
Coping with the multiple dimensions of R&D performance analysis

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Abstract: This study examines the challenging area of R&D performance analysis. Our purpose is to increase the understanding of the essential factors and dimensions related to R&D performance analysis, and to introduce and facilitate a process of choosing applicable metrics of R&D performance for a specific need, context and situation. The research results show the linkages of the measurement dimensions to the selection of R&D measures, which is ultimately a case-specific process.

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

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1 Introduction

In order to sustain their competitive position or gain new competitive advantage in changing business environments, companies need to make crucial investments in research and development (R&D) activities (see e.g., Cooper, 1993, 1998; Cooper and Kleinschmidt, 1996; Balachandra and Friar, 1997; Menke, 1997; Golder, 2000). There are several special characteristics that make 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 e.g., Burgelman et al., 2001). R&D activities at the firm level were earlier often considered as a function isolated from other functions and nearly impossible to be systematically managed and controlled. A defined amount of money was given to R&D, and the managers expected something useful to turn up in the long run.

More recently, new organisational structures, cooperational forms and control models have forced many managers to rethink the factors and mechanisms related to R&D and its control, and to track suitable R&D performance measures. One of the most critical motives for measuring R&D performance at the firm level has recently been 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 must often compete with the other investments in the company. Therefore, there is a definite need for sound measures of R&D performance.

Conducting a selection process for R&D performance indicators is a challenging task (see e.g., Ellis, 1997; Kerssens-van Drongelen, 1999; Akcakaya, 2001). In this study, we propose a selected set of different dimensions of performance analysis for a full recognition and careful consideration of the measurement needs related to a specific selection process of R&D indicators. The proposed five dimensions are the perspectives of the analysis, the purpose of the analysis, type of R&D, the level of the analysis, and the phase of the innovation process. Each of the dimensions influences the selectable set of performance indicators. For instance, the indicators differ significantly from each other when assessing R&D within a business unit or in a collaboration network. These dimensions result from an extensive literature review and close collaboration with a network of companies representing different industries. The main sources of evidence in different parts of the present study have been literature reviews, interviews with company representatives, as well as informal discussions, direct observations and expert meetings, in which there have been several participants from the companies. Participant-observation has also been a source of evidence in some of the meetings where the researchers have participated in the developed processes, the purposes of which have been to promote the selection of performance measures for R&D.

The influence of the dimensions on the measurement subjects, selection criteria and selectable indicators of R&D performance is clarified with the help of a case example where the focus has been set on different dimensional aspects before and after implementing a corporate-wide innovation process in a multi-business-type company.

As a whole, the study aims at increasing the understanding of all the essential factors and dimensions related to R&D performance analysis, and facilitating the process of choosing applicable metrics of R&D performance for a specific situation. The research results, hence, show the linkages of the measurement dimensions to the selection of R&D measures, which is ultimately a case-specific process.

2 Literature review on the categorisation of the dimensions of R&D performance analysis

2.1 Main challenges in 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 with which to make comparisons. 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:

- too much emphasis on internal measurement
- too much focus on behaviour
- the measurement system is too complicated
- the measurement system is too subjective.

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 believe 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; it should be possible to validate the need for such a system and create a more positive attitude to performance analysis in general.

2.2 Dimensions of R&D performance analysis

As stated in earlier studies, there exist 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 categorised in this study on the basis of a thorough literature review and empirical studies 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. Additionally, R&D strategy and the strategic objectives set the areas to be emphasised for 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 organisation. These, as well as the strategic control model chosen for the R&D organisation 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 organisations,

firms emphasise 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.

2.3 Purpose of R&D performance analysis

Measures as such are useless, if they are not utilised 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 organisation, 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. 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 organisational units. In addition to the above-mentioned references, the studies of Gold (1989), Kerssens-van Drongelen and Bilderbeek (1999), Loch and Tapper (2002) and Meyer et al. (1997) have categorised R&D metrics by the purpose of the R&D performance analysis.

2.4 The level of 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. Generally, 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.

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.

For instance, the studies of Brown and Gobeli (1992), Griffin and Page (1996), Kerssens-van Drongelen and Bilderbeek (1999), and Loch and Tapper (2002) have distinguished R&D metrics by the levels of R&D performance analysis.

2.5 Type of R&D

In an earlier literature search, Werner and Souder (1997a) have categorised 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 judgements. 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. In addition to Werner and Souder's study, there are several studies categorising the R&D metrics by the type of R&D (e.g., Loch and Tapper, 2002; Brown and Gobeli, 1992; Werner and Souder, 1997a; Hauser and Zettelmeyer, 1997; Kim and Oh, 2002).

2.6 The 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 system includes contents of input, processing system, output of the processing systems, receiving systems and outcome, as well as their linkages to each other. Output is 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 organisation 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). There are a number of studies categorising R&D metrics by the phases of the R&D process (e.g., Cooper, 1993; Ellis, 1997; Brown and Svenson, 1988; Cordero, 1990; Chiesa et al., 1996; Ellis and Curtis, 1995; Schumann et al., 1995).

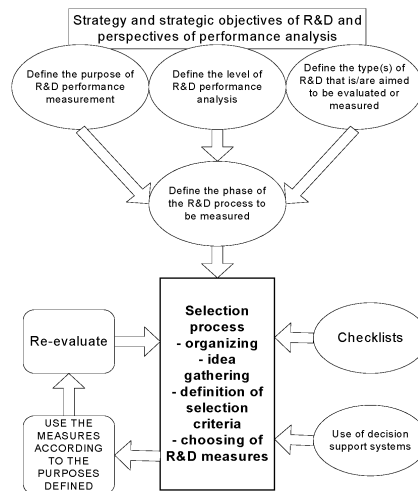
2.7 Perspectives of R&D performance analysis and the linkage of dimensions to the selection process of R&D measures

In earlier studies on R&D performance measurement, several authors have categorised R&D performance metrics as distinguished by different measurement perspectives (see e.g., Cooper and Kleinschmidt, 1996; Akcakaya, 2001; Kerssens-van Drongelen and Bilderbeek, 1999; Griffin and Page, 1996; Curtis, 1994; Curtis and Ellis, 1997; Driva et al., 2000; Hultink and Robben, 1995; Szakonyi, 1994a, 1994b; Tipping et al., 1995; Werner and Souder, 1997b). Here, 'perspectives' are seen as both the measurement areas derived from the strategic objectives, similar to the Balanced Scorecard (Kaplan and Norton, 1996, 2001) approach, but with more alternatives to categorising the areas, and as measurement subjects that are derived from objectives or set and emphasised by the management. The essential question concerning the selectable measurement subjects and measures here is: *Whose perspective* do we take to the measurement?

Several suggestions for the measurement of R&D in different stages or different purposes, or for the kind of evaluation methods to use for certain types of R&D can be found in literature. These aspects 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 utilising the dimensions in the selection of R&D metrics, e.g., the process models depicted in the studies of Ojanen and Vuola (2003) and Ojanen and Tuominen (2002) integrate the different aspects concerning the whole process of choosing the right set of case-specific measures for R&D.

Figure 1 depicts the main principles of the influence of the above-mentioned measurement dimensions on the selection process of R&D performance measures. The simplified approach in Figure 1 can also be seen as one cornerstone in organisation-specific case studies in which the main emphasis, however, has been on the phased selection process of R&D performance measures (Ojanen, 2003). The case studies conducted during several years of research of R&D performance analysis have included case-specific process modifications with a basis on a general framework of R&D performance measure selection process. The approach depicted in Figure 1 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 in the Section 3.

Figure 1 A system approach for selecting and developing performance measures and evaluation methods for R&D



Source: Ojanen (2003)

3 Constructing a practical tool for categorising the dimensional aspects of R&D performance analysis

In order to complement the view of the selection process of R&D metrics we will further develop the utilisation of the above-mentioned dimensions of R&D performance analysis in practice. Table 1 summarises the essential measurement ‘dimensions’ derived from the

different theoretical and empirical sources as described in our earlier study (Ojanen and Tuominen, 2002), and has been further developed by the EIRMA Working Group 62 (EIRMA, 2004). As can be seen in the table, all the combinations of dimensions do not exist or do not appear in the question, but the main idea is to clarify the possible organisation- and case-specific combinations of dimensions for tracking the most essential areas to be measured.

Table 1 The basic dimensions of R&D performance analysis

<i>Measurement perspectives FOR WHOM?</i>	<i>The purpose of measurement WHY?</i>	<i>Measurement level WHERE?</i>	<i>R&D type WHAT?</i>	<i>Process phase WHEN?</i>
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)	
Others	Motivation, rewarding Others	Project Team Individual		

Source: Ojanen and Tuominen (2002) and EIRMA (2004).

The constructed tool and its modifications, related to the innovation process and selection process of R&D metrics have been utilised in practice in several case examples, of which we will briefly describe one, in which the dimensions-table has been utilised in categorising and visualising the dimensional aspects of R&D performance analysis. All the examples that illustrate the utilisation of the constructed tool of the 'dimensions-table' differ significantly from each other, and thus show the case-specificity of the issue of R&D performance analysis. To describe the utilisation of this tool in practice, we will briefly discuss one example illustration ('The company'). In this case the assessment of R&D is analysed with help of the dimensions-table in two milestones, i.e., before implementation of a corporate-wide innovation process in the years 1997–1998 and several years after the implementation of the process, i.e., analysis of what the situation is today. These analysed milestones are illustrated in the dimensions-table by different-coloured circles.

The turnover of the company is several billion euros and it has about 20,000 employees in almost 100 countries. The strategy of the company is to be the leader in its chosen business areas in machinery. The development of a new generation of machinery typically takes from five to ten years, followed by the implementation, which also takes about five years. The target area for assessment in this specific case is related to the implementation of a corporate-wide innovation process. The process was initiated in order to increase the competitiveness of the company, and add more value to the customers of the company.

The metrics used by the company were different in the different stages of the process: before the implementation of the innovation process, when starting to implement the process and after the process was implemented. When starting to implement the innovation process (in 1997–1998) the company used only some leading indicators and some output measures, such as keeping the budget and number of new products.

In 2003, some years after the start of the innovation process implementation, the main indicators at the corporate level are:

- sales from new products (outcome indicator)
- product release on time (linked to the stage-gate process, output and process indicator)
- customer satisfaction related to innovation (how innovative the customers perceive the company to be, outcome indicator).

In addition to these corporate level measures, each business unit has its own additional metrics, e.g., financial and quality measures.

Figure 2 The assessment practices before and after the implementation of the corporate-wide innovation process illustrated in the modified version of the dimensions-table

○ The assessment practices before the implementation of the innovation process.
 ○ The assessment practices after the implementation of the innovation process.

Organizational level (where?)	Purpose of the measurement (why?)	End user (for whom?)	R&D type (what?)	Process phase (when?)	Frequency (how often?)
Company	Strategic control	CEO	Basic research	Input (leading)	Yearly
Partner Network	Innovativeness	Corp. research mgmt / CTO	Exploratory research	In-Process	Twice a year
Corp. Research Center	Validation of investment	SBU mgmt	Applied research	Output of R&D function (lagging)	Every quarter
Competence Center	Benchmarking	SBU R&D	Product development	Outcome (lagging)	Monthly
SBU / department	Resource allocation	Shareholders	Application development	Product/process improvements (incremental)	Project milestones
Process	Development of activities / problem areas	Marketing & Sales	Product/process improvements (incremental)	Breakthrough/Disruptive	Others
Project	Motivation, rewarding	Corp. research center mgmt	Product/process improvements (incremental)	Breakthrough/Disruptive	
Team	Customer perception & market position	Other stakeholders	Product/process improvements (incremental)	Breakthrough/Disruptive	
Individual	Development of skills and competences		New ventures		
	Growth		Licensing		
	Other		Technical services		
			Environment, Health&Safety		

We can now note that the corporate-level metrics are integrated metrics combined from several aspects at lower-level measurement. Looking at the dimensions-table we also note that the three main corporate-level metrics cover most of the dimensional aspects in the table (dark circles), when the situation in the beginning of the implementation of the innovation process was that only few of the dimensional aspects were covered (light circles).

This example illustration shows that systematic development of the innovation process, as well as the selection of sound measures for managing the process is of great value for covering the essential dimensions of R&D performance analysis. The illustration verifies the significance of going through the selection process of R&D indicators, which can be a natural part of the innovation process implementation. The illustration of dimensional aspects with the help of the use of the dimensions-table in the measure selection process makes it easier to take all the essential aspects and needs into account and to recognise the gaps related to the performance analysis of R&D activities.

4 Conclusions

In this study we have constructed and presented a new practical tool for visualising and categorising the dimensional aspects in R&D performance analysis and the selection process of R&D indicators. The tool has been developed in an iterative theory building process with the help of an extensive literature review and close, long-term collaboration with a network of companies representing different industries. 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 main dimensions of R&D performance analysis, such as the perspectives of the 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 tool has been utilised for illustrating the dimensional aspects of R&D performance analysis in several real-world organisations representing different industries, and this illustration is closely connected to the specific selection processes of R&D metrics.

The study also contains a literature review on the categorisation of indicators by the dimensions of R&D performance analysis. The recognition of the state-of-the-art in R&D performance analysis is an essential element in the selection and development process of the R&D indicators of an organisation. First, categorisation 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 utilised as checklists in the measure-mapping phase of the selection process. Earlier studies can also show some valuable examples of different combinations of dimensional aspects in the measurement of R&D performance.

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 in a straightforward way 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. It also needs to be noted

that the categorisation 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 categorised under the specific dimensions of a common framework.

The presented construction of the dimensions-table helps in the structuring of the multi-dimensional, multi-criteria and multi-person task of measure selection, which is often difficult to execute effectively. Especially the understanding and recognition of the combinations of right measurement dimensions are of great value in selecting the right R&D indicators.

The study contributes to the research of R&D performance analysis by increasing the understanding and knowledge related to the dimensional aspects of the measurement of R&D performance, and also by showing with the help of the practical illustration that the significance of going through the selection process of R&D indicators, which can be a natural part of the innovation process implementation, is of great value for covering the essential dimensions of R&D performance analysis. Generally, the illustration of dimensional aspects with the help of the constructed tool in the measure selection process makes it easier to take all the essential aspects and needs into account, and to recognise the gaps related to the performance analysis of R&D activities.

The following practical benefits with regard to the defined problem areas in R&D performance analysis could be found in our developed approaches for case-specific purposes on the basis of the utilisation of the dimensions-table: the selection of R&D measures became more systematic when compared to empirical analysis; the evaluation methods or measures of R&D chosen with the help of the approaches could be more directly utilised in the decision-making because of the thorough consideration of the purpose of measurement and other dimensions of measurement; more balance to the set of R&D measures could be gained through the holistic approaches to the selection processes, i.e., both internal and external factors and different perspectives have been taken carefully into account and the selected measures could track the emphasised factors and perspectives. Additionally, more objectivity could be gained through organising the selection processes so that persons from different organisational levels and functions could participate in the process. The earlier systems in the different studied organisations were often considered as subjective ones in many cases and individual interviews.

How to actually address the challenges and dimensions of R&D performance analysis in collaborative and networked R&D are relatively scantily researched areas, and a topic for future studies on the issue. In relation to this, different organisational forms are used in different organisations and different industries, and a more thorough observation of the influence of industry specific characteristics on R&D performance analysis and a detailed comparative analysis of measurement dimensions in different industries could also provide valuable information for various organisations.

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