Evaluation and Management of Manufacturing Flexibility

Nilsson, Carl-Henric

1992

Document Version:
Publisher's PDF, also known as Version of record

EVALUATION AND MANAGEMENT

OF

MANUFACTURING FLEXIBILITY

Carl-Henric Nilsson

and

Håkan Nordahl

DEPARTMENT OF INDUSTRIAL MANAGEMENT
LUND INSTITUTE OF TECHNOLOGY
LUND, SWEDEN
1992

EVALUATION AND MANAGEMENT
OF
MANUFACTURING FLEXIBILITY

Published by:

Department of Industrial Management
Lund Institute of Technology
Box 118

S-221 00 LUND, Sweden

ISSN 0280-722X
ISRN LUTMDN/TMIO--2005--SE

ISBN 91-630-1013-5

Printed in Sweden
KF-Sigma
Lund 1992

DISSERTATION

This dissertation includes an extended summary, abstracts of five articles and the five articles appended in full. It is a dissertation for the academic level "licentiate degree", which is an academic degree in Sweden between the master and doctoral degree.

Article I

Nordahl, H., Nilsson, C-H. and Martins, G. (1988) Beurteilen der Investitionen von Industrierobotern, Werkstatt und Betrieb, Vol 121, No 12, pp 963-965.

Article II

Persson I., Nilsson, C-H. and Nordahl, H. (1991) Evaluation of Flexible Capital Investments - With Consequences for Decisions and Suppliers, in Pridham, M. and O'Brien, C. (eds.), Production Research: Approaching the 21st Century, Taylor and Francis Ltd., London, pp 371-378.

Article III

Nilsson, C-H., Nordahl, H. and Persson, I. (1992) Analysis and Evaluation of Flexible Capital Investments, accepted for publication in Parsaei, H. R. and Mital, A. (eds.), Economics of Advanced Manufacturing Systems, Chapman and Hall, pp 239-254.

Article IV

Nordahl, H. and Nilsson, C-H. (1992) Managers' Perception of Flexibility in Manufacturing - A Study in the Swedish Engineering Industry, Department of Industrial Management, Lund Institute of Technology.

Article V

Nilsson, C-H. and Nordahl, H. (1992) Making Manufacturing Flexibility Operational - A Framework, Department of Industrial Management, Lund Institute of Technology.

PREFACE

This work has been conducted at the Department of Industrial Management, Lund Institute of Technology, under the supervision of Dr. Ingvar Persson. We would like to express our sincere gratitude to him and to his never-ending support during this work.

We would not have been able to finish this dissertation without the support of a number of generous persons. We would like to express our gratitude to the staff at the Departments of Industrial Management and Working Environment. You all deserve our appreciation and we would like to especially mention the following individuals.

Dr. Hans Landström, for stimulating discussions and his ability to give constructive criticism on our work, especially during the early stages of our research. Peter Bengtsson, Department of Working Environment, for his support during the endless nights in the last months before the dissertation. We managed to finish in time, in spite of your comments.

Our secretary, Eva Lange, for solving all the practical problems.

Finally, we would like to express our gratitude to our families. The patience and support from Gunilla and Jenny have been a prerequisite for bringing the work on the dissertation to an end.

Lund, April 1992

Carl-Henric Nilsson *Håkan Nordahl*

ABSTRACT

The dissertation focuses on manufacturing flexibility. It is based on five articles, reporting findings in three areas:

- Capital budgeting of flexible machine investments.
- Managers' perception of flexibility in manufacturing.
- Management of manufacturing flexibility.

Capital-back (CB), a capital budgeting method that weighs the flexibility and the profitability of an investment in order to form one single measurement, is presented. CB is a method for evaluating flexibility of machinery. It takes into consideration the different investment proposals' abilities to meet radical changes for instance, if the market of the product produced by the machinery suddenly drops. Flexibility in this case means having the possibility of reusing the machinery for other purposes than originally intended, either inside the company or in some other manufacturing process outside the company. An investment could therefore be divided into one flexible part (e.g. industrial robots) and one inflexible part (e.g. gripping appliances and fixtures). The flexible share consists of equipment that can be reused in an other installation. The CB method is analyzed for different variables and situations. If (G_r) is the risky (inflexible) part of the investment, (G_f) is the flexible part of the investment, (a) is the annual net receipt, (n) is the life-span and (i) is the discount rate, the CB-period is calculated as:

$$CB = \frac{G_r}{a - G_f * annuity(n\ years, i\ \%)}$$

Managers' perception of flexibility in manufacturing was investigated in a research case study conducted at six Swedish companies within the engineering industry. The goal of the study was to establish which factors managers perceived as important for manufacturing flexibility and to investigate if differences in perception between companies and departments existed. The

most often mentioned resource characteristics for achieving flexibility in manufacturing were set-up times, multiple skilled labour and multi-product machines. The managers' view of flexibility was found to be partial and they were concerned mainly with short-term response flexibility. Differences in how managers of different departments (finance, marketing, production and product development) perceived flexibility were found.

The concept of flexibility is structured by making distinctions between three generic dimensions:

- utilized flexibility vs. potential flexibility
- external flexibility vs. internal flexibility
- requested flexibility vs. replied flexibility

A flexibility framework is developed showing how to obtain consistency from the manufacturing strategy to the resource characteristics in the production system. The framework connects the market demand for flexibility, the characteristics of the production system and the flexibility of the suppliers. Furthermore, the connection is pursued from the strategic level to single resource characteristics in the production system. The framework is described and made operational using an example.

Keywords: Flexibility, Capital Budgeting, Capital-back, Investment Appraisal, Management, Framework, Manufacturing Strategy, Manufacturing, Production.

CONTENTS

1. INTRODUCTION

Flexibility is a concept that has shown to be of importance for the performance of companies (Swamidass and Newell, 1987). The dynamics of the companies' environment is increasing. Product life-cycles are becoming shorter and new products are superseding each other at an increasingly rapid pace
(Noori, 1990, p 76).

Many companies have failed to recognise that the seller's market of the 1950's and 1960's is long gone. The prime prerequisites of these production systems were to produce large amounts of identical products at a fast pace and at low cost (Abernathy, 1978). These prerequisites for production favoured certain types of production systems and thus certain types of machinery.

As it is well known, the preferences of the market have gradually changed toward customised products (Noori, p 4). What is needed are new strategies directed at gaining and maintaining "some specific and significant advantages against the most, not least powerful of their competitors." (Hill, 1985, p 6). Production systems, with the ability to produce a wide variety of products and yet remain efficient, are gradually becoming economically feasible; "the industrial change is now mainly technology driven." (Ranta et al, 1992).

This has had two important implications: 1. New types of production systems and machinery are being installed. 2. Managers of the new production systems must learn new principles of management in order to take full advantage of the new technology.

Since the importance of issues concerning flexibility is increasing in manufacturing, these issues are also coming into the focus of the resource allocation process. Capital budgeting is an important means of allocating resources within the company. However, none of the standard methods take

flexibility into consideration[1]. There is a need for methods that take manufacturing flexibility into consideration in the capital budgeting process.

The word flexible has been recognised by marketeers of new production systems as a good sales attribute. The apparent simplicity of the word has incorporated flexibility into the loose everyday language of manufacturing businesses, "to that extent that everything carrying the label flexible must be good." (Chambers, 1990). There is a need for analysing the concept of flexibility and for developing methods for managing flexibility in companies.

[1] Weingartner, 1969, argues that the pay-back period can be considered partly as a measure of flexibility.

1.1 The Research Process

During industrial visits, we discovered that when industry representatives were asked in what way flexibility was beneficial and how this was measured, they could not give a satisfying answer.

Our master thesis, performed at ABB (ASEA Brown Boveri) in Västerås, was directed at investigating intangible benefits of investments in industrial robots. An embryo to a capital budgeting method for evaluating flexibility in manufacturing was developed: the capital-back method.

Our research continued with a deeper probe into a quantitative analysis of the measurement of manufacturing flexibility. The first research question was:

> *(1) How can the benefits of flexibility be measured in a quantitative way?*

The capital-back method was further developed by the authors with the active help of the tutor, Ingvar Persson (Persson, 1988). Capital-back is a capital budgeting technique that weighs the flexibility and the profitability of an investment in order to form one single measurement. The method is compared to the standard methods of capital budgeting. This research is described in the appended Articles I, II and III.

The start of the research was concentrated on flexibility of separate machines. However, during numerous interviews with managers in industrial enterprises, we came to the conclusion that flexibility could mean different things for different managers. The mission of a manager is to evaluate the situation and take action in order to bring the business forward in a successful way. What action will be taken is dependent on how the manager perceives the situation. If the perception of the situation is incomplete then there is a risk that the wrong action will be taken. In order to examine how flexibility is managed in practice, one needs to examine how different managers perceive flexibility. The second research question was therefore:

(2) How is flexibility in manufacturing perceived by managers?

An empirical study was performed and the research is described in Article IV.

In order to be able to handle flexibility, one must be aware of what flexibility is and what it can do. Is flexibility the ability to meet the uncertainties of the market, the possibility to produce different products in one machine or both? Flexibility can appear at different levels and can, at each level, be achieved in different ways. To be able to communicate, it is important that a shared understanding of flexibility exists. Otherwise, there is a risk that the discussion never goes further than to an argument on defining what flexibility is. At worst, no action at all is taken.

Working with flexibility requires decisions at many levels, e.g. when defining order winning and qualifying criteria (Hill, 1985) and when doing capital budgeting. In aligning flexibility with the business and creating consistency between different levels, a company needs guidelines for how to make the strategy of the company operational in terms of flexibility. The third research question therefore was:

(3) How can a company manage the process of making manufacturing flexibility operational?

A framework for manufacturing flexibility was developed to show a way of obtaining consistency from the manufacturing strategy to resource characteristics in the production system. This research is described in Article V.

2. FRAME OF REFERENCE

Flexibility is the main topic of the dissertation. Previous research in the field has affected our perception of flexibility and thereby the design of the research. Other research areas that have been important for the conducted research are

capital budgeting and strategy. To some extent, issues relating to human cognition have been important since they affect the use of methods and the actions taken by managers.

First, the concept of flexibility is penetrated. More specific, the issue of manufacturing flexibility is discussed. This is of relevance in all of the five appended articles. The other topics that will be discussed in the frame of reference are discussed mainly in their relationship to manufacturing flexibility.

An important issue in the dissertation is how to evaluate flexibility in capital budgeting. To be able to understand how a capital budgeting method will affect a company, it is of importance to understand how capital budgeting methods are used in a company and why. The issue of capital budgeting is penetrated in Articles I, II and III. The subject is also discussed in Article IV.

Knowledge and learning are of relevance to the dissertation since our study of flexibility is partly performed through studying managers' perception of reality. The way reality is perceived will affect the actions taken in the studied organisations. This subject is primarily discussed in Article IV, but is also relevant for Article V.

Strategy is a concept that is as hard to define as flexibility. Nevertheless, the strategy of a company is of importance to the utilisation of manufacturing flexibility. To be able to align flexibility with the manufacturing mission, the role of manufacturing strategy, as an important basis for flexibility, is discussed. Strategy is mainly discussed in Article V.

2.1 Flexibility

Flexibility can be an important competitive factor. Swamidass and Newell (1987) showed that there is a positive correlation between flexibility and the performance of a company. The literature on flexibility is vast but it can, in general, be divided into three broad groups.

- Definitions and classifications of flexibility.
- Quantitative measures of flexibility.
- Frameworks for flexibility.

Some articles and efforts extend over two or three of these areas. In summary, the literature highlights the fact that flexibility appears at different levels and different perspectives of flexibility can be used.

2.1.1 Definitions and Classifications

What is flexibility? A number of definitions have been suggested. Mandelbaum (1978) defines flexibility as "the ability to respond effectively to changing circumstances". Kumar and Kumar (1987) also take a starting point in the uncertainties. They divide them into uncertainties of the external environment, of input material, of end-products and of the process. These uncertainties are different in nature and require different types of flexibility. Gerwin and Tarondeau (1989) have a similar approach but focus more on the production process.

The domain of flexibility in the literature, is often grouped into classification systems. The examples of different classification systems are numerous (e.g. Andreasson and Ahm, 1984; Gerwin, 1987; Chambers, 1990). The authors focus on different levels and have different scopes in their classification systems.

Flexibility can appear at different levels and "at each level the domain of the flexibility concept may be different and alternative means of achieving flexibility will be available" (Gerwin, 1987, p 38). Slack (1988) uses four levels in a flexibility hierarchy: resources, system flexibilities, production performance and overall company competitiveness. The most interesting level, in our opinion, is the 'system flexibilities', defined in four classes. Each class is defined in terms of range and response. Range is "the ability of the system to adopt different states" and response is "the ability of the system to move between

states" (Slack, 1988, p 26). The eight different types of system flexibilities possible are shown in Table 1.

Table 1. The range and response of the system flexibility classes (Slack 1988, p 26).

Flexibility[2]	Range flexibility	Response flexibility
Product flexibility	The range of products which the company has the design, purchasing and manufacturing capability to produce.	The time necessary to develop or modify the product and processes to the point where regular production can start.
Mix flexibility	The range of products which the company can produce within a given time period.	The time necessary to adjust the mix of products being manufactured.
Volume flexibility	The absolute level of aggregated output which the company can achieve for a given product mix.	The time taken to change the aggregated level of output.
Delivery flexibility	The extent to which delivery dates can be brought forward.	The time taken to reorganize the manufacturing system so as to replan for the new delivery date.

2.1.2 Measurements of Flexibility

Flexibility is often considered as an "intangible". This is, in many cases, e.g. capital budgeting and strategic planning, not satisfying. Life would, in some respects, be easier if a figure could be put on the value of flexibility. There have been many attempts to do so. For example, Option Theory has been suggested as a way of measuring flexibility (Brealey and Myers, 1988).

Kumar and Kumar (1987) have developed a set of flexibility measures on the operational level analogous to the measure of entropy in thermodynamics. Based on a number of axioms, four alternative measures are discussed. Mandelbaum and Brill (1989) define a way of measuring the flexibility of a production system by looking at the individual machine's efficiency and adaptivity. Weingartner (1969) states that the pay-back method is used as a

[2] Slack calls it 'system flexibility types', in Articles IV and V, however, it is defined as 'external flexibilities'.

measurement of an investment's cash flow and is more a time determination than a measure of the profitability. Pay-back can therefore be looked at as a way of managing uncertainties and thus, flexibility.

2.1.3 Frameworks

A number of different frameworks for managing flexibility have been developed. The most interesting ones, in our opinion, are the following:

Gerwin and Tarondeau (1989) have "developed a modified contingency model that places flexibility in a context which also includes environmental uncertainties, company strategy, technological and work organization choices and performance comparisons" (Ibid, p 169). They note that as environmental uncertainties change over time so must the manufacturing strategy. Six critical environmental uncertainties are established along with their corresponding strategic objectives and flexibilities.

Figure 1. The conceptual model (Gerwin and Tarondeau, 1989, p 170).

Kumar and Kumar (1987) have developed "an objective theory of flexibility for manufacturing systems" (Ibid, p 469). An attempt is made to unify the structure of various types of flexibility. The base of the structure is the theory of uncertainty.

Slack (1988) connects four levels of flexibility in a framework. The framework "identifies the series of managerial action planes for flexibility improvement which will best contribute to company competitiveness" (Ibid, p 30). It builds on

the classification system presented in Section 2.1.1. and follows a gap methodology of identifying areas for strategic change. The framework highlights the need for action and in an operative way, shows how to achieve it.

Chambers (1990) presents "a simple analytical framework which can be used to link flexibility types with the stages of manufacturing strategy which is outlined by Hill" (Ibid, p 1). The framework counters the notation that any type of flexibility is desirable by highlighting trade-offs between different types of flexibility. Eight classes of flexibility are presented. Chambers shows how to connect manufacturing strategies to flexibility by outlining a framework that aligns the eight chosen flexibility classes with the elements of Hill's strategy model (Figure 2).

Figure 2. Analysis of flexibility in the context of manufacturing strategy (Chambers, 1990, Table 2).

2.2 Capital Budgeting

Research on Capital Budgeting is done in both Economics and Business Administration. Economists primarily look at investments as a way of achieving balance on an aggregate level. Different macroeconomic models are available, e.g the accelerator model (Begg et al, 1987). The focus of the dissertation is on individual companies, therefore, research in Business Administration is most relevant. There are, in general, two main streams of research being carried out in the field (Yard, 1987).

1. Development of methods and methodologies for investment appraisal.
2. Descriptions and theory development of the capital budgeting process.

The first line of research is focused on the means for helping in the operational work with capital budgeting. The latter is directed at understanding the process of capital budgeting and the behaviour of the individuals involved.

2.2.1 Investment Appraisal

The most important methods for evaluating investments were developed in the period of 1920 to 1960. These methods, e.g. net present value (NPV) and pay-back (PB), are, today, standard methods used in textbooks and in companies. The methods were, for a long time, regarded as very important for capital budgeting, especially when they were developed to be aligned with the budgeting process (Dean, 1951). Later, the models were developed to take, e.g. timing and risk into consideration (Magee, 1964; Wagle, 1968).

A recent progression in Capital Budgeting Techniques (CBT's) is the use of Option Theory. This theory takes into consideration "the option to wait (and learn) before investing" and "the option to make follow-on investments if the immediate investment project succeeds" (Brealey and Myers, 1988, p 495). The development of generalized options have lately been met with interest (Cox and Rubinstein, 1985, pp 371-375). Flexibility can also give pre-options that are difficult to appraise since they are not known (Persson, 1990).

Surveys have shown an increasing adoption of discounted cash-flow techniques in firms (Kim and Farragher, 1981; Hendricks, 1983), although the most advanced methods are seldom used. The assumptions in these surveys seems to be that the use of capital budgeting techniques means that managers trust the results. The pay-back method, which is the most simple method, is among the most frequently used (Yard, 1987, p 134).

All these methods can be useful in helping managers evaluate the estimated cash flow. However, it has been shown that there is a gap between the normative prescriptions of the theory and the methods used in practice (Jönsson, 1974).

2.2.2 The Process School

The process oriented research on capital budgeting began with Cyert and March (1963). They held that the decision process can be analyzed using the variables that effect the goals and expectations of the organization as a starting

point. Furthermore, Aharoni (1966) emphasised the role of managers as dominant actors and creators of strategies. Among the first complete models presented in the area was Bower's (1970). This model is still regarded as important for explaining the resource allocation process. Bower showed that capital budgeting is not done in the way that previous research literature stated. From a theoretical point of view, it can be correct to choose the projects that generate a positive net present value (NPV), but in practice this is only the case for simple investments. According to Bower, capital budgeting should, instead, be looked upon as a process. He thereby criticises the belief that capital budgeting can be reduced to a cash flow evaluation and that top management make decisions between well defined alternatives. Instead, he points out that decisions, in many cases, have already been made when the project reaches top management. Supported by case studies, he designs a conceptual model involving three processes and three phases (Figure 3).

Figure 3. The resource allocation process (Bower, 1970, p 80).

In the definition process, the fundamental economical and technical factors for an investment are determined. The definition process usually starts by a detected discrepancy. High costs, low quality or insufficient capacity can be

initiating factors. The definition process takes place at different organizational levels.

Equally important is the impetus, which is a political process. Every major investment project needs a "general manager at the division president's level, or one level below, to commit himself to sponsor a project ..." (Ibid, p 68) in order for the project to be successful. This is supported by Aharoni (1966) who found it to be essential with commitments in order to gain success for an investment project.

The context is affecting the definition and impetus processes. Determination of context is defined by Bower as a process. He divides the context into a situational and a structural context. The situational context is unique for every capital budgeting process and is therefore difficult to manage. The structural context is partly under the control of management. It consists of e.g. the formal organization, the reward system, the company culture and history. By designing the structural context in a certain way, managers can lead people in a specific direction to act in accordance with the goals of the organization. The processes in the model are described in terms of three phases: initiating, integrating and corporate.

The traditional CBT's are mainly used in the definition and impetus processes of the investments, however with different aims. In the definition process, they are used to describe the economic consequences of different alternatives. In the impetus, the function of the CBT's is to persuade or to motivate. Calculations can thus be made with different aims, which affect the appearance of the calculation.

Another model for the investment process is developed by Persson (1991). He defines initiation as a continuous process that starts new investment projects. This process is primarily focused on action (Brunsson, 1985). A person is faced with a situation. He uses a number of criteria and guidelines, based on experience, in order to evaluate the situation. Depending on the answers given by the criteria and guidelines, a solution area is selected. The solution area selected is dependent on the perspective of the individual. Different persons, confronted with the same situation, can therefore find different solution areas using different criteria and guidelines. If the solution area is acceptable in the company, then the assessment will pursue within the chosen solution area. No formal evaluation techniques are normally used in the initiation process.

What decides the perspective a person places on a situation? The situation is an individual's interpretation of reality. An important factor for the perspective is the experience of the actor. Examples of factors that are part of an individual's experience are:

- Frame of reference.
- Earlier established solutions for similar situations.
- Experiences of what type of behaviour the organization expects.

The last point was stressed by Bower (1970) in what he calls the structural context that guides the behaviour in the capital budgeting process.

A third model is a conceptual cash flow model for management of capital investments over time (Persson, 1990). It states that the dynamics of the

environment of the investments is important. The benefits from an investment are not only dependent on the initiation and project management. More important is how the investment is managed during the life-span. Due to the dynamic nature of the environment, most base investments will have a decreasing annual net receipt over time if no action is taken. This problem must be recognized and, in most cases, complementary investments made in order to maintain a sufficient annual net receipt. The crucial part of an investment is not the appraisal of the investment but managing the investment during the life-span.

2.3 Knowledge and Learning

Our research is directed at developing methods for management of manufacturing flexibility. The methods can change the actions of managers faced with different situations. To be more specific, we can distinguish two possible effects:

- a change of individual manager´s way of thinking.
- a coordination of actions between managers.

The actions taken by an individual are affected by the way he thinks. In order to change actions, the manager´s way of thinking must be changed. Learning can be defined as a changed way of thinking (Björkegren, 1989, p 44), and we consider knowledge as accumulated learning. Knowledge and learning are therefore important issues for understanding how our research can affect reality.

What is knowledge? Rolf (1989) presents a model with the origin, the content and the function of knowledge. The origin of knowledge is how a specific person gains a certain knowledge. The contents of knowledge are e.g. statements, skills and values. The function of knowledge is a person's ability to mobilise his knowledge into action or to collect new knowledge. The conclusion is that an important way of changing the actions taken is to change the knowledge. Knowledge is changed by learning.

The knowledge gained by learning is structured in the mind as frames of knowledge. These are developed through interaction between:

- Assimilation. Experiences are incorporated in existing frames.
- Accommodation. New design or changes of existing frames of knowledge. (Björkegren, 1989, based on Piaget.)

How an individual assimilates and accommodates to events is dependent on his original perspective. This model for learning is similar to Argyris and Schön's

(1978) single-loop and double-loop models. Single-loop learning refers to learning within the existing frames of knowledge. Double-loop learning is changes of the existing frames of knowledge.

The learning of an organization takes place through the learning of the individuals within the organization. Organizational learning is the process by which an organization becomes aware of the connections between past actions, the effectiveness of such actions, and future actions. A cognitive theory for learning and thinking in organizations (Björkegren, 1989) describes the learning process.

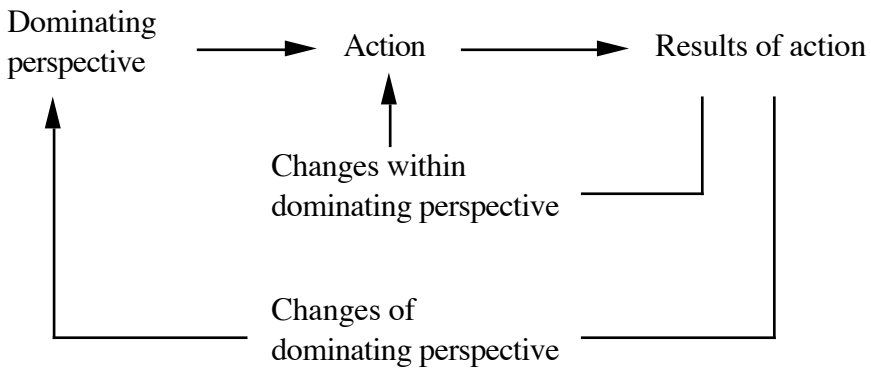

Figure 4. A cognitive theory for learning and thinking in organizations (Björkegren, 1989, p 42).

The dominating perspective is the overall conceptualizations concerning the meaning and functions of the organization which are shared by a majority of the actors in the organisation. It decides what actions are to be taken. The results of the actions are then evaluated. The evaluation can lead to changes within the dominating perspective or changes of the dominating perspective. This will affect future actions.

The methods developed in our research can provide managers with new ideas to consider and learn by, thus adding to their knowledge and providing for a changed way of thinking. This is the basis for individual action which in turn can change the dominating perspective in the organisation and thus change the future actions in the organisation.

2.4 Strategy

Strategy in a company refers to the link between the company's present situation and its objectives (For a deeper discussion on the concepts of strategy and objectives, see Malm, 1975). Strategies exist on different levels in the company and are directed at reaching different objectives. The different objectives must support the same overall objective of the company.

The leading star of a business is its strategic business plan. It outlines the operations of a particular business unit (Thompson and Strickland, 1986). If the company is a single business company, the plan is valid for the company as a whole. In diversified companies, each line of business has to be analysed individually. We will discuss single business companies.

Porter (1980) analyses the strategic aspects of running a company and notes that the external conditions vary between different industries but are equal for companies within an industry. Porter finds that the conditions, however, vary over time. Five forces that affect the company's competitive position are identified. The concept of the value system is brought forth as the basic tool for analyzing the sources of competitive advantage for a business. The value system joins the suppliers with the company and onward to the customers. The suppliers have, in turn, their suppliers and the customers, their customers, thus extending the system of interrelations. Within the company, activities are also related creating the value chain. The value chain is "A systematic way of examining all the activities a firm performs and how they interact..." (Porter, 1985 p 33). One objective of the company is to align the value chain and the value system with each other.

Other researchers, such as Lindberg (1990), have adopted and adjusted Porter's framework. Lindberg introduces the concept of vertical concordance which refers to "the harmonization of volumes, pace and timing of deliveries in the vertical material flow." (Ibid, p 23).

Reaching vertical concordance in the value chain, from the suppliers to the company and onwards to the customers, is of importance. It is also important to reach concordance within the company, between departments, as well as between organisational levels.

2.4.1 Manufacturing Strategy

Manufacturing strategy is a functional strategy which is on the same level as marketing strategy, financial strategy, etc.. Manufacturing strategy refers to "the competitive priorities and key decisions taken in managing a manufacturing system in order to gain comparative advantage"
(Samson, 1991, p 1).

The research area of manufacturing strategy was started approximately 20 years ago by Skinner (1969), in his article "Manufacturing - Missing Link in Corporate Strategy". He pointed out that the strategy of manufacturing is of great importance to the performance of the company and that the manufacturing strategy should support the business strategy.

Concepts such as focused factory (Skinner, 1974) were brought forth. Hill (1989) suggests three ways for focusing a plant:

- by product/market, in which significantly different product families are manufactured separately.
- by process, in which different styles of operations (e.g. job shops and lines) are separated.
- by order-winning criteria, in which products competing on cost and efficiency are separated from, for instance, products competing on delivery reliability.

Hayes and Wheelwright (1984, p 27) suggest concentration of efforts, i. e. focus, as an integral part of strategy. The idea of focus can be applied across many aspects of the firm. These aspects are not orthogonal, but illustrate the "importance of the focus concept as a unifying part of strategy, such that 'strategic focus' in the market place should be linked, for example, to the basis for manufacturing focus..." (Samson, 1991 p 103).

Hayes and Wheelwright (1984, p 33) make three important conclusions:

- A manufacturing strategy is determined by the decisions actually made, not by what the managers say that the manufacturing strategy is.
- The more consistent those decisions are, the more effective the manufacturing strategy is likely to be.
- The main object of manufacturing strategy is to define a set of manufacturing capabilities that will enable the company to pursue the chosen competitive strategy over the long term.

A conceptual model that explains the role of manufacturing strategies in companies has been presented by Hill (1985). He notes that "manufacturing needs to support a product over the whole and not a part of its life cycle and hence it is this total decision which the business needs to address." (Ibid, p 40). The model brings forward an ordered and analytical way to connect the

corporate objectives to the marketing strategy and, via qualifying and order-winning criteria, to the manufacturing strategy.

Hill's model shows, in five steps, the development of strategies in a company. These steps are not sequenced, but are rather an iterating process where the different steps interact with each other (Figure 5).

Figure 5. Framework for reflecting manufacturing policy issues in corporate decisions - steps involved (Hill, 1985 p 41).

"Step 1: Define corporate objectives.
Step 2: Determine marketing strategies to meet these objectives.
Step 3: Assess how different products win orders against competitors.
Step 4: Establish the most appropriate mode to manufacture these sets of products - process choice.
Step 5: Provide the manufacturing infrastructure required to support the production." (Hill, 1985 p 40).

The determinants of whether it will be possible to sell a product or not are divided into two groups:

- Qualifying criteria that must be surpassed in order to stay in the market place. The qualifying criteria are a ticket to taking part in the race for orders.
- Order-winning criteria that will win orders from the competitors.

Examples of typical order-winning criteria are: price, product quality and reliability, delivery speed and delivery reliability. The criteria are specific to each family of similar products. Similar means products that perform in the same way in the marketplace. These criteria are not fixed, but vary over time. The company must therefore continuously probe the market for signals indicating a change in the structure of qualifying and order-winning criteria. The company can, in a proactive way, strive to lead the market to new structures of qualifying and order-winning criteria.

3. SUMMARY AND INTERCONNECTIONS BETWEEN ARTICLES

The research is performed within the realms of manufacturing flexibility. The articles of the dissertation are thus enclosed in the flexibility domain. Sub-topics that were studied with respect to flexibility were capital budgeting, managers' conceptualization and strategy. Articles I - III concern flexibility in manufacturing and the resource allocation process of capital budgeting. Article IV concerns managers' perception of flexibility in manufacturing. Article V concerns the management of manufacturing flexibility and its interconnection to strategy.

The round shapes of the concepts indicate that the areas of research are not strongly defined. The square shapes of the articles indicate that these are defined portions of the research area.

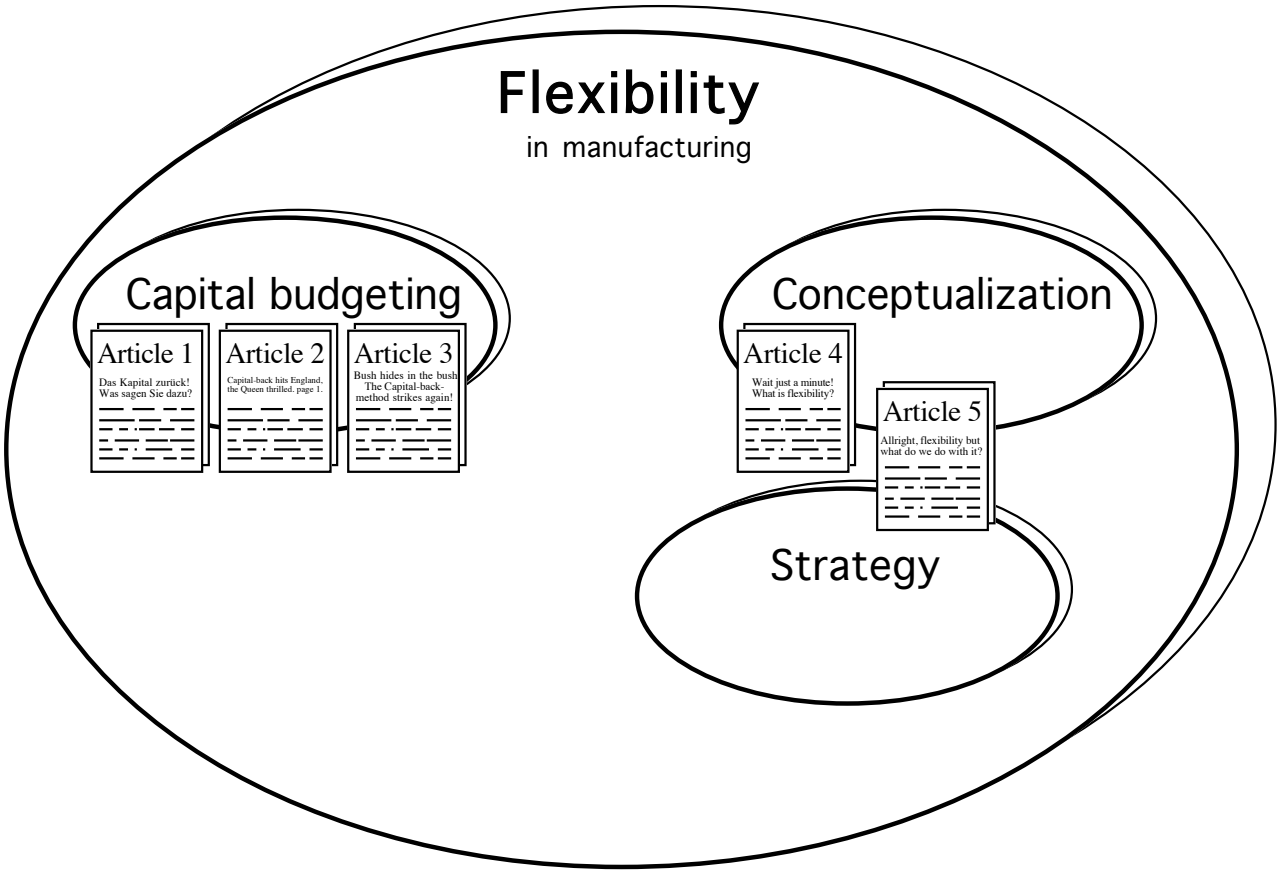

Figure 6. The relationship between the articles and the main areas of research to which they refer.

3.1 Main Contributions

The central contributions of this dissertation are methods for managing flexibility in both a quantitative and a qualitative way, and in the knowledge of how managers perceive the concept of manufacturing flexibility.

Capital-back (CB) is a capital budgeting technique (CBT) that quantifies some of the benefits of flexible production machinery. The method takes into consideration the fact that some parts can be reused in other installations if the original installation becomes obsolete, while other parts can not, and thus have a residual value of zero. This means that different parts of a machinery investment can have different risks for a company and should therefore not be treated as equal.

The contribution to the knowledge of managers' perception of flexibility consists of a number of findings. The findings concern, e.g. the importance of different production resources for flexibility and differences in the perception of flexibility that are related to the companies, and differences that are related to the departments.

A framework for managing flexibility in production, in order to align it with strategic goals and to create consistency between different levels, has been developed. The framework shows how to make flexibility in manufacturing operational. When used, it can create a consensus of what flexibility is in the context of the specific company and how the company should act in order to achieve maximum benefits from its flexibility.

3.2 Articles I-III: The Capital-Back Method

The research started with the observation that flexible machines were treated in the same way as inflexible machines, when it concerns capital budgeting, irrespective of the future options given by flexible machines. Furthermore, managers pointed out that it was hard to motivate investments in, e.g. industrial robots and FMS with the traditional CBT's and current requirements

for profitability. In order to examine if flexible machines, in practice, had been profitable for companies, a project was conducted at ABB (Asea Brown Boveri) in Västerås (Nilsson and Nordahl, 1988). Five installations of industrial robots, made between 1971 and 1981, were studied. The development of the installations, over time, were examined. In the study, we found that the way in which the robots were used had changed over time in each installation. The generality in tasks that could be performed by industrial robots protected them from becoming obsolete even if the environment changed dramatically. In four of the cases, the product produced went through major changes, none of which were conceived at the time of investment. It was, however, still possible to produce the new product in the production cell, due to the generality of the equipment (See Article I for one case description.). Less flexible machinery, such as fixed automation, would, in some of the cases, have become obsolete soon after the installation.

With this as a starting point, we found that an investment could be divided into one flexible and one inflexible part. Examples of flexible parts of an investment are industrial robot, CNC machines and AGV's (auto guided vehicles). Examples of inflexible parts are gripping appliances for the robot, fixtures and the installation costs. With this distinction as an integral part, a method, Capital-back, was developed in order to take flexibility into consideration. The flexible part did not bring any risk to the company and therefore should not be imposed by the normal profitability demands that the company puts on investments. The capital-back period was first defined as:

$$CB = \frac{G - u}{a - d}$$

Where (G) is the total investment, (u) is the reusable (flexible) part of the investment, (a) is the annual net receipt and (d) is the annual depreciation for the flexible part of the investment. The method is further described in Article I. In this form, interest was not considered. The capital-back method was then developed to take interest into consideration (Persson, 1988). From this point on the capital-back period was defined as:

$$CB = \frac{G_r}{a - G_f * annuity(n\ years, i\ \%)}$$

Where (G_r) is the risky (inflexible) part, (G_f) is the flexible part, (a) is the annual net receipt, (n) is the life-span and (i) is the discount rate.

In Article II the CB method, with interest taken into consideration, is examined further. Flexibility is, in this article, stated to have three dimensions: material flow, products and machinery. The scope of flexibility in Article II is machinery. The objective of CB is to release the flexible investments of the unreasonably high demands of a short pay-back (PB) period, which are required due to a high degree of uncertainty and short term planning. In the article a comparison between CB and PB is made. It is shown that capital-back can also be used if the annual net receipts vary over time. The CB condition for the investment is then:

$$G_r = \sum_{x=1}^{CB} (a_x - G_f * annuity(n\ years, i\ \%))$$

Where (a_x) is the annual net receipt year x.

In addition, the consequences for decision making are discussed. The distinction between the flexible and the inflexible part is in itself important since it creates an awareness among managers of some flexibility characteristics of an investment. CB is shown to be an excellent aid in incorporating the strategic importance of flexibility in the capital budgeting process as a part of the structural context. Furthermore, implications of the CB method for financing and for suppliers are examined. Large companies can purchase flexible equipment on a company wide basis and then, internally, lease the equipment to the different plants and subdivisions. An alternative is to lease flexible machines directly from the suppliers. The suppliers have a better knowledge of the market and are best suited to find new users for flexible machinery if the first leaser "ends the contract".[3] The advantages of this procedure are greatest for smaller companies, who lack the possibility of finding new users for flexible machinery within their own company.

Lastly, a deeper analysis is conducted on four factors influencing the CB period: the flexible share of the investment, the level of the discount rate, the life-span of the flexible part of the investment and the profitability of the total investment (measured, for instance with the internal rate of return (IRR) or PB period).

Article III contains a development of the flexibility concept as well as deeper analyses of the CB method itself. Flexibility is, in this article, limited to two perspectives, both with a focus on machinery:

- Product scope (Nilsson and Nordahl, 1988; Molin and Söderlind, 1989), i.e. the width of the variety of products that can be produced in the installation.
- Component flexibility, i.e. the share of the investment that can be reused in another installation.

[3] Compare the leasing of copying machines, where a function is leased.

It is shown how an investment can be divided into sub components (Figure 15.1 in Article III), which is helpful when dividing the total investment into a flexible and an inflexible part. With this as a starting point, component flexibility (f) is defined as:

$$f = \frac{G_f}{G}$$

If component flexibility is used, the CB period can be defined as:

$$CB = \frac{(1 - f)*G}{a - f*G*annuity(n\ years, i\ \%)}$$

The capital-back method is then analyzed along side PB, IRR and NPV. If we assume that the life-span of the flexible part equals the life-span of the risky part, then:

1. The CB period, together with the PB period, indicates whether or not an investment is acceptable and consistent with the IRR and NPV rules.
2. The results we get from CB & PB calculations are meaningful for profitable investments but not for unprofitable ones (however, we do learn that the investment is not profitable which of course is of interest).
3. When the choice among different acceptable investments is considered, the three rules, NPV, IRR and CB & PB, can provide different answers as to which investment is to be chosen.

Neither capital-back nor any other capital budgeting technique provides information as to the degree of uncertainty that prevails regarding the inflexible investment becoming obsolete. Neither will it tell anything about when the investment will become obsolete. This judgement is still left to management. What the CB method can do is to help managers understand investments, especially flexible investments. Therefore, the method is well suited for the future demands of the industry.

3.3 Article IV: Managers' Perception of Flexibility in Manufacturing

After the analysis of the CB method we came to the conclusion that it would be fruitful to take a wider look at the concept of flexibility. Until this point, we mainly looked at flexibility of the machinery in the capital budgeting process. In order to gain deeper knowledge into the nature of flexibility, a broader perspective was used. When examining the literature in the area of flexibility, it was found that numerous perspectives and definitions of flexibility were available. However, little was done on managers' perception of the flexibility concept and on what they want to achieve with flexibility.

A study was designed using case studies of six companies in the Swedish engineering industry. Managers of the finance, marketing, production and product development departments were interviewed and their perceptions of flexibility in manufacturing charted. The study and the results are presented in Article IV.

The objectives of the study were to investigate:

- How managers in Swedish engineering industry perceive flexibility in manufacturing.
  - what the differences are between managers of different departments.
  - what the differences are between managers of different companies.
- Which aspects of flexibility managers perceive as the most important for manufacturing now and in the future.

It was found that managers had a rather low complexity in their perception of flexibility. Most managers only mentioned one or two resources, e.g. machinery, personnel or infrastructure. In addition, the study revealed that the conceptualization of flexibility was different in different companies. The size of the organization, the complexity of the products and the level of technology used in production were factors found to be important for issues concerning manufacturing flexibility.

A lack of concordance was also found between managers' perceptions within the same company. For example, finance and production managers were more concerned with labour aspects for achieving flexibility than product development and marketing managers. Different managers also looked at flexibility as an answer to different problems.

In summary, a limited conformity, within companies, of what flexibility could achieve was found. Different departments, to some extent, strived in different directions. Together, with the fact that managers had a low level of conceptualization, we concluded that there was a need for a framework that

could help companies to gain knowledge about flexibility. A framework could also be helpful in creating conformity within the company in order to align flexibility with the company strategy.

3.4 Article V: Making Manufacturing Flexibility Operational - A Framework

In Article V a framework is presented. The objective of the framework is to show the way of obtaining consistency from the manufacturing strategy to the resource characteristics in the production system. The framework should be useful for both practitioners and scholars. The ground of the framework is the Input-Transformation-Output (I-T-O) -model.

The concept of flexibility is structured by making distinctions between three generic dimensions: utilized flexibility vs. potential flexibility, external flexibility vs. internal flexibility, and requested flexibility vs. replied flexibility. Internal and external flexibility are analysed deeper. Internal flexibility is denominated characteristics.

- External flexibility is what the customers demand from their suppliers and what the suppliers can supply.

- Characteristics are how a company, internally, can accommodate its production facilities in order to fulfil the demand for external flexibility.

External flexibility can only partly be controlled by a company, while the characteristics are entirely in the hands of the company. In order to manage flexibility, it is useful to divide the characteristics into two levels. The external level and the two internal levels give three levels to manage:

- The strategic level, where external flexibilities are defined at the marketplace between the company and its suppliers and customers.

- The production system level, where the characteristics of the production system are defined on a tactical level.
- The production resource level, where the resource characteristics are defined on an operational level.

The framework shows how to connect these three levels and make transformations between them. This is done via matrixes, where the needs of one level are transformed into the characteristics of the next level. The framework can be used for bottom-up planning as well as top-down planning.

A practical way of approaching changes in the flexibility of a company is to use a 'gap' methodology. The different levels are audited for their current flexibility situation. Changes in the context will impose changes in the requested flexibilities. The current inherent flexibilities are confronted with these new requirements, creating a gap between them. The gap is the ground for an action plan to make a sufficient reply possible. It is stressed that flexibility does not have to be just a reactive response to environmental changes, but could and should be used in a proactive way in order to gain competitive advantage. The full framework is shown in the figure on page V:19.

REFERENCES

Abernathy, W. J. (1978) The Productivity Dilemma: Roadblock to Innovation in the Automobile Industry, John Hopkins University Press, Baltimore.

Aharoni, Y. (1966) The Foreign Investment Decision Process, Division of Research, Harvard Business School.

Argyris, C. and Schön, D. (1978) Organizational Learning, Jossey-Bass, San Fransisco.

Andreasson, M. and Ahm, T. (1986) Montageteknik- fleksibel automatiskt montage, Instituttet for Produktudvikling.

Begg, D., Fischer, S. and Dornbusch, R. (1987) Economics (Second Edition), McGraw-Hill Inc., London.

Björkegren, D. (1989) Hur organisationer lär, Studentlitteratur, Lund, Sweden.

Bower, J. L. (1970) Managing the Resource Allocation Process, Division of Research, Graduate School of Business Administration, Harvard University. (Published by Richard D Irwin Inc., 1972, Homewood, Illinois)

Brealey, R. A. and Myers, S. C. (1988) Principles of Corporate Finance, McGraw-Hill Inc., London.

Brunsson, N. (1985) The Irrational Organization - Irrationality as a Basis for Organizational Action and Change, John Wiley and Sons, Chichester.

Chambers, S. (1990) Flexibility in the Context of Manufacturing Strategy, Annual Conference of the UK Operations Management Association, 25/26 June, University of Warwick, England.

Cox, J. C. and Rubinstein, M. (1985) Options Markets, Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Cyert, R. M. and March, J. G. (1963) A Behavioural Theory of the Firm, Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Dean, J. (1951) Managerial Economics, Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Gerwin, D. (1987) An Agenda for Research on the Flexibility of Manufacturing Processes, International Journal of Operations and Production Management, Vol 7, No 1, pp 38-49.

Gerwin, D. and Tarondeau, J-C. (1989) International Comparisons of Manufacturing Flexibility, in Ferdows K. (ed.) Managing International Manufacturing, Elsevier Science Publishers B V, North-Holland.

Hayes, R. H. and Wheelwright, S. C. (1984) Restoring Our Competitive Edge - Competing Through Manufacturing, John Wiley and Sons.

Hendricks, J. A. (1983) Capital Budgeting Practices Including Inflation Adjustments: A Survey, Managerial Planning, Vol 31, No 1, pp 22-28.

Hill, T. (1985) Manufacturing Strategy, MacMillan Education Ltd., London.

Hill, T. (1989) Manufacturing Strategy, Irwin, Homewood, Illinois.

Jönsson, S. (1974) Om nya ansatser i studiet av företagens investeringsbeteende, Erhvervsøkonomisk Tidskrift, No 38, pp 13-26.

Kim, S. H. and Farragher, E. J. (1981) Current Capital Budgeting Practices, Management Accounting, No 11, June, pp 26-30.

Kumar, V. and Kumar, U. (1987) Manufacturing Flexibility: A New Approach to its Measurement, Institute of Industrial Engineers World Productivity Forum and 1987 International Industrial Engineering Conference Proceedings, Washington, pp 469-475.

Lindberg, P. (1990) Manufacturing Strategy and Implementation of Advanced Manufacturing Technology, Doctoral Thesis, Department of Industrial Management and Economics, Chalmers, Sweden.

Magee, J. (1964) Decision Trees for Decision Making, Harvard Business Review, Vol 42, No 4, pp 126-138.

Malm, A. T. (1975) Strategic Planning Systems - A Framework for Analysis and Design, Studentlitteratur, Lund, Sweden.

Mandelbaum, M. (1978) Flexibility in Decision Making: An Exploration and Unification, Ph.D. Thesis, Dept of Industrial Engineering, University of Toronto, Canada.

Mandelbaum, M. and Brill, P. H. (1989) Examples of Measurement of Flexibility and Adaptivity in Manufacturing Systems, Journal of the Operational Research Society, Vol 40, No 6, pp 603-609.

Molin, J. and Söderlind, M. (1989) Investering i flexibel produktionsutrustning - något för Volvo PV?, Master Thesis, Department of Industrial Management, Lund, Sweden.

Nilsson C-H. and Nordahl H. (1988) Investeringsbedömning av industrirobotar - värdering av svårkvantifierbara aspekter, Master Thesis, Department of Industrial Management, Lund, Sweden.

Noori, H. (1990) Managing the Dynamics of New Technology, Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Persson, I. (1988) Capital-Back - Metod för riskanalys eller metod för lönsamhetskalkylering, Aktiv Industriautomation, Vol 1, No 6, pp 56-62.

Persson, I. (1990) Analysis of Capital Investment: A Conceptual Cash Flow Model, Engineering Cost and Production Economics, Vol 20, No 3, pp 277-284.

Persson, I. (1991) The Use of Information Technology in the Investment Process - An Analysis of Some Possibilities, in Sol, H. G. and Vecsenyi, J. (eds.) Environments for Supporting Decision Processes, Elsevier Science Publishers B. V., North-Holland.

Porter, M. E. (1980) Competitive Strategy: Techniques for Analyzing Industries and Competitors, The Free Press, New York.

Porter, M. E. (1985) Competitive Advantage - Creating and Sustaining Superior Performance, The Free Press, New York.

Ranta, J., Tchijov, J. and Dimitrov, P. (1992) Implementation Strategies for CIM Technologies: Goals, Costs and Benefits of Flexibility, in Ranta, J., Jaikumar, R. and Ettlie, J. (eds.) Fewer and Faster: A Story of Technological, Organizational and Managerial Innovations in the Manufacturing Enterprise, Chapter 2, Harvard Business Monograph Series, Harvard Business Press.

Rolf, B. (1989) Tyst kunskap - Wittgensteins osägbarhet och Polanyis personliga kunskap, Didaktisk forskning i Uppsala, Vol 7, Oktober.

Samson, D. (1991) Manufacturing and Operations Strategy, Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Skinner, W. (1969) Manufacturing - Missing Link in Corporate Strategy, Harvard Business Review, May-June, pp 136-145.

Skinner, W. (1974) The Focused Factory, Harvard Business Review, May-June, pp 113-121.

Slack, N. (1988) Manufacturing Systems Flexibility - An Assessment Procedure, Journal of Computer Integrated Manufacturing Systems, Vol 1, No 1, pp 25-31.

Swamidass, P. M. and Newell, W. T. (1987) Manufacturing Strategy, Environmental Uncertainty and Performance: A Path Analytic Model, Management Science, Vol 33, No 4, April, pp 509-524.

Thompson, Jr. A. A. and Strickland III, A. (1986) Strategy Formulation and Implementation - Tasks of the General Manager, Business Publications Inc., Plano, Texas.

Wagle, B. (1968) A Statistical Analysis of Risk in Capital Investment Projects, Operational Research Quarterly, Vol 18, No 1, pp 13-33.

Weingartner, H. M. (1969) Some Views on the Payback Period and Capital Budgeting Decisions, Management Science, Vol 15, No 12, August, pp B594-B607.

Yard, S. (1987) Kalkyllogik och kalkylkrav - samband mellan teori och praktik vid kravställande på investeringar i företag (Swedish with an English summary), Lund University Press.

Author Index

The following list contains the names of the authors referred to, and the pages where the references can be found in the summary as well as in the articles on which this thesis is based.

ABSTRACTS OF APPENDED ARTICLES

The dissertation is based on the five appended articles. All the articles are the result of joint efforts. Making clear distinctions of who has written what is, in many cases, irrelevant and would only violate the truth. Our research has been a process, brought forward by each individual but primarily driven by the interaction with and confrontation to each others ideas.

However, some distinctions can be made concerning the main responsibilities of some parts of the articles.

Authors' Contributions

Article I:

The article was the result of a joint effort by the authors.

Article II:

Ingvar Persson was mainly responsible for the frame of reference. The remainder of the article was a joint effort by the three authors.

Article III:

Carl-Henric Nilsson was mainly responsible for the analyses of the use of capital-back and pay-back in relation to standard methods such as IRR and NPV. Håkan Nordahl was mainly responsible for the system for dividing the components of an installation into sub-systems. He was also responsible for the discussion and definition of component flexibility. The remainder of the article was a joint effort by the three authors.

Article IV:

Håkan Nordahl was mainly responsible for compiling and writing the article, the remainder was a joint effort.

Article V:

Carl-Henric Nilsson was mainly responsible for compiling and writing the article, the remainder was a joint effort.

Article I

Nordahl, H., Nilsson, C-H. and Martins, G. (1988) Beurteilen der Investitionen von Industrierobotern, Werkstatt und Betrieb, Vol 121, No 12, pp 963-965.

The objective of the study is to reveal in what way the inherent flexibility of industrial robots can be utilized during the life-span of the investment, especially in situations that were not conceivable at the time of the investment.

Five robot installations, installed between 1971 and 1981, were studied in order to evaluate how the ability to handle uncertainties during the life-span of the installations were affected by the flexibilities of the equipment.

It should be known to all users of industrial robots that the traditionally used justifications for the equipment - recovery of labour cost, improved quality and improved working environment - do not give the correct picture of the revenue from an industrial robot installation. Other factors will also affect the outcome of the installation, such as the possibility to make changes in the products or in the machinery.

One important incentive for investment in more efficient equipment is the cost savings of labour. This factor is easy to appraise. An improved work environment and an reduced employee turnover rate are two obvious effects of installing industrial robots. The study also revealed that the work content increased for those workers involved in operations of the robot installation.

The tendency towards shorter product life cycles denotes the importance of having an installation that can also be used to produce the following generations of products. In four of the five studied cases the product produced went through major changes, none of which were conceived at the time of investment. Flexible equipment is better prepared to handle such changes and is thus able to be utilized throughout the entire life-span.

Capital-back, a capital budgeting technique, was developed to take into consideration the flexibility inherent in the equipment. The capital-back period is the time it takes

from the time of investment until the sum of the accumulated annual net receipts and the residual value of the flexible part of the investment equals the initial outlay for the investment. The formula for capital-back is:

$$CB = \frac{G - u}{a - d}$$

Where (G) is the initial outlay, (u) is the reusable part of the investment, (a) is the annual net receipt, and (d) is the annual depreciation of the flexible part of the investment.

Capital-back considers the aspects of flexibility in the equipment as well as the profitability of the investment in order to form one single measurement. This can be interpreted as the solidity of the investment. Pay-back considers the liquidity and profitability of the investment. The methods complement each other to form a more complete picture of the investment than could any of the methods alone.

Article II

Persson I., Nilsson, C-H. and Nordahl, H. (1991) Evaluation of Flexible Capital Investments - With Consequences for Decisions and Suppliers, in Pridham, M. and O'Brien, C. (eds.), Production Research: Approaching the 21st Century, Taylor and Francis Ltd., London, pp 371-378.

The objective of the article is to introduce capital-back (CB), a capital budgeting method that weighs the flexibility and the profitability of an investment in order to form one single measurement.

Capital-back is a method for evaluating the flexibility of machinery. It takes into consideration the abilities of different investment proposals to meet radical changes, for instance, if the market of the product produced by the machinery suddenly drops. Flexibility, in this case, means having the possibility to reuse the machinery for purposes, other than what was originally intended, either inside the company or in some other manufacturing process outside the company.

The total investment is divided in two parts, the flexible part and the inflexible or risky part. The flexible part (G_f) is flexible enough to be used for other purposes. Examples of such machinery are industrial robots, CNC machines and parts of FMS. The risky part (G_r) has a residual value of zero, irrespective of the time of use. Examples are specially designed gripping appliances, expenditures for project and design as well as for the physical installation. The total investment (G) is the sum of the flexible and the risky part, $G = G_f + G_r$. The formula for the capital-back period is:

$$CB = \frac{G_r}{a - G_f * annuity(n\ years, i\ \%)}$$

The annuity method is used to describe the residual value of the flexible part of the investment over time, (n) is the life-span, (i) is the discount rate and (a) is the annual net receipt. The CB period can be described as the time it takes to consolidate the invested capital. The flexible part is already consolidated through its flexibility.

The consequences for decision-making and for suppliers of flexible equipment using the capital-back method, are evaluated. CB is an excellent aid to incorporate the strategic importance of flexibility in the capital budgeting process. The CB method illuminates the importance of flexibility and promotes flexible investment alternatives. An interesting way to finance an investment is that the supplier of the flexible part directly leases these parts. The supplier has better knowledge of the market and is best fitted to find new users for the flexible machinery. The flexible part is leased from the supplier thus charging the annual net receipt with a rent. The investment is the risky part.

The impact on the CB period is analysed for four factors: the flexible share of the investment, the level of the discount rate, the profitability of the total investment and the life-span of the flexible part of the investment.

Article III

Nilsson, C-H., Nordahl, H. and Persson, I. (1992) Analysis and Evaluation of Flexible Capital Investments, accepted for publication in Parsaei, H. R. and Mital, A. (eds.), Economics of Advanced Manufacturing Systems, Chapman and Hall,
pp 239-254.

The objective of the article is to analyse capital-back (CB) as a method for evaluating flexible capital investments. CB is compared with pay-back (PB) and the use of CB together with PB is compared to the standard capital budgeting techniques - net present value (NPV) and internal rate of return (IRR).

Flexibility is a broad concept and is dependent upon the circumstances under which it is used. Many authors have discussed and defined flexibility in the manufacturing process. It mainly concerns two dimensions, the product dimension and the material flow dimension. The analyses do not consider the possibilities of reusing the equipment in different manufacturing processes. In this article, flexibility, as it is related to the product scope and flexibility, as it is related to the components of an investment, are discussed.

Product scope is defined as the boundaries within which the critical parameters of the product can be varied.

Component flexibility (f), the parts of the investment that can be reused in another installation, is defined as the flexible share of the investment. (G) is the total investment and (G_f) is the flexible part of the investment.

$$f = \frac{G_f}{G}$$

The PB method emphasizes the short-term planning, uncertainty and the initial strength of the investment. However, for flexible investments, this method can lead to wrong investment decisions. The advantage of the CB method is that it takes into consideration the uncertainty of the risky part and the requirement for profitability

for the flexible part. The two methods, used together, will generate some interesting results. The formula for the capital-back period is:

$$CB = \frac{(1-f)*G}{a - f*G*annuity(n\ years, i\ \%)}$$

The annuity method is used to describe the residual value of the flexible part of the investment over time, (a) is the annual net receipt for the investment, (n) is the life-span and (i) is the discount rate.

When NPV > 0 and IRR > i, it can be shown that $\partial CB/\partial f < 0$. This means that the investment is acceptable and thus the CB period ≤ PB period for all values of f.

When NPV = 0 and IRR = i, it can be shown that $\partial CB/\partial f = 0$. This means that the CB period, as a function of the flexible share of the investment (f) is constant. It turns out that this constant is the PB period.

Article IV

Nordahl, H. and Nilsson, C-H. (1992) Managers' Perception of Flexibility in Manufacturing - A Study of the Swedish Engineering Industry, Department of Industrial Management, Lund Institute of Technology.

This article reports on an empirical study in which the objectives were to investigate:

(1) How managers in the Swedish engineering industry perceive flexibility in manufacturing.
- what the differences are between managers of different departments.
- what the differences are between managers of different companies.

(2) Which aspects of flexibility managers perceive as the most important for manufacturing, now and in the future.

A case study of six companies was conducted. A convenience sample generated from industry contacts was used to chose the six companies in the study. Interviews were granted with managers of finance, marketing, production and product development in each company.

Five major steps in the analysis of the raw interview data were conducted. The first two constitute a within-case analysis, the last three, a cross-case analysis. The different steps were not done in sequence. Instead, an iterating process was used where we turned back and made completions as further insights into the cases and the flexibility concept were gained. The most important findings were the following:

The most mentioned resource characteristics and their main goals were:

- Set-up times - to increase delivery range flexibility.
- Multi-product machines - to provide high product flexibility, both in range and response.
- Multiple skilled labour - to provide volume flexibility, both in range and response.

The predominant position related differences. Different focus areas of managers:

- Finance - set-up times and labour characteristics, but not product flexibility.
- Marketing - set-up times and multi-product machines, but not labour characteristics.
- Production - labour characteristics, multi-product machines and set-up times.
- Product development - product flexibility.

The predominant company related differences were:

- The larger the company, the more complex the managers view of flexibility.
- The more complex products, the more important the infrastructure of the company.
- The higher the level of technology in production, the higher the perceived need for flexibility in the company.

Article V

Nilsson, C-H. and Nordahl, H. (1992) Making Manufacturing Flexibility Operational - A Framework, Department of Industrial Management, Lund Institute of Technology.

The objective of the article is to:

- structure the concept of flexibility and
- develop a framework for flexibility in manufacturing that shows how to obtain consistency from the manufacturing strategy to the resource characteristics in the production system.

Distinctions are made between the concept of flexibility in three generic dimensions:

- utilized flexibility vs. potential flexibility
- external flexibility vs. internal flexibility
- requested flexibility vs. replied flexibility

The model used as a starting point for the building of our framework is the Input-Transformation-Output (I-T-O) -model. The model makes a clear distinction between the inside and the outside of the company. Flexibility inside the company is denominated characteristics.

- External flexibility is what the customers demand from their suppliers and what the suppliers can supply.

- Characteristics are how a company, internally, can accommodate its production facilities in order to fulfil the demand for external flexibility.

The characteristics of the production system are divided into two levels: the production resource level, where the characteristics of machines, labour and infrastructure of the production system are considered. The production system level, where interconnected resources are on an aggregated level, forming production system characteristics. The model thus consists of three distinct levels:

- The strategic level, where external flexibilities are defined at the marketplace.
- The production system level.

- The production resource level.

The framework is compatible with both a top-down approach and a bottom-up approach. The framework uses transformation matrixes in an iterative manner to connect the levels. When the iterating of the processes has come to an end, that is to say, when the chain from input to output is eclipsed by the transformation process, all parts are aligned with each other and with the overall strategy of the company. Having used the framework the company will, at best, have increased its competitiveness and at worst, have gained insight into what is necessary to be competitive. One important aspect of working through the matrix several times, as suggested, is that it creates an awareness for flexibility and its impact on the production system, as well as on the overall strategy of the company. Working through the framework can further conform the conceptualization of flexibility between managers thus increasing the possibility of reaching a favourable solution and creating commitment to this solution.