope of obtaining quotes from adequate resource providers only for offers that can reasonably be expected to be honoured (Mas-Colell et al. 1995, pp. 460-461). Wilson (1980) suggests price equilibrium to exist only in a contracting scenario in which a third-party auctioneer sets the prices of resources in the market. Otherwise, the seller or buyer will self-interestedly seek to increase its profits. In a case of contracting for *skilled resources* it may be reasonable to assume that sellers set the prices or, more precisely, set a *distribution of prices* from which the buyer selects the most appropriate one according to its expectation of the seller's productivity (Wilson 1980, p. 130).

The problems introduced above arise from information asymmetries at the time of contracting, but quite often the informational asymmetries arise or become

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[42] However, if the markets have an excess supply of their products, firms do not wish to increase production.

stronger later on during the contracting period. As the contracting parties anticipate the development of information asymmetries, they seek to design a contract which mitigates the possible difficulties arising after co-operation has been commenced. Usually these problems are associated with situations in which an actor hires another actor as its representative. Hence, such contract design is known as the *principal-agent problem* (Mas-Colell et al. 1995, pp. 477-506). Problems arising from information asymmetries have been divided up in the literature into those resulting from *hidden actions* and those resulting from *hidden information*. The hidden action case, also known as a *moral hazard*, represents a situation in which the firm is unable to observe the selected resource provider's efforts. The hidden action contract design is straightforward when the efforts expected of the resource provider can be unambiguously specified *ex ante* and the resource provider is compensated *ex post* when it has been observed (also by courts or other third parties, if needed) to have fulfilled specified obligations. Problems arise when the efforts of the resource provider are *not directly observable* and an indirect compensation scheme must be designed to encourage the resource provider to put the necessary effort into the contract. More succinctly, in the following discussion e shall denote the resource provider's action choices and π the profits generated during the contracting period. E is the set of the resource provider's possible actions. The resource provider's efforts are usually multidimensional and hence $e \in E \subset \mathrm{R}^{M}$ for some M. Moreover, e will be referred to as the resource provider's *effort level* (or *effort choice*). It should be noted that the efforts of the resource provider should not be deducible from the realised profits π. Hence, profits π are expected to depend on other factors in addition to e. More specifically, a firm's profit is assumed to take a value between

$$[\pi_{\text{low}}, \pi_{\text{high}}] \qquad \text{(Eq. 3-23)}$$

and the profit is expected to have a stochastic relationship to e, described by the conditional density function

$$f(\pi \mid e) : f(\pi \mid e) > 0 \text{ for } \forall\, e \in E \text{ and } \forall\, \pi \in [\pi_{\text{low}}, \pi_{\text{high}}]. \qquad \text{(Eq. 3-24)}$$

Equations (Eq. 3-23) and (Eq. 3-24) suggest, in words, that any potential realisation of π can follow from any effort level e of the resource provider. In order to clarify the implications of moral hazard, the resource provider will have only two possible effort levels, e_{low} and e_{high}. Effort level e_{high}, however, requires *more* from the resource provider, but should lead to a higher profit π. Hence, there is a conflict of interests between the firm and the resource provider. Expressed in mathematical notation, distribution functions $F(\pi \mid e_{low})$ and $F(\pi \mid e_{high})$ satisfy

$$F(\pi \mid e_{low}) \leq F(\pi \mid e_{high}) \text{ for } \forall\, \pi \in [\pi_{\text{low}}, \pi_{\text{high}}]. \qquad \text{(Eq. 3-25)}$$

Equation (Eq. 3-25) thus implies higher profit π when the resource provider chooses an effort level e_{high} instead of e_{low},

$$\int \pi f(\pi \mid e_{high}) d\pi > \int \pi f(\pi \mid e_{low}) d\pi^{43}. \qquad \text{(Eq. 3-26)}$$

Following the notation of equation (Eq. 3-12), *w* will denote the input price (i.e., cost) of the resource provider in the following. The firm wishes to make a *take-it-or-leave-it* offer to the resource provider, which specifies the resource provider's expected *observable* effort level $e \in \{ e_{low}, e_{high} \}$ and compensation cost *w(π)* as a function of profit. It is also assumed that the resource has an expected (average) cost in the competitive market and that the firm wishes to make an offer the resource provider *will* accept. The *optimal contract* for the firm is then

$$\underset{e \in \{e_{low}, e_{high}\}, w(\pi)}{\text{Max}} \int (\pi - w(\pi)) f(\pi \mid e) d\pi . \qquad \text{(Eq. 3-27)}$$

Put simply, an optimal contract for the firm is clearly one that maximises (Eq. 3-27) and equivalently minimises the compensation cost *w(π)*. However, this is constrained by the resource provider's ability to refuse to accept the firm's contract, resulting in a zero profit. To sum up, an optimal contract exists with some effort level *e**. At the same time, an optimal contract with *unobservable efforts* yields practically the same profit and effort levels as a contract with observable efforts (Mas-Colell et al. 1995, p. 482). The hidden information case, in turn, is a situation where the resource provider comes to possess better information of the firm's capabilities than the firm itself *after* the time of contracting, and the resource provider keeps this information to itself. Following the moral hazard case above, the resource provider's effort level is fully observable. The level of resource's *disutility level* (i.e. how much the resource provider has to work to accomplish the required obligations) is not, however, observable to others. In this setting, an optimal contract should insure the resource against fluctuations in the payoff as well as protect the firm's profit. Green and Park (1996) have studied a similar problem, namely choice in uncertainty, using Bayes contingent plans.

Chapter 3.5 discussed information asymmetries in decision-making accounting settings. The concept of information asymmetries clarifies the need of contracting parties to have equal measures to analyse contract profitability. Firms on both sides have clearly an incentive to maximise their profits, and finding a mutually optimal contract is therefore difficult. Incentive plans to motivate contracting are discussed next in chapter 3.6.

3.6. Incentive Plans in Motivating Contracting

The future outcomes of inter-firm contracting are never certain for any firm in the markets. This statement also encompasses unanticipated inventions as well as externalities arising during the contracting period, especially when long-term contracting is concerned. Tirole (1999, pp. 746-751) discusses the concept of *incomplete contracts* (Hart and Moore 1988) which arise when *ex post*

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[43] Integration limits and constraints are suppressed for simplicity.

contingencies and benefits cannot be contractually described *ex ante*. More precisely, the outcomes might not actually be unforeseen but they can still not be describable beforehand. From the incentive point of view, a firm might be willing to make a payoff for one single outcome and not for any other outcome. Grossman and Hart (1986, p. 692) characterise a typical instance of such of problem when contracting concerns an asset-specific (Williamson 1985, pp. 32-35) investment which is worth less to both firms (or either firm) *outside* their contractual relationship. Furthermore, the effort level of the selling firm might be economical, but the seller's profit expectation might exhibit monopolistic pricing. Hence, the outcome of the contract is unsatisfactory to both parties and serves as a good example of the hold up problem introduced by Klein et al. (1978) where both parties could do better off by co-operating but refrain from doing so by acting opportunistically.

In the following, using the example given by Grossman and Hart (1986, pp. 692-709), $\pi_j(\cdot)$ denotes the profit function of firms $j=1,2$ and firm 2 is assumed here to produce an input for firm 1. However, the input price (i.e., cost) of firm $j=1$ will be denoted as firm's $j=2$ profit function $\pi_j(\cdot)$ instead of the earlier notation w. These firms then sign a contract at time $t=0$, which cannot, however, allocate anything but the division of ownership rights to the two firms. The contract is soon (at time $t=1$) followed by investments (on assets) a_1 and a_2. Ownership (or control) over assets, denoted by q_1 and q_2, also takes place at time $t=1$, and the firm having the allocated control from the contract at time $t=0$ can choose q_j, the specific ownership rights. Then the residual ownership rights are left to the other firm and they can possibly be utilised in renegotiations. It is further assumed that $\pi_j(\cdot)$ depends on control (or ownership) rights q_1 and q_2 through some continuous function ϕ_j, and that $\pi_j(\cdot)$ is increasing in ϕ_j. Then an optimal contract must maximise the total net benefits of the two firms, i.e.

$$\text{Max}\, \pi_1(a_1,\phi_1(q_1,q_2)) + \pi_2(a_2,\phi_2(q_1,q_2)).^{44} \qquad \text{(Eq. 3-28)}$$

Letting a_1^*, a_2^*, q_1^* and q_2^* be the (assumably unique) maximisers of $(\pi_1 + \pi_2)$ in (Eq. 3-28), the first-best contract would state that firm 1 must choose investment a_1^* at time $t=0$ and control q_1^* at time $t=1$ or otherwise pay a large penalty to firm 2. Grossman and Hart (1986, p. 701) remark that it is possible to achieve the first-best contract as long as q_j is *ex ante* contractible; if the contract at time $t=0$ specifies $q_j = q_j^*$, firm j has an incentive to choose a_j to maximise $\pi_j(a_j,\phi_j(q_1^*,q_2^*))$, and set $a_j = a_j^*$. Accordingly, Coase (1937, p. 400) considers it unusual for a firm to guarantee definite and predefined outcomes to another firm unless it has control over the other firm's actions. Control over the tangible and intangible assets plays an important role especially in partnering (Hart and Moore 1990), and common ownership of assets is likely to increase the overall efficiency *if* the assets are complementary and firms are important trading partners for each other. Specificity of assets and the value of investments play an important role, too. (Hart and Moore 1990, pp. 1149-1150)

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[44] Naturally, $\pi_2 < 0$ would imply π_2 to be a cost.

3.7. Summary

Alternative modelling frameworks for analysing contracting strategies and market competition were presented in chapter 3. Microeconomic theory provides several useful tools for studying contracting, and especially the microeconomic theory of production (chapter 3.2), cost minimisation and profit maximisation (chapter 3.3) can be utilised in this work. However, the use of these theories requires an extensive understanding of microeconomic theory from the user, thus limiting their usability in practical applications.

The last three microeconomic concepts discussed in chapter 3 cannot directly be utilised in this work. It is, however, important to acknowledge the relevance of market competition (chapter 3.4), private information and opportunistic behaviour (chapters 3.5 and 3.6) to understand the criteria for evaluating the usefulness of the model in practice. In addition to analysing firms and markets using microeconomic theories, transaction cost literature (Coase 1937; Williamson 1985; Williamson 2002) was reviewed in chapter 3. Although transaction cost literature is central in the research theme, transaction cost theory does not consider firms' distinctive assets and activities which are difficult to duplicate as a competitive asset (Madhok 2002; Teece et al. 1997, pp. 513-524). Furthermore, the above theories *per se* are clearly sufficient to characterise various situations in the field, but a framework to use them appropriately in practice is missing.

Control theory and statistical signal processing methods provide useful tools for developing a suitable framework to represent the rules of the application field. Models of microeconomic theory can also be incorporated in the developed model to the extent needed. This approach was taken by Ijiri and Thompson (1970), who applied control theory to accounting and budgeting problems in practice. A control theory input-output model can thus be a good starting point for developing a modelling framework to analyse contracting strategies. The construction of such a generalised model needs to be done with great care, because otherwise the risk of confusing assumptions from different theories – for example, from those on *consumer choice* and *market economy* – decreases the degree of alignment of the model with common theory and hinders its further development.

4. Developing a Mathematical Model of the Research Problem

Microeconomic theory provides several useful tools for studying contracting, but the last three microeconomic concepts discussed in the previous chapter cannot be directly utilised in this work. It is, however, important to understand how market competition (chapter 3.4), private information and opportunistic behaviour (chapters 3.5 and 3.6) are generally modelled to evaluate the usefulness of the modelling framework and that of the model in practice. In contrast, the control theory input-output model provides a convenient frame for modelling the real-world situations. It is important to keep the main target of this research in mind and to focus on achieving it.

The aim of this thesis is to develop a mathematical modelling framework for analysing different contracting strategies from the point of view of life cycle profits (LCP) for use in the managerial decision-making process.

Despite the original motivation for this study comes from the paper industry, the same modelling philosophy can be used for modelling real-world processes in other fields of application. The modelling framework must help managers during a decision-making process by providing the following:

1. Using the modelling framework, decision-maker (with the help of an analyst) is able to develop a model of a real-world process to meet the needs of a decision-making situation.
2. Decision-maker has an opportunity to explore the use of the developed model to become familiar with its predictions and to examine the interactions it implies.
3. Model can easily be changed if its predictions are not sufficient to provide help in decision-making.
4. The model outputs can be used in helping managerial decision-making.

Essentially the target in this study is to develop a modelling framework – i.e. “instructions to generate a specific profitability analysis model for specific real-world problems” – and to use it to sketch a model that can be used in a paper mill’s decision-making situations to evaluate total profitability of paper production inputs in alternative contracting strategies. Thus, the modelling framework should only provide the user a simple way to characterise any real process at a level of needed detail. Hence the *framework* itself is much less significant than the *model* which is developed based on the framework. The development of the framework is easier by constructing a specific example and thus, a specific model to represent the real-world situations of the paper production process with its inputs and outputs is developed next. These model requirements are illustrated in Figure 4-1.

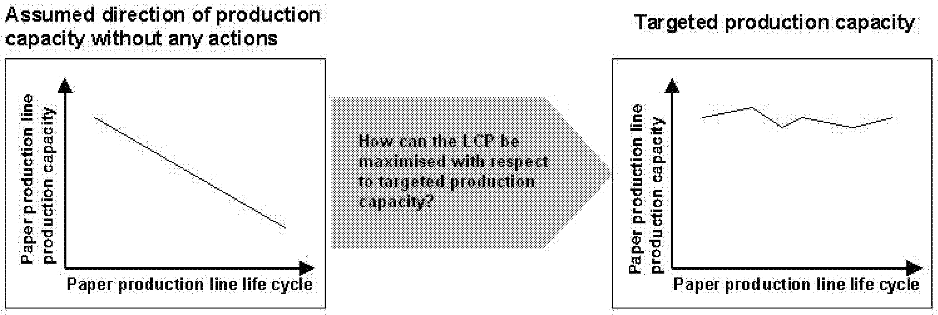

Figure 4-1. Mathematical model should facilitate managerial decision-making in choosing a contracting strategy which maximises the life cycle profits (LCP) of a paper production line with respect to temporarily desired production capacity.

Control theory and statistical signal processing methods provide useful tools for developing suitable models to represent the rules of the application field. For example, the classical CMP and PMP of chapter 3 need to be extended here to cover profit maximisation over a paper production line's life cycle.

4.1. Modelling Framework versus Specific Model

The paper production process can be described in accordance with the production vector of microeconomic theory, as defined in (Eq. 3-1) on page 54. Hence, the paper production process is a vector

$$y = (y_1,\ldots,y_L) \in \mathrm{R}^L, \qquad \text{(Eq. 4-1)}$$

where vector y describes L commodities that the firm's production process (the "black box") contains. Negative elements of y represent production vector inputs and positive elements its outputs. Thus, commodities $y<0$ are consumed in the process while commodities $y>0$ are produced. Commodities $y=0$ are neither consumed nor produced.

It makes sense to classify model parameters as *input-*, *system-* and *output parameters*. Input parameters must conceptualise all factors that the studied system requires in order to produce an acceptable output. System parameters characterise the inner structure, i.e. *production process*, of the studied system. The function of the output parameter(s) is to characterise everything that is gained from the system with respect to the given inputs. The above model parameters include intellectual, financial, labour and physical resources. For simplicity, a single output production process is assumed throughout the thesis. This means that the paper production line can (and is generally willing) to produce only one paper grade. Taking the notation of (Eq. 3-12) on page 57, production plan y can be expressed with production function $f(z)$, which implements the firm's production decision as a choice over input levels z. Accordingly, scalar p denotes the price of the firm's *output product* and vector w

$>> 0$ *input prices*. In mathematical notation, the paper production process can now be expressed as

$$pf(z) - w \cdot z \,. \qquad \text{(Eq. 4-2)}$$

The first expression of (Eq. 4-2) simply represents the net revenue of the firm from producing *f(z)* tonnes of paper sold at price *p*. The second expression represents the total costs of producing *f(z)* and marketing it.

The following parameters are defined to characterise the paper production process using the microeconomic production model notation and adapting the discussion of chapters 2.3 and 2.8 as well as the cost structures of Table 2-1 on page 25. The defined model was then presented to several Finnish paper company experts for review and was refined accordingly to achieve the following parameters:

p = paper sales price
pd = production plan (paper production line's desired annual production). Production plan depends on available technology (z_6) as well as other inputs affecting production capabilities (mainly z_4, z_5 and z_7)
z_1 = production, Sales and General Administration (general overhead costs that may be considered fixed costs in annual budgeting, such as personnel salaries, sales and marketing costs, delivery costs, waste management, etc.)
z_2 = energy (electricity, heat, gas, etc.)
z_3 = raw materials (pulp, chemicals and water)
z_4 = consumed parts
z_5 = maintenance (maintenance personnel's annual salaries, maintenance contracts, engineering design, external maintenance services)
z_6 = technology (enabler of certain grade, quality and production capacity)
z_7 = expertise (of persons that affect paper production line production functions)

All of the above parameters z_i are here taken as independent variables to facilitate computing. In reality these inputs have dependencies because the increased complexity of the paper production technology affects maintenance planning and a firm's selected maintenance strategy and further on maintenance costs, as discussed in chapter 2.1. Some of the comments from practitioners suggested using more industry-specific input parameters – for example, paper companies usually include spare part costs (except so-called "consumable spares[45]") under maintenance costs – but when the philosophy of the model was explained, all parties agreed on using the above parameters.

Parameters z_i have the dimensions e_i (efficiency) and w_i (cost). The two other parameters, *p* and *pd*, have interpretable input values. Paper sales price *p* is EUR/ tonne, which depends on paper grade, quality and on the annual contract between the paper company and its customer(s) (see related discussion on pp. 62-63). Production plan *pd* is simply given in tonnes per year of a specified grade. Unlike

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[45] *Kulutusosat* in Finnish

in microeconomic models of production, input parameters z_i have no physical quantity levels but only relative efficiencies. Microeconomic models are analytical and hence cannot easily represent small differences in the input parameter values. Thus, using a numerical model makes sense as it also makes testing the model in real-world problems easier when empirical data is available. *Efficient input levels* of z_i are assumed to be determined by an expert user from the desired output levels y[46] using given production technology (mainly characterised by parameter z_6) and then assigning proper values to the parameters. Furthermore, production technology is assumed to exhibit constant returns to scale (see related discussion in chapter 3.2), i.e. higher input levels are needed to produce higher output levels. Efficiency values range in an interval of (0, 1), with higher values referring to a better level of input. These parameters also have an associated *annual* cost given in EUR/ a. For example, z_5 = maintenance = (0.7, $\text{cost}_{\text{maintenance}}$). It is worth pointing out that changes in the efficiency value of a parameter should alter the associated cost, too.

The above chosen parameters are quite close to those of firms' income statements and thus most model parameter values have physical, measurable counterparts from actual paper production lines. The first two parameters, *paper sales price* and *production plan*, are probably the most significant ones for paper companies in reacting to development in markets and adjusting their production accordingly. *Production, Sales and general administration* (SGA) includes overhead costs of the paper production line. This parameter should not be confused with the similar accounting term as in this context the SGA parameter signifies *all* general overhead costs that may be considered fixed costs, such as personnel's annual salaries (excluding maintenance personnel), sales and marketing costs, delivery costs and waste management. *Energy* parameter covers all energy costs that are annually needed in one paper production line, from infrastructure heating to a specific machine component's energy consumption. The model's precision level is general enough to consider energy costs fixed in annual budgeting as the energy contracts are negotiated in advance. The *raw materials* parameter embodies costs related to paper production raw materials such as pulp, chemicals and water. Like previous parameters, raw material costs are also fixed as they are estimated in terms of planned production, and in the case of unplanned production line downtime they are consumed although no paper is produced.

Consumed parts encompass components, spare parts and other materials that are consumed in production and maintenance activities. *Maintenance* parameter includes maintenance personnel's annual salaries, maintenance contracts, engineering design and external maintenance services. In other words, maintenance covers services that are needed in keeping the Installed Base technically efficient and is supported by efficient spare part functions. The division between parts and services is often difficult in real life, because maintenance contracts often include some parts, too. It is worth pointing out that consumed parts and maintenance can at the most help to retain the certain production capacity that the paper production line's technology facilitates. *Technology* refers here to the paper production line's technical production capability (in microeconomic notation the number of feasible production plans

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[46] For convenience, y is used here to signify the scalar output of production process.

y=f(z) belonging to a production set *Y*) as well as the source of capital costs related to the paper production line. Investment costs include annual expenses for having the entitlement to utilise certain technology, but the model does not separately consider costs induced in the firm from loan capital. This is because the purpose of the model is to facilitate objective comparison of efficiencies and associated costs of different inputs in alternative contracting strategies, and the user can calculate the cost of input costs outside the model. Hence, the replacement value of the Installed Base is not considered here as in (Komonen 1998). Technical capability embodies variables like paper grades that are possible to produce with the machines, paper quality, production capacity and the need for maintenance. *Rebuilds*, *process improvements* and other similar services that change the technical level of the production line should also be taken into account in technology parameter values. *Expertise* refers to personnel's expertise. In this context the focus is on people who directly affect paper production line efficiency, either in production- or technology-related issues. The rationale behind the expertise parameter is quite simple: high-end machines and parts have little or no significance if they are not properly used.

Even though absolute efficiency might outperform time- and operational efficiency in terms of production line life cycle profits, as suggested by Mardon et al. (1991), it is difficult to achieve absolute efficiency without high time- and operational efficiency. Although insufficient raw materials or inadequate resources might be causes of production losses, unavailability of Installed Base directly hampers production potential and might reduce paper quality indirectly. From the business perspective, a production line that produces desired paper with planned annual production is the main target. Hence, technology, parts, maintenance and expertise should entail these business demands and their significance for the core process can be observed through the production line's technical *availability*, which is a system parameter. As defined in Eq. 2-1, the significance of *availability*,

$$A = \frac{t_{production}}{t_{production} + t_{MB}}, \qquad \text{(Eq. 4-3)}$$

is to represent the technical time efficiency of the paper production line. The longer the possible production time and the shorter the maintenance breaks, be they planned or unplanned, the more paper tonnes can be produced. It is important to state that in this model maintenance is assumed to take place whenever the paper quality is not good enough to be delivered to customers. Furthermore, the parameters *produced tonnes* and *direct production costs* depend merely on production line availability, while paper quality depends also on the quality of raw materials. This shows one of the pitfalls of the above availability parameter; perhaps the Installed Base machines could be adjusted to produce proper paper despite lower-quality raw materials. Still, the availability parameter can be weakened if the production department shuts down the production line because of the poor quality of raw materials. In fact, the mill operating conditions are in continuous change as several process inputs, including chemicals, water, pulp, etc. are subject to quality variations. Furthermore, it may also make commercial sense to temporally produce different paper grades with another feasible production plan *f'(z)* and hence the above example is relevant. However, these measurement pitfalls can be avoided if the non-technology-related production line downtimes are separated from technology-related availability problems. *Net sales*, another system parameter, is a product of produced tonnes and paper sales price, which in practice is the annual customer price for specific paper per tonne. In the notation of (Eq. 4-2), net sales equals the expression *pf(z)*.

Finally, output parameters of the model are the produced paper tonnes and *annual life cycle profits* introduced earlier. Annual life cycle profit is given as a sum of the parameters *net sales* (positive, all other parameters are negative), *SGA*, *energy* and *direct production costs* and accounts for the whole expression of (Eq. 4-2), i.e. $pf(z) - w \cdot z$. Since the inputs do not consider depreciation and other accounting instruments, the LCP parameter practically equals operating profit (OP) in the firm's income statement. In conclusion, the production function considers annual input –output mappings and their economic efficiency, and these parameters can be altered outside the model and then iterated to simulate the temporal evolution of the paper production line life cycle.

Constructing the mathematical modelling framework in chapter 4.1 has mainly involved development of the specific model to characterise profitability analysis in paper production. However, the modelling framework has evolved on the side by placing the model developer in the role of the paper producer's decision-maker. Figure 4-2 illustrates the relationship between the modelling framework and a specific model.

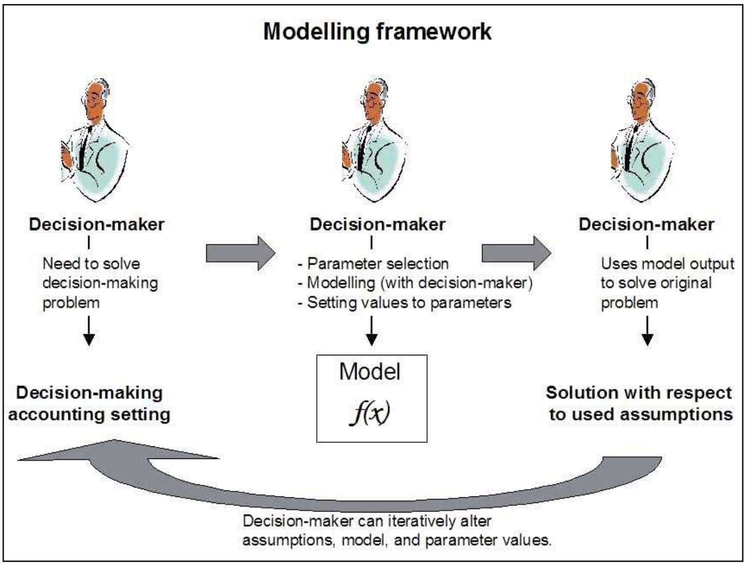

Figure 4-2. Relationship between modelling framework and the model.

Figure 4-2 shows that the decision-maker takes responsibility for developing a specific model for a specific decision-making problem as well as for choosing appropriate parameters and their values. Hence, the modelling framework simply instructs the decision-maker in analysing profitability in the field of application and proposes of the OR approach, one of the modelling approaches introduced in chapter 3, for constructing the model. The decision-maker, however, needs to define the dependencies between input, output and possibly the model's internal parameters to obtain the desired model. It should also be noted that when alternative contracting strategies are compared, the feasibility of parameter values needs to be judged by the decision-maker – not the model. Next, in chapter 4.2, parameter dependencies are defined for the paper production process.

4.2. Dependencies Between Parameters – The Specific Model

The relationship between inputs z_i and output y is characterised by production function $f(\cdot)$. This dependency is here characterised by the mathematical model, presented in Figure 4-3.

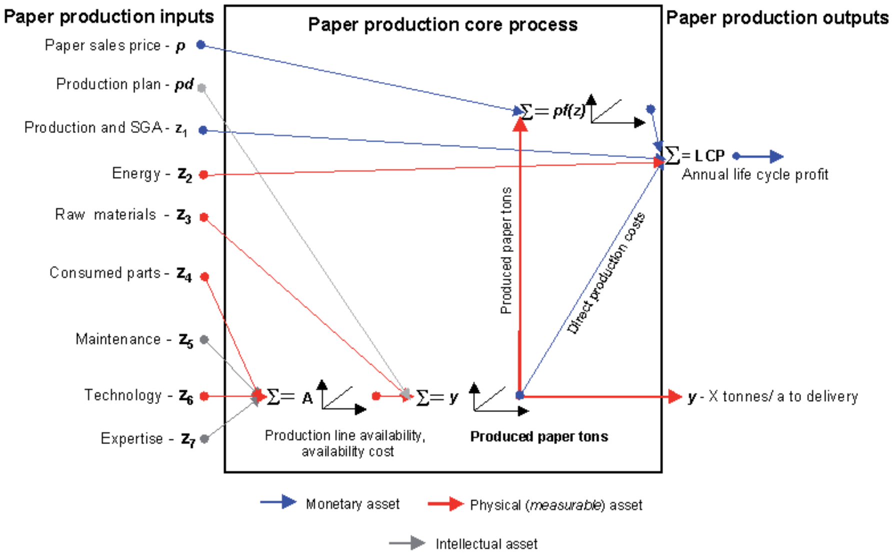

Figure 4-3. Mathematical model.

The presented model is *linear*, i.e. all relationships between connected parameters of Figure 4-3 have linear dependencies, and all connections are *forward connections*, which means that the left-hand parameters affect right-hand parameter values (if connected) but not vice versa. Equations for the model's internal parameters are presented next.

All computable parameters in the equations related to the model are denoted by the subscript *Model* to distinguish them from other equations. There are only four computable parameters, namely production line availability, produced paper tonnes, net sales and annual life cycle profit. As shown in Figure 4-3, e_i and w_i denote the efficiency and associated cost for parameter i when appropriate.

Otherwise, the computed parameter value is expected to be understandable from the context.

Production line availability A_{Model} is given by

$$A_{Model} = e_4 \cdot e_5 \cdot e_6 \cdot e_7 . \tag{Eq. 4-4}$$

Hence, the production line availability is simply computed as a linear product of the input parameter efficiencies, not as defined in (Eq. 4-3), which it conceptually represents. The cost of availability A_{Model} is denoted by $w(A_{Model})$, and it is computed as

$$w(A_{Model}) = w_4 + w_5 + w_6 + w_7 . \tag{Eq. 4-5}$$

The associated costs of inputs are simply summed to characterise the annual production line availability costs. The cost of paper production line availability is not *just* the cost of maintenance, as mentioned in (Komonen 2006), but a combination of costs arising from crew expertise, consumed parts and specific technology.

The number of produced paper tonnes depends on annually planned production, but might (at the *annual level*) be limited for example by poor raw materials or poor technical availability of the production line. Production technology is assumed to exhibit constant returns to scale, so higher input levels are needed to produce higher outputs. The model does not, however, consider the possibility of *increasing* the planned annual production in response to improved inputs. This is in accordance with the assumption that the input parameter z_i levels are assumed optimally determined for the desired output level y. Thus, the number of produced paper tonnes y_{Model} (tonnes/ a) is computed as

$$y_{Model} = pd \cdot A_{Model} \cdot e_3 , \tag{Eq. 4-6}$$

where pd is the production plan (tonnes/ a), A_{Model} technical availability and e_3 efficiency of raw material input. In other words, the model considers poor paper quality to limit the planned production capacity. Production line technical unavailability or poor raw materials may hence indirectly cause paper quality losses. Direct costs $w(y_{Model})$ of paper tonnes *actually* produced (and sold) are given by

$$w(y_{Model}) = w_3 + w(A_{Model}) , \tag{Eq. 4-7}$$

where w_3 is the price (or cost) of raw materials and $w(A_{Model})$ cost of availability.

Net sales, $pf(z)_{Model}$, depends on produced paper tonnes y_{Model} and the sales price of paper p, i.e.

$$pf(z)_{Model} = p_{Model} \cdot y_{Model} \cdot ^{47} \qquad \text{(Eq. 4-8)}$$

The model assumes all production to be sold to the customers. The cost of net sales is taken into account in the SGA parameter and will thus not be counted here.

Finally, the annual profit LCP_{Model} is obtained from net sales, fixed costs and production costs, i.e.

$$LCP_{Model} = pf(z)_{Model} - w_{Model} \cdot z_{Model}, \qquad \text{(Eq. 4-9)}$$

where $pf(z)_{Model}$ is the annual net income and w_{Model} a vector of input costs, i.e. $w_{Model} = (w_1, w_2, \ldots, w_7)$. As the input levels of parameters z_i were assumed optimal, vector z_{Model} is a unity vector.

Finally, the actual life cycle profit is the sum of consecutive annual profits in the observed life cycle

$$LCP = \sum_{Years} LCP_{Model} \, . \qquad \text{(Eq. 4-10)}$$

The specific analysis model for the paper production process was defined in chapter 4.2. The choice of parameters, the dependencies between them and their values require justification, and hence the paper production process analysis model is verified and its parameter values are validated next in chapter 4.3.

4.3. Verification, Validation and Sensitivity of the Developed Model

The developed mathematical model parameters have been selected on the basis of earlier research (see discussion in chapters 2.2 and 2.3) and discussion with Finnish paper companies. Due to the confidential nature of these parameters as well as the modelling assumptions, it is not possible to take validation data directly from paper companies' income statements or ERP systems. However, some data is publicly available (see chapter 2.3, page 25) from earlier research and paper companies' positive attitude towards this research provided operative-level accounting and technical data from several paper production lines for use in *verifying* that the implemented model works according to the model of Figure 4-3 and to *validate* that the model characterises the real-world paper production process both physically and financially. Feasible parameter values were also identified during this process.

The data from the ERP systems was manually treated by paper companies' experts and decision-makers to ensure that the model input requirements were appropriate. Several trials with the model were then made with actual values taken from paper companies' ERP systems. Validation parameter values

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[47] For convenience, paper sales price is denoted by just p instead of by p_{Model} as there is no chance of misinterpretation.

presented later in this chapter have been modified from the actual figures by averaging them to conceal the confidential nature of the actual figures. Hence, the paper companies' real data from LWC production lines has been only privately available during the trials and only the adapted values are disclosed. The presented validation data is very close to the actual figures of the real process and they coincide with other research, too. Cost factors adapted from The Finnish Paper Industry report (2006) are also shown for comparison in Table 4-1 although these values are originally given in EUR/ tonne instead of annual costs. Thus, only a few cost factors can directly be compared between the two data sources, but when appropriate cost factors (see column *Cost structure* in Table 2-1) are combined, they yield values similar to the validation data. Furthermore, energy and raw material (mainly chemicals) costs have increased significantly after year 2003, as Table 4-1 shows. It should also be noted that the 10 MEUR cost difference of *SGA* costs is explained by the *consumed parts* and *maintenance* categories' costs.

Table 4-1. Production cost validation data. The first column represents model input cost factors while the second column shows respective annual values. The third column shows cost factors adapted from The Finnish Paper Industry report (2006, Table 6.2, p. 40) with respective values in the fourth column.

Model inputs (annual)	**Annual costs with an estimated annual realised production of 300 000 tonne**	**Cost structure division from Table 2-1**	**2003 cost/ tonne**
SGA	60 MEUR (234 EUR/ tonne x 300 000 tonne = 70,2 MEUR)	- Labour - Other costs	90 EUR 144 EUR SGA tot: 234 EUR
Energy	15 MEUR (40 EUR/ tonne x 300 000 tonne = 12 MEUR)	- Energy	40 EUR
Raw materials	100 MEUR (231 EUR/ tonne x 300 000 tonne = 69,3 MEUR)	- Wood raw material - Other raw materials and supplies	66 EUR 165 EUR Raw materials tot: 231 EUR
Consumed parts	3 MEUR	N/A	
Maintenance	6 MEUR	N/A	
Technology	15 MEUR[48]	N/A	
Expertise	0,15 MEUR	N/A	
TOTAL COSTS	**199,15 MEUR (~664 EUR/ tonne)**		**505 EUR (151,5 MEUR annually)**

There is a significant difference (159 EUR/ tonne) in production costs of Table 4-1 between the validation data and those adapted from The Finnish Paper Industry report (2006, Table 6.2, p. 40). It may be explained by differences in cost accounting principles, i.e. what has been the target of the analysis, as well as the dramatic changes in the Finnish paper industry between years 2003 and 2006. It is also worth noting that roughly 60…70% of the costs are variable costs.

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[48] The annual technology cost of EUR 15 million is based on an approximately 100+ million initial investment and on an annually fixed 10-year depreciation time (UPM-Kymmene Annual report 2005, p. 69).

The model was implemented with Matlab® (see Appendix 1) and was then examined with Finnish paper companies' experts according to the following validation steps (Gass 1983, p. 616):

> *"1. The analyst assures himself that the model performs the way he intends it to; using test data, and if available, real historical data.*
> *2. Reasonableness is checked by:*
> *(a) showing that key subsystem models predict their part of the world well (using historical data);*
> *(b) showing that…the parameters have reasonable values;*
> *(c) having people who are knowledgeable about the situation (preferably including the decision-maker) review the model in detail and agree to its structure and parameters;*
> *3. The decision-maker has an opportunity to explore the use of the model to become familiar with its predictions and to examine the interactions it implies. At this point the analysts and decision-maker may be able to agree as to what is a close enough fit between model output and actual data.*
> *4. The model is used for decision-aiding. Careful records are kept of its predictions and of actual results. (This may involve a time span of years, so that the evaluation procedure has to be set up carefully)".*

The validation process was carried out at several paper mills in Finland which produce LWC paper. During these meetings the analyst used the model according to decision-makers' and other experts' instructions and parameter values. The validation process was started with steps *1* and *2 c* above; the structure of the model was examined first (step *2 c*) by the paper companies' experts, followed by a presentation of initial input values to investigate how the model would react to these inputs (step *1* above). In addition to the cost factors in Table 4-1, there are two more input parameters in the model, namely *paper sales price* and *production plan*. Paper sales price *follows* market development but is still typically agreed between buyer and seller in annual terms (see related discussion on pp. 62-63, 70). The calculation of the *production plan* parameter is much more problematic, because the annual production plan above assumes 300 000 tonnes/a to be the *realised production* of the line. The actual production, however, depends strongly on the production line's availability, which is calculated according to the definition in Eq. 4-11:

$$A = \frac{t_{production}}{t_{production} + t_{MB}}. \qquad \text{(Eq. 4-11)}$$

Now, $t_{production}$ equals the time a paper production line produces paper and t_{MB} equals the total time used for maintenance breaks, *including planned and unplanned breaks*. An estimated planned maintenance time of an efficient LWC production line can be assumed to be 12 working days, *ex ante*, thus yielding maximum *planned availability*

$$A_{planned} = \frac{365-12}{(365-12)+12} = \frac{353}{365} = 0.967. \qquad \text{(Eq. 4-12)}$$

Web and emergency maintenance breaks can be estimated to reduce the planned availability by an additional 3…5 % ‘safeguards’. When planned production cutbacks occur, the value of $t_{production}$ decreases along with production line downtime. Thus, the ratio between $t_{production}$ and t_{MB} remains unchanged. These assumptions are based on paper companies’ experience and empirical knowledge and thus they can be anticipated in the production planning. In conclusion, with an expected *realised* production[49] of 300 000 tonnes/ a, the production plan input parameter value should be approximately

$$\frac{1}{0.95} * 300\,000 \text{ tonnes/a} \approx 1.052 * 300\,000 \text{ tonne} \approx 315\,800 \text{ tonnes/ a}.$$

Resulting from the validation process steps *1* and *2 c* above and modifications carried out to conceal confidential parameter values, the following validation parameter values are used as model inputs:

p = 700 EUR/ tonne[50]
pd = 315 800 tonnes/ a
w_1 = -60 MEUR, e_1 = 1
w_2 = -15 MEUR, e_2 = 1
w_3 = -100 MEUR, e_3 = 1
w_4 = -3 MEUR, e_4 = 1
w_5 = - 6 MEUR, e_5 = 1
w_6 = -15 MEUR, e_6 = 1
w_7 = - 150 kEUR, e_7 = 1

Sensitivity analysis (Bullard and Sebald 1988; Clemen and Reilly 1999) of validation steps *2 a*, *2 b* and *3* on page 80 was then applied pragmatically in the validation process to study if the model predicts the intended part of the real process and if the parameters have reasonable values. The sensitivity analysis used relied strongly on expert involvement instead of drawing input value combinations from generic probability distributions. The paper companies’ decision-makers and experts had an opportunity to play with the model to become familiar with its predictions and to examine the interactions between the model inputs and outputs. The most significant test using data on real paper production lines concerned the dependency between input parameter z_5 (maintenance) and output parameter LCP; with all other parameter values fixed between two trials for the same production line, the efficiency value of z_5 was decreased by 1%. This resulted in 1 % decreased production line availability, resulting directly from (Eq. 4-4), inducing an annual profit loss of 1 % of the total input costs. This result was considered as a rule-of-thumb among practitioners and convinced decision-makers to agree that the fit between model output and actual data was very accurate.

Production line availability thus directly indicates the combined effects of those input parameter efficiency changes which are of most interest in the context of

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[49] Possible production cutbacks have already been removed from this production plan.
[50] *FOEX (2006)*

this thesis. Availability is also a meaningful indicator to practitioners and its validity can easily be evaluated, as most Finnish paper companies measure the value of this indicator (Komonen 2002b). Resulting from this, the search for feasible parameter values can be limited to examining the range (i.e. correspondence between model and real process) of the availability parameter. Table 4-2 shows the model validation results using the above input parameter values.

Table 4-2. Validation results.

Model outputs	Break-even values	Maximum productivity values
Availability	0.90089	0.97
LCP	0.04154 EUR	15.2782 MEUR

Validation results draw reasonable limits for the availability parameter in Finnish LWC production lines. Paper production downtime at the break-even point, with $A_{break\text{-}even}=0.90089$, is given by

$$A_{break-even} = \frac{X}{365} = 0.90089 \Rightarrow X = 365 \cdot 0.90089 \approx 36 \text{ days.} \qquad \text{(Eq. 4-13)}$$

This unavailability is three times more than planned maintenance down-time, and thus the loss of profits seems acceptable and reasonable. Likewise, it is not reasonable to expect dramatic improvements in the maintenance efficiency, either. The 12-day expectancy is based on paper companies' experience and if safeguards are needed, the actual availability with real production lines is between 0.917…. 0.937. In the worst case, with an availability of $A_{low}=0.917$, the production line yields a 3.562 MEUR annual profit, which cannot be considered as a good financial result in today's economy. However, the validation data with its cost structures and efficiencies represents the situation in LWC paper production in Finland, and the total costs directly affect the acceptable (i.e. positive) efficiency values, too. In other market areas the cost factors as well as annual availabilities might be lower. Such speculative values cannot be exactly justified with real data and are hence left outside the validation process. Yet, the dependency of availability with respect to the four input parameter efficiencies e_4, e_5, e_6 and e_7, i.e. *Consumed parts*, *Maintenance*, *Technology* and *Expertise* should be valid in all market areas. Defining "reasonable" values for the inputs is quite difficult as they also depend on cost structures and are hence left to the decision-maker. In the validation process, acceptable input values were tested and compared with the resulting availability parameter value. Table 4-3 shows the dependency of the availability parameter value with respect to input parameter efficiencies e_4, e_5, e_6 and e_7.

Table 4-3. Sensitivity analysis for acceptable parameter efficiencies e_4, e_5, e_6 and e_7, range (1, …, 0).

		Value of single input parameter										
		1	**0.9**	**0.8**	**0.7**	**0.6**	**0.5**	**0.4**	**0.3**	**0.2**	**0.1**	**0**
Number of changed input parameters	**1**	1	0.9	0.8	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0
	2	1	0.81	0.64	0.49	0.36	0.25	0.16	0.09	0.04	0.01	0
	3	1	0.729	0.512	0.343	0.216	0.125	0.064	0.027	0.008	0.001	0
	4	1	0.6561	0.4096	0.2401	0.1296	0.0625	0.0256	0.0081	0.0016	0.0001	0

Values shown at the top of Table 4-3 are the input parameter efficiencies e_4, e_5, e_6 and e_7. Respectively, the elements of Table 4-3 represent the resulting production line availability when one, two, three or four of the input parameter efficiencies e_4, e_5, e_6 and e_7 are simultaneously assigned the same value in the range between (1,…, 0) with 10 % decrements. Unacceptable availability values (those < 0.9) are marked in red, thus showing that only one parameter value could be changed by 10 %. The same effect is also presented in Figure 4-4.

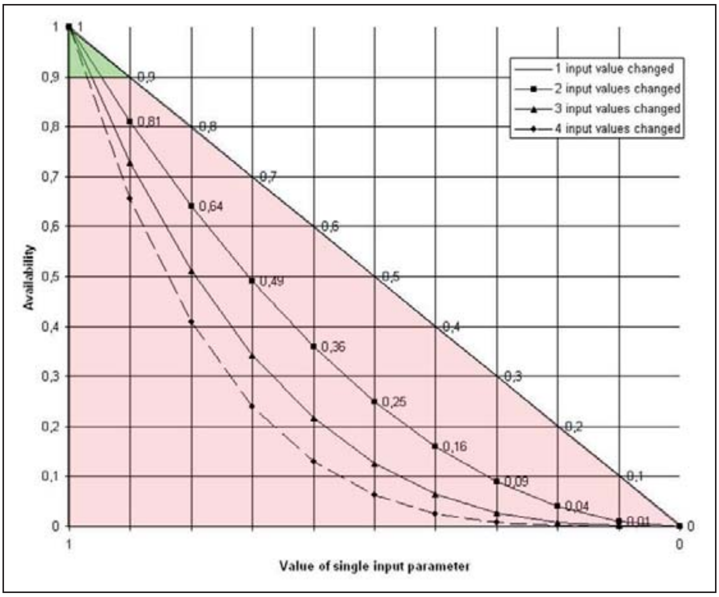

Figure 4-4. Sensitivity analysis for acceptable parameter efficiencies e4, e5, e6 and e7. The green triangle in the upper left corner of the figure represents acceptable input values.

As Table 4-3 and Figure 4-4 show, the model user needs to present input efficiencies on a very fine scale. Focusing on the top left corner of Figure 4-4, Table 4-4 shows sensitivity analysis for the same parameters using a range of (1,..,0.9).

Table 4-4. Sensitivity analysis for acceptable parameter efficiencies e_4, e_5, e_6 and e_7, range (1, …, 0.9)

		Value of single input parameter										
Number of changed input parameters		**1**	**0.99**	**0.98**	**0.97**	**0.96**	**0.95**	**0.94**	**0.93**	**0.92**	**0.91**	**0.9**
	1	1	0.99	0.98	0.97	0.96	0.95	0.94	0.93	0.92	0.91	0.9
	2	1	0.9801	0.9604	0.9409	0.9216	0.9025	0.8836	0.8649	0.8464	0.8281	0.81
	3	1	0.9703	0.9412	0.9127	0.8847	0.8574	0.8306	0.8044	0.7787	0.7536	0.729
	4	1	0.9606	0.9224	0.8853	0.8493	0.8145	0.7807	0.7481	0.7164	0.6857	0.6561

Elements of Table 4-4 represent resulting production line availability when one, two, three or four of the input parameter efficiencies e_4, e_5, e_6 and e_7 are simultaneously assigned the same value in the range between (1,…, 0.9) with 1 % decrements. Unacceptable availability values (those < 0.9) are marked in red, thus showing that all parameter values can be changed by 1 % decrements. The same effect can also be seen in Figure 4-5.

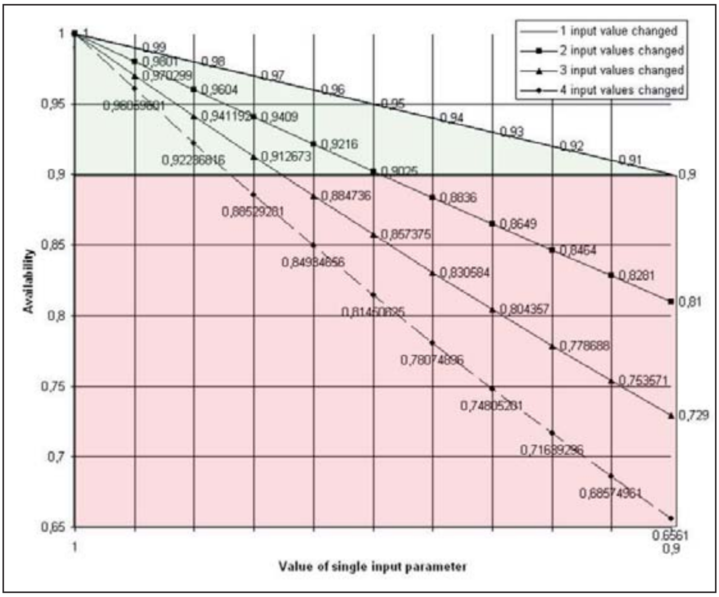

Figure 4-5. Sensitivity analysis for acceptable parameter efficiencies e4, e5, e6 and e7, input value range (1, …, 0.9). The green triangle represents acceptable input values.

In the validation process, only small parameter values were used to keep the availability parameter at an acceptable level with respect to the real process. Using small increments and decrements in the input efficiencies was difficult at first, but quite soon the experts and decision-makers learned to alter them appropriately to characterise changes in the real process. The real process counterparts for these efficiencies were difficult to define, but comprehending the significance of these *beliefs* as well as then using them proved to be quite easy.

Validation step *4* on page 78 can only be achieved if the developed model is put to active use, and records of modelling and actual results can later be used for refining the model.

4.4. Summary

The possibility to validate the model with several paper production lines' empirical data was a great opportunity. The results suggested that the developed model works very well under the used assumptions. The difference between realised paper companies' annual profits and the annual profit computed with the model was between 1…2 %. Also the availabilities of the actual production lines were close to those computed by the model, with errors less than 1 % (for example: model availability 91 % - actual 91,7 %).

Figure 4-6 represents the dependency between paper production line availability and profitability in the model.

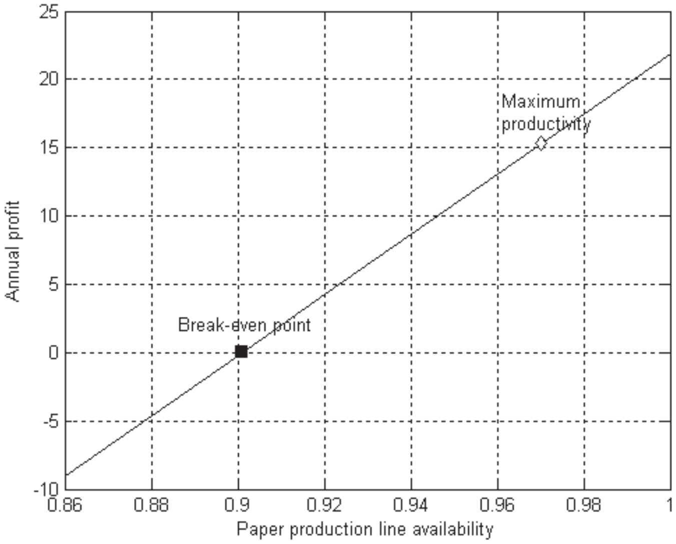

Figure 4-6. Dependency between paper production line availability and profitability.

As Figure 4-6 shows, the linearity of the model causes it to react quite dramatically to availability changes, mainly because production line availability directly limits produced tonnes and hence lowers net income. Availability problems are not assumed to reduce input expenditures although *they do depend on each other* when examined at a more accurate level of detail. Thus the model assumes that variable costs remain constant even though production line unavailability causes loss of production. Under this assumption, the production technology exhibits constant returns to scale in terms of production line technical availability, but the input efficiencies e_i now play an essential role in productivity instead of input levels. Furthermore, the model values have been validated in Finland and several input costs are different in other market areas. In conclusion, the linear model imitates the real-world quite well even though linear models and averages tend to obscure the nuances of the real-world (Fogelholm 2000, pp. 17, 44).

The validation process above also partially confirms that the *modelling framework* is useful in the managerial decision-making process. However, even though the practitioners agreed that the *model* gives accurate predictions with respect to the assumptions made, the validation process only considered a one-year life cycle. Of course, the decision-maker takes responsibility for choosing appropriate life cycle analysis length and chooses parameter values to represent the real-world situation during this period. Still, evidence of the usefulness of the *modelling framework* is the *model* which was achieved to characterise the real process of a paper production line, but an extended validation process is needed to validate that the framework can also be used during a managerial decision-making process. Next, chapter 5 presents a validation process for the modelling framework's usefulness with a few scenarios imitating the decision-making problems in the field in a way similar to that in which the model trialling process was carried out with the practitioners.

5. Validation of the Model Usefulness: Analysing Profitability of Alternative Contracting Strategies in Paper Production

The purpose of this chapter is to validate the usefulness of the model with a real-like workflow which imitates a plausible managerial decision-making process. Hence, an example of analysing profitabilities of three different contracting strategies for delivering paper production core functions is discussed in this chapter. Some of the paper industry development trends are also discussed in the light of these example results. Microeconomic theories introduced earlier concerning market competition and private information produce requirements for model usefulness, because quite often these phenomena evoke managerial strategic decision-making processes. These microeconomic concepts and especially their realisations in the paper industry are thus reviewed to justify the validation parameter values for the tests in this chapter, because testing with some real data would possibly expose the current business plans of the practitioners to public observation.

Contracting is here assumed to take place mainly for *economising reasons* (Williamson 1985) although other drivers and implications of contracting are discussed as well. Hence, the main methodology for analysing the different contracting models relies on *transaction cost economics*. Williamson (1985, p. 2) defines transaction cost economics as a means of analysing comparative costs in planning, adapting and monitoring task completion within alternative governance structures. Transaction costs are an economics counterpart of friction in the physical sciences, and the focus of this thesis is to study how the different contracting strategies affect transaction costs. Komonen (1998) took a similar approach in studying maintenance management in the Finnish process industry.

According to the validation results in chapter 4, the developed mathematical model can be used to imitate the accounting settings and production planning, or more specifically the outcomes of these, of *paper companies'* decision-making process. The developed model does not, however, (directly) consider the various decision-making accounting settings of the *technology suppliers*. Three contracting strategies for delivering paper production technology inputs and the respective accounting settings are considered in this research, and they are discussed in more detail in the next sub-chapters. Contracting models concern delivery and management of the model input parameters *Consumed parts*, *Maintenance*, *Technology* and *Expertise*, while other model parameter values are influenced indirectly, at most, by changes in these four parameters. The three contracting strategies dealt with in this research for delivering the above four inputs are

- *Competitive bidding* in which a paper company manages all activities internally and practices competitive bidding when applicable.
- *Co-operation* where a paper company has co-operation agreements with several suppliers competing in the delivery of the same activities.
- *A partnering* model, with one supplier managing all activities.

This thesis addresses mainly direct effects of the above contracting strategies through efficacy of resource allocation, technology management and opportunistic behaviour. Capital costs and other external effects are left outside the scope although they have significance in the real-world. However, such effects are very firm-specific and thus cannot be generalised here in a meaningful manner. In contrast, opportunistic (or self-interested) behaviour is apparent in all (the above) forms of contracting (Williamson 1985, pp. 47-48). The economic efficiency of these contracting strategies should be measured and compared with the developed modelling framework. The relationship of the original technology supplier and the paper company is of central interest within this thesis and hence profitability as well as control over tangible and intangible assets related to production line Installed Base in the different contracting strategies is addressed.

The control rights of firms 1 and 2 over assets, denoted by q_1 and q_2, are allocated at the time of signing a contract at time $t=0$. Profit $\pi_j(\cdot)$ is further assumed to depend on control (or ownership) rights q_1 and q_2 through some continuous function ϕ_j, as earlier discussed. An optimal contract must then satisfy

$$\text{Max } \pi_1(a_1,\phi_1(q_1,q_2))+\pi_2(a_2,\phi_2(q_1,q_2))-\beta(a_j,\phi_j(q_1,q_2)), \quad \text{(Eq. 5-1)}$$

where β denotes costs paid to *other* suppliers and which depends on the division of control over assets. Naturally, both parties should be better off *if* the two firms could mutually operate in all production functions without additional transaction costs. Market competition, however, suggests that other firms' involvement is fruitful by challenging some input deliveries and thus increasing $\beta > 0$.

Generally, the idea is to examine a ten-year life cycle of a green-field LWC paper production line during which the same setbacks and benefits are faced with the alternative contracting strategies. The life cycle assumes a production line life cycle similar to the one presented by Kelly (1984, p. 6) and follows the Paper mill Installed Base life cycle definition given earlier on pages 38-39. In addition to the earlier definition, Paper mill Installed Base life cycle describes the general technical level of the *production line under study* instead of the whole mill. Accordingly, the Installed Base life cycle characterises the technical age of the individual machines in the production line, of which *Planning*, *Roll-out* and *Operation* states are considered here. Figure 5-1 illustrates the assumed first ten years of a paper production line's life cycle.

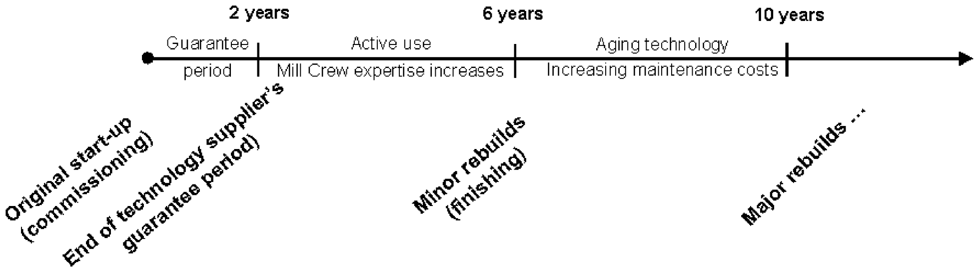

Figure 5-1. Paper production line life cycle assumed in the analysis.

Productivity and profitability of a paper production line are the main interests here during the paper mill Installed Base life cycle. Similarly, the Installed Base product life cycle, which specifies the technical and operational level of an individual machine in the paper mill's Installed Base, has an important role. Model inputs directly affect (and indirectly, too) to both the lengths of product life cycle states (*Planning*, *Roll-out*, *Operation* and *Disposal/ Closure*) and the efficiency of the products within these states.

Values of the input parameters (denoted $\cdot_i^t$) for the production line life cycle in Figure 5-1 for years $t=1,\ldots,10$ have been adapted from the validation data of chapter 4, and have been chosen in testing the model usefulness – not to make conclusions regarding the results. Accordingly, these parameters are not validated with paper companies' experts in the same way as model validation data earlier on. For simplicity, some input values are assumed to be independent of external effects and to depend merely on the effects of the contracting strategy. These parameters are paper sales price p = 700 EUR/ tonne[51] and the value of the initial green-field investment = 100 MEUR, which is then annually depreciated in equal amounts. Similarly, a 10 MEUR investment is made after 6 years of operation to increase productivity. A two-year guarantee period (after start-up) exists for the initial production technology and it covers a momentarily annual production capability of 300 000 tonnes.

Annual production of year t with the given input values above is given by

$$y_{Model}^t = pd \cdot A_{Model}^{t-1} \cdot e_3^{t-1}. \qquad \text{(Eq. 5-2)}$$

(Eq. 5-2) illustrates well the notational nuances of temporal evolution (i.e. passing of time); the outputs at time $t=1,\ldots,10$ are derived from inputs at time $t-1$. In a similar fashion, direct costs of annually produced (and sold) paper tonnes is given by

$$w(y_{Model}^t) = w_3^{t-1} + w(A_{Model}^t), \qquad \text{(Eq. 5-3)}$$

where w_3^{t-1} is the price (or cost) of raw materials and $w(A^t_{Model})$ the cost of availability at time t. It should be noticed that the system parameters $w(y^t_{Model})$ and $w(A^t_{Model})$ are computed at time t from inputs at time $t-1$. It is assumed in this thesis that the production technology exhibits constant returns to scale (CRS), which means that the production line outputs (paper tonnes) are proportional to the inputs. Hence the rebuild characterised in Figure 5-1 is expected to *enable* increased annual production, but increase of production requires input levels to increase, too. This satisfies the *no free lunch*[52] assumption. Figure 5-2 shows the development of the production curve during the ten-year life cycle discussed in this thesis.

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[51] *FOEX (2006)*

[52] Supposedly $y \in Y$ and $y \geq 0$ so that vector y does not use any inputs. The *no free lunch* property is satisfied if the production vector y does not produce any output, either. (Mas-Colell et al. 1995, pp. 130-134)

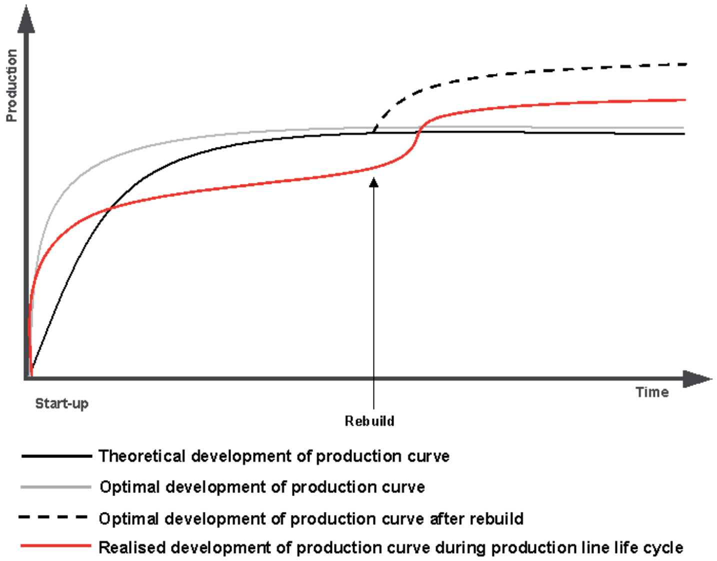

Figure 5-2. Development of paper production line production curve during ten-year life cycle.

The paper company might expect the productivity of a newly invested production line to develop according to the solid black curve in Figure 5-2. Furthermore, they might assume the rebuild at year 6 to increase annual production capacity according to the dashed curve. However, poor technical availability of the production line *would* reduce the annual production from the theoretical levels. It is important to notice that the technology supplier does not guarantee availability of the production line or production capabilities - only possible manufacturing defects are covered by warranty. The "realised" production curve illustrated with the red curve in Figure 5-2 thus points out the significance of the production line's technical availability – without capable inputs it is not possible to make the most out of the technology.

Accordingly, net sales $pf(z)^t_{Model}$ depends on produced paper tonnes y^t_{Model} and the sales price of paper p

$$pf(z)^t_{Model} = p \cdot y^t_{Model} \,.^{53} \qquad \text{(Eq. 5-4)}$$

Finally, the annual life cycle profit is then given by

$$LCP^t_{Model} = pf(z)^t_{Model} - w^t_{Model} \cdot z^t_{Model} \,, \qquad \text{(Eq. 5-5)}$$

where vector z is a unity vector.

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[53] For convenience, paper sales price is denoted by just p instead of p_{Model} as there is no chance of misinterpretation.

5.1. Competitive Bidding Model

Competitive bidding is dealt with first. This contracting strategy assumes that the paper company manages all activities at the mill and negotiates delivery of inputs through annual contracts. The paper company is assumed here to be an opportunist in terms of pricing and hence to be willing to change suppliers over the ten-year period if lower cost levels can be obtained. On the other hand, the suppliers, too, wish to operate opportunistically by making short-term optimum deals with the paper company.

Knowledge transfer is also assumed to be quite poor in this model, and the significance of screening (Spence 1976; Rothschild and Stiglitz 1976) is apparent. The paper company wishes to obtain several bids simultaneously by attempting to get quotes from as many adequate suppliers as possible and then to select the (possibly cost-wise short-term) best for the situation at hand. As a result of these emerging information asymmetries, the different input efficiency levels become differentiated.

In the start-up phase of the new production line, maximum productivity is seldom possible. The mill crew is on a learning curve and the technology supplier provides technical back up during the start-up as well as the guarantee period at least to avoid penalties for inadequate product design (i.e. signalling). Later in the Paper mill Installed Base life cycle, all input efficiencies are expected to change as the mill crew gains competence in managing the Installed Base machines and information asymmetry between the paper company and the technology supplier emerges. Table 5-1 illustrates the imaginary development curves of different competencies within the first ten years of a production line's life cycle in competitive bidding strategy.

Table 5-1. Development of competencies in production line life cycle in competitive bidding contracting strategy.

YEAR	1	2	3	4	5	6	7	8	9	10
Paper price	700	700	700	700	700	700	700	700	700	700
pd	300 000	315 000	315 800	315 800	315 800	315 800	320 000	325 000	325 000	325 000
e1	1	1	1	1	1	1	1	1	1	1
e2	1	1	1	1	1	1	1	1	1	1
e3	1	1	1	1	1	1	1	1	1	1
e4	1	1	0.99	0.98	0.98	0.97	0.98	0.98	0.98	0.98
e5	0.95	0.95	0.97	0.97	0.97	0.975	0.975	0.98	0.98	0.99
e6	1	1	1	0.998	0.997	0.995	1	1	1	1
e7	0.98	0.985	0.96	0.965	0.97	0.975	0.97	0.975	0.98	0.985

The effects of such inputs as raw materials and energy are assumed here fixed even though they, in real life, normally *do* fluctuate. The start-up phase of the production line incorporates a strongly effective learning curve, especially in technical inputs. It is also expected that the production line will not operate at full annual capacity during the first year and hence the production plan is set to a smaller level (300 000 tonnes/ year), but will soon be set to the maximum annual production level (315 800 tonnes/ year). Consumed parts are assumed to be the best possible ones available as the original technology supplier delivers them, and technology is also assumed to be efficient during the first three years. The expertise level is quite high, consisting of (at least partially) a well-trained mill crew supported by the technology supplier's technical back up during the first two-year guarantee period. Considering the self-interested behaviour of the firms, the technology supplier is most likely to cut costs during engineering design in this strategy and optimise its profitability within the guarantee period (and additionally to establish a reference for future sales, too). As a result of this assumption, the efficiency of technology decreases after the mill crew takes full responsibility (and the supplier's guarantee period ends) for production and maintenance activities, but increases again after the rebuild at year 6. Profits of the two firms $\pi_j(\cdot)$ are assumed to depend on control rights q_1 and q_2 over assets through some continuous function ϕ_j. In this strategy, paper company's assets a_1 include all investments (inputs) while the technology supplier's assets a_2 are mainly intellectual. In the competitive bidding strategy, the paper company wishes to maximise its profit annually over the ten-year period

$$\text{Max}\ \pi_1(a_1,\phi_1(q_1,q_2)) - \beta(a_2,\phi_1(q_1,q_2))^{54}, \qquad \text{(Eq. 5-6)}$$

where β denotes input costs (depending on the control rights over assets a_2) that the paper company needs to pay to external suppliers. Conjecturally speaking, 60 % of input orders that concern consumed parts, maintenance and expertise are now assumed to be secured in favour of the technology supplier due to asset-specificity of Installed Base. Rivalling component manufacturers, for example, cannot easily achieve cost-effective manufacturing of machine specific parts and hence the original technology supplier has a strong foothold as a production line's main supplier as well as in the markets. Similarly, the technology supplier wishes to maximise its annual profit over the ten-year life cycle, too, namely in compliance with the equation

$$\text{Max}\ \pi_2(a_2,\phi_2(q_1,q_2)) - \beta(a_1,\phi_2(q_1,q_2))^{55}, \qquad \text{(Eq. 5-7)}$$

by minimising orders β booked by its rivals. As a result of the Installed Base asset specifity, the technology supplier has[56] now 60 % control over assets a_2 needed by the paper company and it thus wishes to gain more control over assets a_2 from the paper company to increase its sales. In this strategic setting the paper company does not, however, give up its control in favour of the technology supplier, because the paper company wishes other firms to challenge its main supplier in price as well as efficiency competition. Following from the above assumptions, technology efficiency is assumed to decrease resulting from the mill crew's inability to prioritise maintenance and consumed parts in terms of production line technology. Instead, maintenance efficiency fluctuates during the life cycle due to production machinery changes and cost-cutting actions in the supplier selection by the paper company. The mill maintenance department's skill

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[54] β encompasses assets a_2 which are *not controlled* by the paper company.
[55] β encompasses assets a_1 which are *not controlled* by the technology supplier.
[56] To be precise, the paper company has *all* control rights for assets.

level, however, increases during the mill life cycle as most of the mill crew learns to manage with the Installed Base on a daily basis.

The rebuild at year 6 is expected to have several impacts. Once again, the technology supplier provides new knowledge to the mill crew during new machine installations. There is still a 5 % annual decrease in expertise because the mill crew cannot be assumed to utilise all new knowledge within the first year. Still, the overall maintenance efficiency continues to grow as maintenance expertise is not directly linked with technology. The overall costs, however, increase along with depreciation (annually 5 MEUR over four years, 20 MEUR total investment) of new machines and increased raw material expenditures. Table 5-2 shows the development of input costs in the competitive bidding strategy.

Table 5-2. Development of input costs in production line life cycle in competitive bidding contracting strategy.

YEAR	1	2	3	4	5	6	7	8	9	10
w1	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€
w2	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€
w3	-100 M€	-100 M€	-100 M€	-100 M€	-100 M€	-100 M€	-105 M€	-105 M€	-105 M€	-105 M€
w4	-1 M€	-1 M€	-1 M€	-1.5 M€	-1.8 M€	-3 M€	-2.2 M€	-2.1 M€	-2.3 M€	-2.3 M€
w5	-5 M€	-6 M€	-6 M€	-6 M€	-6 M€	-6 M€	-6 M€	-6 M€	-6 M€	-6 M€
w6	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-15 M€	-15 M€	-15 M€	-15 M€
w7	-0.25 M€	-0.25 M€	-0.1 M€	-0.1 M€	-0.1 M€	-0.1 M€	-0.25 M€	-0.1 M€	-0.1 M€	-0.1 M€

Direct costs of annually produced (and sold) paper tonnes $w(y^t_{Model})$ are given by the price (or cost) of raw materials w_3^{t-1} and cost of availability $w(A^t_{Model})$ at time t. Raw material costs depend mainly on the annual production plan, which determines the costs through delivery contracts with the suppliers of these inputs. Availability costs, in contrast, depend on the technology efficiency and maybe even more on the efficacy of the daily activities at the mill. Table 5-3 characterises production line production and profitability values in the first 10 years in competitive bidding contracting strategy.

Table 5-3. Production line production and profitability values in the first 10 years in competitive bidding contracting strategy.

YEAR	pd^t	$w(y^t_{Model})$	A^t_{Model}	Y^t_{Model}	LCP^t_{Model}
1	300 000	-116.25 MEUR	0.9310	279 300	4.26 MEUR
2	315 000	-117.25 MEUR	0.9357	294 761.25	14.082875 MEUR
3	315 800	-117.1 MEUR	0.9219	291 132.2304	11.692561 MEUR
4	315 800	-117.6 MEUR	0.9155	289 113.1132	9.779179 MEUR
5	315 800	-117.9 MEUR	0.9193	290 319.9151	10.323940 MEUR
6	315 800	-119.1 MEUR	0.9175	289 745.1479	8.7216036 MEUR
7	320 000	-128.45 MEUR	0.9268	296 587.2	4.161040 MEUR
8	325 000	-128.2 MEUR	0.9364	304 326.75	9.828725 MEUR
9	325 000	-128.2 MEUR	0.9412	305 887.399	10.921179 MEUR
10	325 000	-128.4 MEUR	0.9556	310 585.275	14.009693 MEUR

Total production costs, produced tonnes of paper and profits over the ten-year period in the competitive bidding strategy are 1218.45 MEUR, 2 951 758 tonnes and 97.7807956 MEUR. Profitability development in the first 10 years under competitive bidding strategy fluctuates a lot, as Table 7-3 shows. Development of direct production costs satisfies the *no free lunch* assumption, and hence the consumption of raw materials increases along with increased output (an offset of roughly 10 MEUR after rebuild at year 6). Figure 5-3 illustrates the relationship between annual profit and production line availability. This dependency comes from the model, as also suggested by Mardon et al. (1991, pp. 87, 91) and Chan et al. (2003, p. 72).

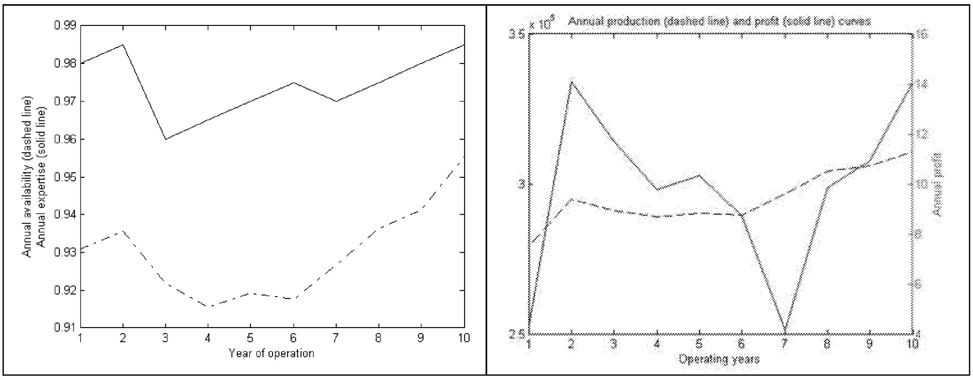

Figure 5-3. Development of expertise and availability (left figure), and annual productivity and profitability (right figure) in paper production line life cycle in competitive bidding strategy.

The model also considers dependency between production line availability and mill crew expertise (Figure 5-3, left figure), and production line productivity and availability (Figure 5-3, left and right figures). This is once again in accordance with the remarks by Mardon et al. (1991, p. 90). Mill crew expertise encompasses expertise of the whole organisation and technical backup from the technology supplier. Furthermore, annual profit seems to follow realised annual production, but the profit curve is much more sensitive to capital expenditure changes, as one could expect. Figure 5-3 (right figure) shows quite clearly how the rebuild investment costs are reflected in the short-term profitability (operating years 6, 7 and 8), but on the other hand increase productivity, thus anticipating higher profits in the long run (from year 9 onwards).

In conclusion, the selected modelling parameters yield quite good results in competitive bidding strategy. The parameters encompass a dedicated mill crew and a continuously learning mill organisation, but this advantage may be compromised if the organisation is continuously changing due to resource re-allocations, for example. Secondly, the inputs are very inflexible to changes due to sensitivity of the production process, and hence the cost structures, too, are difficult to change. In one sentence, competitive bidding strategy requires a rigid organisation and production process within the assumptions and parameter values selected here.

5.2. Co-Operation Model

Co-operation strategy encompasses here so-called frame agreements with paper companies and (practically all suppliers, but in particular) technology suppliers. As concluded above, the production process inputs are very sensitive and hence suppliers of production process inputs *wish* and *have the ability* to retain good profit margins for their products. However, the paper production process *still* varies significantly despite strong standardisation attempts, such as the co-operation agreements, and suppliers having a strong market position have a tendency to increase their prices. On the other hand, if the prices are fixed, the quality of service might decrease as a somewhat fixed money flow is anticipated from customers with a co-operation agreement. Because of these factors, paper companies wish to maintain a competitive setting in the supplier markets with co-operation strategy, and the main target of co-operation agreements for them is negotiating longer-term price reduction for the main suppliers' inputs.

Co-operation strategy, too, assumes that the paper company manages all activities at the paper mill. As in the competitive bidding strategy, the paper company negotiates annual contracts for the inputs with its suppliers, but additionally utilises scale effects by setting annual prices to cover all paper mill inputs of the whole corporation. Hence, the paper company is assumed here to be also an opportunist in terms of pricing and also to be willing to change suppliers over the ten-year period if lower cost levels can be obtained. Accordingly, suppliers wish to operate opportunistically in this model, and short-term optimum deals can no longer be necessarily obtained because of the commitment from the co-operation agreement to deliver for a larger customer base for a fixed price. Thus, the suppliers' service quality level might suffer as suppliers anticipate annual orders within the co-operation agreement limits. Instead of focusing on serving customers who have co-operation agreements, the suppliers might actually focus on getting new orders from customers *not having* co-operation agreements if they can generate additional business by providing these customers with appropriate inputs. The number of transactions is also expected to *increase* at the supplier side compared with the situation in the competitive bidding strategy. This is a consequence of the fact that paper companies might, in fact, reduce their procurement organisations along with centralisation of procurement and resulting co-operation agreements, and hence do less screening work in selecting which suppliers to ask quotations from. This effect can be seen in the model parameters from the fact that the efficacy e_4 of consumed parts as well as prices w_4 are lower than in competitive bidding strategy.

The start-up phase of the new production line maximum productivity should follow the same pattern as in competitive bidding strategy. Maintenance development is managed by the paper company and is thus also expected to develop equally in competitive bidding strategy. The cost of maintenance, however, decreases, as the external maintenance services (including consumed parts in the maintenance services) are included in the co-operation agreement. Co-operation strategy is not expected to influence any other parameters.

Table 5-4 illustrates the development of different competencies within the first ten years of a production line's life cycle in co-operation strategy.

Table 5-4. Development of competencies in production line life cycle in co-operation contracting strategy.

YEAR	1	2	3	4	5	6	7	8	9	10
Paper price	700	700	700	700	700	700	700	700	700	700
pd	300 000	315 000	315 800	315 800	315 800	315 800	320 000	325 000	325 000	325 000
e1	1	1	1	1	1	1	1	1	1	1
e2	1	1	1	1	1	1	1	1	1	1
e3	1	1	1	1	1	1	1	1	1	1
e4	1	1	0.99	0.98	0.97	0.97	0.975	0.98	0.985	0.98
e5	0.95	0.95	0.965	0.97	0.96	0.975	0.98	0.98	0.985	0.99
e6	1	1	1	0.998	0.997	0.995	1	1	1	1
e7	0.98	0.985	0.96	0.965	0.97	0.975	0.97	0.975	0.98	0.985

Contracting in co-operation strategy is not expected to be reflected in engineering design and the technology supplier is most likely to optimise its profitability within the guarantee period, and of course, also establish a reference for future sales just as in competitive bidding strategy. Both firms are expected to act self-interestedly, and hence the efficiency of technology will most likely decrease after the mill crew takes full responsibility for production and maintenance activities after the technology supplier's guarantee period has ended.

In addition to the self-interested behaviour of firms, information asymmetries develop during the co-operation agreement period. Even though *both firms* wish to improve communication and share knowledge more efficiently, there are no real incentives for either party to increase the other firm's knowledge and thus strengthen its bidding capabilities. Co-operation contracting strategy between paper machine technology supplier and paper company is hence a typical example of a hold up problem introduced by Klein et al. (1978): hold up problem can most easily be illustrated with the profit functions of the two firms $\pi_j(\cdot)$, which are assumed to depend on control rights q_1 and q_2 over assets. Co-operation strategy assumed the paper company's assets a_1 to include all investments (inputs), while the technology supplier's assets a_2 are mainly intellectual. In the co-operation strategy the paper company wishes to maximise its profit annually over the ten-year period, i.e. according to the equation

$$\text{Max}\ \pi_1(a_1,\phi_1(q_1,q_2))-\beta(a_2,\phi_1(q_1,q_2))\text{[57]}, \qquad \text{(Eq. 5-8)}$$

where β denotes input costs (depending on the control rights over assets a_2) that the paper company needs to pay to external suppliers. In competitive bidding strategy 60 % of input orders concerning consumed parts, maintenance and expertise were assumed secured in favour of the technology supplier due to asset-

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[57] β encompasses assets a_2 which are *not controlled* by the paper company.

specificity of the Installed Base. Due to earlier assumptions about co-operation strategy business drivers, namely reduction and centralisation of a paper company's corporation-level procurement organisation as well as reduced input costs, 70 % of input orders (i.e. a 10 % increase in sales) concerning consumed parts, maintenance and expertise are now assumed to be secured for the technology supplier.

Once again, paper machine component manufacturers cannot easily achieve cost-effective manufacturing of machine-specific parts and hence the original technology supplier has a strong foothold in the markets. Similarly, the technology supplier wishes to maximise its annual profit over the ten-year life cycle, too, according to the equation

$$\text{Max}\ \pi_2(a_2,\phi_2(q_1,q_2)) - \beta(a_1,\phi_2(q_1,q_2))\ ^{58} \qquad \text{(Eq. 5-9)}$$

by minimising orders β booked by its rivals. The technology supplier *does not gain more control* over assets a_1 (i.e. assets are not moved from a_1 to a_2), but transactions with the same customer are expected to increase by 10 %. This strategic setting might actually emphasise the paper company's desire to let other firms challenge its main supplier in price as well as efficiency competition to strengthen its bargaining power. The technology supplier's tightening situation will most likely cause fluctuation in the input efficiency levels. The rebuild of year 6 is assumed to equal that of competitive bidding except that the price levels are smaller. Table 5-5 shows the development of input costs in the co-operation strategy.

Table 5-5. Development of input costs in production line life cycle in co-operation contracting strategy.

YEAR	1	2	3	4	5	6	7	8	9	10
w1	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€
w2	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€
w3	-100 M€	-100 M€	-100 M€	-100 M€	-100 M€	-100 M€	-105 M€	-105 M€	-105 M€	-105 M€
w4	-1 M€	-0.9 M€	-0.9 M€	-1.1 M€	-1.3 M€	-2.4 M€	-2 M€	-2 M€	-2.1 M€	-2.1 M€
w5	-5 M€	-5.5 M€	-5.5 M€	-5.5 M€	-5.6 M€	-5.8 M€	-6 M€	-6 M€	-6 M€	-6 M€
w6	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-15 M€	-15 M€	-15 M€	-15 M€
w7	-0.25 M€	-0.25 M€	-0.1 M€	-0.1 M€	-0.1 M€	-0.1 M€	-0.25 M€	-0.1 M€	-0.1 M€	-0.1 M€

Table 5-6 characterises production line production and profitability values, computed with earlier definitions, in the first 10 years in co-operation contracting strategy.

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[58] β encompasses assets a_1 which are *not controlled* by the technology supplier.

Table 5-6. Production line production and profitability values in the first 10 years in co-operation contracting strategy.

YEAR	pd^t	$w(y^t_{Model})$	A^t_{Model}	Y^t_{Model}	LCP^t_{Model}
1	300 000	-116.25 MEUR	0.9310	279 300	4.26 MEUR
2	315 000	-116.65 MEUR	0.9357	294 761.25	14.682875 MEUR
3	315 800	-116.5 MEUR	0.9171	289 631.55	11.242084 MEUR
4	315 800	-116.7 MEUR	0.9155	289 113.11	10.679179 MEUR
5	315 800	-117.0 MEUR	0.9006	284 395.02	7.076513 MEUR
6	315 800	-118.3 MEUR	0.9175	289 745.16	9.521603 MEUR
7	320 000	-128.25 MEUR	0.9268	296 587.2	4.361040 MEUR
8	325 000	-128.1 MEUR	0.9364	304 326.75	9.928725 MEUR
9	325 000	-128.2 MEUR	0.9508	309 016.66	13.111664 MEUR
10	325 000	-128.2 MEUR	0.9556	310 585.275	14.209692 MEUR

Direct production costs, produced tonnes and profits over the ten-year life cycle in co-operation strategy are 1214.15 MEUR, 2 947 462 tonnes and 99.073375 MEUR. Hence, the production cost difference is 4.3 MEUR in favour of co-operation strategy, while competitive bidding strategy produces 4 296 tonnes more than co-operation strategy. However, the difference in production cost still yields a 1.2925794 MEUR higher profit for the paper company over the ten years. Annual profitability fluctuates, too, in co-operation strategy, as Table 5-6 and Figure 5-4 show. According to the *no free lunch* assumption, raw materials consumption increases along with increased output (an offset of roughly 10 MEUR after rebuild at year 6).

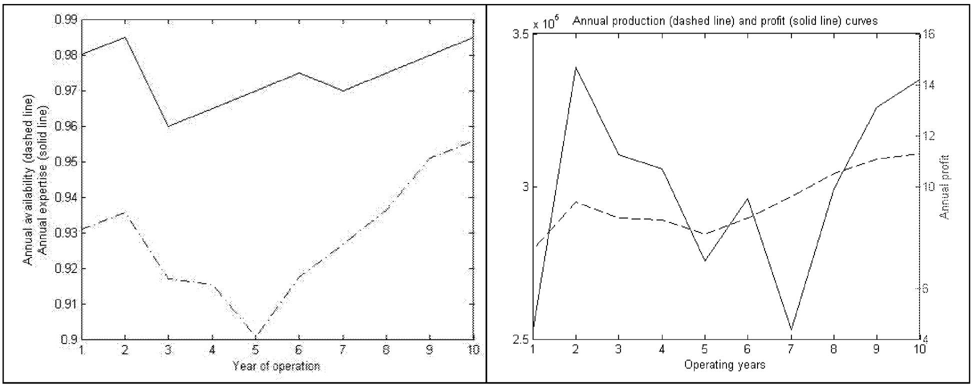

Figure 5-4. Development of expertise and availability (left figure) and annual productivity and profitability (right figure) in paper production line life cycle in co-operation strategy.

Figure 5-4 shows that both expertise and production levels seem to fluctuate more with these parameter values than those in competitive bidding strategy. This is assumed to result from the technology supplier's 10 % increase in sales (i.e. more transactions) *without* the possibility of negotiating price levels. In fact, it might be that the paper company does not order as much from the technology supplier after all, but occupies the supplier's sales organisation with additional bids for which the paper company would not ask for a quotation in competitive bidding strategy. Hence, the transaction costs per order increase, but the actual sales volume might decrease. In addition, the technology supplier has no option to alter the assets to achieve scale advantages in its production activities.

Referring to the transaction cost literature (Coase 1937; Williamson 1985; Williamson 2002; Madhok 2002), firms might overlook managing resource allocations or streamlining transactions in their strategy planning. The chosen validation parameter values do not consider appreciation of intellectual assets, either, and hence the highest profit margins are only accepted along with physical products (mainly consumed parts, in this case). Using the assumptions and model parameter values used here, co-operation contracting strategy can be seen to focus mainly on reducing directly measurable costs of the paper company.

5.3. Partnership Model

A firm's competitive advantage depends not only on its internal capability and resources but also on the strength of its network with other companies. For some reasons these collaborative relationships sometimes fail, however. The risk of failure is considerable due to long-term commitment of resources on both sides, such as investments, manpower, technology and time. Furthermore, the cost of failure might go beyond the actual costs of the resources deployed and the involved firms may fail in achieving expected synergistic gains or positive spill-over effects. Hence, developing a better understanding of how to improve performance of contracting (and interfirm relationships) is essentially important.

Lee and Cavusgil (2006, p. 899) suggest that firms should choose a mixture of hierarchical and market-based governance structures in balancing between the efficiency of the transactions and protection of transaction-specific assets against opportunism (as suggested by Williamson (1985) and also illustrated in Figure 2-25 earlier). While contractual-based governance may reduce the risks of alliance partnership, facilitate knowledge transfer and enhance alliance performance, market-based transactions, instead, involve an exchange between autonomous economic entities and frequently serve as efficient contracting modes. Classical contracts can provide an efficient safeguard by which firms can protect themselves from a partner's opportunism (Lee and Cavusgil 2006, p. 899), as an explicit contract ensures that the terms of transactions will be enforceable. This explains why firms may prefer contractual agreements, such as competitive bidding and co-operation agreements, to control the type and amount of information shared among firms, thus reducing the risks of knowledge transfer (Lee and Cavusgil 2006). Lee and Cavusgil (2006, p. 904) also mention relying on inflexible contractual-based governance alone without mutual trust as being risky in conditions of high environmental turbulence. They admit that contracts provide the security of transaction terms being enforceable but simultaneously lessen flexibility between firms. Resulting from this, firms are likely to choose hierarchical rather than market-based structures as technological uncertainty increases. Poppo and Zenger (2002) mention that an increase in technological change discourages the use of complex contracts. As a consequence of technological and environmental turbulence, co-operation agreements suffer from contractual incompleteness.

Lee and Cavusgil (2006, p. 899) suggest that trust is an important mechanism for persuasion and for encouraging future business relationships and thus partnerships based on trust are more likely to develop into loyal and stable alliances. Their suggestion receives support from several studies (Hart and Moore 1988; Nöldeke and Schmidt 1995). Lambert et al. (2004, p. 22) define partnership as *"a tailored business relationship based on mutual trust, openness, shared risk and shared rewards that results in business performance greater than would be achieved by the two firms working together in the absence of a partnership."* Lee and Cavusgil (2006) also suggest that firms who are able to maintain efficient interfirm partnerships are also the ones most likely to achieve sustainable competitive advantage in the markets. Figure 5-5 presents a simple way to reach a contractual partnering solution between the paper company and the technology supplier according to the previous definition of partnership in which core competencies are dispersed in a natural way.

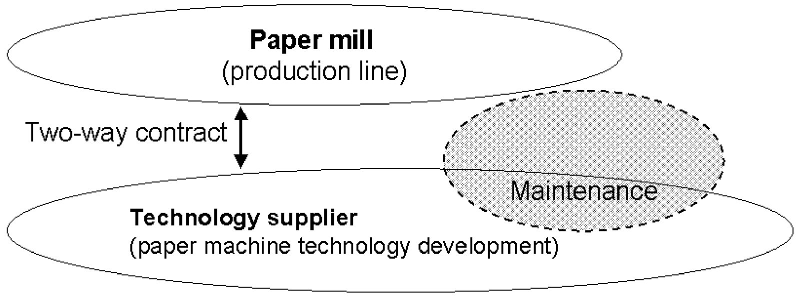

Figure 5-5. Contractual partnership between paper company and technology supplier. The technology supplier does not necessarily need to own maintenance organisation, but needs to have control over maintenance activities unlike in the case of competitive bidding and co-operation strategies.

Firstly, the contract depicted in Figure 5-5 differs from the competitive bidding and co-operation contracting strategies. In these two strategies the technology supplier has no *ex ante* defined contingencies for the paper company's *ex post* financial outcomes. Secondly, it defines the contract *completely* between the firms and thus reduces the risk of misunderstanding. Thirdly, as Herbig and O'Hara (1994, p. 42) conclude, component manufacturers are expected to benefit from committing themselves with the technology suppliers instead of competing against them by selling their products directly to paper companies. Making this situation stable and efficient requires, of course, finding an appropriate partnership model (Papalia and Bertarelli 1998).

Both firms will most probably continue to act self-interestedly, and hence the partnership contract should *not be complex* but as close to a so-called *standard contract* as possible. In this way the hold up problem (Klein et al. 1978) might easily be avoided. Profit functions of the two firms $\pi_j(\cdot)$ depend on control rights q_1 and q_2 over assets, as earlier on page 67. Partnership strategy assumes the paper company's assets a_1 as well as ownership of control q_1 to include inputs z_1 (production, Sales and General Administration), z_2 (energy), z_3 (raw materials), and z_6 (technology). In another words, the paper company acquires the technology from the technology supplier with an investment equal to that in the earlier two strategies. In contrast, inputs z_4 (consumed parts), z_5 (maintenance) and z_7 (expertise) are the assets a_2 controlled by the technology supplier with ownership of control q_2 for an (practically) *annually fixed price*. Equation (Eq. 5-10) represents the paper company's viewpoint

$$\text{Max}\ \pi_1(a_1,\phi_1(q_1,q_2)) - \beta(a_2,\phi_1(q_1,q_2))^{59}, \qquad \text{(Eq. 5-10)}$$

in which β denotes annual input costs for acquiring *technical availability* of the paper production line.

Why technical availability[60]? The paper company's rationale behind contracting over *technical availability* is that it *is precisely what the paper company needs in order to successfully carry out its production plan.* Additionally, delivering technical availability can quite naturally be assumed to be the technology suppliers' core competence, excluding the daily maintenance activities, as discussed earlier. However, measurement of technical availability requires honest reporting of the production line's daily activities as well as removing production cutbacks, for example, from stressing the technical availability value. Deficiencies of other inputs, instead, can be seen as mutual problems that are part of daily maintenance, and their effects on firms' profits must be dealt with in another way. Probably the easiest way to set a mutual incentive for the firms (and thus to avoid the hold up problem) is to let function $\phi_i(q_1,q_2)$ in equation Eq. 5-10 include a *bonus/ penalty* which depends on the annual profit of the paper company and the technology supplier's ability to maintain the agreed technical availability level. Specific levels of these incentives most probably need to be sought iteratively and through experience.

Partnership strategy contractually guarantees to the technology supplier all input orders that concern consumed parts, maintenance and expertise. Once again, paper machine component manufacturers cannot easily achieve cost-effective manufacturing of machine-specific parts and hence technology acts as a safeguard against sub-contractors and component manufacturers. The new contractual agreement, however, provides the technology supplier with new means to maximise its annual profit over the ten-year life cycle by managing activities in β by outsourcing appropriate entities. The technology supplier *now gains more control* as some assets are moved from a_1 to a_2, as Equation (Eq. 5-11) shows:

$$\text{Max}\ \pi_2(a_2,\phi_2(q_1,q_2)) - \beta(a_1,\phi_2(q_1,q_2))^{61} \qquad \text{(Eq. 5-11)}$$

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[59] β encompasses assets a_2 which are *not controlled* by the paper company.

[60] For a definition, see Equation Eq. 5-1 and the related discussion.

[61] β encompasses assets a_1 which are *not controlled* by the technology supplier.

The partnership contracting model is expected to *decrease the number of transactions* at the technology supplier's side compared with the competitive bidding and co-operation strategies. This is expected to follow from better allocation of resources and increased sharing of knowledge between the firms, whereas the technology supplier can better anticipate and even control situations at the paper production line. These assumptions are reflected in the model parameters as improved and, more importantly, more stable efficiencies of consumed parts e_4, maintenance e_5, technology e_6 and expertise e_7. Prices of these inputs (except technology), instead, are expected to increase because of the technology supplier's increased risk. On the other hand, the *paper company* now looses some bargaining power by committing itself with one supplier, and hence the entry barrier to change this supplier might become too high. Thus, the partnerships also need to be dissolvable (de Frutos and Kittsteiner 2004) so that other firms can possibly replace the original supplier.

The start-up phase of the new production line follows the same pattern as with the earlier strategies, and maintenance development is expected to develop equally although the technology supplier now manages it. After all, the same resources can be assumed to manage the tasks regardless of their employer. The only difference is that now the technology supplier has an incentive to continuously provide technical support to maintenance development, unlike in the previous contracting strategies. Still, is should be remembered that the technology supplier might *not have* the core competence in the *maintenance work* itself but only in the technical issues. Table 5-7 illustrates the development of different competencies during the first ten years of the production line's life cycle in partnership strategy.

Table 5-7. Development of competencies in production line life cycle in partnership strategy.

YEAR	1	2	3	4	5	6	7	8	9	10
Paper price	700	700	700	700	700	700	700	700	700	700
pd	300 000	315 000	315 800	315 800	315 800	315 800	320 000	325 000	325 000	325 000
e1	1	1	1	1	1	1	1	1	1	1
e2	1	1	1	1	1	1	1	1	1	1
e3	1	1	1	1	1	1	1	1	1	1
e4	1	1	0.99	0.98	0.975	0.975	0.99	0.99	0.985	0.98
e5	0.95	0.95	0.97	0.97	0.975	0.98	0.98	0.985	0.98	0.99
e6	1	1	1	0.998	0.997	0.996	1	1	1	1
e7	0.98	0.985	0.99	0.99	0.985	0.985	0.985	0.98	0.985	0.99

Partnership strategy is not expected to be reflected in engineering design productivity-wise, and the technology supplier is most likely to optimise its profitability for a longer time period, unlike in competitive bidding and co-operation strategies. In practice, this can mean longer lasting expensive spare parts (so yes, partnership *does* influence engineering design after all although probably through expertise and better efficacy than increased paper production) and better optimisation of resources in maintenance support and development. Put simply, development of information asymmetries should not be as dramatic as in competitive bidding and co-operation agreement strategies. Table 5-8 shows the development of input costs in the partnership strategy.

Table 5-8. Development of input costs in production line life cycle in partnership strategy.

YEAR	1	2	3	4	5	6	7	8	9	10
w1	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€	-60 M€
w2	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€	-15 M€
w3	-100 M€	-100 M€	-100 M€	-100 M€	-100 M€	-100 M€	-105 M€	-105 M€	-105 M€	-105 M€
w4	-	-	-	-	-	-	-	-	-	-
w5	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€
w6	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-10 M€	-15 M€	-15 M€	-15 M€	-15 M€
w7	-	-	-	-	-	-	-	-	-	-

Table 5-9 characterises the production line's production and profitability values computed with the earlier definitions in the first 10 years in partnership strategy.

Table 5-9. Production line production and profitability values in the first 10 years in partnership strategy.

YEAR	pd^t	$w(y^t_{Model})$	$\mathbf{A}^t_{Model}$	$\mathbf{Y}^t_{Model}$	LCP^t_{Model}
1	300 000	-120 MEUR	0.9310	279 300	0.51 MEUR
2	315 000	-120 MEUR	0.9357	294 761.25	11.332875 MEUR
3	315 800	-120 MEUR	0.9507	300 230.11	15.161079 MEUR
4	315 800	-120 MEUR	0.9392	296 603.09	12.622163 MEUR
5	315 800	-120 MEUR	0.9336	294 817.15	11.372006 MEUR
6	315 800	-120 MEUR	0.9374	296 031.81	12.222269 MEUR
7	320 000	-130 MEUR	0.9556	305 807.04	9.064928 MEUR
8	325 000	-130 MEUR	0.9556	310 585.27	12.409692 MEUR
9	325 000	-130 MEUR	0.9508	309 016.66	11.311664 MEUR
10	325 000	-130 MEUR	0.9605	312 161.85	13.513295 MEUR

Direct production costs, produced tonnes and profits over the ten-year life cycle in partnering strategy (from Table 5-9) are 1240 MEUR, 2 999 314.23 tonnes and 109.519971 MEUR. Partnering strategy outcomes are depicted in Figure 5-6.

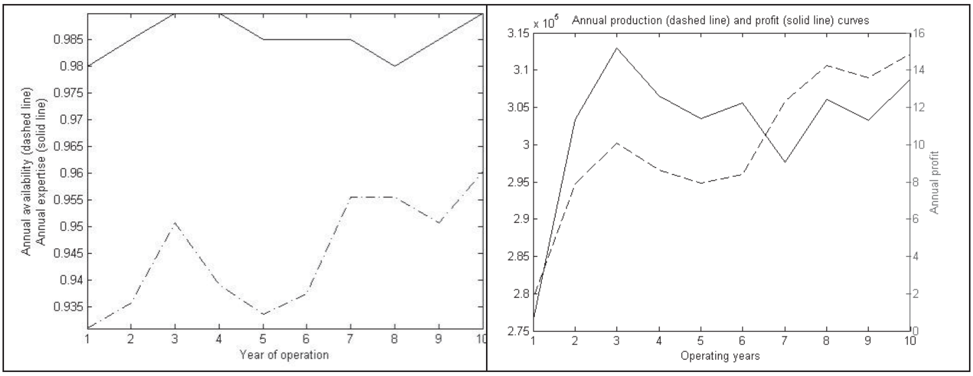

Figure 5-6. Development of expertise and availability (left figure) and annual productivity and profitability (right figure) in paper production line life cycle in partnership strategy.

The expertise level is very high in this strategy. This is understandable given the assumptions that both firms are expected to participate in the production line's development. Production line technical availability, however, fluctuates more than might be anticipated a priori. Still, the variation has quite low magnitude, thus making it a more or less "noisy" development trend. Production levels also seem to develop quite efficiently with some minor setbacks, which supports development of profits. Unlike in the two earlier strategies, intellectual assets are now appreciated, too and hence *partnering strategy focuses on achieving availability with anticipated costs*. Most importantly, the technology supplier now has an option to alter some of the assets to achieve scale advantages in its production activities. Overall, the model parameters used do not fluctuate as much as in the other strategies. However, partnering strategy also increases the risk of the supplier.

5.4. Summary – Can the Modelling Framework be Utilised in Practice?

This chapter discussed the usefulness of the developed modelling framework in supporting the strategic decision-making process of choosing the most profitable contracting strategy for the paper-making process in a ten-year life cycle. In addition, the validity of the assumptions used in comparing the contracting strategies is evaluated next in terms of plausibility as well as validation parameters.

Assumably, paper companies wish to utilise their Installed Base according to their annually budgeted production plan. Production plans depend, first and foremost, on the paper grade and production technology which are characterised in the input parameter "technology". This technological productivity can be compromised by poor production line availability resulting from inadequacies in different production process inputs. Hence, availability should be seen as an equally important factor to the paper company as technology. Annual availabilities achieved in the different strategies with the assumptions and calculations of chapters 5.1, 5.2 and 5.3 are depicted in Figure 5-7.

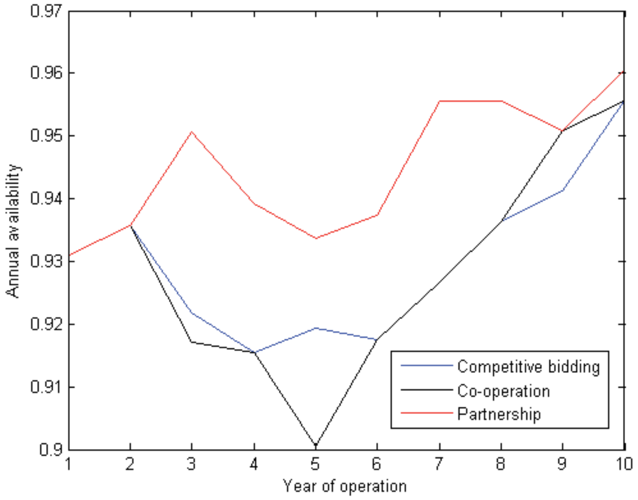

Figure 5-7. Development of availability within the ten-year life cycle in different contracting strategies.

As Figure 5-7 shows, all strategies seem to fluctuate with the test data over the production line's life cycle. The difference between competitive bidding and co-operation is not very significant, and the difference between the average availabilities of these two strategies is quite small. In contrast, partnership strategy provides annually at least as good availability as the other two strategies and its average availability is also much better than that of the other two. The average efficiency levels of input parameters as well as computed availabilities of the compared contracting strategies over the ten-year life cycle are shown in Table 5-10.

Table 5-10. Average efficiency levels and availabilities in different contracting strategies.

STRATEGY	AVG(e_4)	AVG(e_5)	AVG(e_6)	AVG(e_7)	AVG(A^t_{Model})
Competitive bidding	0.9840	0.9710	0.9990	0.9745	0.9301
Co-operation	0.9830	0.9705	0.9990	0.9745	0.9287
Partnership	0.9865	0.9730	0.9991	0.9855	0.9450

The computed differences in availability between the different strategies mainly result from differences in the input parameter efficiency values e_4 (consumed parts), e_5 (maintenance) and e_7 (expertise). For example, better values of e_7 characterise the firms' willingness to continuously give *their* share of the information that is expected to improve *both* firms' profitability. The magnitude of changes in the efficiencies can, however, be argued. Furthermore, the model linearity also emphasises the effect of changes in the input parameter values. Still, all equations and starting values are given in the calculations and are thus available for further discussion and improvements in later research. In fact, this aspect of the modelling framework facilitates observability of efforts and profits due to contracting terms by providing a way to disclose relevant expectations of costs and efficiencies in the contract.

Increasing technological change seems to discourage using complex contracts (Poppo and Zenger 2002). Hence, managers may lose confidence in contracts when risks become particularly severe. In paper production the financial risks are considerable and thus firms wish to withhold the control rights to their core assets. Core competencies are actually spread in quite a natural way in the competitive bidding strategy, but there is redundancy in the firms' organisations. In contrast, co-operation strategy does not really provide any advantage to the technology supplier, because its rivals can also make similar contracts with the paper company. The only firm benefiting from co-operation, in the assumptions considered here, is the paper company, which can bargain for certain input prices even on the corporate-level. Hence, the co-operation does not (contractually) support development of trust or expertise at the production line level. Still, good relationships and trust between the firms do not *need* a contractual solution, as good relationships and trust can equally exist in competitive bidding and co-operation strategy. On the other hand, the involved risks act as an entry barrier to firms wishing to integrate forward; for example, to a technology supplier who wishes to assume control over maintenance. In fact, partnerships are usually considered as entry barriers, but as Eerola and Määttänen (2003) conclude, banning partnerships posts an entry barrier, too. Free entry assumption should hold, as well, when there are at least two firms in the markets capable of competing with similar assets. Figure 5-8 shows the development of direct annual production costs in the different contracting strategies.

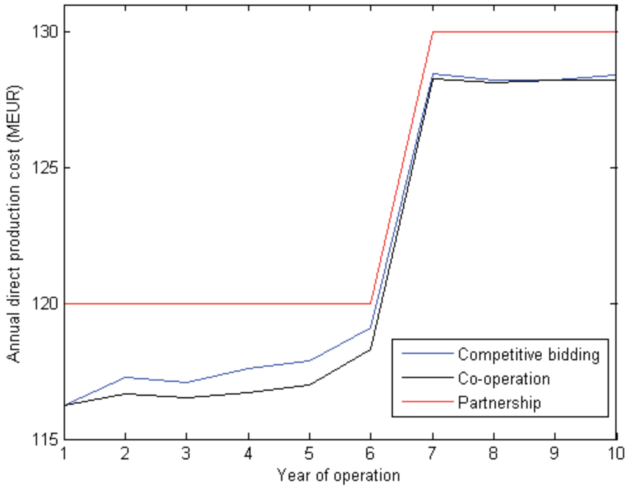

Figure 5-8. Development of direct production costs within the ten-year life cycle in different contracting strategies.

Computed cost development in competitive bidding and co-operation strategies seems to be nearly identical. According to the earlier assumptions, the paper company can lower the production costs moderately compared with the situation in the competitive bidding strategy. It should also be noted that in co-operation and partnership strategies the possibly decreased procurement organisation might also reduce the input cost z_1 (production, Sales and General Administration), which is taken in these calculations as a fixed cost. However, this input value does not affect direct production costs in the model, but only the annual profit. Computed annual production costs are presented in Table 5-11.

Table 5-11. Development of direct production costs in different contracting strategies.

YEAR	COMPETITIVE BIDDING	CO-OPERATION	PARTNERSHIP
1	-116.25	-116.25	-120
2	-117.25	-116.65	-120
3	-117.1	-116.5	-120
4	-117.6	-116.7	-120
5	-117.9	-117	-120
6	-119.1	-118.3	-120
7	-128.45	-128.25	-130
8	-128.2	-128.1	-130
9	-128.2	-128.2	-130
10	-128.4	-128.2	-130
Total (MEUR):	-1218.45	-1214.15	-1240

Direct production costs are clearly higher in the partnership strategy, because the risk level is also considerably higher for the technology supplier. Similarly, the possibilities of the technology supplier are much wider, because *knowledge* is now valuated within the contract *along with* physical assets. While competitive bidding and co-operation strategies only measure *direct costs* of distinct, pre-defined inputs, partnership contracting strategy measures the direct cost of a higher-level input – availability, that is – which is needed to utilise the technology. Contracting in competitive bidding and co-operation strategies compromises the valuation of knowledge, because paper companies seem to select *skilled resources* from suppliers' bids according to their expectation of the suppliers' productivity (Wilson 1980, p. 130). This is a typical example of a *moral hazard* (Mas-Colell et al. 1995, pp. 477-506). Unlike in the other two strategies, partnership enables an innovation process on the technology suppliers' side, namely streamlining of the *delivery of availability* by having control over intellectual and physical assets. This appreciation of knowledge-intensive services has been increasing in service business (Toivonen 2004, pp. 86-88).

One of the core assumptions made earlier was that all produced paper is definitely sold to customers at the given price. In reality, markets tend to fluctuate, thus posing requirements to reduce production. These market fluctuations also influence paper sales price and make the profitability calculations more complex. Figure 5-9 illustrates annual productivity development in the different contracting strategies with the test data.

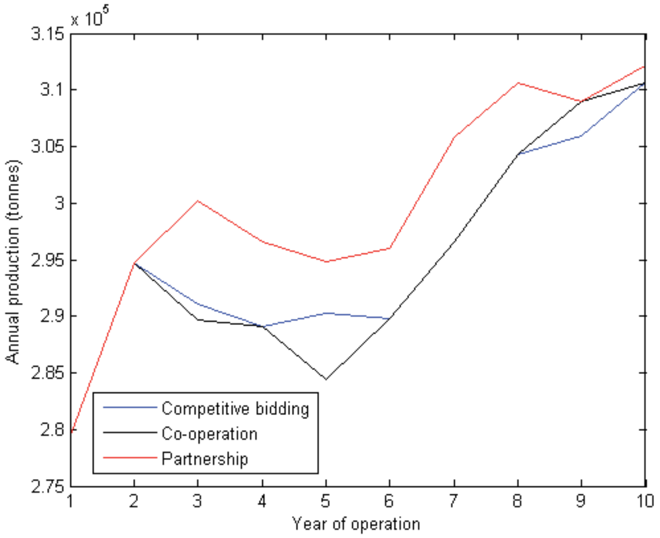

Figure 5-9. Development of produced tonnes within the ten-year life cycle in different contracting strategies.

Clearly, partnership strategy yields the highest tonnes over the ten-year period. Direct production costs, produced tonnes and profits over the ten-year life cycle in partnering strategy (from Table 5-9) are 1240 MEUR, 2 999 314.23 tonnes and 109.519971 MEUR. The respective figures for co-operation strategy are 1214.15 MEUR, 2 947 462 tonnes and 99.073375 MEUR. Hence, the production cost difference is 25.85 MEUR in favour of co-operation strategy for the ten-year period. Annual test data productivity figures are presented in Table 5-12.

Table 5-12. Development of annual production in different contracting strategies using the test data.

YEAR	COMPETITIVE BIDDING	CO-OPERATION	PARTNERSHIP
1	279 300	279 300	279 300
2	294 761.25	294 761.25	294 761.25
3	291 132.23	289 631.55	300 230.11
4	289 113.11	289 113.11	296 603.09
5	290 319.92	284 395.02	294 817.15
6	289 745.15	289 745.16	296 031.81
7	296 587.20	296 587.20	305 807.04
8	304 326.75	304 326.75	310 585.27
9	305 887.40	309 016.66	309 016.66
10	310 585.28	310 585.28	312 161.85
Total (tonnes):	2 951 758	2 947 462	2 999 314.23

On the other hand, partnering strategy produces 51 852.255 tonnes more sellable paper than co-operation strategy, and yields 109.519971 MEUR ten-year profit for the paper production line. The profitability development of the three strategies is presented in Figure 5-10.

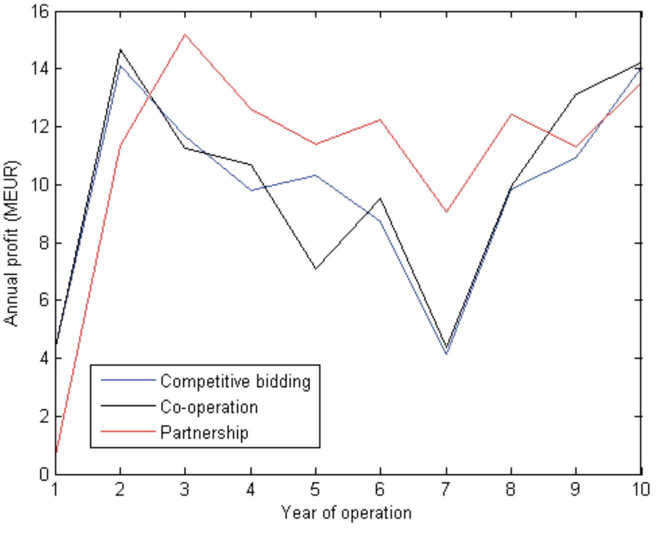

Figure 5-10. Development of profitability within the ten-year life cycle in different contracting strategies.

It can easily be noticed from Figure 5-10 that competitive bidding and co-operation strategies yield higher profits at early states in the production line's life cycle using the test data. However, the average profitability in a partnership strategy is better, due to better allocation of resources and stronger commitment to long-term development. Market development and other inputs (raw materials, for example) create fluctuations in the actual management of daily activities in the real-world and hence set challenges for resource management. Profitability figures are shown in Table 5-13.

Table 5-13. Development of profitability in different contracting strategies using the test data.

YEAR	COMPETITIVE BIDDING	CO-OPERATION	PARTNERSHIP
1	4.26	4.26	0.51
2	14.082875	14.682875	11.332875
3	11.692561	11.242084	15.161079
4	9.779179	10.679179	12.622163
5	10.32394	7.076513	11.372006
6	8.7216036	9.521603	12.222269
7	4.16104	4.36104	9.064928
8	9.828725	9.928725	12.409692
9	10.921179	13.111664	11.311664
10	14.009693	14.209692	13.513295
Total (MEUR):	97.7807956	99.073375	109.519971

In conclusion, the modelling framework seems to provide a normative result by suggesting that partnership strategy yields most profits within the ten-year period, namely 109.519971 MEUR – provided that the used assumptions and chosen parameter values hold. This total profit is better than the profits given by co-operation strategy (99.073375 MEUR) and competitive bidding (97.7807956 MEUR). Of course, if the time interval were shorter, say two years, competitive bidding and co-operation would yield better outcomes with the chosen parameter values. In order to imitate real-world scenarios, some effort might be needed to develop the contracting terms to narrow down the annual costs during the technology supplier's guarantee period below those of competitive bidding and co-operating strategies. Still, it should be once again noted that even the partnership contracting strategy should not increase the technology supplier's guarantees for the technology. Instead, the contract defines the means and monetary boundaries for striving towards the targeted availability level of the production line. The contract incentives should then reflect the success of this attempt.

The validation parameter values of partnership strategy characterise the efficacy of a somewhat simple contracting schema, in which contracting terms provide safeguards for the firms' core assets. As discussed earlier, Williamson (1985, pp. 32-35) points out that a product or a service may be achieved with either a general- or special-purpose technology. Figure 5-11 (as shown earlier in Figure 2-25), in which symbol *k* acts as a measure of transaction-specific assets, shows how the break-even prices *p* of delivering a product or service depend on the type of technology used (*k=0* characterises general-purpose technology, *k>0* characterises use of special-purpose technology). Safeguards that may be used to protect a contracting scheme, such as co-operation and partnerships, are represented with the symbol *s*.

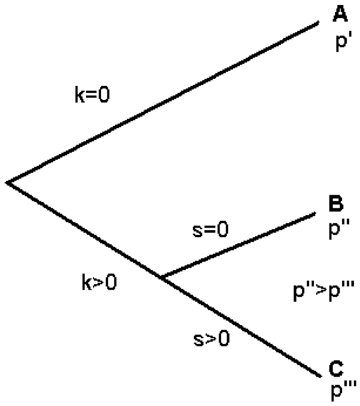

Figure 5-11. Delivery of product or service in alternate contracting strategies (Williamson 1985, p. 33).

The two special-purpose technology branches in Figure 5-11 show that the break-even price can be lower (*p'''<p''*) when a safeguard is used, because the supplier is assumed to have a smaller risk of breaking even. However, in the scenario

studied, the term general-purpose technology cannot be used in its most obvious meaning. Instead, whereas co-operation strategy acts as a cost-based safeguard for the paper company, partnership strategy would provide a safeguard for the technology supplier to manage the technical assets with a wider control over assets. Partnership strategy is expected to decrease transaction costs and thus encourage the technology supplier to integrate forward.

Measurement, modelling and comparing the development of profits in the alternative contracting strategies are very difficult tasks. However, the modelling framework has proven to have potential in solving some of these problems; the validation process of chapter 4.3 suggests that the annual predictions given by the paper production model are very accurate and that the model reacts to changes in input values realistically. Still, choosing the input parameter efficiency values correctly to characterise "reality" is very difficult, and the linear model might react too strongly to some changes in the inputs. Some guidelines to estimate the effects of the input parameter efficiency values on production line availability and profitability can be obtained by applying a similar sensitivity analysis as above in chapter 4.3. For example, by choosing efficiency values of input parameter z_7 (expertise) under study and decreasing annual efficiency values e_7 by 1 % from those in Table 5-7 while holding cost levels and other input parameter values unchanged should indicate the direction and magnitude of changes on production line availability and profitability. Table 5-14 shows the efficiency values for the sensitivity analysis.

Table 5-14. Sensitivity analysis applied on partnership strategy; input efficiency values for parameter e_7 are decreased by 1 % compared to those in Table 5-8.

YEAR	1	2	3	4	5	6	7	8	9	10
Paper price	700	700	700	700	700	700	700	700	700	700
Pd	300 000	315 000	315 800	315 800	315 800	315 800	320 000	325 000	325 000	325 000
e1	1	1	1	1	1	1	1	1	1	1
e2	1	1	1	1	1	1	1	1	1	1
e3	1	1	1	1	1	1	1	1	1	1
e4	1	1	0.99	0.98	0.975	0.975	0.99	0.99	0.985	0.98
e5	0.95	0.95	0.97	0.97	0.975	0.98	0.98	0.985	0.98	0.99
e6	1	1	1	0.998	0.997	0.996	1	1	1	1
e7	0.97	0.975	0.98	0.98	0.975	0.975	0.975	0.97	0.975	0.98

Production and profitability values computed from the sensitivity analysis values are shown in Table 5-15 for a ten-year life cycle.

Table 5-15. Production line production and profitability values computed from the sensitivity analysis values during a ten-year life cycle.

YEAR	pd^t	$W(y^t_{Model})$	$\mathbf{A}^t_{Model}$	$\mathbf{Y}^t_{Model}$	LCP^t_{Model}
1	300 000	-120 MEUR	0.9215	276 450	- 1.485000 MEUR
2	315 000	-120 MEUR	0.9262	291 768.75	9.238125 MEUR
3	315 800	-120 MEUR	0.9411	297 197.49	13.038239 MEUR
4	315 800	-120 MEUR	0.9297	293 607.1	10.524969 MEUR
5	315 800	-120 MEUR	0.9241	291 824.08	9.276858 MEUR
6	315 800	-120 MEUR	0.9279	293 026.41	10.118490 MEUR
7	320 000	-130 MEUR	0.9459	302 702.40	6.891680 MEUR
8	325 000	-130 MEUR	0.9459	307 416.04	10.191226 MEUR
9	325 000	-130 MEUR	0.9412	305 879.44	9.115606 MEUR
10	325 000	-130 MEUR	0.9508	309 008.70	11.306090 MEUR

Compared with the average efficiency levels shown above in Table 5-10, a 1 % change in the annual efficiency values e_7 changes the average efficiency of e_7 and ten-year average availability quite dramatically, as Table 5-16 shows.

Table 5-16. Average efficiency levels and availabilities in different contracting strategies.

STRATEGY	AVG(e_4)	AVG(e_5)	AVG(e_6)	AVG(e_7)	AVG($\mathbf{A}^t_{Model}$)
Competitive bidding	0.9840	0.9710	0.9990	0.9745	0.9301
Co-operation	0.9830	0.9705	0.9990	0.9745	0.9287
Partnership	0.9865	0.9730	0.9991	0.9855	0.9450
Partnership (sensitivity analysis)	0.9865	0.9730	0.9991	0.9755	0.9354

Direct production costs remain at 1240 MEUR, but by using sensitivity analysis efficiency values (from Table 5-15) partnering strategy yields a total of 2 968 880.41 tonnes of paper and 88.2163 MEUR profits over the ten-year life cycle, respectively. This means that the rather small change in the input value efficiencies results in a 21 MEUR loss of profit over a ten-year life cycle when compared with the original partnership strategy results shown above in Table 5-13. The above sensitivity analysis results hence points out the central weak point of the model; it is very difficult for the decision-maker to distinguish a 1 % difference in the efficiency of crew expertise in the real process, while this small change influences expected life cycle profits in a dramatic way.

Even though the above trial scenarios suggest that the *modelling framework* is useful in practice, its validation process is not as sufficient as for the paper production *model* in chapter 4.3. The above trial strategies also left one important real-world scenario untreated; the developed model cannot be used for analysing a situation where a paper company would like to have more than one supplier for any of the defined model inputs. Still, the *modelling framework* helps decision-makers to modify the model so that the number of inputs meets the purpose of analysis. Distinguishing transaction costs from the data is also very difficult and hence no specific analyses of transaction costs have been presented in this thesis.

Measurement of transaction costs could possibly be developed from the basis of empirical evidence. For example, Koskinen (2004, p. 56) suggests that merely 10 % of spare parts that are ordered from one paper machine technology supplier have an annual ordering pattern. In this way, direct measurements from these transactions could be developed, and empirical data for analysing the effects of transaction costs might become available in the future.

6. Discussion and Recommendations

In matters of science, a thousand proclamations by so-called experts are outweighed by the humble reasoning of a single individual.

- *Galileo Galilei*

Galileo Galilei's statement above brings out the essential simplicity of the research problem in this thesis. Increasing competition in the maturing paper industry has emphasised the importance to reduce costs as well as search for new business opportunities (Kuusisto et al. 2005; Komonen 2006). The area of opportunities in the paper industry appears to lie in innovations (paper companies' side – higher contribution margins) as well as in standardised assets (technology suppliers' side – higher volumes). Furthermore, perhaps firms could share activities in a network of well-selected partners (Rotemberg and Saloner 1995; Saloner and Shepard 1995; Rotemberg and Saloner 1995, p. 1331) and thus improve their individual core competencies instead of making only bilateral contracts. Herbig and O'Hara (1994) encourage technology suppliers to focus on specific technological aspects and utilise multi-discipline service firms for maintenance activities. Technology suppliers could then provide these service firms with the technological inputs needed to manage daily activities efficiently at the production line. Such a setting would actually split up the different firms' core competencies in a natural way.

The problem of comparing the profitability of paper production management in alternative contracting strategies originated from the advent of such new business opportunities for paper machine technology suppliers. Looking at the problem from the technology suppliers' side, the challenge is to measure and valuate their intellectual assets in delivering Installed Base management services appropriately. On the other hand, paper companies are facing the same challenge as prospective buyers of these services. In addition, paper companies also need to re-evaluate their use of resources at a more strategic-level to find new business opportunities. Existing analysis tools and methodologies seemed difficult to use because of heterogeneous input parameters, and development of a new modelling framework was called for.

A new modelling framework was developed in this work from a pragmatic viewpoint for analysing contracting strategies in the paper industry, but the developed model can easily be used in other fields, too. The modelling framework's theoretical harmony with earlier research, such as microeconomic theory of production, remained at a quite general level. Central concepts and mathematical modelling methodologies were briefly reviewed, but resulting from the overall unclear understanding of the research problem, applying these theories to specific sub-problems was not possible at this point. Modelling frameworks discussed above merely highlight the sub-problems in several of the disciplines related to paper production. The economic viewpoint addressed in firms' financial statements is just *one* viewpoint despite its central role in today's business world. However, organisation of production and maintenance at the production line as well as the efficacy of other production function inputs dictate the economic outcomes – be they good or bad.

The modelling framework developed in chapter 4 provides a model for numerically presenting annual paper production line efficiencies and costs at the production line level. Hence, the target of the research – *development of a mathematical modelling framework for analysing alternative contracting strategies to support managerial decision-making* - was achieved. The model itself does not comprise anything new, *per se*, but the case-specific parameter selection and way to model the real-world problem constitute a new way to evaluate financial and physical dependencies between different production inputs and outputs. Figure 6-1 illustrates the developed model's significance as a tool in managerial decision-making.

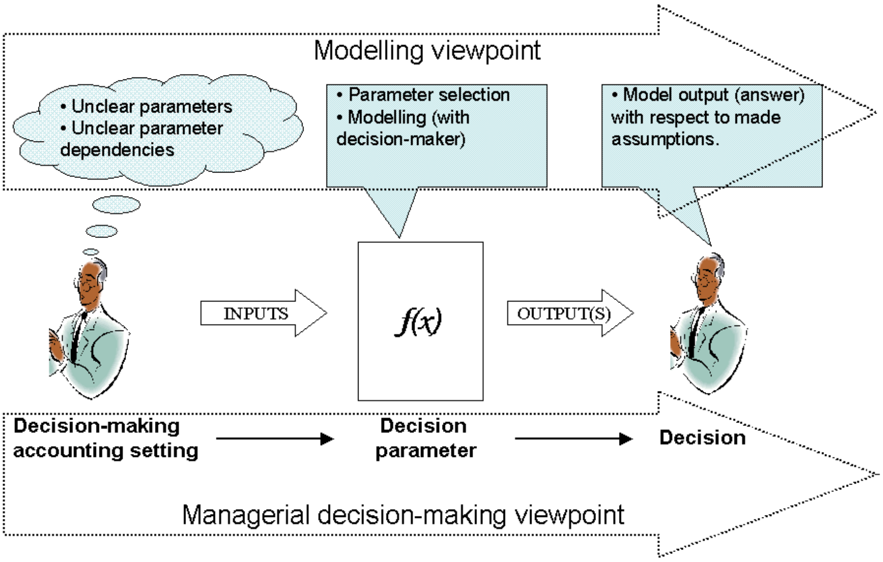

Figure 6-1. Significance of developed modelling framework in managerial decision-making.

Figure 6-1 shows how the two different viewpoints – managerial and modelling – are dependent on each other; the managerial viewpoint places the decision-maker facing a decision-making accounting setting, possibly comprising diverse parameters and ambitions. The decision-maker then needs to define the decision parameter, i.e. define the decision criteria for choosing between alternative choices.

Managers quite often choose renowned monetary decision criteria, and firms' financial statements are good examples of *models* that measure the economic superiority of different decisions. The problem with purely economic models is that they tend to ignore underlying assumptions and (in)direct effects of *other inputs*. The developed modelling methodology allows the decision-maker (possibly with the help of other resources) to develop a tailor-made model for the decision problem, which considers all parameters that are considered relevant.

Furthermore, examining the validity of made assumptions is relatively easy, because numerical representation enables easy trials to be made with real-world data. Practitioners' arguments can also be *focused* on specific efficiencies or cost levels.

The model is quite easily comprehensible as it encompasses only linear forward connections between computable parameters. The accuracy of the model outcomes could possibly be improved, but this would make the model more abstract and complex as well as more difficult to understand for practitioners. Clearly, paper production process and its management are much more complex processes with much more nuances than covered by the developed model, but empirical validation of the model in chapter 4.3 suggests that it works quite well with error margins of 1…2 % of the real-world values. In the light of validation results, the developed modelling framework could very well be used in analysing contracting strategy profitability in a general sense, too. However, the model parameters and their dependencies must be developed in accordance with the specific decision-making requirements currently at hand.

It is important to note that the input parameter efficiencies are practically *beliefs* of the practitioners, despite the fact that their values coincide with their counterparts in the physical world. For example, the production line "availability" in the model is computed from the beliefs concerning appropriate input parameter values instead of paper industry standards. The resulting value, however, coincides with the actual values of the paper industry standard. This modelling schema improves the usefulness of the model in practical applications. The input parameter efficiencies might, however, be too fine-scaled for practitioners to choose meaningful parameter values to represent different decision-making situations. This viewpoint is quite an important one and should be assessed in coming research. An example scenario of using the developed model to compare three different contracting strategies in the paper industry was presented in chapter 5.

There are plenty of fruitful directions for future research - development of the introduced model, gathering more empirical data and unifying central microeconomic theories with the modelling framework. However, *developing the introduced model forwards and unifying central microeconomic theories with it* remain as the main direction of future research. In addition, even though the model validity was empirically tested with paper companies' data, the validation process should be developed further. For example, testing the current model with real production data from paper production lines in the growing market areas with different cost structures, input efficiencies and availabilities might provide interesting results. The imagined, real-like analysis scenario of chapter 5 should hence be bravely elicited in *actual* decision-making situations with real data and also test the usefulness of the modelling framework in other fields of application. Perhaps the most interesting outcome of the thesis is the modelling framework's possible real-world applications, which in turn could provide directions for future development. The results of this work also coincide with earlier research and could very well improve the profit-making capability of production assets. In paper industry terms, this means better utilisation of the production technology and more sellable paper tonnes, as concluded by Mardon et al (1991).

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Appendix

Developed Matlab© functions for in the thesis to implement mathematical model of Figure 4-3.

```
function [availability, price_of_availability, produced_paper_tonnes,
direct_production_costs, paper_quality, net_sales,
Annual_Life_Cycle_Profit] = vaikkari_main_new(input_efficiencies,
input_prices);

% Doctoral thesis algorithm, a mapping between paper-making process
inputs and outputs.
% (C) Juha-Pekka Koskinen, Tampere University of Technology
% 02.10.2006

% INPUTS (9 inputs, each input parameter has the following
attributes; efficiency (when applicable), price (>0 if brings money
to system, <0 if a cost), and weight, e.g., significance of input to
process)
% input_efficiencies - vector of input parameter efficiency values
% input_prices       - vector of input parameter price values
% INPUT parameters (in this order!) are:
%   - paper_price       - market price of specific paper grade,
annual average (price_paper, w_paper)
%   - production_plan   - desired annual (theoretical) production
capacity of the production line for a certain paper grade (scalar/
tonnes)
%   - SGA               - annual overhead production line costs
(price_SGA, w_SGA)
%   - energy            - annual energy price (price_energy,
w_energy)
%   - raw_materials     - annual raw_materials quality and price
(eff_raw_materials, price_raw_materials, w_raw_materials)
%   - parts             - annually consumed spare parts mounted to
machines and their quality (eff_parts, price_parts, w_parts)
%   - maintenance       - annual maintenance goodness and price
(eff_maintenance, price_maintenance, w_maintenance)
%   - technology        - annual technology efficiency and respective
price, e.g., technology annual life cycle cost (eff_technology,
price_technology, w_technology)
%   - expertise         - personnel expertise annually
(eff_expertise, price_expertise, w_expertise)

% OBSERVABLES_1 1st layer (internal system parameter having the
following attributes; efficiency, price, and weighting coefficient)
%   - availability
%   - price_of_availability

% OBSERVABLES_2 2nd layer (internal system parameter having the
following attributes; tonnes, price, quality, and weighting
coefficient)
%   - produced_paper_tonnes
%   - direct_production_costs
%   - paper_quality

% OBSERVABLES_3 3rd layer (internal system parameter having the
following attributes; efficiency, price, and weighting coefficient)
```

```
%   - net_sales     - how much money (euros) can be earned with
certain amount of paper tonnes produced of certain quality in
response to the given inputs (price_net_sales, w_net_sales)

% OUTPUTS (scalar)
% Life_Cycle_Profit           - life cycle profit (respective to
input)
%-------------------------------------------------------------------
------

% Make sure inputs are column vectors and display them as rows
input_efficiencies = input_efficiencies(:);
input_prices = input_prices(:);

disp('INPUTS: Paper sales price | Production plan (tonnes/ year)| SGA
| Energy | Raw materials | Consumed parts | Maintenance | Technology
| Expertise')
Input_parameter_efficiencies = input_efficiencies.'
Input_parameter_prices = input_prices.'


% OBSERVABLES_1 1st layer computing
 availability = 0; % initial values
 price_of_availability = 0; % initial values

    % Compute parameter values
    % Efficiencies (no weighting!)
    availability = prod([input_efficiencies(6) input_efficiencies(7)
input_efficiencies(8) input_efficiencies(9)]);

    % Prices (+ for incoming money, - for costs, no weighting used!)
    price_of_availability = sum([input_prices(6) input_prices(7)
input_prices(8) input_prices(9)]);

% OBSERVABLES_2 2nd layer computing
 produced_paper_tonnes = 0;
 direct_production_costs = 0;
 paper_quality = 0;

    % Compute parameter values
    % Efficiencies (no weighting!)
    produced_paper_tonnes = prod([input_efficiencies(2)
input_efficiencies(5) availability]); % paper production/ tonnes

    % Prices (+ for incoming money, - for costs, no weighting used!)
    direct_production_costs = sum([input_prices(2) input_prices(5)
price_of_availability]); % price of paper production/ tonne exc.
energy

    % Quality
    paper_quality = prod([availability]); % quality factor of paper


% OBSERVABLES_3 3rd layer computing
net_sales = 0;

    % Compute parameter values
```

```
    net_sales = prod([input_prices(1) produced_paper_tonnes]); % net
sales income/ euros


% OUTPUTS (scalar)
 Annual_Life_Cycle_Profit = 0; % initial value

    % Compute parameter values
    % Efficiencies (no weighting!)
    Annual_Life_Cycle_Profit = sum([net_sales input_prices(3)
input_prices(4) direct_production_costs]);

return
```