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R&D PERFORMANCE ANALYSIS: Case Studies on the Challenges and Promotion of the Evaluation and Measurement of R&D

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ABSTRACT

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Due to the intense international competition, demanding, and sophisticated customers, and diverse transforming technological change, organizations need to renew their products and services by allocating resources on research and development (R&D). Managing R&D is complex, but vital for many organizations to survive in the dynamic, turbulent environment. Thus, the increased interest among decision-makers towards finding the right performance measures for R&D is understandable. The measures or evaluation methods of R&D performance can be utilized for multiple purposes; for strategic control, for justifying the existence of R&D, for providing information and improving activities, as well as for the purposes of motivating and benchmarking.

The earlier research in the field of R&D performance analysis has generally focused on either the activities and considerable factors and dimensions – e.g. strategic perspectives, purposes of measurement, levels of analysis, types of R&D or phases of R&D process - prior to the selection of R&D performance measures, or on proposed principles or actual implementation of the selection or design processes of R&D performance measures or measurement systems. This study aims at integrating the consideration of essential factors and dimensions of R&D performance analysis to developed selection processes of R&D measures, which have been applied in real-world organizations.

The earlier models for corporate performance measurement that can be found in the literature, are to some extent adaptable also to the development of measurement systems and selecting the measures in R&D activities. However, it is necessary to emphasize the special aspects related to the measurement of R&D performance in a way that make the development of new approaches for especially R&D performance measure selection necessary: First, the special characteristics of R&D - such as the long time lag between the inputs and outcomes, as well as the overall complexity and difficult coordination of activities - influence the R&D performance analysis problems, such as the need for more systematic, objective, balanced and multi-dimensional approaches for R&D measure selection, as well as the incompatibility of R&D measurement systems to other corporate measurement systems and vice versa. Secondly, the above-mentioned characteristics and challenges bring forth the significance of the influencing factors and dimensions that need to be recognized in order to derive the selection criteria for measures and choose the right R&D metrics, which is the most crucial step in the measurement system development process.

The main purpose of this study is to support the management and control of the research and development activities of organizations by increasing the understanding of R&D performance analysis, clarifying the main factors related to the selection of R&D measures and by providing novel types of approaches and methods for systematizing the whole strategy- and business-based selection and development process of R&D indicators. The final aim of the research is to support the management in their decision making of R&D with suitable, systematically chosen measures or evaluation methods of R&D performance. Thus, the emphasis in most sub-areas of the present research has been on the promotion of the selection and development process of R&D indicators with the help of the different tools and decision support systems, i.e. the research has normative features through providing guidelines by novel types of approaches.

The gathering of data and conducting case studies in metal and electronic industry companies, in the information and communications technology (ICT) sector, and in non-profit organizations helped us to formulate a comprehensive picture of the main challenges of R&D performance analysis in different organizations, which is essential, as recognition of the most important problem areas is a very crucial element in the constructive research approach utilized in this study. Multiple practical benefits regarding the defined problem areas could be found in the various constructed approaches presented in this dissertation: 1) the selection of R&D measures became more systematic when compared to the empirical analysis, as it was common that there were no systematic approaches utilized in the studied organizations earlier; 2) the evaluation methods or measures of R&D chosen with the help of the developed approaches can be more directly utilized in the decision-making, because of the thorough consideration of the purpose of measurement, as well as other dimensions of measurement; 3) more balance to the set of R&D measures was desired and gained through the holistic approaches to the selection processes; and 4) more objectivity was gained through organizing the selection processes, as the earlier systems were considered subjective in many organizations.

Scientifically, this dissertation aims to make a contribution to the present body of knowledge of R&D performance analysis by facilitating dealing with the versatility and challenges of R&D performance analysis, as well as the factors and dimensions influencing the selection of R&D performance measures, and by integrating these aspects to the developed novel types of approaches, methods and tools in the selection processes of R&D measures, applied in real-world organizations. In the whole research, facilitation of dealing with the versatility and challenges in R&D performance analysis, as well as the factors and dimensions influencing the R&D performance measure selection are strongly integrated with the constructed approaches. Thus, the research meets the above-mentioned purposes and objectives of the dissertation from the scientific as well as from the practical point of view.

Keywords: performance analysis, measurement, evaluation, research and development (R&D)

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Lappeenranta, November 2003

Ville Ojanen

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Publication 2. Ojanen V., Kärkkäinen H., Piippo P. and Tuominen, M. (1999). Selection of R&D Performance Measures from the Whole Company's Point of View. Refereed paper published in the Proceedings Vol-2: Papers Presented at PICMET '99 (CD-ROM), Portland International Conference on Management of Engineering and Technology, 25.-29.7.1999, Portland, Oregon, USA, ISBN 1-890843-04-0.

Publication 3. Ojanen V., Torkkeli M. and Tuominen M. (2001). Managing the Selection and Development Process of R&D Indicators as Part of the Strategy Process. Paper published in the Proceedings of R&D Management 2001 Conference (CD-ROM), 7.-9.2.2001, Wellington, New Zealand.

Publication 4. Ojanen V., Piippo P. and Tuominen M. (2002). Applying Quality Award Criteria in R&D Project Assessment. *International Journal of Production Economics*, vol. 80, No. 1, pp. 119-128, ISSN 0925-5273.

Publication 5. Ojanen V. and Koivuniemi J. (2001). Challenges of R&D Performance Evaluation in the Infocom Industry. Paper published in the Proceedings of R&D Management Conference, 6.-7.9.2001, Dublin, Ireland, pp. 369-377.

Publication 6. Ojanen V. and Tuominen M. (2002). An Analytic Approach to Measuring the Overall Effectiveness of R&D – a Case Study in the Telecom Sector. Paper published in the Proceedings: Volume II of IEMC 2002, International Engineering Management Conference, 18.-20.8.2002, Cambridge, U.K, pp. 667-672, ISBN 0-7803-7385-5.

Publication 7. Ojanen V., Koivuniemi J. and Blomqvist K. (2002). Strategic Competence Development and Monitoring in a Multi-disciplinary Research Institute. Paper published in the Proceedings: Volume II of IEMC 2002, International Engineering Management Conference, 18.-20.8.2002, Cambridge, U.K, pp. 520-525, ISBN 0-7803-7385-5.

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Abbreviations

AHP	Analytic Hierarchy Process
BSC	Balanced Scorecard
DSS	Decision Support System
EI	Effectiveness Index
EIRMA	European Industrial Research Management Association
GDP	Gross Domestic Product
GDSS	Group Decision Support System
ICT	Information and Communications Technology
IMD	The International Institute for Management Development
LUT	Lappeenranta University of Technology
OECD	Organization for Economic Co-operation and Development
PDMA	Product Development Management Association
R&D	Research and Development
SBU	Strategic Business Unit
TQM	Total Quality Management
UNDP	United Nation's Development Programme
WEF	World Economic Forum

PART I: SUMMARY OF THE DISSERTATION

1 INTRODUCTION

1.1 Background and origins

Research and Development[1] (R&D) activities have turned out to be crucial elements for organizations[2] that aim to sustain their competitive position or gain new competitive advantage in changing business environments (see e.g. Roussel et al., 1991; Cooper, 1993, 1998; Cooper and Kleinschmidt 1996; Balachandra and Friar, 1997; Menke, 1997; Golder, 2000). The strategic and operative management of R&D are considered as very challenging tasks because of the several special characteristics of R&D that make the R&D a functional area of business differing significantly from other functional areas of business, i.e. a significant amount of industry specific knowledge is needed to manage R&D effectively (see Figure 1).

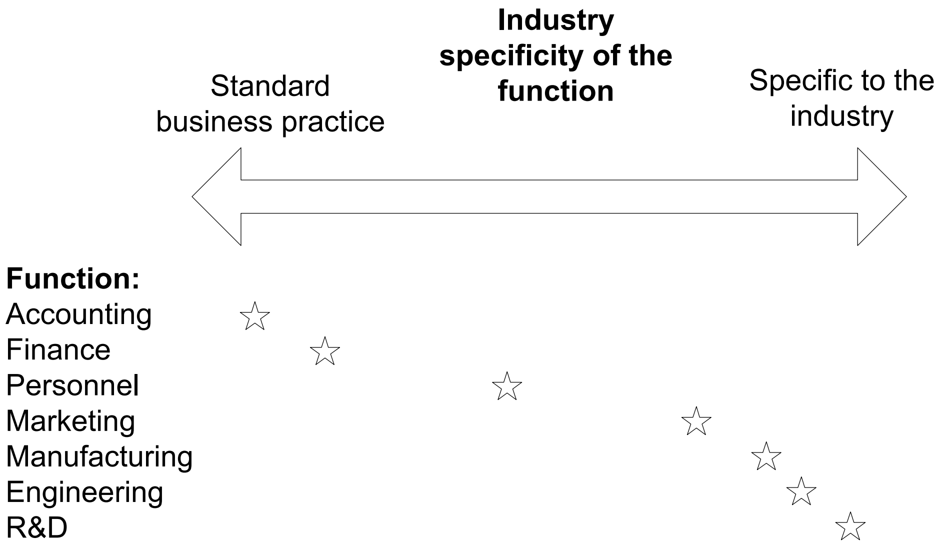

Figure 1. Industry specificity of some organizational functions[3] (adapted from Burgelman et al., 2001).

In the 1990's, Clark and Fujimoto (1991) argued that there were three forces that have emerged over the past few decades in many industries worldwide: intense international competition, the creation of fragmented markets populated by demanding, and sophisticated customers, and diverse transforming technological change. These forces are increasingly powerful in the beginning of the 21st century, and they force the industrial competition to focus heavily on R&D and new product development (see e.g. Tidd et al., 2001). Changing operating environments and fierce competition have compelled industrial companies to re-

[1] The categorization of R&D types has been studied, e.g. by Pappas and Remer (1985), who distinguished the five main types of R&D; basic research, exploratory research, applied research, product development and product improvements. The emphasis in this study is on product development, but different types of R&D are also concerned in different parts of the thesis. The emphases and limitations of the study are clarified more in detail in Chapter 1.3.
[2] In this study, "organizations" refer mainly to industrial companies, but since parts of the study also concern evaluation of research activities in non-profit organizations, like universities, the scope of the research, in that sense, is more extensive than the scope of profit-gaining companies.
[3] In Figure 1, "Accounting" refers mainly to financial accounting.

allocate their resources on a continuous base. This means that R&D organizations need to validate the R&D investment and justify their existence by indicating their performance and impacts of R&D activities to the whole organization. The increased interest among decision-makers towards finding the right performance measures is understandable in this context.

Validating the R&D investment and the assessment of the contribution of R&D activities to the company's profit are typical company-level motives for building a measurement system for R&D. There are also several other reasons or purposes for the measurement of R&D performance (see e.g. Lee et al., 1996, Kerssens-van Drongelen, 1999). The measures of R&D can provide valuable information for e.g. diagnosing and improving the problem areas in R&D, for motivating and rewarding employees, and for benchmarking purposes. In a report of the European Industrial Research Management Association (EIRMA) (1995) it is concluded that whichever method is used for the evaluation of R&D efforts, the most important outcome of a properly structured evaluation is improved communication.

Noteworthy problems in the evaluation and measurement of R&D can be caused by the special characteristics of R&D (see e.g. Roussel et al., 1991), for instance insecurity related to planning and decision-making, assessment of the contribution of R&D to profits, long time lag between efforts and outcomes, creative personnel, complex coordination etc. The problem areas have to be identified and paid attention to when starting to build a measurement and control system for R&D. In addition to money spent, lots of human resources are used for research and development activities, and thus in different organizations it is vital to follow the R&D performance and choose a suitable, balanced set of measures to avoid sub-optimization of R&D activities, which could be caused by wrong measures of performance.

In a recent survey of 363 firms, Griffin (1997) tracked new product development trends and best practices. In her study it was concluded that compared to the other firms in the study, best-practice firms use more multi-functional teams, are more likely to *measure product development processes and outcomes*, and expect more for their new product development programs. This could motivate different organizations to track good measures of R&D performance, although some find the performance analysis too difficult, complex, time-consuming or even useless. Additionally, on the basis of a recent DELPHI[4] study by Scott (1998, 2001) it can be concluded, for instance, that the three technology management problems that were ranked to be of most importance by the respondents of the study, i.e. strategic planning of technology products, new product project selection and organizational learning about technology, are problems which could probably be reduced with effective performance measures. Ellis (1997) referred to the earlier (1993-1995) Industrial Research Institute surveys on the biggest R&D problems of its members (over 200 responses), where *"measuring and improving R&D productivity/effectiveness"* was ranked as the most often cited problem in both years.

Globally, the field of R&D performance analysis has been of great interest for both academics and practitioners especially since the 1990s, as it is still an emerging research area. There are recent studies discussing the principles related to the measurement of R&D and the **selection**

[4] DELPHI is a method in which every individual member can take the group's solution further but at the same time remain at the individual level as well. The members of the group can check their status and conceptions step by step as the group's solution develops and progresses, and at the same time they can pose relevant suggestions for correcting and changing the solution. The final solution is an agreement familiar to every one, i.e. a consensus. The key elements of the method are structuring the information, feedback between the members and anonymity (see e.g. Linstone and Turoff, 1975).

of R&D measures (Ellis, 1997, Kerssens-Van Drongelen and Cook, 1997, Nixon and Innes, 1997; Akcakaya, 2001), but relatively few studies concentrating especially on the promotion of measure selection and design of measurement systems. As pointed out by researchers in the field (e.g. Kerssens-van Drongelen, 1999), there is a further need to study the systematic approaches and methods to be utilized in the selection and development process of R&D performance indicators. The earlier research in the field of R&D performance analysis has generally focused on either the activities and considerable factors and dimensions prior to the selection of R&D performance measures, or on proposed principles or actual implementation of the selection or design processes of R&D performance measures or measurement systems. This study aims at integrating the consideration of essential factors and dimensions of R&D performance analysis to developed selection processes of R&D measures, which have been applied in real-world organizations.

Choosing the right set of measures is a very company specific issue and general, universal approaches to this problem cannot be found. There are, however, strategic performance management approaches, like the Balanced Scorecard (BSC) (Kaplan and Norton, 1992, 1996, 2000), which have been developed to promote the creation of strategy-based measurement systems for corporate performance, but have also been adapted for R&D performance measurement (e.g. Curtis and Ellis, 1997). More recently, researchers (e.g. Toivanen, 2001) have developed models for the effective implementation of BSC projects. In addition to the technology and R&D management point of view, there is also a need to reflect the results of the present study to the general doctrine of developing corporate performance measurement systems.

From another point of view, Neely et al. (1996) suggest that one way of overcoming the inherent complexity of performance measurement system design might be to employ structured design methodologies. The researchers surveyed over 850 companies, and their data showed that although few firms used structured methodologies for performance measurement system design, those that did often found it significantly easier to a) decide what they should be measuring; b) decide how they are going to measure it; c) collect the appropriate data and d) eliminate conflicts in their measurement system (Neely et al., 1996).

Several sub-areas can be found in the literature review of R&D performance analysis (see Chapter 2). To cover the research aims as a whole and in the separate case studies, the research area of R&D performance analysis in this dissertation as a whole includes the following sub-areas:

- Recognition of the state-of-the-art of the research area of R&D performance analysis
- Analysis of the adapted and desired R&D measures in the studied industrial companies and their comparison with earlier studies
- Measurement dimensions and essential major factors to be taken into account in choosing R&D measures
- A strategy-based approach for the selection process of R&D indicators
- Utilization of decision support systems and different practical tools in the selection process of R&D measures
- Industry specific challenges of R&D performance analysis in the information and communications technology (ICT) sector
- R&D performance analysis incorporated to Total Quality Management (TQM) and Quality Award Criteria as well as to the BSC approach
- Monitoring competence development in the applied research

As a whole, this study has been executed as a part of two applied research projects[5]. The first one "Strategic Aiming and Assessment of Product Development" was carried out during the years 1996-1999 in co-operation with five Finnish medium- and large-sized manufacturing companies operating in the metal and electronics industry. In this larger research project, the purpose was to promote the management of the early phases of product development in order to increase the value of new product development for the whole company and to help companies to ensure the competitiveness of new products. One of the sub-areas was the evaluation of R&D performance in order to improve the management and control of the early phases of R&D as well as R&D as a whole.

The second project "Product Development Management in the Networked Economy" is also a three-year project, started in 2000. The three co-operational companies[6] of the project are from the ICT[7] sector. The five research sub-topics of the project are customer need assessment, technology selection, R&D project selection, measurement of R&D performance and diffusion of innovations. In the larger research project, the author of this dissertation has been responsible for the research on the measurement of R&D performance.

In the first project, the main development needs of the product innovation management were mainly clarified through interviews made by the project researchers. Many of the clarified development needs supported the significance of better alignment and control of R&D activities through effective R&D performance measurement. The main development needs of R&D performance evaluation and measurement were related to the gaps between the used and desired measures or evaluation methods of R&D and general needs for systematic approaches to select the right measurement subjects and measures of R&D performance. The key aspects of the first project were also utilized as results of pilot-cases for the second research project were more detailed approaches to the measurement and selection of R&D measures were constructed in close co-operation with the case organizations.

1.2 Scope and objectives

Industrial management as a scientific discipline examines industrial enterprises mainly by means of applied research projects (e.g. Olkkonen, 1994). The operations of enterprises are examined comprehensively by combining technical, economical and behavioral processes. The aim of the research in the discipline of industrial management is efficient, economical and environmentally considered utilization of technology. With the help of research in the field new possibilities are created for analyzing and improving the productivity, profitability and competitiveness of organizations[8].

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[5] See Appendices 1 and 2 for more detailed information on the utilized data sources and gathering methods concerning these larger research projects.

[6] Additionally, in the last phase of the research project (years 2002-2003), there is also fourth company involved, not from the ICT sector, but a co-operational partner of a large ICT company.

[7] According to OECD (2003) the agreed definition of the ICT sector is based on the following principles:
For manufacturing industries, the products of a candidate industry must 1) be intended to fulfill the function of information processing and communication including transmission and display, and 2) use electronic processing to detect, measure and/or record physical phenomena or to control a physical process. For services industries, the products of a candidate industry must be intended to enable the function of information processing and communication by electronic means.

[8] See e.g Olkkonen (1994) for more comprehensive discussion on research in Industrial Management.

In the research area of this study, R&D performance analysis, many of the sub-topics included in the discipline of industrial management are overlapped. These are for instance R&D and technology management, strategic management, management accounting, quality management and decision support systems. In the department of Industrial Engineering and Management at Lappeenranta University of Technology (LUT), there is expertise in all these sub-areas of industrial management. Thus, there have been excellent possibilities to include the main relevant points concerning this study and this broad research area from several viewpoints of these overlapping elements, for instance with the help of deep discussions and expert meetings concerning the sub-topics and research papers.

Different elements of this research have, however, been emphasized differently in this study. In Figure 2 below, the overlapping elements and the scope of this research are depicted. The weightings of the elements concerning this study are depicted with the size of the circles illustrating them. The focus area of the research and the main research fields are depicted against the scope of the research. The research area has its basis in two main doctrines: the technology management (including R&D management) doctrine, and the strategic performance measurement doctrine, which consists of strategic management and management accounting. In the middle of Figure 2, the area of decision support systems is marked with the dashed line, as this element does not form the main doctrine as such, but is strongly related to each of the elements.

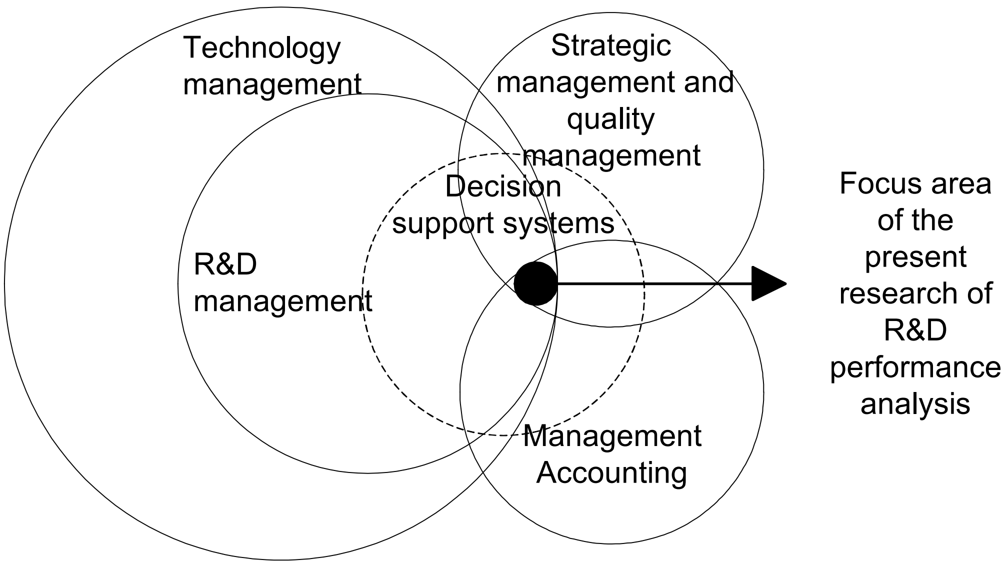

Figure 2. The scope and focus of the research of R&D performance analysis.

The main objective of this study is to support the management and control of the research and development activities of organizations by increasing the understanding of R&D performance analysis, clarifying the main factors related to the selection of R&D measures and by providing novel types of approaches and methods for systematizing the whole strategy- and business-based selection and development process of R&D indicators. The final aim of the research is to support the management in their decision making of R&D with suitable, systematically chosen measures or evaluation methods of R&D performance. The overall research area includes several sub-areas and research questions:

1. *What are the gaps between the utilized and desired measures or evaluation methods of R&D in the studied organizations?*
2. *Which are the main challenges encountered in analyzing R&D performance in general and especially in the studied organizations, i.e. why do the gaps exist?*
3. *a) Which are the main factors and dimensions influencing the selection of purposeful measures or evaluation methods of R&D performance and b) how do they have to be taken into account in the selection process of R&D performance measures?*
4. *a) How can the selection and development process of R&D performance measures be promoted effectively? b) Which supporting methods, tools or support systems are potentially effective in which phases of the process?*

Through these research questions the emphasis in most sub-areas of the present research has been on the promotion of the selection and development process of R&D indicators with the help of different approaches, tools or decision support systems, i.e. the research has normative features through providing guidelines by novel types of approaches. For instance, a group decision support approach to be utilized in the selection process of a set of measures for different types of R&D has been developed (see Appendix 3). The aim in studying the utilization of the decision support systems in the process is to clarify their benefits and restrictions in the process and to find the right method features and methods or tools for different phases of the process.

1.3 Limitations

As described in the previous section, the scope of this research as a whole is relatively broad. However, there are certain limitations and emphasized areas regarding the different aspects of measuring R&D performance. These aspects are related to the level of analysis, the different stages or types of R&D activities and phases of R&D process, which are discussed and analyzed in this section.

Rummler and Brache (1995) have distinguished three main levels for performance measurement and improvement; 1) the organizational level, 2) the process level, and 3) the job / performer level. To be more precise, the relevant, possible levels at which to measure the performance of R&D can be the macro (national) level, industry level, company level, strategic business unit level, R&D department level, R&D process level, R&D project level, R&D team level and individual researcher's or employee's level. This research covers most of these levels, when the emphasis is on measuring performance from the company's and business unit's point of view so that the R&D process of an organization could be effectively controlled and measured. In addition, many aspects of project level measurements are discussed and linked to upper level measurements. Since the aim of the study is to support the management in the decision-making of the organization's R&D activities, measurements at macro or industry level are not discussed in detail. In addition, the individual researcher's level assessment was only discussed in one of the publications included in the second part of the thesis, but it was not emphasized because of the holistic managerial view towards R&D performance analysis.

The types of R&D can be categorized by their time span, risks and closeness to the markets. Typically R&D can be divided into the basic and applied research carried out at universities and other research institutes, and product development carried out at industrial companies.

Pappas and Remer (1985) categorize the types of R&D into 1) basic research, 2) exploratory research, 3) applied research, 4) product development and 5) product improvements. Most of the research in this study has been carried out in co-operation with industrial companies, and hence, the main emphasis is on categories 4 and 5. However, two case studies have been carried out concerning the R&D in non-profit university / research institute organizations. In these cases, also the categories 1-3 (mainly applied research) are considered. Additionally, all the case studies in this study have been executed in Finnish organizations, i.e. cultural differences between countries that might occur in measuring R&D performance are not included in the study.

One of the utilized approaches in this study is an adapted version of the framework of measurement of R&D process as a system presented by Brown and Svenson (1988). In their approach, which is depicted in Figure 3, R&D as a processing system includes several phases that contain several subjects for the measurement of performance. First, inputs for R&D are for instance people, information, ideas, equipment, requests and funds needed for activities. The processing system in this approach is normally the R&D lab, which turns the inputs into outputs by conducting research and development and reporting results etc. The outputs of processing systems are e.g. publications, new products or processes, knowledge and patents. The receiving systems of R&D outputs in the whole process are for example manufacturing, marketing, engineering or other departments. Finally, the outcomes, i.e. the accomplishments that have value for the organization, have to be measured. These can be for instance cost reductions or sales or product improvements (Brown and Svenson, 1988) [9]. The approach in Figure 3 is a complemented picture of Brown and Svenson's approach, where we have added the arrows that depict the future indications from the earlier phases of the process and smaller arrows which show that measurement results in later phases can be utilized in several of the earlier phases, not only in the input phase and resource allocation. We would also like to pay attention to several activities such as strategies, competencies etc., which are involved in the front-end of the innovation process, and have influence on R&D expenditure and other inputs of the R&D process.

[9] With regard to Brown and Svenson's approach we have to keep in mind that depending on the level of the analysis, the receiving system can be seen either as being a part of the research and development process or as not being a part of it. For instance, concerning the issue at the process level, we can include the receiving system at the process, but when assessing R&D as a function, the receiving system is not included. Additionally, as the co-operation and networking in R&D between different organizations has significantly increased lately, the assessment of different phases of the process is much more complicated than in this simplified, more traditional view towards this.

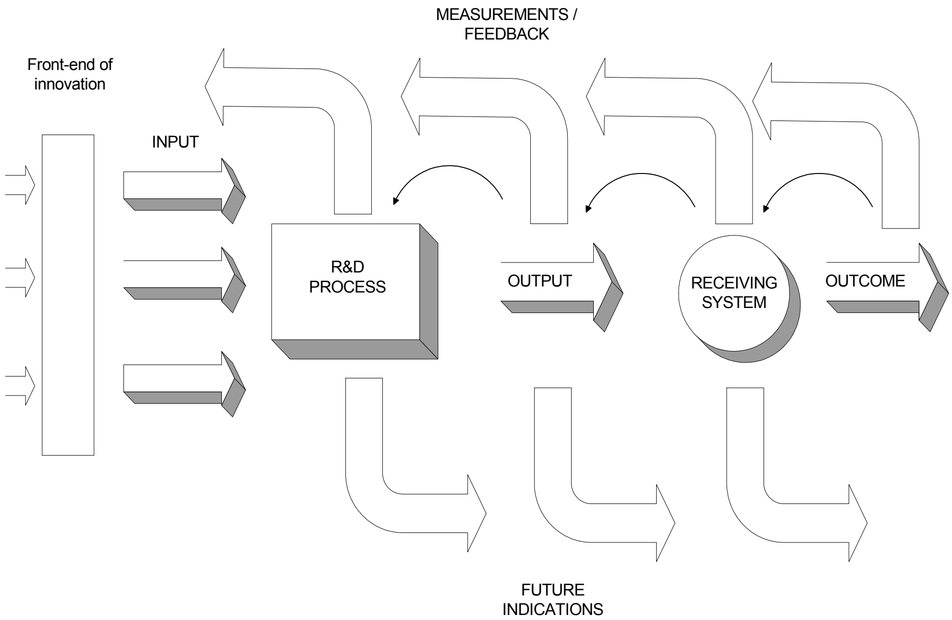

Figure 3. R&D as a processing system (adapted from Brown and Svenson, 1988).

The emphasis in most parts of our research has been on in-process evaluation and measurement of R&D output. Outcome measurements are also discussed, but for practical reasons the actual measurement of the final outcome is often difficult due to the time-lag between the input and outcome phases, which can in some industries be several decades. Aspects from earlier phases in the R&D process, i.e. early in-process measurements and input evaluations are also discussed. For complementing the whole picture, a part of our study also addresses the issue of measuring the competencies and their development. This has influence on the input and early phases of the R&D process and it is linked to the front-end of the innovation process (see e.g. Murphy and Kumar, 1997; Khurana and Rosenthal, 1998).

1.4 Key concepts

For clarity, it is necessary to clarify the concepts and keep track of the jargon and acronyms that are related to the management of R&D and R&D performance analysis. Many of the concepts discussed in this section overlap each other or they are used as synonyms in different studies. The definitions of the concepts discussed below are presented especially from the scope and viewpoint of this particular study.

Research and Development, R&D, as a concept, was already discussed in the previous section through the categorization principles of different types of R&D. In this study we can for most parts follow the definitions by Pappas and Remer (1985), who have identified the five main types of R&D:

- **Basic research**: Directed to the search of fundamental knowledge.
- **Exploratory research**: To determine if some scientific concept might have useful application.
- **Applied research**: Directed to improving the practicality of a specific application
- **Development**: Engineering improvement of a particular product or process.
- **Product improvement**: Directed to changes for a product or process that can increase its marketability, and reduce its cost or both.

We can also distinguish the concept of **product innovation** from **product development**. According to Mansfield (1981), R&D (incl. product development) is only a part of the activity leading to technological success. Of the total cost of product innovation, on average 40 % goes for tooling and for the design and construction of manufacturing facilities, 15 % for manufacturing and marketing start-up. However, a company's ability to produce significant innovations is closely related to the amount it spends on R&D (Mansfield, 1981). According to the general definition of Betz (1998), **innovation** means introducing a new or improved product, process or service into the marketplace. On the other hand, **invention** is the creation of a functional way to do something, an idea for a new technology. Invention results in knowledge, and innovation results in commercial exploitation of knowledge in the marketplace (Betz, 1998).

Several concepts of **performance** analysis presented in the literature are mixed and interrelated to each other. In the present study as a whole, we use the concept of performance in an extensive sense so that e.g. the concepts of *effectiveness, efficiency and productivity are included in it*.

Of these concepts, almost all definitions of **productivity** formulate it as follows (Rantanen, 1995):

$$\text{Productivity} = \frac{Output}{Input}$$

Productivity thus comprises the relationship of outputs and inputs. The content of these outputs and inputs depends on the level under examination (see e.g. Rantanen, 1995).

According to Tidd and Driver (2000), there is a demand for measures of the **efficiency and effectiveness of the innovation process**: efficiency in the sense of how well companies translate technological and commercial inputs into new products, processes and services; effectiveness in the sense of how successful such innovations are in the market and their contribution to financial performance.

More generally, according to Sink (1985), "effectiveness is the degree to which the system accomplishes what is set out to accomplish", i.e. how capable an organization has been in accomplishing the measurable objectives of its monetary and real, practical process. In his thesis, Rantanen (1995) differentiates the terms effectiveness and efficiency as by Horngren and Foster (1987): "Effectiveness is the degree to which a predetermined objective is met" and "efficiency is the degree to which inputs are used in relation to a given level of outputs".

According to the Product Development Management Association's (PDMA) Handbook of New Product Development (Rosenau et al., eds., 1996), **metrics** can be defined as a set of measurements to track product development and allow a firm to measure the impact of process improvements over time. These **measures** generally vary by firm, but may include measures characterizing both aspects of the process, such as time to market, and duration of particular process stages, outcomes from product development such as the number of products commercialized per year and percentage of sales due to new products. **Performance indicators** in the new product development are, by definition, criteria on which the performance of a new product in the market are evaluated, and a performance measurement system is defined as the system that enables the firm to monitor the relevant performance indicators of new products in the appropriate time frame (The PDMA Handbook of New Product Development, 1996).

At the general level, in this study we follow the good general definitions of performance measurement provided by Neely et al. (1996):

- **Performance measurement**: the process of quantifying the efficiency and effectiveness of action,
- **Performance measure**: a metric used to quantify the efficiency and/or effectiveness of action,
- **Performance measurement system**: the set of metrics used to quantify the effectiveness and efficiency of actions.

In some parts of our study, the term **evaluation** is used together with the term **measurement**. When discussing the concept of evaluation, the pre-evaluation of R&D projects or processes is not included in this study. On the other hand, in-process evaluation and post-evaluation are included. Generally, we use evaluation especially when discussing the qualitative aspects, which cannot be easily measured by numbers. Especially in this introductory part we use the term **performance analysis**[10] to include both performance evaluation and performance measurement. In order to make the matter complicated enough, the word **assessment** has also been used in some parts of the study. This concept has been used especially when concerning the self-assessments of R&D related to the quality management practices.

Other related concepts regarding the present research are **decision support systems (DSS)** and **Total Quality Management (TQM)**. According to The PDMA Handbook of New Product Development, (1996) TQM can be defined as follows: 'A business improvement philosophy which comprehensively and continuously involves all of an organization's functions in improvement activities'. According to Oakland (1993) TQM is an approach for improving the competitiveness, effectiveness and flexibility of a whole organization. It is essentially a way of planning, organizing and understanding each activity, and depends on each individual at each level (Oakland, 1993). DSS is discussed mainly in relation to **Group Decision Support System (GDSS) and the Analytic Hierarchy Process (AHP)**[11]. The GDSS, according to DeSanctis and Gallupe (1987), is an interactive computer-based system that facilitates the solution of unstructured problems by a group of decision-makers[12]. The AHP can be defined as a decision-making tool for complex, multi-criteria problems where both qualitative and quantitative aspects of a problem need to be incorporated (e.g. Saaty, 1980). The AHP clusters decision elements according to their common characteristics into a

[10] Here, we have to notify that *performance analysis* has different meanings in different contexts. *Performance analysis* in the *performance measurement* –literature is still a rarely used term. However, defining the term in the broad meaning as described here has been considered useful for the purposes and context of this study.

[11] The motives for utilizing these methods are discussed in Chapter 2.4.3 of this dissertation.

[12] According to Sauter (1997), also the DSS itself can be defined as a *computer-based* system that supports choice by assisting the decision maker in organizing information and modelling outcomes. However, the definition of the DSS in the present study consists of both manual and computer-based systems supporting decision-making.

hierarchical structure similar to a family tree or affinity chart (The PDMA Handbook of New Product Development, 1996).

Strategy is an essential element especially in two of the research articles included in this dissertation. In one of the articles, strategy is defined as by Quinn (1996): “A strategy is the pattern or plan that integrates an organization’s major goals, policies and action sequences into a cohesive whole”. Goals or objectives state what is to be achieved and when results are to be accomplished, but they do not state how the results are to be achieved. Major goals -– those that affect the entity’s overall direction and viability – are called strategic goals (Quinn, 1996). When all actions closely linked to strategy are collected together, we can talk about a **strategy process**. By definition (Lares-Mankki, 1994) the strategy process is a way of considering, deciding and realizing strategies. In the other publication we also discuss the concepts of **competencies and dynamic capabilities** in strategic management. The dynamic capability view of the firm can be seen as originating from the influential core competence thinking (Prahalad and Hamel, 1990) where the firm’s potential for competitive advantage and competitive strategy may be traced to specific core competencies distinguishing one firm from the other. According to Teece (1998) a dynamic capability is “the ability to sense and then to seize new opportunities, and to reconfigure and protect knowledge assets, competencies and complementary assets and technologies to achieve sustainable competitive advantage”. This view distinguishes three elements of corporate innovation strategy: 1) competitive and national positions, 2) technological paths and 3) organizational and managerial processes (see e.g. Teece et al., 1997, Tidd et al., 2001).

Additionally, In relation to strategy and strategic performance measurement, **the Balanced Scorecard (BSC)** -approach (Kaplan and Norton, 1992; 1996; 2001) provides an example of linking the performance measures of different perspectives and putting the strategy and vision at the center. The Balanced Scorecard complements financial measures of past performance with measures of the drivers of future performance. The objectives and measures view organizational performance from four perspectives: financial, customer, internal business process, and innovation and learning. BSC principles are utilized both in industrial companies and public organizations. The indicators of the different perspectives of the scorecard are based on **critical success factors**, which are the factors needed to gain the defined strategic objectives of each perspective.

2 AN OVERVIEW OF R&D PERFORMANCE ANALYSIS

2.1 R&D spending and performance in Finnish industry

The purpose of this particular section is to discuss the significance of R&D for Finnish industry, and the causal relationships between R&D spending and performance in general. Clarification of the phenomenon at the higher (national and industry) levels helps us to understand the significance of dealing with the issue at the lower levels (e.g. company, process or department), at where this study is mainly conducted.

Finland is assessed to be one of the most competitive countries in the world as assessed by several international institutions. The World Economic Forum (2003) rated Finland in 2002 the second both in its growth competitiveness ranking[13] and in its microeconomics competitiveness ranking[14]. In 2001 (WEF, 2002) Finland was rated the best in both rankings, when it overtook the United States of America in growth competitiveness, rising to the top from the sixth place of the year 2000. The International Institute for Management Development (IMD) (2002) in turn rated Finland in 2002 the second in its competitiveness ranking, right after the USA. The Finnish technological infrastructure was rated in 2001 the third best in the world after the USA and Sweden. In the scientific infrastructure index Finland came sixth. According to a report of the United Nation's (UN) development organization UNDP (2002), Finland is technologically the most advanced country in the world. Two criteria, which put Finland ahead of the US, which came second, were Internet penetration and the population's above-average know-how.

At the national level, R&D spending as a percentage of Gross Domestic Product (GDP) is an indicator of R&D input. The share of R&D expenditure in GDP expresses a country's relative efforts to create new knowledge, to disseminate and to exploit the existing knowledge bases both in the public and the business sector. Figure 4 shows how the spending on R&D has changed in some OECD-countries during the years 1993-2000 (Statistics Finland, 2003). Many of the countries assessed to be at the top in the global competitiveness rankings spend more on R&D than many non-competitive countries. This indicates some kind of positively correlative relationship between R&D spending and competitiveness. There are also earlier studies in which it is concluded that there is a significant positive correlation between R&D spending and economic growth (e.g. Mansfield, 1981; Bean, 1995). However, many of the impacts that arise from spending on R&D take several years to become forth. This is why no direct cause-and-effect relationships can be put between the spending on R&D and a nation's or company's performance. The interest of researchers concern mainly the following questions: What is the right, reasonable amount to be spent on R&D and what is the right timing of spending on it? There is no easy answer to this, because we have to remember that R&D spending is by no means the sole determinant of new product performance or even sales generated by new products (Cooper, 1993). Even though there is encouraging evidence in Finland to spend more on R&D in order to be more competitive, we cannot directly recommend spending more, because more can never be enough. In addition, the structures and clusters of industry are different in different countries, and R&D spending in e.g. the

[13] The overall Growth Competitiveness Index measures the capacity of the national economy to achieve sustained economic growth over the medium term, controlling for the current level of development (WEF, 2003).

[14] The Microeconomic Competitiveness Index examines the microeconomic bases of a nation's prosperity measured by its level of GDP per capita (WEF, 2003).

information and communications cluster can be strategically much more significant than in a more traditional industry.

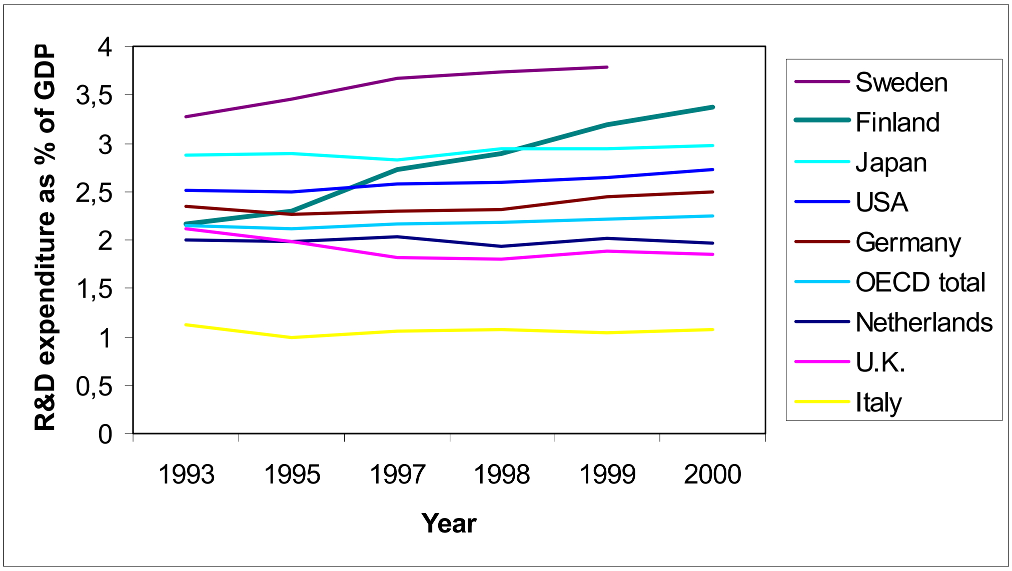

Figure 4. R&D expenditure as percentage of GDP in selected OECD-countries 1993-2000 (Statistics Finland, 2002; 2003)[15,16].

Our study addresses R&D management and performance measurement at research institutes and industrial companies from the ICT and manufacturing (metal and electronics) industry. The development of the management of R&D through effective measurements in all these sectors puts forward the sustainability and improvement of high-level competitiveness and justification for significant amounts spent on R&D at national level, as well.

2.2 Dimensions of R&D performance analysis

This section deals with the main dimensions to be taken into account prior to the actual selection of performance measures for R&D. The main dimensions concerned in this study are the purpose of R&D performance analysis, the level of R&D performance analysis, the type of R&D to be evaluated, the phase of the R&D process to be measured and the perspectives of performance measurement. It can be argued that strategy and the strategic objectives set emphasized areas to the various measurement perspectives. Other influencing dimensions not discussed in the present research in detail are for instance the type of industry and the size of the organization. These, as well as the strategic control model chosen for the R&D organization have been found to be of importance (e.g. Kerssens-van Drongelen, 1999) in developing the measurement systems for R&D. In this study, these factors can be seen as constraints that have consequential influences on the dimensions presented below in Table 1. For instance, depending on the industry characteristics in which to operate and on the general control model of the organizations, firms emphasize certain types of R&D and have certain

[15] The data concerning the year 2000 was not available for Sweden. However, the preliminary data of R&D in Sweden in 2001 show the R&D expenditure as percentage of GDP to be 4,28 % (Statistics Finland, 2003).
[16] Preliminary data of R&D in Finland in 2001 (Statistics Finland, 2003) shows that the growth of GDP share of R&D has decelerated significantly as compared to the 1990s, having been 3.40 % in 2001, and 3.37 % in 2000.

purposes for measuring, which could be for example R&D benchmarking of competitors in a fiercely competitive industry. Actually the impact of industry specific characteristics on the measures and challenges of R&D performance analysis concerning the ICT industry have been discussed and also compared to more traditional industries in Publication 5 of this dissertation, but the industry specific emphasized characteristics are here seen as constraints that influence certain challenges more than others (see Publication 5), and again, these emphasized challenges can have consequential influences on the dimensions presented in Table 1 below.

Table 1. The dimensions of R&D performance analysis in the present study (see e.g. Ojanen and Vuola, 2003a)[17].

The purpose of measurement	Measurement level	R&D type	Process phase	Measurement perspectives
Strategic control	Industry	Basic research	Input	Customer
Justification of existence	Network	Exploratory research	In-Process	Internal
Benchmarking	Company	Applied research	Output	Financial, shareholders
Resource allocation	Strategic Business Unit (SBU) / department	Product development	Outcome	Other stakeholders
Development of activities / problem areas	Process	Product improvements (incremental)		Learning
Motivation, rewarding	Project			Etc.
Etc.	Team			
	Individual			

In the literature we can find several suggestions for the measurement of R&D at different stages or different purposes, or what kind of evaluation methods to use for certain types of R&D. These aspects and measures discussed in the sections below can be used as checklists prior to the selection process of R&D measures. The emphasis of different factors set different requirements for evaluation criteria in the final selection of R&D performance measures. As we can see in Table 1 above, all the combinations of the dimensions do not exist or do not come into the question, but the main idea is to clarify the possible organization- or case-specific combinations of dimensions for tracking the most essential areas to be measured. The studied dimensions of R&D performance analysis with regard to our research are discussed in Chapter 4. Additionally, the publications in the second part of the thesis deal with the essential issue of the linkages of various dimensions of R&D performance analysis to the requirements and criteria of measure selection, to the methods applied in the selection

[17] The areas in each of the dimensions should be treated as examples; they are drawn from both literature reviews and empirical material of R&D performance analysis. Similar areas of the dimensions can be discussed by different terms in other publications. The content of the dimensions concerning this particular study are discussed in the sections below.

process, the factors of performance, measurement areas, and finally, the measures or evaluation methods of R&D performance. The dimensions-table and its linkage to the selection process of R&D indicators have been utilized in practice for various purposes (see Ojanen and Vuola, 2003b).

Figure 5 below depicts the main principles of the influence of measurement dimensions on the selection process of R&D performance measures. In Chapter 4, I will also clarify the context of the selected publications of the second part of the thesis with the help of the three of measurement dimensions, i.e. level of analysis, type of R&D and the purpose of R&D performance measurement in the case studies. The simplified approach in Figure 5 can also be seen as one cornerstone to organization-specific case studies (see the publications in the second part of the thesis), in which the main emphasis, however, has been on the phased selection process of R&D performance measures.

The approach depicted in Figure 5 consists only of the main components of this construct. For instance, the influencing dimensions include several "dimensional aspects" and sub-areas, which are presented in Table 1 above and more in detail in Chapters 2.2.1-2.2.5 below. As mentioned above, the selection process itself and its promotion has been the emphasized area in different case studies. The case studies conducted during several years of research of R&D performance analysis have included case-specific process modifications (e.g. Appendix 3) with a basis on a general preliminary framework of R&D performance measure selection process, which is presented in Publication 2 of this dissertation.

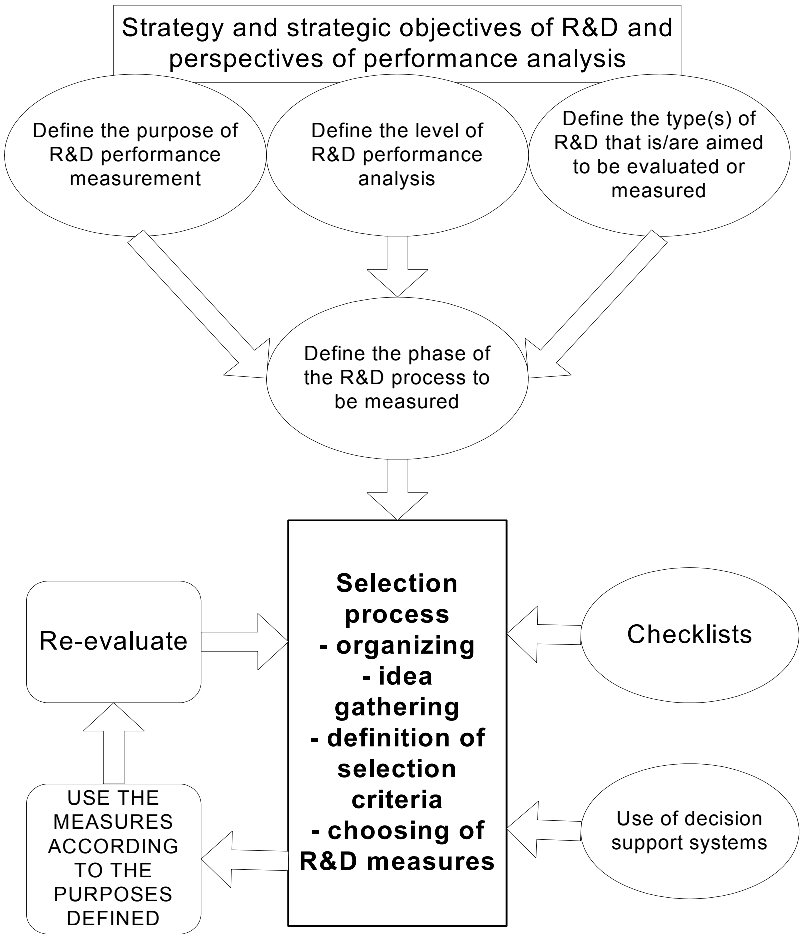

Figure 5. Simplified system approach for selecting and developing performance measures and evaluation methods for R&D (Ojanen and Vuola, 2003a; adapted from Publication 6).

2.2.1 Purposes of R&D performance analysis

Measures as such are useless, if they are not utilized in the decision-making and management. Therefore, it is very essential to clarify the main purposes of measurement prior to the measure selection. If the purposes are communicated throughout the organization, the employees may also be more motivated and they might have a less negative attitude towards all kinds of measurements, which is one of the problem areas in R&D performance analysis. The problems and challenges in R&D performance analysis will be discussed more in detail in Chapter 2.3 below.

Generally, the meaning of measurement in steering and management is based, for instance, on following aspects: measurement a) motivates, b) underlines the value of measurement subject, c) directs to do the right things, d) clarifies objectives, e) poses competition, and f) creates prerequisites for rewarding (Uusi-Rauva, 1994).

Park et al. (1996) have mentioned the following reasons for measuring performance in general:

- To characterise, and to gain understanding of processes, products, resources and environments, and to establish baselines for comparisons with future assessments
- To evaluate, and to determine the status with respect to plans
- To predict, and thus enable planning
- To support improvement by gathering information that helps to identify problems, and by planning and tracking improvement efforts.

Lee et al. (1996) argue that measuring the effectiveness of R&D is important in determining whether the investment is justified and whether its maximum productivity is achieved. It is also essential in motivating and rewarding workers and in assessing the contribution of R&D to the company's business. Kerssens-van Drongelen and Cook (1997) present two clusters of purposes for performance measurement, each requiring its own approach to measuring. First, performance measurement can serve the purpose of motivating people. Secondly, there is a group of purposes associated with diagnosing activities (e.g. projects) and organizational units.

Kerssens-van Drongelen and Bilderbeek (1999) have studied empirically the purposes for measurement at different levels of analysis. The most often mentioned purposes are presented in Table 2 below.

Table 2. The most often mentioned purposes of R&D performance measurement at different levels (Kerssens-van Drongelen and Bilderbeek, 1999).

Level	Purpose
Team	Progress control / correction
Individual	Decision-making about promotion prospects
Department	Assignment of resources
Company	Correction

Other relevant references that distinguish R&D measures by different purposes for measurement are, for instance, the studies of Gold (1989), Schumann et al. (1995), Meyer et al. (1997) and Loch and Tapper (2002).

2.2.2 Levels of R&D performance analysis

Business performance can be measured at many levels. For instance, Lynch and Cross (1995) have presented a Performance Pyramid, which is a four-level pyramid of objectives and measures and it ensures a link between strategy and operations by translating strategic objectives from the top down and measures from the bottom up.

The joint total effect of several sub-areas and functions and complex causal relationships affect the whole corporate performance. Cordero (1990) proposes technical performance to be evaluated at the level of R&D unit, commercial performance to be evaluated at the level of e.g. marketing or manufacturing unit, and overall performance to be evaluated at the firm or SBU level.

According to Griffin and Page (1996) success of a development project may be measured not only at the level of the individual project, but also at the program level. In their study, empirically validated recommended project-level success measures that depend on the project strategy, and recommended firm-level success measures that depend on the firm's innovation strategy, are presented. As argued by the authors, firms with least innovative strategies find it useful to focus on measuring the efficiency of their product development program, firms with moderately innovative strategies find that measures that provide information about both the efficiency and effectiveness of their programs are most useful, and firms with more innovative strategies need to measure how product development has contributed to growth (Griffin and Page, 1996).

At the firm level, several earlier research papers have tried to explain the contribution of R&D to the whole company performance. For instance, Mcgrath and Romeri (1994) have proposed an effectiveness index (EI) that combines growth through new products with current return. The formula is

$$EI = \frac{\%\ \text{New Product Revenues} \times (\text{Net Profit}\ \% + \text{R \& D}\ \%)}{\text{R \& D}\ \%}$$

The originators define an index greater than 1.0 when the return from new products is greater than the investment in them. For example, if a company has a 9% net profit percentage and it invests 6% of its revenue to research and development, and 40% of the total revenues are derived from new products, the company would have an EI of 1.0. However, R&D managers will quickly realize that this formula expects results on a very short time frame, as opposed to the investment nature of R&D (Ellis, 1997). In the study reported by Mcgrath and Romeri (1994), the R&D EI was computed for companies participating the study. Of the participants, 39 % had an R&D EI greater than 1.0, indicating that new products generated more profit than the investment made in R&D. The index has been validated through a study of 45 electronic systems companies. The researchers have found a strong relationship between R&D effectiveness and other performance factors.

Werner and Souder (1997a) present an example of an **integrated metric** to company-level measurement, in which several objective and subjective metrics are combined:

$$A = \text{Effectiveness index} = \frac{\begin{array}{c}\text{Present value of revenue generated from}\\ \text{products introduced in the last 5 years}\end{array}}{\text{Present value of last 5 years cumulative R \& D costs}}$$

$$B = \text{Timeless index} = \frac{\begin{array}{c}\text{Number of projects completed on time}\\ \text{during some representative period}\end{array}}{\text{Number of projects started in that period}}$$

$$C = \text{Future potential index} = \frac{\begin{array}{c}\text{Present value of expected future revenues from}\\ \text{technologies currently under development}\end{array}}{\begin{array}{c}\text{Present value of all costs to develop}\\ \text{these technologies}\end{array}}$$

D = Peer rating audit of unfilled future needs that will inhibit the achievement of future greatness, expressed on a scale from 0 to 100%.

O = Overall assessment of the value of R&D = A + [(C × B) × D]

Integrated methods of R&D performance evaluation combine objective and subjective metrics, thereby enhancing the advantages of both types of measurement. Integrated metrics are often more complicated than individual measures, and their use can be more costly and time-consuming than that of simple metrics. However, they do not only measure R&D performance but suggest also means for improvement and are reliable (Werner and Souder 1997a).

Other relevant references helping in categorization on the basis of the level of R&D performance analysis are e.g. the studies of Loch and Tapper (2002), Kerssens-van Drongelen and Bilderbeek (1999) and Brown and Gobeli (1992). Of these, Loch and Tapper's study presents performance measures of GemStone's Research Group categorized to group level and project level output measures and project level process measures. Kerssens-van Drongelen and Bilderbeek's study presents the results of an empirical study focusing on the effectiveness of R&D performance measurement practices in the Netherlands. They categorize the measures of different perspectives to the team level, individual level, departmental level and company level. Brown and Gobeli (1992) have utilized "R&D hierarchy of activities" as a framework, including three basic levels; 1) division goals, 2) project management and 3) activities and processes within R&D. Each of the basic levels contains several important activities that need to be measured.

2.2.3 Types of R&D

Traditionally, R&D activities can be divided into functions or stages in which the various evaluation techniques are adapted. According to Pappas and Remer (1985), qualitative techniques are best suited for basic (or exploratory) research, semi-quantitative techniques for applied research and quantitative techniques for product development and improvements. Quantitative techniques usually follow a specific algorithm or predefined ratio to generate numbers that can be compared with other projects and past experiences. Semi-quantitative techniques are basically qualitative judgments that are converted to numbers, and qualitative techniques are intuitive judgments.

In addition to this, in an earlier literature search, Werner and Souder (1997a) have categorized the reported assessment methods of different types of R&D into quantitative-objective metrics, quantitative-subjective, and qualitative-subjective metrics depending on whether the nature of measurement is numerical or non-numerical and whether the measures are based on objective information or the assignment of subjective judgments. According to their study, the most successful approach to R&D effectiveness measurement appears to be integrated metrics that combine multiple objectives and subjective methods. Integrated metrics that contain an articulated but separable suite of quantitative and qualitative techniques can be flexibly applied across all types of R&D.

To understand better how the metrics vary, Hauser and Zettelmeyer (1997) have introduced a tier metaphor, which makes it possible to categorize a diverse continuum of projects, programs and explorations and focus on key characteristics. “Tier 1” is defined as basic research that attempts to understand basic science and technology. Tier 1 explorations may have applicability to many business units or may spawn new business units. “Tier 2” is defined as those activities that select or develop programs to match the core technological competence of the organization. “Tier 3” is defined as specific projects focusing on the more immediate needs of the customer, the business unit and/or the corporation. For applied projects, market outcome metrics are most relevant. In their study, Hauser and Zettelmeyer present R&D metrics, both qualitative judgments and quantitative measures, reported by interviewees, as well as their relevancy for the Tiers.

Additionally, the studies of Brown and Gobeli (1992), Kim and Oh (2002) and Loch and Tapper (2002) are examples of several studies that categorize measures of R&D by different types of R&D.

2.2.4 Phases of R&D process

As suggested in several studies (e.g. Cooper, 1993, Tidd et al., 2001), innovation and R&D should be managed as a process. This suggestion is also followed in the present study. The influences of the process can be manipulated to affect the outcome – that is, it can be managed (Tidd et al., 2001). Managing the R&D process contributes to the effectiveness of innovation performance and makes the desired impact on downstream operations (Ellis, 1997).

In the approach presented by Brown and Svenson (1988), R&D as a processing system includes a number of phases that contain several subjects for the measurement of performance. The contents of inputs, processing systems, outputs of processing systems, receiving systems and outcomes, as well as their linkages to each other, were discussed above in Chapter 1.3. Outputs are traditionally measured on three dimensions: quality, quantity and cost. Outcomes must also be measured, since the real value that the R&D facility adds to the organization can only be assessed by measuring the outcomes. Therefore, it is necessary to consider an array of metrics including both results or lagging metrics such as outcomes and outputs, and candidates for precursors of leading indicators in interactions, processes and inputs (see e.g. Ellis, 1997).

According to the model presented by Cordero (1990), it is necessary to measure marketable outputs, technical outputs, resources to commercial units, and resources to technical units to evaluate the overall innovation performance of a firm.

Other references presenting measures or evaluation methods of R&D as distinguished by the different phases of R&D or innovation process are e.g. the studies of Brown and Gobeli (1992), Schumann et al. (1995), Ellis and Curtis (1995), Chiesa et al (1996), Lee et al (1996).

2.2.5 Measurement perspectives in R&D performance analysis

Performance analysis in general has recently been widely discussed in the context of strategic management. The Balanced Scorecard (BSC) -approach (Kaplan and Norton, 1992; 1996; 2001) provides an example of linking the performance measures of different perspectives and putting the strategy and vision at the center. The BSC can be seen as a cornerstone of a strategic management system (Kaplan and Norton, 1996; Martinsons et al., 1999) and it has also been adapted for R&D management (see e.g., Curtis and Ellis, 1997; Kerssens-van Drongelen and Bilderbeek, 1999). BSC principles are utilized both in industrial companies and public organizations. The indicators of the different perspectives of the scorecard are based on the critical success factors needed to gain the defined strategic objectives of each perspective.

In this study, "perspectives" are seen as both the measurement areas derived from the strategic objectives, similar to the BSC approach, but with more alternatives to categorizing the areas, and as measurement subjects that are derived from strategic objectives or set and emphasized by the management. The essential question concerning the selectable measurement subjects and measures here is: Whose perspective do we take into the measurement? Depending on the situation and the main reasons for measuring, the perspective to the measurement of R&D can be e.g. the chief executive officer's or chief technology officer's perspective. The selectable measures are different in different perspectives, and finally, the whole set of measures usually consists of selected measures from several perspectives.

Earlier studies have reported several ways of categorizing the measures by different measurement perspectives. According to Kerssens-van Drongelen and Cook (1997), all the metrics that have been identified in the literature can be categorized as operationalizations of one or more of the five top level measures – cost, quality, time, innovativeness and contribution to profit. Kerssens-van Drongelen and Bilderbeek (1999) also present reported measures of performance as categorized by the principles of the Balanced Scorecard – approach.

The study of Hultink and Robben (1995), based on a literature review and surveys in the Netherlands, resulted in five general categories of success and failure measures, namely: measures of firm benefits, program-level measures, product-level measures, measures of financial performance and measures of customer acceptance.

Curtis's study (1994) analyzes the use of time as an alternative performance measure to cost for managing financial performance. The focus of the study is on new product development and it presents methods and internal and external factors to be taken into account in avoiding the "acceleration trap" and in achieving better results in the key measures of time and financial performance.

The study of Curtis and Ellis (1997) presents a balanced scorecard for new product development supported by four years of survey research in a wide variety of technology- or market-driven industries. The study presents recommended measures for the following desired innovation process outcomes: financial performance, speed-to-market and customer satisfaction.

Tipping et al. (1995) presents top 11 metrics out of 33 metrics in their "technology value pyramid" as assessed by 165 industrial companies. Their model provides a top-down perspective that is output-oriented. The top 11 metrics were:

- Financial return to the business
- Strategic alignment with the business
- Projected value of R&D pipeline
- Sales or Gross profits from new products
- Accomplishment of project milestones
- Portfolio distribution of R&D projects
- Customer satisfaction surveys
- Market share
- Development of cycle time
- Product quality & reliability
- Gross profit margin

The interesting results of a study of Driva et al. (2000) show that a gap does exist between the measures recommended by the academics and those used in practice. The main difference lay in the fact that companies use basic time, cost and quality measures, whereas academics would like to see an increased use of customer-related measures at the design and development stages. The empirical results of the study are based on a company survey of 150 responses.

In their study of U.S. and German practices of R&D performance measurement, Werner and Souder (1997b) concludes that quantitative output metrics are favoured in the U.S., whereas German managers prefer input metrics that simply measure the intrinsic worth of R&D. Additionally, they report primary measurement methods by country and industry.

Akcakaya (2001) presents a model for assessing R&D effectiveness. In his model, both quantitative and qualitative assessment criteria exist. Quantitative information is categorized to general information, product development, technology development and technology sales, whereas qualitative self-assessment criteria are categorized to intangible results, conditions and methods.

Cooper's and Kleinschmidt's benchmarking study (1996) of 161 business units includes ten performance metrics, which capture how well the business unit's total new product effort performs:

- Success rate: The proportion of development projects that became a commercial success
- Percentage of sales by new products (introduced within the last three years)
- Profitability relative to spending
- Technical success rating
- Sales impact
- Profit impact
- Meeting sales objectives
- Meeting profit objectives
- Profitability versus competitors
- Overall success

Additionally, the study of Griffin and Page (1996) categorizes project-level measures to customer-based success, financial success, and technical performance success. In their study the average utility of the success measures is calculated for each project strategy.

2.3 The problems, challenges and development needs of R&D performance analysis

The challenges and problems concerning the evaluation and measurement of R&D have been observed in a large number of earlier studies (see e.g. Gold, 1989, Brown and Svenson, 1988). One of the most problematic aspects is the selection of a suitable set of appropriate measures for the right subjects of measurement, but besides this there is also the problem of determining the right norms to compare with. Other substantial problems are the definition of the contribution of R&D and the time lag between the initial stage of the process and the outputs or the outcomes. Brown and Svenson (1988) list several reasons that cause R&D evaluation or measurement systems to fail: 1) too much emphasis on internal measurement, 2) too much focus on behavior, 3) the measurement system is too complicated, 4) the measurement system is too subjective. Especially when planning the measures or evaluation methods to be implemented for basic or exploratory research, many problems can appear. The time lag between the inputs and outputs is even longer than with development or engineering activities, the future outputs themselves can be vague, and the overall uncertainty is high.

In her study, Kerssens-van Drongelen (1999) also brings forth the problem of the acceptance of performance measurement in R&D. Traditionally, many engineers and scientists have believed that the design and implementation of a measurement system is counterproductive, as the very act of measurement is thought to discourage creativity and to reduce motivation among highly educated technical people (Pappas and Remer, 1985). This problem cannot be passed by in the development of measurement systems, to be able to validate the need for such a system and create a more positive attitude to performance analysis in general.

2.3.1 Quest for more versatile sets of R&D measures

The following statements related to the problem areas in R&D performance analysis are drawn from empirical interviews in ICT and manufacturing companies. The interviewees are managers or directors from R&D or function closely related to R&D. These functions are business management, marketing, sales, manufacturing, after sales and quality management.

”The balance of R&D measurements should be deployed so that the significance of the financial measures should be little less emphasized.”
- An interviewee (Director, R&D), an ICT company

”Time is the number one criterion, then costs, then quality.”
- An interviewee, (Manager, R&D), an ICT company

"The results of R&D should be measured in several ways, for instance, by comparing the product to the competitor's product, by assessing whether R&D can produce business, by clarifying the customer utilities of products, and by assessing the length and efficiency of projects."
- An interviewee (Product Manager), a manufacturing company

"The (R&D performance measurement) system should be able to balance the effectiveness and creativity and to develop both of them."…"Competitiveness and customer satisfaction are the ultimate measures of R&D, not the cycle time of product development."
- An interviewee, (Development Manager), a manufacturing company

These statements drawn from our empirical research of R&D performance analysis practices in several units of manufacturing and ICT companies reflect the need for measurement of R&D performance from several perspectives with the support of several dimensions of measurement.

In manufacturing companies, the gap between the used and desired measures, evaluation methods and areas of measurement is revealed in Publication 1 in the second part of the thesis. The analysis clearly shows the need for more versatile sets of R&D measures. Similar trends can be traced in qualitative analysis in the ICT sector, even though in a minor scale. Additionally, similar trends can be traced in the literature reviews (see e.g. Chapter 2.2.5 for studies on different perspectives of R&D performance analysis).

According to the analyses executed in companies, a holistic, objective view towards measurement is needed for minimizing the sub-optimization effects of activities and making the measurement systems less subjective, which has been recognized as a central problem also in earlier studies (e.g. Brown and Svenson, 1988). This development need has influenced the approaches we have developed for selecting the measures for R&D in the way that all essential factors influencing the choosing of measures would be carefully taken into account.

2.3.2 Quest for R&D measures directly utilizable in the management and decision-making of R&D

The following statements related to the problem areas in R&D performance analysis are drawn from empirical interviews in ICT and manufacturing companies. The interviewees are managers or directors from R&D or a function closely related to R&D. These functions are business management, marketing, sales, manufacturing, after sales and quality management.

"At the moment, measures are not directly and clearly utilized in decision-making."
-An interviewee (Manager, R&D), an ICT company

"The measures should steer activities objectively."
- An interviewee (Manager, R&D), an ICT company

"One of the vital deficiencies is that right cases (projects) cannot be selected, the other one is the evaluation of the real impact (of R&D)."
-An interviewee, (Manager, R&D), a manufacturing company

"*For steering purposes, all the business dimensions should be concerned in the measurement.*"
-An interviewee (Manager), a manufacturing company

This development need is strongly linked to the very essence of the purpose of R&D performance analysis, which has been reported in the several earlier studies (Chapter 2.2.1). In addition to the interview statements above, several individual opinions were related to the quest of more directly utilizable measures. Even though there have been different measures in use, their utilization in practice has not been on a desired level.

This development need influences the selection process of measures as well. The main influence is on the selection criteria, when the purpose of measurement plays an essential role in the early phases of the selection process, and the simplicity and ease of use could be very noteworthy criteria in the selection, when the aim is to find measures that are effectively utilized and understandable for use in practical management.

2.3.3 Quest for systematic approaches for choosing the right measurement subjects and measures for R&D

The following statements related to the problem areas in R&D performance analysis are drawn from empirical interviews in ICT and manufacturing companies. The interviewees are managers or directors from R&D or a function closely related to R&D. These functions are business management, marketing, sales, manufacturing, after sales and quality management.

"The selection (of measures) should be systematized and various parties should participate in it."
-An interviewee (Director, R&D), an ICT company

"Evaluation (of R&D) is very difficult and good measures have not been found, even though several references and models have been studied for it."
- An interviewee, (Development Manager), a manufacturing company

This development need can be derived from the two others discussed above. Similarly, some of the opinions of the interviewees that stressed the recognition of the need for more systematic approaches and tools for selecting the right measures for R&D. As discussed earlier, the literature reviews have also revealed the lack of systematic, practical approaches for the selection and development processes of R&D measures. Both literature reviews and empirical interviews have stressed, for instance, the problems of focusing on internal measurement and subjectivity of measurement systems.

Through the literature reviews and our empirical case studies and interviews we have steered our research of R&D performance analysis towards constructing new approaches for selecting the R&D measures. The selection process should therefore

- take all the essential dimensions of measurement and other factors influencing the selection more strongly into account,
- support the choosing of purposeful measures that could be as directly as possible utilized in R&D management,
- be systematic and objective.[18]

2.4 Selection of R&D performance measures as part of the development of R&D measurement systems

2.4.1 Earlier models of constructing performance measurement systems in general and in R&D

In addition to the technology and R&D management point of view, there is also a need to reflect the present study to the general doctrine of developing corporate performance measurement systems, e.g. BSC-based approaches. Toivanen (2001) has developed a model for a successful implementation of a Balanced Scorecard –based project. The model was developed because of the flaws that were found in earlier Balanced Scorecard project models. According to Kaplan and Norton (2001) the failures in BSC projects can be either design failures (e.g. no overall coordination or linkage for group and corporate-level synergies) or process failures. Seven types of different process failures in companies' scorecard projects have been identified by Kaplan and Norton (id.):

1. Lack of senior management commitment
2. Too few individuals involved
3. Keeping the scorecard at the top
4. Too long a development process; the Balanced Scorecard as a one-time measurement project
5. Treating the Balanced Scorecard as a systems project
6. Hiring inexperienced consultants
7. Introducing the Balanced Scorecard only for compensation.

Toivanen's model was based on the empirical interviews of managers and consultants as well as on an extensive literature review on performance measurement systems design and implementation models. In the construction of his model Toivanen utilized e.g. the BSC-model (Kaplan and Norton, 1992; 1996; 2001), the Performance Pyramid (Lynch and Cross, 1995), Tableau de Bord (e.g. Epstein and Manzoni, 1998), Maisel's model (Maisel, 1992) and Laitinen´s (1998) dynamic performance measurement model. According to conducted

[18] A recent quantitative survey (Lempinen, 2003) on R&D performance measurement in 60 Finnish manufacturing companies supports the relevance of the observed main challenges of our qualitative analysis. The results of the survey show that measurement is seen as a complicated issue in many companies, because there is a lack of systematics and experience of measurement. The results also show that organizations aim to more versatile sets of R&D measures. Additionally, the R&D managers that participated in the survey strongly agreed that R&D can be steered in accordance with the strategic objectives with the help of performance measurement.

surveys and case studies, Toivanen's model was more suitable for Finnish business culture than the earlier models. The model consists of ten main steps:

1. Clear decision to start the BSC project
2. Management's real commitment to the project
3. Clarification of vision and strategies
4. Definition of the critical success factors
5. Setting of objectives and selection of measures
6. Commitment of the organization
7. Cutting down and supplementing the measures
8. Accommodation of the set of measures to different parts of the organization
9. Setting game plans to achieve the objectives
10. Development of the measurement systems according to the principles of continuous improvement

By market tests, Toivanen's model has been proved to be working. The well-working aspects when compared to earlier BSC models are e.g. questioning the whole BSC-project and the value-added provided by it in the first phase of the process, and on the other hand the commitment of the managers and the whole organizations to the project. Toivanen's model is also more focused on BSC to be a strategic steering system rather than a control system by paying more attention to the cause-and-effect relationships between the measures. The commitment aspects as well as the strategic steering aspects have been, however, emphasized more also in the latest studies of Kaplan and Norton (2001). For practical utilization Toivanen's model is very useful as it is relatively flexible and not too heavy to be adapted for different organizations.

There are also models for designing measurement systems particularly for R&D. In her thesis, Kerssens-van Drongelen (1999) presented a PSDA (Performance measurement system Systematic Design Approach) model. The model consists of four main phases, which are 1) Problem definition phase, 2) Conceptual design phase, 3) Detail design phase, and 4) Implementation phase. Each phase includes several proposed R&D performance measurement system design tools and guidelines. There is empirical evidence that this approach has also added value in the design of R&D performance measurement systems when compared to earlier models. Additionally, in his thesis, Akcakaya (2001) proposes a procedure for the assessment of R&D performance in a manufacturing company. His model takes into account the main factors in the determination of R&D performance of a firm, i.e. results of R&D activities (both tangible and intangible), as well as the conditions (assets and environment) in which R&D unit operates, and the effort spent. The developed methodology in his thesis combines useful aspects of previous approaches to generate a simple but comprehensive tool for assessment of R&D effectiveness (Akcakaya, 2001).

2.4.2 Factors and criteria influencing the selection

In the development of measurement systems for R&D, the selection of measures is a very crucial task, which is strongly emphasized in this study. The selection process should be guided by recognition of the essential dimensions of measurement discussed above. Especially, clear definition of the purpose of measurement in the early phases of measurement system development gives a strong basis for the selection of right measures, which can be effectively utilized in the decision-making of R&D. The recognition of the situation-specific combination of measurement dimensions has also influence on the final selection criteria of measures. For instance, the study of Griffin and Page (1996) presents recommended measures for both project-level and firm-level measures. The study combines the levels of analysis and strategic perspectives of measurement. As argued by Griffin and Page (1996), firms with least innovative strategies find it useful to focus on measuring the efficiency of their product development program, firms with moderately innovative strategies find that measures that provide information about both the efficiency and effectiveness of their programs are most useful, and firms with more innovative strategies need to measure how product development has contributed to growth.

As stated in the literature, R&D performance metrics have to meet certain demands; they should fit the strategic vision of the business (Schmitt, 1991) and reflect the critical success factors (Nixon and Innes, 1997). Corporate strategy, customer needs and technological capabilities must be taken into account when defining the objectives for R&D and new product development. A clearly defined strategy and R&D objectives are significant preconditions for successful R&D and performance control. Several studies exist about the common critical factors influencing the success of a new product (e.g. Cooper and Kleinschmidt, 1996; Bahalandra and Friar, 1997; Lester, 1998).

Some earlier studies deal with the choosing of R&D metrics and design principles for the development of measurement systems. Nixon and Innes (1997) have come to the conclusion that the choice of measures and the way they are used in specific situations are influenced by at least four factors: (a) top management views on R&D measurement; (b) different perspectives that need to be accommodated and balanced; (c) risks inherent in R&D; and (d) features specific to certain industries. Ellis (1997) puts forward the following considerations for the selection of a manageable list of leading or precursor indicators:

- Select those measurements that have been found important by earlier studies.
- Select those measurements that have been shown to have more than a minor correlation with outcomes of interest to general management.
- Select a set of metrics balanced as to their value as precursors of each of the four major outcomes: customer satisfaction, timeliness, new products and/or services, and financial results.
- Select those metrics that more nearly match your company's strategic intent.

According to Akcakaya (2001) the requirements for an R&D assessment model can be stated as:

- Usability; simplicity of use, acceptability by the reviewers, top management, R&D management and R&D staff
- Usefulness; providing beneficial results and guidance
- Objectivity and credibility
- Comprehensiveness; need to take into account all aspects of R&D
- Adaptability (to different types of organizations).

Kerssens-van Drongelen and Bilderbeek (1999) have studied R&D performance measurement by linking theory and practice. They made empirical interviews and used questionnaires in various companies. In their empirical research, the major parameters for R&D measurement system design were: the structure of the measurement system, the measures of performance (metrics), standards to measure performance against, measurement techniques, and the frequency of measurement and reporting. The choices concerning these parameters are primarily determined by the purpose of measurement and the objectives formulated for the subject of measurement. Other contingency factors that influence these choices are: the organizational level at which measurements are done, the type of R&D, the type of industry, the company size, the R&D organization size and the strategic positioning of and control model chosen for the R&D department.

It is obvious that suitable metrics must be found for essential measurement subjects. The metrics have to pay attention to the whole where they are used. Otherwise, the use of the metrics can lead to sub-optimization, and the measures can cause trouble rather than be useful. There are certain common requirements for single performance measures (e.g relevance, validity, reliability, timeliness, diagnosticity, informativeness, cost efficiency, demonstrativeness) and for the measurement systems (see e.g. Laitinen, 1996). However, in R&D all the important aspects and subjects that should be evaluated cannot be quantitatively measured. In R&D, the identification of the subjects for follow-up is more essential than finding explicit and measurable evaluation criteria. The recognition of the essential measurement dimensions (Table 1, Chapter 2.1), in the first place, helps us to identify the measurement subjects. In the previous chapters (2.2.1-2.2.5) the earlier studies of performance analysis were categorized by the dimensions. The impact and weightings of the dimensional aspects are case-specific, but some general proposals of utilizable models can be found in the literature: For instance, there is Brown and Svenson's (1988) model to be recognized for the dimension of R&D process phase, Pappas and Remer's (1985) and Werner and Souder's (1997a) models for the use of different evaluation methods for different types of R&D, the BSC approach (Kaplan and Norton, 1992) for general recognition of the measurement perspectives or Kerssens-van Drongelen and Bilderbeek's (1999) approach for adapting the BSC for R&D management. Additionally, Kerssens-van Drongelen (1999) has presented requirements and guidelines deduced from literature regarding the different measurement functions, i.e. purposes, and Griffin and Page (1996) propose different product development success measures for different strategies and different levels of analysis.

2.4.3 Utilization of decision support systems in the selection process

The decision about selecting the right measures for R&D is a crucial element in the performance analysis of R&D. The selection decision is not an easy one: several opinions, measurement dimensions and influencing factors have to be taken into account, a huge amount of potential measures exists for different purposes, and the decision results can have multiple effects on different levels of organization and individual persons. Thus, we can summarize that the selection of right R&D measures is a multi-dimensional, multi-criteria, and multi-person task, which is difficult to execute effectively, and the adapted decision support systems provide features that can support the handling of different challenges in relation to these task characteristics. Because of the complexity of the matter, the adaptability of various decision support systems is assumed to bring effectiveness to the selection of a suitable set of performance measures for R&D.

There exists a great amount of decision support systems. Regarding the present research and the case studies included in it, I will discuss in detail only two utilized approaches – Group Decision Support Systems (GDSS) and Analytic Hierarchy Process (AHP). These approaches were chosen through comparisons between the defined case organizations' needs and the possibilities and benefits that the approaches can provide on the basis of the literature review and experiences in similar types of multi-criteria decision-making situations.

In the context of the present research it has to be kept in mind that the use of decision support systems is only discussed as means and supportive tools for the developed selection process approaches of R&D performance measures, the purpose of which is to structure, simplify, make efficient and justify the developed processes, which as a whole are the main contribution of the research.

Analytic Hierarchy Process

The AHP was developed by Saaty (1980). As described by Saaty (1999), the AHP combines two fundamental approaches to solving problems: the deductive approach and the systems (inductive) approach. The application of the AHP is based on four principles (see e.g. Hafeez et al., 2002; Lee et al., 1995; Saaty, 1999):

- Decomposition of hierarchy
- Prioritization with pairwise comparisons
- Synthesis to provide an overall assessment of the available alternatives
- Sensitivity analysis for determining the stability of the outcome

As a flexible approach, the AHP can be applied in several types of decision problems, e.g. setting priorities, generating a set of alternatives, choosing the best policy alternative, determining requirements, allocating resources, predicting outcomes and assessing risks, measuring performance, designing a system, ensuring system stability, optimizing, planning, and resolving conflicts (Saaty, 1999). It is obvious that many of these are directly or indirectly related to problem of the present research, i.e. the process of selecting the measures and evaluation methods of R&D performance. Examples of applying the principles of the AHP in the context of this research area are presented for instance in Publications 3 and 6 in the second part of the thesis. In the selection process of R&D measures, AHP principles have been utilized in structuring two types of hierarchies: in generating and prioritizing the factors of performance and generating the measures or measurable areas for each factor, and on the other hand, in the actual selection of R&D measures by structuring and prioritizing the selection criteria and then by prioritizing and finally selecting the best alternatives, i.e. measure proposals. The reported real-world case studies in the publications of the second part of this thesis do not include the utilization of all the principles of the AHP, which have only been comprehensively utilized in illustrative exploratory case studies of selecting the measures of R&D performance.

Generally, the AHP-method seems to be suitable for constructing a solution conditioned by the constructive research approach (e.g. Saravirta, 2001). According to Saaty (1999) there are ten arguments for the use of the analytic hierarchy process:

1. Unity; a flexible model for a wide range of unstructured problems,
2. Complexity; integration of deductive and systems approaches in solving complex problems,
3. Interdependence; ability to deal with interdependent factors, does not insist on linear thinking,
4. Hierarchic structuring; reflecting the natural tendency of the mind to sort factors into different levels and to group like elements in each level,
5. Measurement; a scale for measuring intangibles and a method for establishing priorities,
6. Consistency; tracking the logical consistency of judgments used in determining priorities,
7. Synthesis; an overall estimate of the desirability of each alternative,
8. Tradeoffs; considering relative priorities of factors, supporting people to choose the best alternative,
9. Judgment and consensus; does not demand consensus, but derives a representative outcome from diverse judgments,
10. Process repetition; supports people in refining their definition of a problem and improving their judgments and understanding through repetition.

Group Decision Support Systems

The purpose of GDSS is to support and develop the group decision making process. The goal of the GDSS is to improve the productivity of decision-making meetings, either by speeding up the decision-making process or by improving the quality of the resulting decisions (Ellins et al., 1991). A GDSS, according to DeSanctis and Gallupe (1987), is an interactive computer-based system that facilitates the solution of unstructured problems by a group of decision-makers. The GDSS supports group decision making by eliminating the barriers of communication, by offering different tools for the group and by leading the use of time and handling of items systematically. The components of a GDSS include hardware, software, people and procedures.

The GDSS can affect group productivity and effectiveness in several ways. The GDSS offers the following general possibilities to support a group to promote its co-operation and effectiveness (see e.g. Jessup and Valacich, 1993; Turban and Aronson, 1998):

- GDSS enables parallel communication among group members. Every group member can contribute simultaneously and in parallel.
- GDSS offers equal and anonymous opportunity to contribute ideas and opinions.
- GDSS eliminates too big domination of participants in meetings.
- GDSS makes it is possible to find out rapidly the opinions the group members have agreed and disagreed on.
- GDSS helps to manage the schedule and agenda of the meeting.
- GDSS provides effective automatic electronic documentation capabilities.

Of these benefits, for instance anonymity and encouragement can be seen as significant benefits, since the participants of the selection process come from different organizational levels, and measurement is generally a very sensitive issue. The use of GDSS supports the choice of R&D measures by helping to handle different managerial views and different perspectives that need to be balanced, which are the earlier mentioned factors influencing the choice and use of R&D measures (see e.g. Nixon and Innes, 1997). Additionally, many useful measure proposals could be among the ideas that could not make it to the next phase of the process. Therefore, the automatic documentation possibilities of GDSS must be utilized so that the proposals or ideas can later be used as checklists.

The AHP can be applied to both individual and group decision problems, whereas the GDSS offers more possible benefits when there are many factors in the studied problem, and when a presence of a bigger (5-12 people) group of people and consensus among them are needed. In addition to the choice task described in the present study, the consensus reaching task, the problem finding task and the idea generation task have been used in GDSS research in different phases of decision processes.

In order to utilize the possibilities of the GDSS, the system should be applied for suitable areas and in a right way. Generally the GDSS has been utilized in business development, strategic planning, competitor analyses, customer panels, quality planning and improvements, risk analyses and analyses of war operations (Nunamaker and Weatherall, 1995).

The Department of Industrial Engineering and Management at LUT has a GDSS-laboratory for the research of group decision support processes and systems. The laboratory is used for teaching, research and cooperation with companies for group decision and group work. The purpose of the research done in the GDSS-laboratory is to develop planning and evaluation processes for demanding management tasks in industrial enterprises. The research subject is when and how a computer-aided GDSS is worth using and when not (see e.g. Torkkeli, 2002). The laboratory consists of networked computers, standard and specialized software and group decision support processes designed by researchers at LUT.

The idea of using the GDSS-laboratory and its facilities in the selection process of R&D performance indicators was in the first place a result of earlier studies related to the problem area of selecting suitable measures for R&D. In the earlier studies, we discussed the problems related to the selection of measures and measure requirements, derived the main factors to be taken into account in the selection, and presented a common framework for the selection process of R&D performance measures. When studying the requirements and problems in the selection of measures and comparing the common possibilities a GDSS can offer, it became obvious that it would be worth trying to fulfill the gaps shown by earlier research with the help of the GDSS. The positive results and experiences of GDSS utilization in multi-criteria decision-making situations also supported the continuation of this research. In order to be effectively utilized, software, hardware, people, and also a systematic procedure are needed. Therefore, a GDSS-based selection process was developed (an example is presented in Appendix 3).

3 RESEARCH STRATEGY AND METHODOLOGY

3.1 Introduction to the research strategy

This thesis consists of seven research articles partly independent and partly interrelated to each other, and all strongly related to the research topic of R&D performance analysis. In many of the articles, methodological issues are discussed only superficially if at all. Thus, in this introductory part of the dissertation it is necessary to discuss the aspects of philosophy of science, different research strategies and methodologies in order to properly understand and rationalize the strategic and methodological choices related to this research as a whole, as well as its separate sub-areas, i.e. the chosen research articles.

As stated by Burrell and Morgan (1979), all theories of organizations are based upon a philosophy of science and a theory of society. Social science can be conceptualized in terms of four sets of assumptions (Burrell and Morgan, 1979):

- Assumptions of ontological nature – assumptions which concern the very essence of the phenomena under investigation
- Assumptions of epistemological nature – assumptions about the grounds of knowledge
- Assumptions concerning human nature and the relationship between human beings and their environment
- Assumptions of methodological nature

Different ontologies, epistemologies and models of human nature are likely to incline social scientists towards different methodologies (e.g. Burrell and Morgan, 1979; Morgan and Smircich, 1980). We can have either a subjectivist approach or an objectivist approach for analyzing each of the four sets of assumptions.

From the researcher's point of view, the definition of the research **paradigm** helps in the perception of what the interesting research problems are and which methodological approach can be used to tackle them. The basic premises and value judgments held by the researcher are referred to as the scientific paradigm (Gummesson, 1991). Burrell and Morgan (1979) have argued that social theory can usefully be conceived in terms of four broad paradigms – functionalist, interpretive, radical humanist and radical structuralist. According to Gummesson (1991) the subject of paradigms is often discussed in the terms of an antithesis between two schools of philosophy: the positivistic, traditional natural science school, and the humanistic school. In order to avoid too much detail and confusion Gummesson (1991) calls the humanistic school a hermeneutic[19] school.

In business administration and management both schools are influential, although the academic community in general, and other disciplines have earlier been favoring the positivistic paradigm at the expense of the hermeneutic paradigm (Gummesson, 1991). This thesis also has influences from both paradigms through the several sub-areas and 'multi-method approach' of the research (described more in detail in Chapter 3.5), but the emphasis in the present research as a whole is on the hermeneutic paradigm, since the stress is on interpretation and understanding, the view to the issue is holistic, the subjectivity related to the research topic is recognized, and the data utilized is mainly qualitative.

[19] 'Hermeneutics' comes from the Greek *hermeneuien*, 'to interpret'.

The constructive research approach (described in Chapter 3.3.) utilized in the study is associated with qualitative research typology (see Chapter 3.2. below). In this study, qualitative data is accessed mainly through the principles of the case study research (e.g. Yin, 1994, in more detail in Chapter 3.4).

3.2. Qualitative research

Qualitative research entails general problems – such as labor-intensiveness of data-collection, frequent data overload, possibility of researcher bias, time demands for processing, adequacy of samples, generalizability of findings, and credibility and quality of conclusions – are related to the qualitative research (see e.g. Miles and Huberman, 1994). However, qualitative methods provide powerful tools for research in management even though their use is often opposed and they are classified as being second rate. With qualitative data one can preserve chronological flows, see precisely which events led to which consequences, and derive fruitful explanations (Miles and Huberman, 1994). Gummesson (1991) argues that the limited and often incorrect use of methods as well as the exaggerated reliance on quantitative techniques is due not only to tradition, but also to ignorance within both the academic and the business community. However, he is neither for nor against any methods. Methods should be used where they are appropriate (Gummesson, 1991).

Qualitative methods in management are often applied to the processes and projects of decision making, implementation and change. Broadly speaking these projects are related to issues in corporate strategy, organizational structure and management control systems. In studying the processes, the researcher encounters the following main challenges (Gummesson, 1991):

- Access to reality
- Preunderstanding and understanding
- Quality of research

The researcher can adopt different roles to gain access to companies and their employees; e.g. the role of a researcher, the role of a consultant or the role of an employee (Gummesson, 1991). In our study, the access to real-world processes and data has been possible through several contacts in larger applied research projects. Gummesson (1991) concludes that the role of a change agent creates substantial opportunities for access, and the combination of a researcher and a change agent is known as action research or science. The various data gathering methods concerning this dissertation in the larger applied research projects have been presented in Appendix 1 of this dissertation.

The concept of preunderstanding refers to people's insights into a specific problem and social environment before they start a research program, and understanding refers to the insights gained during a program (Gummesson, 1991). In the present study, preunderstanding on R&D performance analysis is gathered via extensive literature reviews as well as discussions and interviews with experts and key informants from companies. This made it possible to choose suitable research methods and to understand the multiple factors and the weightings and causalities related to the R&D performance analysis. Our understanding on the issue increased during the process through the comparative analyses and experiences in different industries.

Quality assessment involves a wide variety of requirements. The quality criteria of research emanate from basic sets of values – the scientific paradigm. Gummesson (1991) has presented quality criteria for case study research, e.g. the conduction of a research project, the presentation of paradigms, credibility of the research, adequate access, the validity of the research, the contribution of the research, the dynamics of the research process, as well as commitment and integrity. The criteria in relation to our research on R&D performance analysis are discussed in Chapter 5.

3.3. Constructive research approach

The constructive approach is associated with the qualitative research typology as a normative and empirical approach (see Figure 6). In Finnish methodological discussion, a widely accepted approach has been presented by Neilimo and Näsi (1980) who distinguish four main types of research approaches useful in business economics and industrial management, namely the concept-analytical approach, the nomotethical approach, the decision-methodological approach and the action-analytical approach. Of these, one special form of the action-analytical approach is the constructive approach, which is the main utilized approach in our study.

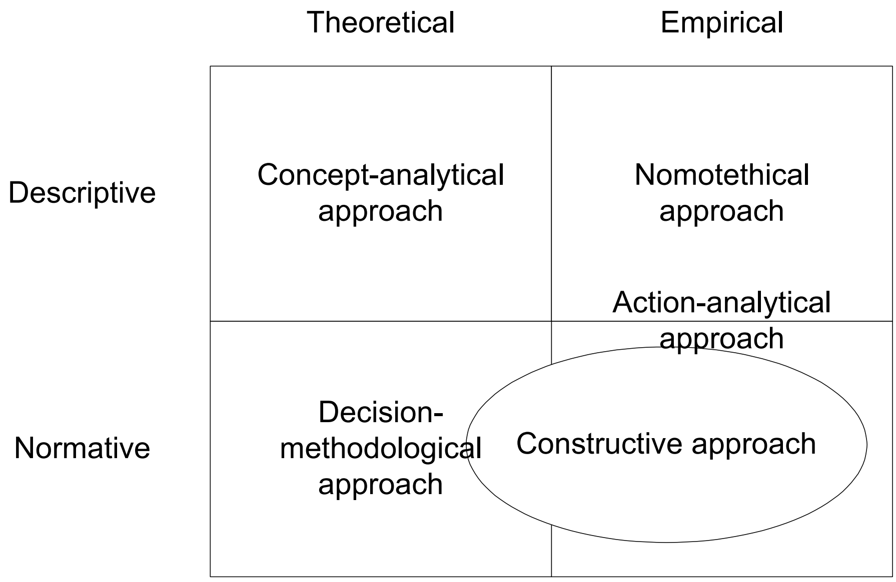

Figure 6. Constructive research approach in relation to the other research approaches (Neilimo and Näsi, 1980; Kasanen et al., 1991).

Brief descriptions of the other research approaches will help us to understand the similarities and differences between them and the constructive research approach. In the **concept-analytical approach**, the goal is to construct new concept systems when the background is the earlier conceptual or empirical research. Here, the research subjects can be facts, values or norms and the results can be both descriptions and normative. The goal of the **nomotethical approach** is to explain causal relations with the help of behavioral sciences used in a natural-scientific way. Here, the empirical part plays a very essential role and the methodological rules system is very rich. The results of this type of research are typically in form of regularities or recommendations. As in the nomotethical approach, positivism is at the background in the **decision-methodological approach** as well. The micro theory, game theory and decision theory are also at the background when the aim is to design problem-solving methods. Here, the empirical part is usually an example, and the results of the research are in the form of solutions to explicit problems. In the **action-analytical approach** the goal is to understand or to change while the teleological explanation is often at the background. The empirical part is presented by selected cases and there are no established methodological rules system. The results are often concept systems of different levels (Neilimo and Näsi, 1980; Olkkonen, 1994).

The purpose of **constructive research** is to solve real managerial problems and to test the functionality of the solutions (constructs) during the research process. Lukka (2000) suggests that there are seven main phases in the constructive research process[20]:

1. Find a practically relevant problem, which also has potential for theoretical contribution.
2. Examine the potential for long-term research co-operation with the target organization(s).
3. Obtain deep understanding[21] of the topic area both practically and theoretically.
4. Innovate a solution idea and develop a problem solving construction, which also has potential for theoretical contribution.
5. Implement the solution and test how it works.
6. Ponder the scope of applicability of the solution.
7. Reflect the findings to prior literature.

The main goal in the constructive approach is to build new constructs that are tied into current doctrines and theories. This construct may be a model, plan, scheme or other construct designed for the purposes of management problem solving. The results of the research are evaluated on the basis of newness and applicability in the progress of scientific knowledge. Demonstration and validation of practical usability is also important in evaluating the results (e.g. Olkkonen, 1994).

The adaptability of a construction to a real world problem is determined by its relevancy, simplicity and ease of use. When tests are done, not only the construction, but also the utilization process of the construction is concerned. Market tests will show the quality and reliability of the research. The market tests of the constructive approach, presented by Kasanen et al. (1993) are based on the concept of innovation diffusion, i.e. managerial constructions are viewed as products competing in the market of solution ideas (Kasanen et al., 1993):

- Weak market test: Has any manager responsible for the financial re-suits of his or her business unit been willing to apply the construction in question in his or her actual decision-making?
- Semi-strong market test: Has the construction become widely adopted by companies?
- Strong market test: Have the business units applying the construction systematically produced better financial results than those not using it?

Generally, this type of constructive research is widely used in technical sciences, mathematics, operations analysis and clinical medicine. In addition to this, Kasanen et al. (1993) have also studied the potential of the constructive approach in management accounting

[20] This is a slightly modified version of the original description of the constructive research process presented by Kasanen et al. (1991).

[21] This is comparable to the concept of "preunderstanding" (Gummesson, 1991), see Chapter 3.2.

research. One research topic where the constructive approach can be utilized in management science is constructing performance measurement systems (see e.g. Tuomela, 2000).

In our study, different case studies have produced “mini-constructs”, i.e. solutions for selecting R&D measures and developing R&D performance measurement systems for defined organizations and for defined measurement purposes with the help of the developed approaches and decision support systems. The models constructed in the case studies can also been seen as parts of a larger construction aiming to integrate the different measurement dimensions and taking into account the essential factors influencing the selection process of eligible measures and developing of measurement systems for R&D.

As discussed in Chapter 2, there exist a number of international research publications of R&D performance analysis, but despite of this, selecting the right measures for R&D to be utilized in R&D management is still a practically relevant problem. The extensive literature reviews have helped us to increase our understanding on the issue and to position our research, as well as to find potentials for theoretical contributions, especially through integrating the different R&D measurement dimensions, criteria and decision support tools in the selection process of R&D measures, which were applied in real-world organizations. We also had possibilities for long-term relationships with the studied organizations. The “mini-constructs” were innovated and tested in close co-operation with the studied organizations. The different aspects from the constructs in the case studies were utilized for developing the broader construct and for generalizability, which can be sharpened through reflecting the findings to the prior literature (see e.g. Lukka, 2000).

3.4. Case study research

Case study as a research strategy contributes uniquely to our knowledge of individual, organizational, social and political phenomena. Thus, it has been a common research strategy in psychology, sociology, political science, business, social work, and planning (Yin, 1994).

When choosing a research strategy we have to take into account the following three conditions: a) the type of research question, b) the control the investigator has over actual behavioral events, and c) the focus on contemporary as opposed to historical phenomena. In general, case studies are the preferred strategy when “how” or “why” questions are being posed, when the investigator has little control over the events, and when the focus is on a contemporary phenomenon within some real –life context (Yin, 1994). Such “explanatory” case studies can be complemented by two other types – “exploratory” and “descriptive” case studies (Yin, 1994).

When case study is chosen as the research strategy, the aim is often to build new theories. Eisenhardt (1989) proposes a process for theory building from case study research. The process is an iterative one. While an investigator may focus on one part of the process at a time, the process itself involves constant iteration backward and forward between steps (Eisenhardt, 1989). The proposed process includes the main steps and activities in the steps, as depicted in Table 3.

Table 3. The main steps and activities in the process of theory building from case study research (Eisenhardt, 1989).

Step	Activity
Getting started	Definition of research question Possibly a priori constructs
Selecting cases	Neither theory nor hypotheses Specified population
Crafting instruments and protocols	Multiple data collection methods Qualitative and quantitative data combined Multiple investigators
Entering the field	Overlapping data collection and analysis, including field notes Flexible and opportunistic data collection methods
Analyzing data	Within-case analysis Cross-case pattern search using divergent techniques
Shaping hypotheses	Iterative tabulation of evidence for each construct Replication, not sampling, logic across cases Search evidence for "why" behind relationships
Enfolding literature	Comparison with conflicting literature Comparison with similar literature
Reaching closure	Theoretical saturation when possible

According to Yin (1994) there are four types of case study designs, a) single-case (holistic) designs, b) single case (embedded) designs, c) multiple-case (holistic) designs, and d) multiple-case (embedded) designs. Single cases are rational for instance when we have a critical case in testing a well-formulated theory, or when the case presents an extreme or unique case. Depending on the research questions and selected scope of research, either a holistic or embedded view to the case study can be taken, i.e. single unit of analysis or multiple units of analysis.

In her study, de Weerd-Nederhof (2001) concludes that carrying out qualitative case study research is first and foremost a matter of "learning by doing"[22]. In the conduction of case studies we can have several methods for data and evidence collection, for instance documents, archival records, interviews, direct observations or participant-observations can be utilized (see e.g. Yin, 1994). In the present study, we have used multiple methods in the data collection. The use of multiple methods, multiple sources of evidence and triangulation are more discussed in closer detail in the next section.

As argued by Eisenhardt (1989), cases bring some strengths to theory building, e.g. likelihood of generating novel theory, testability, and empirical validity, which arise from the intimate linkage with empirical evidence. Second, case study research is particularly well-suited to new research areas or research areas for which existing theory seems inadequate (Eisenhardt, 1989).

[22] '…while taking into account all useful advice one can get of course' (de Weerd-Nederhof, 2000).

According to Yin (1994) there are four main criteria for judging the quality of case study research:

- Construct validity: establishing correct operational measures for the concepts being studied.
- Internal validity (for explanatory or causal studies): establishing a causal relationship, whereby certain conditions are shown to lead to other conditions, as distinguished from spurious relationships.
- External validity: establishing the domain to which the findings of a study can be generalized.
- Reliability: demonstrating that the operations of a study – such as the data collection procedures can be repeated with the same results.

These criteria together with other criteria for qualitative research (Gummesson, 1991) concerning this study are discussed in detail in Chapter 5.

3.5. Multi-method strategy

Our research of R&D performance analysis has been mainly implemented with the help of qualitative case studies, since the phenomena to be studied and the theoretical basis for the study are wide in nature, complex and partly unknown. With regard to the interests of the present research, the development of measurement systems has been studied widely. Also studies on measuring performance in R&D have increased remarkably since the 1990's. However, studies providing valuable guidelines for the selection of R&D indicators and holistic approaches for developing the R&D measurement systems are still relatively rare. The characteristics of R&D, the needs of different types of organizations and the whole multi-dimensionality of the issue still make the research area relevant, and new approaches need to be constructed for the selection of well-suited R&D indicators in real-world organizations.

The terms *qualitative* and *case study* are often used interchangeably, but case study research can involve qualitative data only, quantitative only, or both (Eisenhardt, 1989; Yin, 1994). Moreover, according to Eisenhardt (1989), the use of multiple investigators has two key advantages; first, they enhance the creative potential of the study, and second, the convergence of observations from multiple investigators enhances confidence in the findings.

Triangulation (see e.g. Yin, 1994) is a rationale for using multiple sources of evidence. Kekäle (2001) has studied triangulation in the creation and testing of theory in the constructive research approach, which is also the main research approach in this study. According to Patton (1987) there are four types of triangulation in evaluations; i.e. triangulation

1. of data sources (data triangulation),
2. among different evaluators (investigator triangulation),
3. of perspectives on the same data set (theory triangulation), and
4. of methods (methodological triangulation).

Yin (1994) proposes the use of multiple sources of evidence as the first principle in data collection, i.e. data triangulation. Other principles are creation of a case study database and maintenance of a chain of evidence. In addition to the data triangulation, the potential problems of construct validity can be addressed with different types of triangulation, because the multiple sources of evidence essentially provide multiple measures of the same phenomenon (Yin, 1994).

An alternative approach to the traditional research trajectory designs is presented by Kerssens-van Drongelen (2001). It is called the "iterative theory-building process", the main feature of which is that research questions may be changed over time based on the material collected and the requirement that the research strategies, data collection and analysis methods and tactics should fit the (changing) research questions and process phases (Kerssens-van Drongelen, 2001).

The research method in the larger applied research project, which the first part of the present research of R&D performance analysis was a part of, was a three-phased approach including in-depth interviews, a small-scale survey with a questionnaire and an inter-company expert meeting with the studied companies (see Publication 1). The results of the study helped the companies to clarify and structure the most essential problems and aspects involved in product development performance measures and their selection from the whole company's point of view. We also created the preconditions for a systematic approach to the selection process of R&D measures (see Publication 2).

The main sources of evidence in different parts of the present study were literature reviews, interviews with company representatives, as well as informal discussions, direct observations and expert meetings, in which there where several participants from the companies. Participant-observation was in question in some of these meetings where the researcher participated in the developed processes, the purposes of which were to promote the selection of performance measures for R&D. Small-scale surveys were utilized only as complementing the interviews and other qualitative data. In the second larger applied research process we focused the research topics through interviews complemented by a questionnaire of problems and challenges in R&D performance analysis received from selected R&D management experts. No large-scale (statistical) surveys were conducted in this research. As argued by Kerssens-van Drongelen (2001), if a research topic is not yet much researched and the researcher is interested in getting a thorough understanding of the subject, a survey does not seem to be a very suitable research strategy, since it will be difficult to draft an appropriate questionnaire. We could argue that the present research area, R&D performance analysis, is, as a whole, already relatively widely researched, but many of the particular topics of different sub-areas are less researched. The purposes and nature of this research make it also significant to gain as thorough understanding of the subject as possible in order to promote the selection and development process of R&D indicators in an efficient way.

This research is composed of several sub-areas and conducted in a way that makes the use of different types of triangulation possible. We have co-operated with different organizations in different phases of the research. The structure and organizing of the research make the use of the "iterative theory-building" process (see e.g. Kerssens-van Drongelen, 2001) and multiple methods (see e.g. Brewer and Hunter, 1989) relevant when concerning our research as a whole.

4 RESEARCH STRUCTURE AND SUMMARY OF PUBLICATIONS

This thesis consists of seven research articles, the linkages of which are clarified in this introductory part of the thesis. The research articles are all incorporated to the whole research of R&D performance analysis, and concurrently they have a specific purpose and value as independent studies. In this chapter, the aim is to discuss the contribution of the separate articles as such, as well as their contribution to the whole research of R&D performance analysis and their linkages to each other.

The author of this dissertation is the leading author in all the seven publications, and his name is in the first place in all the publications. The Publications 1 and 2 are a part of a larger Strategic Aiming and Assessment of Product Development research project, in which the author of this dissertation has been the responsible person of the research area of R&D performance analysis, and therefore, is a main contributor of each of the articles in this area. In Publications 1 and 2, the other authors have significantly contributed to the data gathering, e.g. interviews concerning product development management in the studied companies, and in development proposals concerning the analyses and main results produced by the present author, who has had the main responsibility in producing the research results concerning this research topic.

In Publication 3, the other authors have contributed to the paper as experts of decision support systems by providing comments and proposals on the adaptability of systems in the selection process of R&D performance measures. In Publication 4, the co-author from a manufacturing company has contributed to the empirical practical results together with the present author. In both articles the present author has constructed the processes, approaches and conclusions of the papers, and been responsible for data gathering and analysis.

Publications 5, 6, and 7 have been sub-results of a larger project of Product Development Management in the Networked Economy, which has been executed in co-operation with ICT-companies. Again, in this project the present author has been the corresponding researcher in the area of R&D performance analysis. The other authors have participated e.g. in the industry analyses in Publication 5, and in development of the strategic management framework in Publication 7. The co-author in Publication 6 has had a role of an expert of decision support systems, and has also been the responsible leader of both the larger applied research projects. The author of this dissertation has gathered the data, developed the processes and approaches, planned and been responsible for conducting the whole case study in Publication 6, and finally, made all the main analyses regarding the measurement of R&D performance in all the articles. Additionally, the present author has actually written major parts of all the seven papers listed below, nearly ninety percent on an average in a rough estimate.

Publication 1. Ojanen V., Piippo P. and Tuominen, M. (1999). An Analysis of Product Development Performance Measures in Finnish High-Tech Manufacturing Companies. Paper published in the Pre-Prints of 6th International Product Development Management Conference, 5.-6.7.1999, Cambridge, U.K, pp. 857-871.

Publication 2. Ojanen V., Kärkkäinen H., Piippo P. and Tuominen, M. (1999). Selection of R&D Performance Measures from the Whole Company's Point of View. Refereed paper published in the Proceedings Vol-2: Papers Presented at PICMET '99 (CD-ROM), Portland International Conference on Management of Engineering and Technology, 25.-29.7.1999, Portland, Oregon, USA, ISBN 1-890843-04-0.

Publication 3. Ojanen V., Torkkeli M. and Tuominen M. (2001). Managing the Selection and Development Process of R&D Indicators as Part of the Strategy Process. Paper published in the Proceedings of R&D Management 2001 Conference (CD-ROM), 7.-9.2.2001, Wellington, New Zealand.

Publication 4. Ojanen V., Piippo P. and Tuominen M. (2002). Applying Quality Award Criteria in R&D Project Assessment." *International Journal of Production Economics*, vol. 80, No. 1, pp. 119-128, ISSN 0925-5273.

Publication 5. Ojanen V. and Koivuniemi J. (2001). Challenges of R&D Performance Evaluation in the Infocom Industry. Paper published in the Proceedings of R&D Management Conference, 6.-7.9.2001, Dublin, Ireland, pp. 369-377.

Publication 6. Ojanen V. and Tuominen M. (2002). An Analytic Approach to Measuring the Overall Effectiveness of R&D – a Case Study in the Telecom Sector. Paper published in the Proceedings: Volume II of IEMC 2002, International Engineering Management Conference, 18.-20.8.2002, Cambridge, U.K, pp. 667-672, ISBN 0-7803-7385-5.

Publication 7. Ojanen V., Koivuniemi J. and Blomqvist K. (2002). Strategic Competence Development and Monitoring in a Multi-disciplinary Research Institute. Paper published in the Proceedings: Volume II of IEMC 2002, International Engineering Management Conference, 18.-20.8.2002, Cambridge, U.K, pp 520-525, ISBN 0-7803-7385-5.

The purpose of **Publication 1** was to analyze problems, shortcomings and development needs related to product development performance measures, and to discuss supporting means for the development of a more versatile set of measures. The analysis approach utilized in the research was a three-step approach that consisted of semi-structured individual interviews, a survey (questionnaire) and an inter-company expert meeting with the studied five Finnish manufacturing companies. The developed analysis made it possible to form a comprehensive picture of the problems and their reasons and consequences from individual opinions and factors. In each studied company, about ten representatives of business management, R&D management, marketing, sales, manufacturing, after sales and quality were separately interviewed. One of the main topics of the individual interviews was R&D performance evaluation and measurement. A summarizing analysis was made after the interviews for each of the companies. The documents were reviewed and analyzed company by company. The common development needs of the present state of R&D performance measurement were defined on the basis of the analysis. In addition, the existing and desired R&D performance measures were sorted out for further analysis. A survey including a questionnaire with R&D measure proposals from different perspectives was executed for deeper analysis of product development performance measurement in the studied companies. The measure proposals were results of idea gathering at the university and a wide literature review. The proposals were divided into groups based on the Balanced Scorecard – approach. Each company evaluated and commented the suitability of each measure from their own company's standpoint. The emphases of the different perspectives were also evaluated in each company.

On the basis of the results of this part of the study we could separate the most suitable measure proposals for different perspectives. The companies can use the proposals as checklists when composing a company specific set of measures. In an inter-company expert meeting the evaluation results of the two earlier phases were reviewed and discussed together with the company representatives. The representatives also presented special comments and development needs from their own company's standpoint. Common problems and interest areas were determined through summarization of the comments and opinions. In addition, as a result of the meeting, the essential focus of further research on the issue was determined to be on the *selection process of R&D measures*.

In **Publication 2**, for most parts, the same data sources as in **Publication 1** were utilized. Especially the aspects from the individual interviews and an inter-company expert meeting were drawn for further analysis. The aim of the study was to clarify and derive from the literature and empirical interviews the major factors to be taken into account when defining the most important sub-areas to be measured and selecting an effective and versatile set of R&D measures. Five major factors to be taken into account when defining the sub-areas to be measured and selecting appropriate R&D performance measures at the firm level were defined as follows:
1. corporate strategy and R&D objectives based on the strategy
2. recognition of R&D impact chain
3. critical success factors of R&D and the whole company
4. purpose of R&D performance measurement
5. company specific R&D contingency factors.

The factors were derived from an extensive literature review and empirical experiences on the issue. In the empirical part of the study, it was studied how well the present measures reflect the determined major factors and how reasonable these factors are. Even though the studied companies generally had their strategies and objectives for R&D well defined, the performance measures did not necessarily reflect the principles and the determined factors. The important factors determined in this study can be generally utilized in the selection of a new set of R&D performance measures. The utilization and better understanding of the main factors can help different companies to clarify how determined sub-areas could be more strongly taken into account in the selection process from the whole company's point of view. On the basis of the positive opinions of company representatives in an expert meeting related to the issue of R&D performance measurement, and on the basis of reflection of the factors to the companies' development needs, the proposed derived factors were considered as reasonable and significant to be taken into account in the R&D measure selection. On the basis of the empirical material and extensive literature reviews in **Publication 2** we also created a preliminary framework for the phased R&D performance measure selection process which was further developed in the later publications. The different aspects of the developed framework were derived from several studies in the general literature of R&D performance measurement (see references in Publication 2), but also from aspects of performance measurement system design literature and practice. The proposed framework had not yet been tested, e.g. with the help of a case study, when this paper was written, but the further developed approaches for case-specific purposes were implemented and presented in later papers.

To complement the above-mentioned interviews as a source of evidence, in **Publication 3** we analyzed two case studies of strategy-based selection and development of R&D performance measures in different types of organizations. The purpose of the paper was to promote the building of R&D performance measurement systems with a systematic approach and to provide guidelines for strategy-based selection of R&D performance measures. We developed our previously (Publication 2) deployed approach further, i.e. we clarified the potential advantages and restrictions related to the use of various approaches, methods and decision support systems in idea mapping and gathering, as well as in the evaluation, prioritization and final selection of R&D indicators. The selection process of R&D indicators discussed in the study was mainly related to strategy formation or updating, and the utilization of measures and different aspects of measurement systems were linked to strategic control. The utilized supporting methods in the case studies were based on the use of the Balanced Scorecard – approach and Group Decision Support Systems. The developed systematic process approach has several purposes. It aids in identifying and selecting the key performance indicators of R&D, it takes the factors (especially strategic factors) influencing the system design and selection of measures into account, it provides guidelines for the use of decision supporting methods in the different phases of the process, and it promotes the communication of strategic R&D performance measurement and the purposes of measurement throughout the organization. The novelty of our approach, when compared to earlier approaches, is in systematizing the strategy-based selection process by integrating the various tools and methods in the different phases of the process, where different requirements for method features exist.

Publication 4 had multiple purposes. The main aim of the study was to study the application of quality award criteria in the assessment of R&D projects by combining theory and practice. The literature review helped to identify the possibilities and potential problems related to the issue at conceptual level. The meaning of different sub-areas of quality award criteria was analyzed from the point of view of R&D activities and single projects. New measures, performance criteria and concrete measurable aspects for R&D project-level performance measurement were derived on the basis of the analysis. In practice, the analysis of the application of criteria for R&D project assessment was discussed from the viewpoint of a case company that had successfully applied the quality award criteria in its business development and aimed to utilize them more comprehensively in the assessment of R&D. Example derivations of measures for R&D project assessments were described in the study. The derived measures were also reflected and related to the development needs of R&D performance analysis in the case company. The executed derivation process helped to create common measures for both the project and functional level, and increased the understanding of links between functional level and project level measurement of R&D.

Publication 5 aimed to clarify the problem areas and challenges of R&D performance evaluation in the information technology and telecommunications (infocom) industry through taking the special characteristics of the industry strongly into account. Comparisons between the measurements and problems in measurement in the infocom and the more traditional industries were made with the support of empirical evidence, i.e. interviews, expert meetings and case studies. Many problems are similar in different industries, but the specific characteristics of the infocom industry can significantly increase the known problems of R&D performance measurement. Especially the characteristics that were emphasized in a small-scale survey that aimed to clarify the most significant industry specific characteristics (Elfvengren et al., 2001), and on the other hand, the characteristics that strongly affect the performance evaluation as such, were emphasized in the analysis. The results of the analysis support organizations operating in a turbulent business environment to clarify the influence of industry specific characteristics to R&D performance evaluations and problems in it. Understanding of the influence of these characteristics is vital in finding suitable means to avoid problems and to select the best possible organization- or case-specific set of R&D performance measures.

The aim of **Publication 6** was to promote the definition of the factors and actors that influence the overall effectiveness of R&D and the choice of effectiveness measures with the help of an analytic approach. Defining the main factors that influence the maximization of the effectiveness of R&D helped to recognize the most significant measurable areas and to create and choose suitable measures for the measurement subjects. The use of decision support systems and methods was discussed in the context of a systematic R&D measure selection process. To illustrate the use of our approach in practice we presented an example application in the telecom sector. Our approach for defining the factors that influence the overall effectiveness of R&D and for choosing the set of measures to support the evaluation of the overall effectiveness of R&D had been empirically tested with the help of a group of R&D management experts in a telecom company. The main defined purpose for utilizing our approach in practice was the justification of R&D existence. The decisions regarding the use of our approach were supported by the GDSS and AHP. As a result of the case study, the main factors influencing the internal and external effectiveness were defined. The best measure proposals for reflecting the main factors were chosen with the systematic analysis approach.

To complement the picture of R&D performance analysis, the purpose of **Publication 7** was to propose a framework that consolidates personal skills, capabilities and competencies, and the monitoring and measurement of their development with the strategic performance management perspective of a research institute operating in a rapidly changing environment. Our approach helped to map the most essential competence areas and the measurement areas concerning the capabilities and competencies. New challenging competence measurement areas could be found with the help of our analysis: both individual and research institute-level competence measurement areas were suggested for the measurement perspectives of innovation and learning, collaboration, integration, substance competence and project management. The main managerial implications regarding the utilization of our framework in practice are related to integration of the tracking and assessment of individual competencies with research institute-level development activities and strategic re-orientation.

As can be seen in Figure 7, the research process has been an iterative one. First, we have analyzed the R&D measures used in the studied organizations and compared them to the development needs in R&D performance analysis. We have also studied the main factors that influence the selection of appropriate R&D measures and reflected them with the used measures. As a result of these analyses, we have constructed a preliminary common framework for a phased selection process of R&D performance measures. Then we have constructed more detailed and organization-specific approaches for the process in different contexts. The developed process models have been reflected to the earlier literature, and the common process as a whole has been further developed in an iterative manner with the help of the lessons learned in the organization-specific case studies.

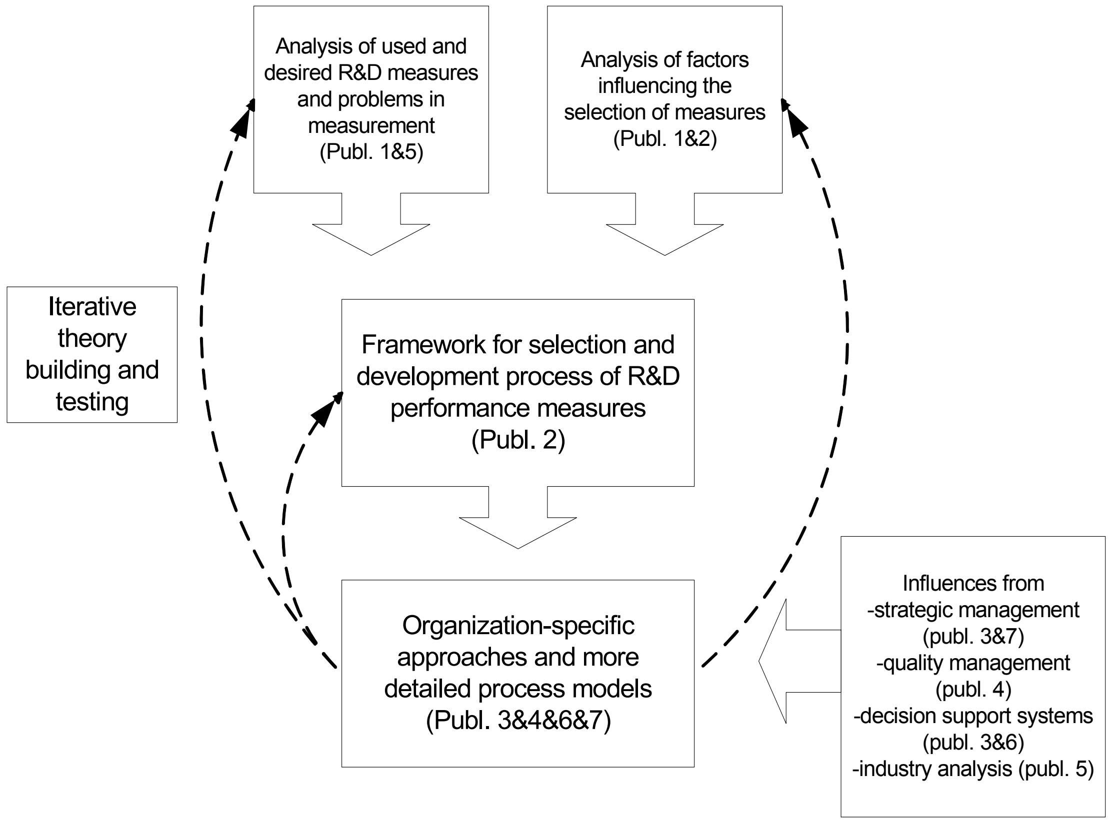

Figure 7. The iterative research process.

As discussed above, several sources of evidence have been utilized in the different publications (more about the data sources in Appendix 2). Table 4 below summarizes the main aspects concerning the data and the methods utilized in separate publications, as well as the main results of each publication.

Table 4. Summary of data, methods and results of publications.

Publication	Data / methods	Main results
1	Literature review, interviews (manufacturing companies) + questionnaire + "expert meeting"	Research gap: used vs. desired R&D measures; evaluation of new measure proposals based on the development needs
2	Literature review, interviews (manufacturing companies) + "expert meeting"	Analysis of factors to be taken into account in the selection process of R&D measures; preliminary framework for the selection process
3	Literature review, one manufacturing company case + one university department case, interviews, meetings, participant observations; BSC and GDSS utilized, several participants	An approach for the selection and development process of R&D indicators as part of the strategy process
4	Literature review, one manufacturing company case, interviews	An approach for derivation of new measurement areas, evaluation methods and measures for R&D from the quality award criteria framework
5	Literature review, formal interviews (+questionnaires) + informal discussions (ICT industry)	Analysis of the influence of industry specific characteristics on R&D measurement problems
6	Literature review, a unit of an ICT company –case, interviews; GDSS (+AHP) utilized; 5+3 participants in the main meeting	An analytic approach for the clarification of factors of R&D effectiveness and selection of R&D effectiveness measures
7	Literature review, research institute -case, interviews and meetings	A model for continuous development and monitoring of R&D competencies; new competence measurement areas

Additionally, Table 5 below brings forth the dimensions of R&D performance analysis which were discussed in Chapter 2 above, in relation to the contexts of the selected publications. It can be seen that several types of R&D have been concerned in different parts of the research and the performance of R&D has been analyzed and measured in multiple levels. Especially the publications with the case-specific approaches have also presented different purposes for measurement. No difference has been made with the dimensions of R&D process phases or measurement perspectives, for reasons explained above in Chapter 1.3.

Table 5. The context of the publications against three R&D performance analysis dimensions.

Publication	Type of R&D covered	Level of performance analysis	Purpose of measurement
1	Product Development (+ improvements)	Company / BU	Several purposes covered
2	Mainly Product Development	Company	Several purposes covered
3	(Basic +) Applied Research + Product Development	BU / department	Purpose: Strategic steering
4	Product Development (+ improvements)	(Process +) Project	Purpose: More thorough utilization of quality award criteria + TQM in R&D assessment
5	Mainly Product Development	Industry + Company + BU	Several purposes covered
6	Product Development (+ improvements)	BU (+Process and Project)	Purpose: Measurement of overall effectiveness of R&D; Justification of existence
7	Applied Research	Strategic unit of an expert organization	Purpose: Strategic steering; Measurement of competencies

As discussed above, the research as a whole consists of several minor constructs, i.e. developed approaches and detailed selection processes of R&D metrics for specific needs and situations. Figure 5 in Chapter 2.2. can be seen as a larger construct integrating the influencing factors and dimensions as well as possible checklists from the literature review and use of decision support systems to the selection process itself. Here, the checklists are mainly the proposed measures or evaluation methods derived from a literature review combining different dimensional aspects influencing the R&D measure selection. The recognition of the state-of-the-art is an essential element especially in the measure-mapping phase of the selection and development process of the R&D indicators of an organization. However, relying too much on the checklists should be avoided, because suitable measures or evaluation methods cannot be often found straight from the reported studies. More important is that the demands set by the noteworthy dimensions of measurement are valuable to understand before generating ideas for more precise measurable areas, measures and evaluation methods for case-specific purposes.

In the two larger three-year applied research projects, the researcher has had an opportunity for long-term research co-operation with the studied organizations. On the other hand, the studied organizations in the case studies have varied and been rather different from each other, which could influence e.g. the generalizability of research results. However, even though the potential adequacy of the constructs for more general use should be examined, the role of generalizability in the research assessment of the constructive research approach is different from some other research approaches, because the constructions, i.e. the solutions to the defined problems in an organization under investigation, are finally case-specific. Generally, the experiences in different types of organizations have been very valuable for the holistic approach to R&D performance analysis conducted in this research as a whole. The experiences reflect the complexity and multi-dimensionality of the issue: organizations have different purposes for measurement, they measure various levels from various perspectives, and the outputs and outcomes of the R&D process are different in e.g. applied research and product development. These are all factors that need to be taken into account already in the preplanning phase of the selection process of R&D measures, even though there can also be general process phases that can be adapted in various case studies.

5 DISCUSSION

5.1 Contribution

According to Olkkonen (1994), the contribution of a research means addition to existing knowledge. To be more precise, the different perspectives and possibilities are related to the concept of contribution as stated by Davis (1972):

- The work should be based on a significant question, problem or hypothesis.
- The work should be original.
- The work should be related to, explain, solve or add proof to a question, problem or hypothesis.
- The research is additive, i.e. it adds to the knowledge.
- The results are usually expected to result in a generalization.

As stated in Chapter 1, the aim of the research has been to support the managerial decision-making of R&D in different organizations by helping to increase the understanding of R&D performance analysis, by clarifying the main factors related to the selection of suitable R&D measures, and by systematizing the whole strategy- and business-based selection and development process of R&D indicators. Novel types of processes and systematic approaches for different measuring purposes were the main practical results of the studies and separate publications. With the help of the developed processes the possibilities to choose eligible R&D measures for different purposes were promoted.

In the first larger applied research project with five industrial manufacturing companies, frequency analysis based on semi-structured interviews and multilevel and multi-person analyses was executed. Through the frequency analysis the most common and important development needs of the studied companies were clarified. The aim of the analysis was to describe and emphasize the essential development needs that several interviewed persons had pointed out and about the significance of which there existed some kind of consensus (Piippo et al., 1998)[23]. The most often mentioned development need in the studied manufacturing company, the case of which was discussed in Publication 3, was "*Business demands and strategies do not direct R&D sufficiently"*. Several individual opinions underlined the significance of this problem. The new approach depicted in Publication 3 increased the understanding between the strategy process and R&D performance analysis and selection process of measures by integrating the aspects of the strategy process and their influences to the systematic choosing of R&D performance indicators. More precise consideration of strategy and strategic objectives was also one of the main factors influencing the selection of R&D measures, as discussed in Publication 1 and especially in Publication 2. Taking strategic objectives strongly into account may provide new requirements and criteria for choosing the final set of measures.

The accurate analysis of interviews revealed a gap between the used R&D measures and the desired measures – especially a gap between the desired and actually used non-financial measures or evaluation methods of R&D performance. This was one of the results of

[23] The development needs and managerial problems of R&D in the studied companies were also revealed by causal analyses and developed self-reinforcing loops of managerial problems (e.g. Kärkkäinen, 2002), which have extended the understanding about the product innovation management systems in a comprehensive, company-wide context.

Publication 1, which directed the research to focus on the crucial element of R&D performance analysis: the selection of measures. The gathering of data from metal and electronic industry companies (e.g. Publication 1) as well as from the ICT sector (Publication 5) helped us to formulate a comprehensive picture on the main challenges of R&D performance analysis in different organizations, which is very essential, as recognition of the most important problem areas is a very crucial element in the constructive research approach utilized in this study. In addition to R&D activities, the above-mentioned gap between used and desired measures is a very common phenomenon discussed in several earlier studies on corporate performance measurement (see e.g. Kaplan and Norton, 1992; Olve et al., 1998; Toivanen, 2001; Malmi et al., 2002).

When considering the research questions presented in Chapter 1.2, the answers to the questions can be found in the different papers included in this dissertation. *Research question 1* was stated as follows: *What are the gaps between the utilized and desired measures or evaluation methods of R&D in the studied organizations?* As discussed in the previous section, *research question 1* is mainly answered in Publication 1, where the imbalance between the used and the desired, as well as the financial and non-financial measures was revealed and analyzed.

Similar types of gaps as earlier revealed in the manufacturing companies could also be found in the later qualitative analyses of ICT companies. Thus, the general answers to *research question 1* can be stated as follows: *The studied organizations aimed for more balanced sets of R&D measures, i.e. more non-financial measures in relation to the financial measures in R&D, and more long-term measures of R&D in relation to the short-term measures of R&D*. In general, the studied companies analyzed their performance on a short-term basis, and they needed appropriate strategic measures for the end stage of the R&D impact chain, i.e. measures related to competitiveness or long-term future revenues. The case companies in Publication 1 also hoped for *more external measures linked to customers and competitiveness, as well as measures connected to communication and learning.* The interviewees of the case companies wished both quickly utilized in-process measures and end-of-process measures, which indicate the impacts of process outputs. The common measurement subjects, such as time and costs were followed in many companies, often during the process, in several milestones. The desired measures are different in the studied organizations because of the *different purposes of measurement.* However, each studied manufacturing company seemed to have a common purpose for the selection of appropriate measures for R&D. It was related to the needs of existing or becoming bonus/reward systems. This sets certain demands, like simplicity, quickness and variability, for the selectable measures.

In general, the studied companies did not have systematically used appropriate R&D measures that would be systematically derived from strategy and critical success factors, or from the main purposes of measurement. This indicated a need for new methods for systematic selection of R&D measures. Later, the purposes of measurement and the case-specific needs for the new R&D measures were carefully mapped in the early phase of each conducted case study of R&D performance measure selection discussed in other publications (Publications 3,4,6 and 7).

Research question 2 was stated as follows: *Which are the main challenges encountered in analyzing R&D performance in general and especially in the studied organizations, i.e. why do the gaps exist? Research question 2* was mainly answered in Publications 1 and 5. Generally, the common challenges in the studied organizations from the manufacturing and

ICT sectors *were 1) a need for better versatility of the set of R&D measures, 2) a need for measures that could be more directly utilized in the managerial decision-making, and 3) a need for systematic and new approaches for the selection of R&D performance measures*. Individual challenges which can be found in literature and are also common in the empirical analyses of this research are, for instance, *a long time lag between the initial stage (inputs) and outputs and outcomes in the R&D process, as well as assessment of the contribution of R&D for the success of a new product and for the performance of the whole company*. In addition to these, there were also the following common, frequently mentioned challenges derived from empirical analyses, which can be better influenced by management: *The selection of measures is not systematic, single measures cannot be linked to the overall set of measures, measures cannot be directly utilized in decision-making, and there exists incompatibility of R&D measures with other control or measurement systems of the organization*. Additionally, as described in Publication 5, there exist industry specific characteristics that may multiply the influence of some R&D performance measurement challenges. For instance, ICT specific characteristics, such as convergence, networking, emerging markets and new business models make such issues as the assessment of the contribution of R&D for the success of a new product and for the performance of the whole company, and the threat of sub-optimization in the utilization of measurement results even more challenging.

Research question 3 was formulated as follows: *a) Which are the main factors and dimensions influencing the selection of purposeful measures or evaluation methods of R&D performance and b) how do they have to be taken into account in the selection process of R&D performance measures?* The answers to *research question 3* (and its sub-questions, a) and b)) are found especially in Publication 2, but these aspects are also dealt with in each of the conducted case studies, and the emphasis and weightings of different factors have been assessed in each case to meet the requirements of the particular case study.

The conducted case studies in manufacturing companies (see Publication 2) answer research question 3a) by *clarifying the major factors to be taken into account when defining the sub-areas to be measured and selecting appropriate R&D performance measures at the firm level, defined as follows: 1) corporate strategy and R&D objectives based on the strategy, 2) recognition of R&D impact chain, 3) critical success factors of R&D and the whole company, 4) purpose of R&D performance measurement, and 5) company specific R&D contingency factors*. The factors were derived from an extensive literature review and empirical experiences on the issue. Additionally, this introductory part of the dissertation has gathered the main dimensions in R&D performance analysis concerning the overall research area with the linkage to the selection process of R&D performance analysis. These *derived main influencing dimensions in the whole research are the perspectives of performance analysis, the purpose of R&D performance analysis, the type of R&D, the level of the analysis, and the phase of the innovation process*. Concerning research question 3b), *the influencing factors and dimensions need to be taken into account in the early phase of the R&D performance measure selection process for a full recognition and careful consideration of the measurement needs related to a specific selection process of R&D indicators*. The dimensions-table (Table 1) has been utilized as a tool for visualizing and categorizing the dimensional aspects in R&D performance analysis and in the selection process of R&D indicators. *The emphasis of different factors and areas of dimensions set different requirements for the evaluation criteria in the final selection of R&D performance measures*. If suitable measures or evaluation methods cannot be found straightforward from the reported studies, the demands set by the noteworthy dimensions of measurement are still valuable to understand before generating ideas for more precise measurable areas, measures and evaluation methods for case-specific purposes.

Finally, publications 3, 4, 6 and 7 deal with the new approaches that are related to *research question 4* (a and b) stated as follows: *a) How can the selection and development process of R&D performance measures be promoted effectively?, and b) Which supporting methods, tools or support systems are potentially effective in which phases of the process?* Concerning question 4a), it can be first said that we should have *a systematic, phased process for the selection of R&D indicators.* Certain starting points for the creation of measurement systems and metrics, e.g. the purpose of measurement, must be clear before the organization of the selection process. The top management must also be committed to the project and understand the usefulness of performance measurement. Right people from all essential functions should then be selected to the selection process team. The selection process of R&D measures in general includes several phases (see e.g. Publication 6), i.e. pre-planning (including organizing), construction of models and precise objectives, idea generation and voting phases (for both the influencing factors and the measure proposals), final selection on the basis of voting with the chosen criteria, and discussion of the utilization and process feedback phases.

Concerning question 4 b), various supporting methods and tools can be utilized in the process. As stated above, we propose *the utilization of a table of measurement dimensions* for understanding and clarifying the influencing factors and dimensions that need to be taken into account in the early phase of the R&D performance measure selection process for a full recognition and careful consideration of the measurement needs related to a specific selection process of R&D indicators.

In the developed approaches, depending on the purposes of the case study, different methods have been utilized. The use of decision support systems, particularly AHP and GDSS are included in the selection process of R&D measures in Publications 3 and 6, and especially the integration of these systems is discussed in Publication 6. Guidelines for effective utilization of supporting methods have been given in each case. *All the main phases can be promoted with the help of GDSS*, which actually includes several tools to support the different phases. According to the experiences in the case study, the use of GDSS can be proposed to be effective *especially in the idea mapping and voting (selection) phases*. For more effective utilization of the process, the features of AHP, e.g. decomposition of hierarchy, prioritization with pairwise comparisons and sensitivity analysis of the results are proposed to be utilized when practical to gain the case-specific objectives. The AHP helps decision makers structure the important elements of a complex multi-factor problem into a hierarchical structure, in which each level of the hierarchy is composed of specific elements. Various other supporting methods, like *the use of Quality Award Criteria (see Publication 4), BSC or the performance pyramid (e.g. Publication 3), can be utilized when clarifying and explaining the connection of the measurement to the business and strategies*. E.g. the BSC-approach can be utilized in the grouping of measure proposals and finding the causal effects between sub-areas and metrics.

Generally, *strategic management accounting approaches*, like The Balanced Scorecard or The Performance Pyramid can be used *especially in developing the structure and a more precise procedure for identifying and assigning the potential strategy-based performance indicators*. *Methods linked to the decision theory*, like The Analytic Hierarchy Process can also be utilized in several phases, but *especially in generating and assigning weights for objectives, perspectives or selection criteria, and also for measure proposals*. Various tools and methods in the *GDSS* can support the *idea generation* and the *multi-criteria selection* process. *Integration of different tools and methods in the process* should be considered in the first phase when planning the process to be implemented.

At least the following practical benefits with regard to the defined problem areas could be found in our developed approaches (Publications 3, 4, 6 and 7): 1) the selection of R&D measures became more systematic when compared to empirical analysis, as it was common that there were no systematic approaches utilized in the studied organizations earlier, 2) the evaluation methods or measures of R&D chosen with the help of the approaches can be more directly utilized in the decision-making, because of the thorough consideration of the purpose of measurement and other dimensions of measurement, 3) more balance to the set of R&D measures was desired and gained through the holistic approaches to the selection processes, i.e. both internal and external factors and different perspectives were taken carefully into account and the selected measures could track the emphasized factors and perspectives, 4) more objectivity was gained through organizing the selection processes so that persons from different organizational levels and functions could participate in the process. The earlier systems were considered as subjective in many cases and individual interviews.

The selected metrics in the different case studies were meant for different purposes and various levels of organizations, to be utilized in the more effective management of R&D. Here, it is also important to recognize that the set of metrics that is selected will influence the behaviour and people on several levels. Thus, for dealing with the sensitiveness of this issue and for justifying the decisions related to the selected metrics with a systematic approach, it is significant to organize the selection process of R&D measures with an organizationally balanced group of people.

The novel types of approaches for selecting purposeful R&D measures and developing measurement systems helped the management of the studied organizations by bringing forth the dimensions of measurement, the criteria and requirements for the measures to be selected, and new possibilities to enhance the selection process with supportive and integrated methods in different parts of it. The approaches in publications 3, 4, 6 and 7 are organization- and case-specific and they aimed at taking the main development needs of the studied organization strongly into account. Similarly they provide guidelines for different organizations through generalization of the main phases of the process. The applicability and benefits have been derived by asking questions from and interviewing the individuals that have participated in the selection processes, and through post-session expert meetings, as well as from the researcher's analysis of participant-observation in the conducted cases.

From the scientific point of view, the main novelty in the whole research of R&D performance analysis can be seen in combining several elements of the research (see the scope of the research in Figure 2) into a cohesive whole. The present study as a whole has increased the general understanding of R&D performance analysis and created a comprehensive picture of it by presenting the research gap and problems of R&D performance analysis, clarifying the dimensions of measurement and other factors influencing the measure selection, and systematizing and supporting the whole selection and development process of R&D measures.

This study has also succeeded in filling research gaps shown by earlier studies. As discussed in Chapter 1, there exist a number of previous studies on different perspectives of R&D performance analysis. Some of the studies discuss the selection of measures and present factors influencing the selection. Some even present novel types of systematic methods for selecting the measures and constructing a measurement system. However, there has been a lack of studies presenting the actual use of systematic methods in measure selection in practice and integrating the essential factors and dimensions (prior to the selection) to the actual selection process itself. This study has aimed at contributing to this usage on the basis of the various development needs of the studied real-world organizations. Similarly, integrated decision support systems, methods and tools have been utilized in the selection process where considered useful and appropriate.

As a whole, this dissertation makes a contribution to the present body of knowledge of R&D performance analysis by comprehensively facilitating dealing with the versatility and challenges of R&D performance analysis, as well as the factors and dimensions influencing the selection of R&D performance measures, and by integrating these aspects to the developed novel approaches, methods and tools in the selection processes of R&D measures, applied in real-world organizations.

5.2 Assessment of research quality

The quality and limitations of the present research are assessed with the help of the criteria of qualitative case study research presented by Gummesson (1991) (see Chapter 3.2) and Yin (1994) (see Chapter 3.4), as well as the criteria of the constructive research approach (see e.g. Kasanen et al., 1991).

In this study, we selected case studies from organizations of metal and electronic industry, as well as ICT industry[24]. We complemented the variety of cases with empirical evidence from non-profit organizations, such as a university department and a research institute. As stated earlier, R&D activities in profit-gaining companies and in non-profit organizations differ significantly from each other. As the holistic approach to the research of R&D performance analysis has been pursued in this study, the dimension of different types of R&D activities cannot be passed by.

In each of the selected organizations, research and / or development activities play very essential roles for the well-being of the organization. In data collection from the organizations, the *construct validity* of the research was ascertained as suggested by Yin (1994); i.e. using multiple sources of evidence, establishing the chains of evidence and having the key informants review the draft case study reports. The *reliability* of research was achieved in the data collection phases of the research by using the case study protocol, i.e. the case procedures were carefully documented. The results of the case studies were also carefully reviewed and compared to the literature reviews. This increases the *external validity* of the research, which is a major barrier in doing case studies (Yin, 1994). The generalization of different case studies, which is strongly related to the external validity, has been separately discussed in each of case studies of the research articles in this dissertation, and the generalization concerning this research as a whole is discussed below in this section. The *internal validity* is used as a criterion only in explanatory or causal case studies, and thus it is only discussed in small parts concerning the present research. Pattern-matching, i.e.

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[24] We have to keep in mind that one essential reason for the selection of case organizations of this research, is also their participation and commitment to the larger applied research projects (see Chapter 1). The confidentiality requirements agreed with the companies in the research projects have set some limitations to the description of the research results in the publications of this dissertation.

comparing the empirically based pattern with a predicted one, has been, however, used to enhance the internal validity of the research.

Regarding the additional criteria of case study research identified by Gummesson (1991), this whole introductory and summary part of the dissertation aims to adequate presentation of *conduction of the research project, presentation of paradigms, and the contribution of the research*. With the help of the good linkages to the studied organizations in the larger research projects we could also have *adequate access* to the data and processes of the organizations. The researcher could also gain *commitment and integrity* to the research, in the words of Gummesson (1991) 'be deeply involved in the project but at the same time retain a certain distance'. Using self-assessment, the research process itself could possibly have been more *dynamic*, even though the researcher has certainly learned continuously more on the issue. The creativity and checking of the impressions, which are related to the dynamic process, have not been possible to be gained in all parts of the research, because of the goals set to the cases and other practical reasons, e.g. schedules.

The evaluation of research should also consider the gained theory development. A theory, according to Bacharach (1989), is a statement of relations among concepts within a set of boundary assumptions and constraints. It is no more than a linguistic device used to organize a complex empirical world (Bacharach, 1989). There exist consensus that data, variables, hypotheses, diagrams, references, typologies or metaphors are not theory as such (see e.g. Bacharach, 1989; Sutton and Staw[25], 1995). All of these can, however, be of great value when developing theories. The primary goal of a theory is to answer the questions of *how, when* and *why*, rather than the question of *what*, which is the goal of description (Bacharach, 1989). Of these, especially the question of how (*e.g. how to promote the selection and development process of R&D performance measures effectively*) has been of great importance in the present research. In relation to this question, we have succeeded to bring forth several factors and dimensions influencing the process, as well as several aspects which promote the effectiveness of the process and provides guidelines for choosing the most suitable measures of performance. The main derived influencing dimensions in the whole research have been the perspectives of performance analysis, the purpose of R&D performance analysis, the type of R&D, the level of the analysis, and the phase of the innovation process.

In addition and in relation to the assessment above the quality of this research has to be assessed in the light of the criteria of the constructive research approach. The constructed models presented in different parts of the research are based on observed real-world problems of R&D performance analysis, i.e. the *practical relevance* for the constructs exists. The *theoretical novelty and contribution* was already discussed above (Chapter 5.1) as these were related to the development and presentation of the actual use of the systematic methods in R&D measure selection in practice and to integrating the essential factors and dimensions (prior to the selection) to the actual selection process itself.

In addition to the criteria of relevancy, the applicability of the constructs in practice is assessed by their *simplicity* and *ease of use*. The presented phased process models in our research were clearly understandable for the participants and no special efforts for clarifying them were needed in the pre-meetings before utilizing the principles in practice. Generally, if all the possible supportive methods of the process, such as the use of the GDSS in some cases,

[25] Weick (1995) presents a critical review of Sutton and Staw's (1995) article, in which he complicates the issue by focusing on the *process of theorizing* rather than theory as a product, and argues that of Sutton and Staw's forms of 'no theory', some seem closer to theory than others, and all can serve as means to theory construction.

are not available, this might be a constraint for using some of the detailed process models in practice. However, the phases and basic ideas of the process to be utilized are flexible enough to be adapted with the supportive methods available. Also the participant surveys after the executed GDSS-sessions brought forth the benefits of systematic processes, e.g. many-sided and systematic consideration of different aspects, speed, richness of ideas and democracy. However, according to participant comments there were also some constraints in the process, e.g. too little focus on the relations between the different phases of the process; i.e. analytic considerations, idea generations and voting phases (see Appendix 3).

In our case studies, the development needs of the studied organizations were carefully mapped for practical relevancy and for applying the developed constructs to the development needs. The cases where the constructs were applied were planned together with the key persons in the applied organizations, who were directors and / or managers of research and development activities, i.e. persons with significant financial responsibility in their business units. Directly after the conducted case studies, the participants were asked to evaluate the usability of the constructs and to compare the constructs with other possible methods, for instance comparing the use of GDSS with the more traditional manual decision support systems, which the participants had used in similar types of decision-making problems. The evaluations and results of the comparisons were generally positive concerning the new approaches, and also encouraged for further development of the new type of constructs (see e.g. Appendix 3). The co-operation with the organizations continued also after the actual applications of the constructions, and the new R&D measures that where derived with the help of the developed constructs were taken into use. Some direct benefits of the use of new metrics could be shown, e.g. with regard to the internal managerial measures which are used in the decision-making and resource allocation of R&D process. The overall benefits concerning e.g. the financial outcome metrics could not be as directly shown as with managerial metrics. Some of the benefits take years to come forth and in our cases the studied organizations also operated in a relatively dynamic and turbulent environment, which has caused significant changes in organizational structures, which in turn has made the post-evaluation of the overall benefits or “strong market tests” in the long-term very difficult, or in some cases not even possible to do objectively.

The aim in using the constructs in practice regarding the present research was for the above-mentioned reasons limited purposefully to their weak market tests. Their applicability was tested from the points of view of single cases. However, as stated by Kasanen et al. (1991), if a solution is produced to a problem of a firm, it is very likely that this solution can be applied to other firms of the same type, as well. In general, one of the main points is that the actual question to be asked is the reverse to that presupposed by the claim of generalizability: after designing a working managerial construction, we may begin to consider what are the more general features which are revealed by the creation of a new reality (Kasanen et al., 1991). As stated above, as a whole the developed constructs in Publications 3, 4, 6 and 7 are case-specific, but they provide guidelines for different organizations through generalization of the main phases of the process. Many of the generalized aspects, for instance the suggested influencing factors of the measure selection processes and the essential dimensions of R&D performance analysis can be applied in the organizations outside of larger research projects which this study is a part of. The utilized solutions in our case studies provided good results, i.e. new measurable areas, evaluation methods and measures for organizations’ specific purposes. The managers who participated in the cases were open and interested enough to apply the suggested constructs. The use of the presented constructs in the long run and stronger market tests in the future will show their final applicability.

Regarding the generalizability of the larger construct of this dissertation it should also be noted that the use of the dimensions-table (Table 1 and its modifications) and its linkage to the selection process of R&D measures has received considerable interest also in organizations outside the larger applied research projects which this study has been a part of. Several large-sized companies from different industries have utilized the developed larger construct and "dimensions-table" for various purposes: for increasing the understanding and knowledge related to the dimensional aspects of the measurement of R&D performance, for visualizing and categorizing the dimensional aspects in R&D performance analysis and in the selection process of R&D indicators, as well as for taking all the essential aspects and needs into account, and for recognizing the gaps related to the performance analysis of R&D activities (see Ojanen and Vuola, 2003b).

When assessing the overall validity of the main constructs developed, there is also a need to compare the aspects of our approaches to earlier models of designing performance measurement systems in general and to earlier models of designing PM systems to R&D in particular. Many of the earlier models include significant aspects and phases that can be generally adaptable to the development of metrics and measurement systems in different R&D environments. There are empirically validated approaches, e.g. BSC and Toivanen's model for general strategy-based performance measurement system construction, and Kerssens-van Drongelen's PSDA model for the design of a R&D performance measurement system. Regarding our approach, the essential elementary principles drawn for the general design theory (see Kerssens-van Drongelen, 1999), such as 1) hierarchical decomposition or factorisation, 2) abstraction, 3) systematic variation and 4) solution selection on the basis of the satisficing principle, are taken carefully into account.

Similar types of main phases as in the earlier models can be found also in our approaches of selecting the R&D metrics. These are e.g. the definition of reasons and objectives for measurement system development, commitment of the organization to the development project, and selection of measures and system implementation. However, when comparing the developed approach to earlier approaches in general, it can be noted that in our approach more emphasis is put on the definition of the criteria for the selection of measures on the basis of influencing factors. In our approach, the dimensions influencing the measurement of R&D performance are carefully clarified and linked to the selection criteria. In addition, the group decision support systems and analytic hierarchy process principles have been utilized in systematizing the conduction of the process, especially the phase of actual measure selection.

Particularly in the R&D performance measurement area, the earlier studies (e.g. Kerssens-van Drongelen, 1999; Akcakaya, 2001) have provided excellent support in the form of guidelines drawn from e.g. literature reviews. On the other hand, from the empirical point of view, for instance Kerssens-van Drongelen (1999) has named the validation of the developed PSDA model with the help of reflective case studies to be one of the suggested further research areas.

In the case studies of the present dissertation, we have tested the principles and phases of selection processes of R&D measures in real-world organizations, and included also the experiences from practical case studies to the iterative theory building process related to the selection of R&D measures.

The developed models for corporate performance measurement (e.g. Toivanen, 2001) are to some extent adaptable also to the development of measurement systems and selecting the measures in R&D activities. However, there is a need to emphasize the special aspects related to the measurement of R&D performance in a way that make the development of new approaches for especially R&D performance measure selection necessary. These aspects are gone through in this dissertation, and are the following: First, the special characteristics of R&D, such as the long time lag between the inputs and outcomes, as well as the overall complexity and difficult coordination of activities influence the R&D performance analysis problems, such as the need for more systematic, objective, balanced and multi-dimensional approaches for R&D measure selection, and incompatibility of R&D measurement systems to the other corporate measurement systems and vice versa. Secondly, the above-mentioned characteristics and challenges bring forth the significance of the influencing factors and dimensions that need to be recognized in order to derive the selection criteria for measures and to choose the right R&D metrics, which is the most crucial step in the measurement system development process. Speaking of the dimensions, for instance the recognition of R&D types emphasizes the diversity of R&D activities, and recognition of the purposes for R&D measurement clarifies the multiple possibilities for the selectable measures to be utilized in the management of R&D.

5.3 Further research

Several topics concerning the performance analysis in R&D still remain only superficially researched and several problems remain unresolved. Thus, new avenues can be built for several potential future studies.

As the main constructs were linked to the process of selecting and developing the performance measures and measurement systems for R&D, on the basis of experiences in utilizing the constructed solutions we can further develop the whole process for being as applicable as possible for the R&D activities of different types of organizations. For instance, due to the observed requirements and method features, we could only test a limited number of solutions, tools and decision support systems. There are many possibilities to integrate the benefits of different tools and study; for instance, the utilization of manual and computerized methods in the process via more detailed comparative analyses is a potential future area of study. In addition, the actual implementation and usage of the measures according to the purposes of measurement, after the measures have been selected from the process, is of great importance. Therefore, the research of R&D performance analysis and R&D metrics should be complemented and integrated with the research of R&D performance management.

Some special topics can be drawn from the sub-areas of this dissertation. In the Publication 5, for instance, the challenges of a networked R&D environment were discussed from the viewpoint of R&D performance analysis problems in ICT industry. How to actually address the challenges in collaborative and networked R&D is a relatively scantly researched area, and need to be studied more in detail, since networks have lately been increasingly popular organizational forms. In relation to this, different organizational forms are used in different organizations and different industries. More thorough observation of the influence of industry specific characteristics on R&D performance analysis and detailed comparative analysis of measurement dimensions in different industries could provide valuable information for various organizations. Several types of organizations from different industries were involved in this study, but still, the sample in an industry-specific comparative study would need to be larger.

Incorporation of R&D and quality management practices (discussed in Publication 4) is a relatively widely researched area, although a difficult one, and involves many unresolved issues. One potential future study here could be related to the integration of assessments based on quality management principles with the strategic performance measurement systems drawn from strategic management accounting. This would enhance the role of performance analysis in R&D, and measures of R&D could be more interrelated to the other performance indicators of the company. Speaking of strategy, the conceptualized model for monitoring the competence development in an applied research institute (Publication 7) needs to be further developed and applied to other organizations if possible. The growing interest in measuring intangible assets forces us to strongly take into account the evaluation of capabilities, competencies and knowledge transfer processes in R&D.

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Appendix 1.

Interview protocol:
Important topic areas concerning R&D performance analysis.

- (Background questions included questions of the role of R&D in the organization in general, the R&D process and problems in R&D)
- The evaluation and measurement of R&D at different levels of analysis
- The evaluation and measurement of R&D at different phases of the R&D process
- Problems in the present measures and evaluation methods of R&D
- The purpose of R&D performance analysis in the organization
- The balance of R&D measures (qualitative vs. quantitative methods, internal vs. external measurements, financial vs. non-financial measures)
- The choosing of R&D performance measures
- The relation of R&D measures to strategy and business objectives
- The characteristics of a good measure / measurement system
- Computer-aided support of R&D performance analysis
- The control and measurement of communication and information flow in networked R&D
- The utilization of measurement results in R&D decision-making
- The relation of R&D performance analysis to the other assessment / measurement systems of the organization
- The factors and measurement of the overall effectiveness of R&D

Appendix 2, 1(2).

<u>The main data sources of the present research.</u>

1. Data from the larger applied research project "Strategic Aiming and Assessment" (TOP) 1996-1999:

- co-operation with five medium- and large-sized industrial manufacturing companies
- 44 semi-structured interviews on product innovation management systems, one sub-area in the interviews being R&D performance evaluation and measurement
  - interviewees managers / directors from R&D and closely related functions (e.g. quality management, marketing, production, after sales)
  - interviewed by the project researchers
- a questionnaire (discussed in Publication 1) of measures for R&D performance analysis to each company in 1998
- an inter-company expert meeting of R&D performance measurement in 1998
  - ca. 15 participants from five manufacturing companies and from a university
- a case study of creating a strategic performance analysis system for R&D in a manufacturing company in 1998-1999 (reported in detail and confidentially as an undergraduate student's Master's thesis work)
- a case study of applying quality award criteria to R&D performance analysis in a manufacturing company in 2000-2001 (continued co-operation between one of the manufacturing companies and the researcher)
- informal interviews, discussions, e-mails

2. Data from the larger applied research project "Product Development Management in the Network Economy" 5T (5TT since 1.8.2002) 2000-2003:

- co-operation with three companies from the ICT sector
- several semi-structured individual interviews in companies, of which six in-depth interviews on R&D performance analysis (interviewed by the author of the present study) and five interviews on assessing and developing the communication quality in R&D (interviewed by undergraduate students)
- three expert meetings / group interviews and workshops on selected R&D management issues in 2000-2002
  - -ca. ten company participants in each session
- questionnaires for complementing the individual and group interviews to selected R&D management experts on the significance of problems of R&D performance analysis (described in Publication 5) and to workshop participants on most significant ICT industry characteristics (described in Publication 5); total amount of 8+8=16 responses of selected experts
- a case study on the selection of measures for the overall effectiveness of R&D in an ICT company, five company participants, three university researchers
  - a one-day GDSS session of eight participants
  - two pre-session meetings of three participants
- informal interviews, discussions, e-mails

Appendix 2, 2(2).

3. Other important data sources

A strategy-based selection process of research measures for a university department in 1999
- two half-day GDSS-sessions of nine participants from different organizational levels
- pre-session meetings

A process for developing and measuring strategic competences in a research institute in 2002
- several multi-person meetings
- a one-day workshop

Appendix 3, 1(2).

An example of a GDSS-based approach to the selection process of R&D performance measures (Ojanen et al., 2000).

INPUT ➔	THE PHASES OF THE PROCESS	➔OUTPUT
▪ The purpose and tasks of the set of measures to be utilized ▪ The goals and schedule of the indicator selection process ▪ Possibilities of a GDSS	A. PLANNING AND REVIEW OF INDICATOR SELECTION PROCESS Preparation meetings with the company representatives and a review in the introduction of the selection session	• Specified goals and exact schedule for selection session • Adjusted selection process • Tools to be used ▪ Organization of the selection process
▪ Purpose of measurement ▪ Corporate strategy and its components ▪ Different perspectives of a balanced set of measures ▪ Opinions and expert knowledge of departments and sections	1. IDEA MAPPING, COMMENTING AND FURTHER IDEATION Categorizer tool (*Iterative phase*)	▪ Possible measure proposals for every strategy area ▪ Measure proposals adjusted by supporting comments ▪ New measure proposals ▪ Understandable alternatives ▪ Concrete measures
▪ Corporate business strategies, mission, vision, goals and critical success factors ▪ Measurement system requirements of different departments ▪ Expert knowledge ▪ Recognition of R&D impact chain	2. REQUIREMENTS MAPPING AND GATHERING FOR THE SET OF MEASURES Categorizer tool	▪ Preliminary selection criteria ▪ Adjusted goals for measurement ▪ Documented requirements for the measurement system
▪ Preliminary selection criteria ▪ Purposes and goals of measurement	3. SPECIFYING AND PRIORITIZATION OF SELECTION CRITERIA Voting tool	▪ Prioritized measure selection criteria ▪ The most significant criteria to be considered in the selection of a balanced set of measures
▪ Alternative measure proposals ▪ The most significant criteria to be considered in the selection of a balanced set of measures ▪ Expert opinions of different sub-areas	4. SELECTION OF MEASURES Alternative Analysis tool	▪ Weighted total score given to each measure proposal ▪ The best measure proposals according to the evaluation ▪ Divergence of expert opinions
▪ Evaluation results ▪ The best measure proposals ▪ Divergent opinions ▪ The cause-and-effect relationships between different sub-areas	5. THE REVIEW OF THE EVALUATION RESULTS AND SELECTION OF THE MEASURES TO BE UTILIZED Discussion of the results of the Alternative Analysis tool	▪ The balanced set of measures ▪ The tasks and applicable areas of the measurement system to be utilized ▪ The cause-and-effect relationships between the measures
▪ The selected balanced set of measures ▪ The expertise of different departments and opinions about the selected set of measures	6. MAPPING OF THE IMPACTS OF THE BALANCED SET OF MEASURES Topic Commenter tool	▪ The impacts of the measures on the different departments and their operations ▪ the ability of the set of measures to measure the fulfilment of the strategy and to steer activities ▪ The principles of the follow-up of the set of measures
▪ The questions for evaluation of the functionality of the developed selection process ▪ The opinions of the expert participants concerning the success and functionality of the session	B. EVALUATION OF DEVELOPED SELECTION PROCESS AND SESSION Survey tool	▪ The applicability of the GDSS for the selection of a balanced set of R&D measures ▪ The advantages and problems related to the process ▪ Further development needs related to the process and further studies

Appendix 3, 2(2)

Some evaluation results from an executed GDDS session and the selection process of R&D performance measures (a participant survey of a GDSS session; 9 participants):

The benefits of the GDSS in the measure selection were found to be the following:
- many-sided systematic consideration
- clear progress, systematizes activities
- quickness
- divergence in opinions becomes forth
- plenty of ideas
- democratic voting

The restrictions or limitations were found to be the following:
- the relationships between analytic considerations, idea generation and voting should be taken into account more strongly
- many duplicates
- the use of numbers would be clearer in evaluations with selected voting methods
- further use of the results would require more discussion

Evaluation of the results of the GDDS session: How well were the set goals (selected measures for strategic objectives) of the session achieved? 6 of the 9 participants answered this question.
- mean value=8.5 (scale 1-10, where 10 = goals achieved perfectly), standard deviation=0.55, n=6