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Categorizing the Measures and Evaluation Methods of R&D Performance – A State-of-the-art Review on R&D Performance Analysis

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1 INTRODUCTION

The present study concentrates on reviewing previous studies on research and development (R&D) performance analysis and recognizing and categorizing the reported measures and evaluation methods of R&D performance. The main purpose of the study is to increase and structure the understanding of the influence of the factors and dimensions of R&D performance analysis on the applicable measures or evaluation methods of R&D performance.

The measures and evaluation methods of R&D can be categorized in several ways. In the present study the main groupings are made on the basis of the purposes of R&D performance measurements, suggested or reported measurement levels, types of R&D as measurement subject, the perspectives of measurement, and the phase of the R&D process where the measure or evaluation method is suggested to be most applicable. Additionally, if reported, a distinction is made between measures utilized in real-world applications and those suggested in the academic literature. The analysis of reported measures offers comments and suggestions on the applicability of the measure or evaluation method to certain situations and purposes of measurement.

Earlier, R&D activities at the firm level were often considered as a 'black box' and an isolated function, which was nearly impossible to be systematically managed and controlled. A defined amount of money was given to R&D, and in the long run the managers expected something useful to turn up. The characteristics associated with R&D activities and R&D personnel also increase the difficulty of performance analysis. New, different organizational structures and control models have forced many managers to rethink the mechanisms related to R&D and its control. One of the most critical motives for measuring R&D performance at the firm level is the validation of the chosen investment level on R&D, i.e. the R&D function has to prove its productivity and significance for the whole company. The fact is that R&D investments often must compete with the other investments in the company.

At the national level, the investments to research and development have increased in many countries. As such, the ratio between the R&D investment and the Gross Domestic Product (GDP), or at the company level, the R&D investment compared to the firm's turnover, do not tell much about the real effectiveness of R&D activities or the utilization of R&D investments and its results. However, the positive effects of suitable R&D investments to competitiveness are recognized by the policy-makers.

A great number of measures or evaluation methods indicating R&D performance have been reported in the literature during the last decades. In this study we aim to clarify the complexity of different types of R&D metrics by categorizing them with the help of measurement dimensions that should be notified in all organizations. The final set of measures to be utilized depends on a number of factors and is specific for the type of organization. This means that common, universal sets of R&D measures do not exist. However, with the help of the recognition of different types of reported measures and measurement dimensions, organizations can become more aware of different possibilities, and can use the earlier reported measure proposals as checklists for certain measurement purposes.

2 CATEGORIZATION OF REPORTED R&D PERFORMANCE MEASURES AND EVALUATION METHODS

2.1 Dimensions of R&D performance analysis and factors influencing the selection of R&D measures

We can distinguish a number of different factors that have an influence on the selectable measures or evaluation methods of R&D performance, as well as measurement dimensions to be taken into account in the early phase of the selection and development process of R&D performance measures. The main measurement dimensions we have categorized 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 and the phase of the R&D process to be measured. One dimension influencing all the other dimensions is the strategy of R&D and the strategic objectives that set the emphasized areas to the perspectives of measurement. 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 discussed above. 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 purposes for measuring, which could be, for example, R&D benchmarking of competitors in a fiercely competitive industry.

Additionally, as described in earlier studies (e.g. Ojanen et al. 1999), we can include the critical success factors of R&D and the whole company, the recognition of R&D impact chain, and other contingency factors in the set of factors that have an influence on the selection of R&D measures. The influencing factors set requirements for the selectable measures and the final selection criteria.

In the literature we can find several suggestions for the measurement of R&D in different stages or different purposes, or for what kind of evaluation methods to use for certain types of R&D. These aspects, discussed in the chapters below, can be used as checklists prior to the actual selection of R&D measures. The emphasis of different factors set different requirements for the evaluation criteria in the final selection of R&D performance measures. For utilizing the dimensions in the selection of R&D metrics, the process depicted in Figure 1 below integrates the different aspects concerning the whole process of choosing the right set of organization-specific measures for R&D. This study provides categorizations, examples of evaluation methods and measures of R&D performance to be utilized as checklists when an organization aims at tracking the most suitable R&D measures for its own purposes. The recognition of the state of the art can help in sparing time and other valuable resources in the time-consuming measure selection process.

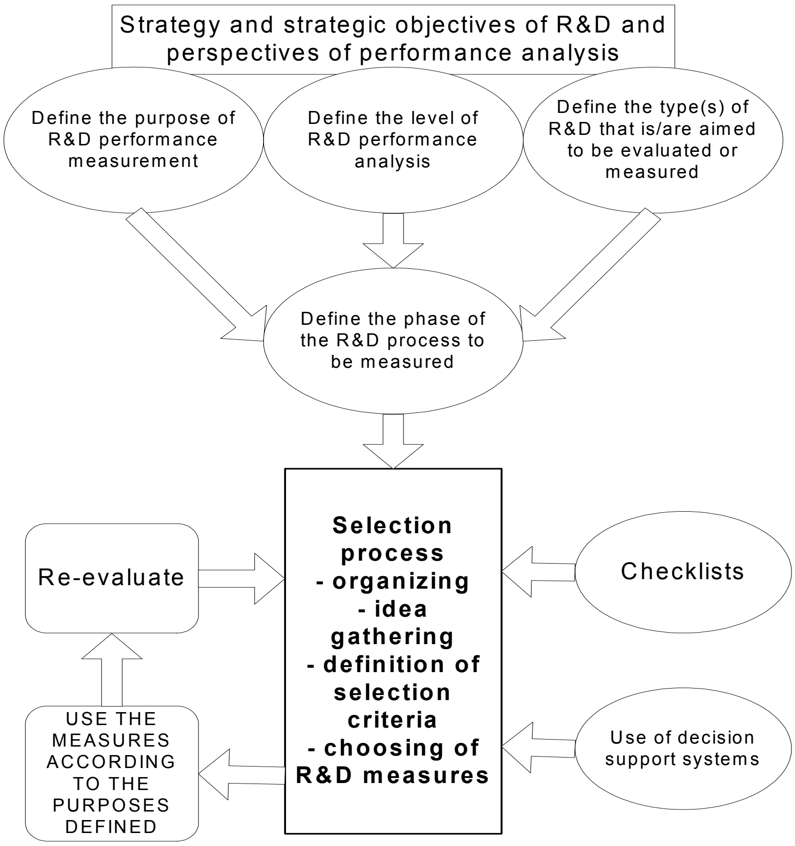

Figure 1. A simplified system approach of selecting and developing performance measures and evaluation methods for R&D (adapted from Ojanen and Tuominen 2002).

2.2 R&D measures categorized by the measurement perspectives

Performance measurement 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 in 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 chapter, “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 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 to the measurement?

The measures or evaluation methods of R&D as distinguished by the different measurement perspectives have been studied e.g. in the following references (Table 1):

Table 1. The selected references categorizing R&D measures by the perspectives of R&D performance analysis.

Reference	**Short description of the study**
Akcakaya (2001)	The author 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 and Kleinschmidt (1996)	A benchmarking study of 161 business units includes ten performance metrics, which capture how well the business unit's total new product effort performs. The metrics are listed below.
Curtis (1994)	The study analyses the use of time as an alternative performance measure to the cost for managing financial performance. The focus on the study is on new product development and it presents the methods, and internal as well as 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.
Curtis and Ellis (1997)	The study 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.
Driva et al. (2000)	The interesting results of the study show that a gap does exist between the measures recommended by the academics and those used in practice. The main difference lies 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.
Griffin and Page (1996)	The study categorizes the project-level measures to customer-based success, financial success, and technical performance success. Average utility of success measures is calculated for each project strategy.
Hultink and Robben (1995)	The study is based on a literature review and surveys in the Netherlands, resulting 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.
Kerssens-van Drongelen and Bilderbeek (1999)	The researchers present reported measures of performance as categorized by the principles of the Balanced Scorecard –approach. See Table 2 below.
Szakonyi (1994a, 1994b)	The approach developed by the author helps to compare the performance of the R&D department with the performance of an "average" R&D department. Ten basic activities of R&D have been assessed with a six-point-scale. The results of the "average" department have been drawn from 60 real-world examples. The ten basic activities are listed below.
Tipping et al. (1995)	The authors present top 11 metrics out of 33 metrics in their "technology value pyramid" as assessed by 165 industrial companies. The model provides a top-down perspective that is output-oriented. The top 11 metrics are listed below.
Werner and Souder (1997b)	In their study of U.S. and German practices of R&D performance measurement, the researchers conclude 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. The studied companies were from aerospace (2), automotive (8), chemicals (5), consulting (7), electronics (8), mining and materials (3), oil and chemicals (2), and telecommunications (5) industries.

As an example of the studies presented above, the metrics reported by Cooper and Kleinschmidt (1996) are

- Success rate: The proportion of development projects that became 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

The ten assessed activities of R&D in the study of Szakonyi (1994a; 1994b) are

- Selecting R&D
- Planning and managing projects
- Generating new product ideas
- Maintaining the quality of R&D process and methods
- Motivating technical people
- Establishing cross-disciplinary teams
- Coordinating R&D and marketing
- Transferring technology to manufacturing
- Fostering collaboration between R&D and finance
- Linking R&D to business planning

The top 11 metrics reported by Tipping et al. (1995) are

- 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

Table 2. Reported measures of performance as categorized by the principles of the Balanced Scorecard –approach (Kerssens-van Drongelen and Bilderbeek 1999).

Financial perspective objectives	**Metrics**
Survive	Present Value of R&D accomplishments / R&D expenditure
Succeed	Percentage of sales from new products
Prosper	Market share gained due to R&D
Customer perspective objectives	
High customer satisfaction	Score on customer satisfaction audit
Anticipation of internal and external customers' needs	Percentage of customer driven projects
High level of design for manufacture	Engineering hours on projects / engineering hours on projects and troubleshooting
R&D hit rate	Percentage of projects terminated before implementation
Internal business perspective objectives	
Productivity	Hours spent on projects / total hours of R&D
Speed to market	Current t.t.m. / reference t.t.m.
Technology/ design re-use	Rate of re-use of standard design/proven technology
Reliable delivery of outputs	Sum of revised project duration / sum of planned duration
Quality of output	Number of times rework
Innovation and learning perspective objectives	
Technology leadership	Number of patentable discoveries per $ spent on R&D
Long term focus	Percentage of budget spent internally and externally on basic and applied research
High absorptive capacity	Percentage of projects in co-operation with a third party
Learning organization	Percentage of project evaluation ideas applied in new projects

2.3 R&D measures categorized by the purpose of measurement

Evaluation methods or measures, as such, are useless, if they are not utilized in the decision-making and management. Therefore, it is 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.

According to Lee et al. (1996), 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.

The measures or evaluation methods of R&D as distinguished by the purposes of R&D performance analysis are studied e.g. in following references (Table 3):

Table 3. Selected references categorizing R&D measures by the purpose of R&D performance analysis.

Reference	Short description of the study
Gold (1989)	The study defines major types of contributions which R&D programs could provide, and then discusses their bearing on evaluating: R&D performance alone, R&D contributions to the overall performance of the firm, and the R&D performance of a given firm in comparison with that of its competitors.
Kerssens-van Drongelen and Bilderbeek (1999)	In the Chapter 2.4 below, the categorization by the levels of measurement in Kerssens-van Drongelen and Bilderbeek's study is presented. Additionally, the authors empirically have studied the purposes mentioned for measurement at different levels. The most often mentioned purposes are presented in Table 10 in Chapter 3 of this paper.
Loch and Tapper (2002)	The study describes a process of developing and implementing a comprehensive performance measurement system for an applied research group. The system addresses the first three of the four basic functions of performance measurement: strategic alignment and prioritisation, evaluation and incentives, operational control, and learning and improvement.
Meyer et al. (1997)	The authors propose platform efficiency and platform effectiveness for the measurements of R&D performance focused on platforms and their follow-on products within a product family, i.e. the degree to which a platform allows economical generation of derivative products and the degree to which the products based on a platform produce revenue for the firm relative to development costs.

2.4 R&D measures categorized by the level of measurement

Rummler and Brache (1995) have distinguished three main levels for performance measurement and improvement; 1) organizational level, 2) process level, and 3) job / performer level. To be more precise, the relevant, possible levels at which to measure the performance of R&D are macro (national) level, industry level, network 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 level. Generally, business performance, as well as R&D 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 measures or evaluation methods of R&D as distinguished by the different levels of R&D performance analysis have been studied e.g. in the following references (Table 4):

Table 4. Selected references categorizing R&D measures by the levels of R&D performance analysis.

Reference	Short description of the study
Brown and Gobeli (1992)	As will be discussed in Chapter 2.6 below, the study presents indicators for different phases of R&D process. The authors have utilized "R&D hierarchy of activities" as a framework which includes 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 which need to be measured.
Griffin and Page (1996)	According to the authors, the 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 an example, Table 11 in Chapter 3 depicts the recommended firm-level success measures by business strategy.
Kerssens-van Drongelen and Bilderbeek (1999)	The paper presents the results of an empirical study focusing on the effectiveness of R&D performance measurement practices in the Netherlands. The authors categorize the measures of different perspectives to the team level, individual level, departmental level and company level.
Loch and Tapper (2002)	The study presents the performance measures of GemStone's Research Group categorized to group level and project level output measures and project level process measures.

2.5 R&D measures categorized by the type of R&D

R&D activities can be divided into functions or stages in which the various evaluation techniques are adapted. Quantitative techniques for evaluating performance 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 (Pappas and Remer 1985). Figure 2 below depicts the best-suited evaluation techniques for different types of R&D.

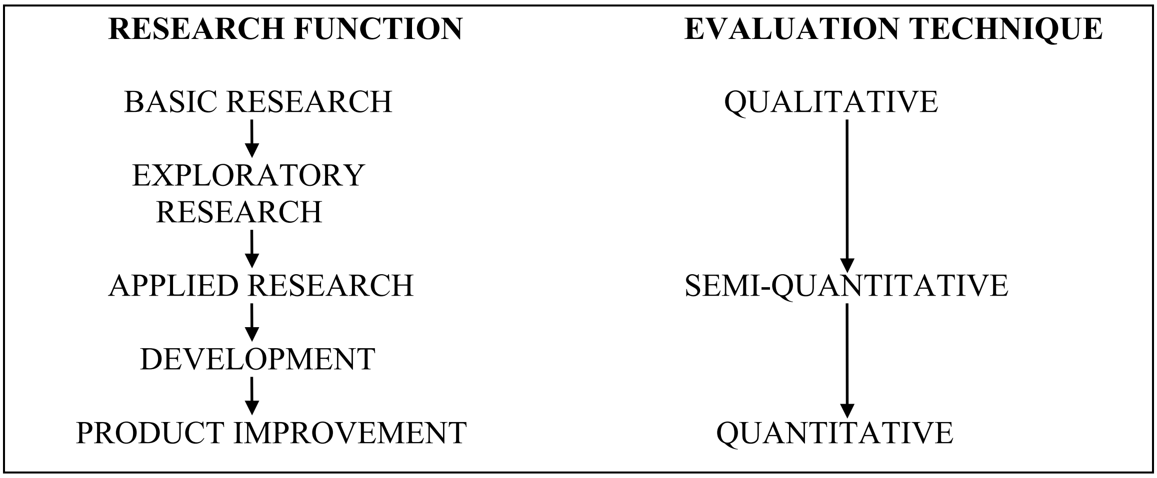

Figure 2. General uses of evaluation techniques by different types of R&D (adapted from Pappas and Remer 1985).

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.

The measures or evaluation methods of R&D as distinguished by different types of R&D have been studied e.g. in the following references (Table 5):

Table 5. Selected references categorizing R&D measures by the type of R&D.

Reference	**Short description of the study**
Brown and Gobeli (1992)	The study presents examples of R&D productivity indicators as identified by case study participants. They categorized the indicators to predominantly qualitative indicators and predominantly quantitative indicators. In this study, the qualitative, semi-quantitative and quantitative indicators are discussed on the basis of the framework of Pappas and Remer's (1985) suggested evaluation techniques for different types of R&D.
Hauser and Zettelmeyer (1997)	The authors introduce a tier metaphor, which enables us to categorize a diverse continuum of projects, programs and explorations, and focus on key characteristics. "Tier 1" is defined as basic research, which 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. The study presents R&D metrics, both qualitative judgments and quantitative measures, reported by interviewees, as well as their relevancy for the Tiers (see Table 12 in the Chapter 3 as an example of metrics for "Tier 3").
Kerssens-van Drongelen and Bilderbeek (1999)	In a survey of R&D performance measurement conducted in the Netherlands, the researchers categorize the types of R&D to basic research, applied research and development. In this study, the researchers surprisingly did not find support for their proposition on differences in measurement procedures for applied research and for development.
Kim and Oh (2002)	Categorization is made on the basis of the type of R&D in a survey of effective R&D performance measurement systems in Korea. The types are basic R&D, applied R&D and commercial R&D.
Loch and Tapper (2002)	The authors categorize the measures of a "performance radar chart" at GemStone to areas of knowledge repository, research process, new technologies and technical support.
Werner and Souder (1997a)	According to the study, the most successful approach to R&D effectiveness measurement appears to be integrated metrics that combine multiple objectives and subjective methods. The study presents examples of integrated metrics that contain an articulated but separable suite of quantitative and qualitative techniques which can be flexibly applied across all types of R&D.

2.6 R&D measures categorized by the process phase

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

An article that can be used as a framework in the evaluation and measurement of R&D performance is the approach presented by Brown and Svenson (1988). In their approach, 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 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, sales, or product improvements* (Brown and Svenson 1988). The approach in Figure 3 is a complemented picture of Brown and Svenson's approach. We have added the arrows that show the future indications from earlier phases of the process and smaller arrows that 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.

Regarding Brown and Svenson's approach we have to keep in mind that depending on the level of 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, if we take a look at 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.

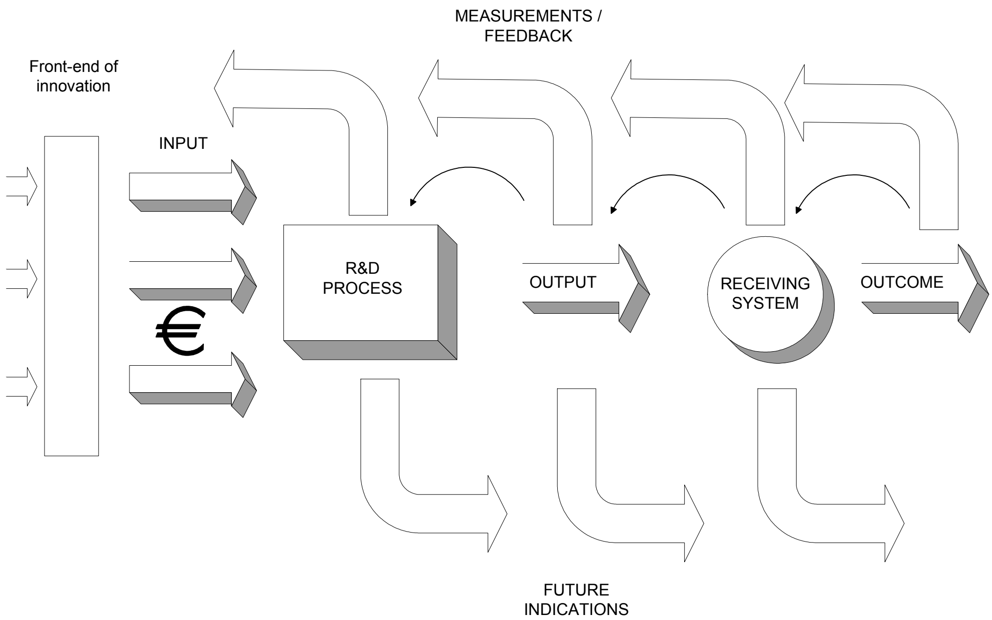

Figure 3. R&D as a processing system (adapted from Brown and Svenson 1988).

The measures or evaluation methods of R&D as distinguished by the different phases of the R&D or innovation process have been studied e.g. in the following references (Table 6):

Table 6. Selected references categorizing R&D measures by the phases of the R&D process.

Reference	Short description of the study
Brown and Gobeli (1992)	The study presents "top ten" R&D productivity indicators on the basis of classification to measurements of 1) resources, 2) project management, 3) people management, 4) planning, 5) new technology study and development, 6) outputs, and 7) division results / outcomes, of which 1, 6 and 7 can be seen as process phases.
Brown and Svenson (1988)	The authors present a model for measuring R&D productivity by categorizing the system to inputs, processing system, outputs, receiving system, outcomes, in-process measurements, output measurements and outcome measurements.
Chiesa et al. (1996)	See the measures below in Table 7. The measures have been tested with the help of case studies.
Cooper (1993)	Cooper presents the stage-gate™- product development process model, including the stages of preliminary investigation, detailed investigation, development, testing & validation and full production & market launch, and gates as go/kill –decision points after each main stage.
Cordero (1990)	The author presents a model and example measures to measure innovation performance by categorizing the measurements into resources to technical units, resources to commercial units, technical outputs and marketable outputs.
Ellis (1997)	In addition to other aspects, the book presents measurements in an R&D process model, and processes as a function of time. In the R&D process evaluation, the book discusses interaction and input metrics, evaluation of internal R&D processes and external evaluation of R&D (e.g. customer satisfaction evaluation and measurement).
Ellis and Curtis (1995)	The article reports a survey research that links cycle times and financial performance. The three cycle-time measures in the innovation value chain are the idea-to-customer cycle time, time-through-R&D and market-development cycle time. The study concludes that the financial improvement resulting from reducing cycle time is small, and leads to an acceleration trap.
Lee et al. (1996)	The study presents evaluation criteria and their operationalizations in following R&D system phases: Input, Throughput, Output and Outcome. A measurement scheme with 15 criteria has been validated empirically by respondents from 28 industrial firms (see Table 8 below).
Schumann et al. (1995)	The study presents a quality-based approach that considers the R&D process elements for measurement to be people-process-output-internal customers-external customers-society.

As examples of the studies presented above, we present the reported measures, evaluation methods and measurement areas in the "technical innovation audit" by Chiesa et al. (1996) and the reported criteria for measuring R&D effectiveness by Lee et al. (1996).

Table 7. Metrics in technical innovation audit (Chiesa et al. 1996).

Concept generation

- Number of new product ideas, product enhancement ideas evaluated in the last year
- Number of new product-based business areas/ventures started in the past 5 years
- Customer satisfaction
- Product planning horizon
- Average product life cycle length

Product Development

- Time to market
  - Average concept-to-launch time
  - Time for each phase
  - Average overrun
  - Average time of product enhancement
  - Average time of redesign
- Product performance
  - Cost
  - Technical performance
  - Quality
- Design performance
  - Manufacturing cost
  - Manufacturability
  - Testability
  - Number of product redesigns

In addition to the above R&D performance measures, Chiesa et al. (1996) report measures under the topics “Process innovation”, “Technology Acquisition”, “Leadership”, “Resourcing”, and “Systems and Tools”. These measures are not reported here in detail due to the scope of the present study.

Table 8. Fifteen important criteria for measuring R&D effectiveness (Lee et al. 1996).

System phases	Evaluation criteria
Input	Enough R&D investments Enough R&D facilities Degree of professionalization Skill level of R&D personnel
Throughput	Feasibility of R&D plans Adequate education/training Validity of selected R&D topics Collaboration between R&D and Production/Marketing Effort to strictly follow plans Adequate information management Expansion and diversification of research areas
Output	Degree of goal achievement Usefulness of developed technology
Outcome	Expected profit increment Effects on general management improvement

As a practical example, Exxon Chemical has utilized three **in-process measures**; 1) penetration, i.e. the percentage of NPD budget utilizing an innovation process, 2) the percentage of new projects utilizing an innovation process and 3) Focus / Culling, i.e. the percentage of No Go or Hold decisions made during a period of time by the end of stage two of the innovation process, as well as **three results-based measures**; 1) speed of innovation, 2) performance, i.e. second year Earning Before Interest and Tax versus gate four of the innovation process and 3) percentage of revenue from products more than five years old (Ahmed and Zairi 2000).

2.7 Integrated measures of R&D performance

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 simple metrics. However, they do not only measure R&D performance but suggest also means for improvement and are reliable (Werner and Souder 1997a).

Werner and Souder (1997a) present an example of an integrated metric that combines several objective and subjective metrics:

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

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

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

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]

Mcgrath and Romeri (1994) have developed an R&D effectiveness index for measuring the overall success of product development. The formula is

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

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.

Ahmed and Zairi (2000) have reported practical examples on integrated methods to R&D and innovation performance measurement. For instance, Hewlett-Packard has tracked overall effectiveness of product development with the help of two measures:

$$\text{Staffing level effectiveness} = \frac{\text{Staff initially forecast as needed for a project}}{\text{Staff actually needed by project}} \times 100\%$$

This measure monitors how close the projections for the staff needed on a project matched the actual staffing required by the project (Ahmed and Zairi 2000).

$$\text{Stability of the design} = \frac{\text{Number of design changes in a project}}{\text{Total cost of project}} \times 100\%$$

This measure tracks the number of design changes made. As large projects might need more changes simply because they are larger, this metric, by dividing against the cost of the project, adjusts for the size of the project (Ahmed and Zairi 2000).

Additionally, the overall effectiveness of the innovation process at HP is followed by the following measure (Ahmed and Zairi 2000):

$$\text{Innovation effectiveness} = \frac{\text{Number of projects finishing development}}{\text{Number of projects started development}} \times 100\,\%$$

3 SUMMARY OF THE DIMENSIONS, THEIR COMBINATIONS AND LINKAGES TO THE MEASURE SELECTION

A summary of the essential measurement “dimensions” that can be derived from the different theoretical and empirical sources is listed in Table 9. Reported, suggested and applied R&D performance measures and evaluation methods can be categorized in several ways. The present study categorizes the reported measures by the five dimensions of measurement, i.e. the phase of R&D process, the level of R&D performance analysis, the purpose of R&D performance measurement, the type of R&D to be evaluated, and the perspective of measurement. As can be seen in Table 9, all the combinations of dimensions do not exist or do not come in the question, but the main idea is to clarify the possible organization-specific combinations of dimensions for tracking the most essential areas to be measured.

Table 9. The dimensions of R&D performance analysis in this study.

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

Next, we present some example approaches of integrating the aspects from different dimensions of measurement. First, Table 10 presents the most often mentioned purposes of R&D performance measurement at the different levels of analysis as they were presented in the study of Kerssens-van Drongelen and Bilderbeek (1999).

Table 10. 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

As discussed above, 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 an example, Table 11 presents recommended firm-level success measures by four business strategies.

Table 11. Recommended firm-level success measures by business strategy (Griffin and Page 1996).

Prospector	Analyzer	Defender	Reactor
% profits from products < n years old	Degree products fit business strategy	Development programs ROI	Development programs ROI
Degree today's products lead to future opportunities	Development programs ROI	Degree products fit business strategy	Success / failure rate
% sales from products < n years old	% profits from products < n years old		Degree products fit business strategy

As argued by Griffin and Page (1996), the firms with least innovative strategies find it useful to focus on measuring the efficiency of their product development program, the firms with moderately innovative strategies find that measures that provide information about both the efficiency and effectiveness of their programs are most useful, and the firms with more innovative strategies need to measure how product development has contributed to growth.

Hauser and Zettelmeyer's (1997) approach categorizes the metrics of R&D by three types of projects. The "Categories" in Table 12 can be seen as perspectives of measurement, and thus the study combines the types of R&D and the measurement perspectives. Table 12 presents suggested metrics for Tier 3 (near-market projects) by different categories.

Table 12. Metrics for Tier 3 (Hauser and Zettelmeyer 1997).

Category	Metric
Strategic goals	Competitive response
Quality/Value	Quality of the research Peer review of the research Benchmarking comparable research activities Value of top 5 deliverables Gate success of concepts Yield = [(quality×opportunity×relevance×leverage)/overhead]×consistency of focus
People	Managerial involvement
Process	Productivity Timely response Deliverables delivered Fulfillment of technical specifications Time for completion Speed of getting technology into new products Time to market Time of response to customer problems
Customer	Relevance Customer satisfaction Service quality (customer measure) Number of customers who found faults
Revenues/Costs	Revenue of new product in 3 years/R&D cost Percent revenues derived from 3-5 year-old-products Gross margin on new products Economic value added Break-even after release Cost of committing further Overhead cost of research

Additionally, an illustrative example may provide guidelines for how to utilize the results of this paper: for instance, an industrial company aims to find and select new measures for R&D. The company seeks company-level measures for product development and improvements; in other words, the evaluation techniques will be mainly quantitative or semi-quantitative (e.g. Pappas and Remer 1985). No long-term research activities are executed. Before selecting the measures, the company also has to define the possible purposes of measurement, which in this case are the strategic control of the whole R&D and possibly benchmarking of activities. However, in the first phase the company is satisfied of its internal measurements and seeks now output and outcome measures or evaluation methods for financial and especially customer perspective measures. In this case, if the company follows the prospector strategy it could consider the recommended firm-level measures of Griffin and Page (1996) for this strategy, e.g. profit and/or sales from new products less than three years old. Additionally, Kerssens-van Drongelen and Bilderbeek (1999) have reported customer perspective measures among other measures. For the mentioned purposes, other relevant references to check out are for instance Schumann et al. (1995), Curtis and Ellis (1997), and Hauser and Zettelmeyer (1997). This need of R&D measurements could be illustrated in the table of dimensions in the manner presented in Table 13 below.

Table 13. Combination of dimensions of R&D performance analysis in the illustrative example.

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

4 CONCLUSIONS

The emphasis of this study has been on the necessary steps in the early phase of the selection process of R&D performance indicators. This phase prior to the actual selection of measures includes recognition and careful consideration of the measurement needs with the help of the following main dimensions of R&D performance analysis: 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.

The study contains a literature review on, and the categorization of, indicators by the dimensions of R&D performance analysis. The recognition of the state of the art is an essential element in the selection and development process of the R&D indicators of an organization. The following general utilities can be drawn from the literature review conducted in this study: First, categorization via the several dimensions influencing the selection reveals the complexity of the whole selection decision. Second, the earlier reported measures or evaluation methods for certain situations and purposes can be utilized as checklists in the measure mapping phase of the selection process. Again, 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 the ideas for more precise measurable areas, measures and evaluation methods for case-specific purposes. The categorization of R&D measures as described in the present study is one alternative to address the issue. All the previous studies on the topic of R&D performance analysis cannot be categorized under the specific dimensions of a common “umbrella”. However, the presented framework helps in the structuring of this multi-dimensional, multi-criteria and multi-person task of performance measure selection, which is often difficult to execute effectively.

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