R&D measurement methods and models

Fingrid Measure 1.0 / Phase 1

Review and analysis of R&D measurement approaches

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1. Introduction

The aim of the Fingrid Measure 1.0 project is to develop a measurement tool for evaluation of efficiency, productivity and impact of R&D projects. The Fingrid Measure 1.0 initiative consists of three phases: 1) R&D methodology review with an outline for Fingrid, 2) Development of R&D measurement methodology for Fingrid, and 3) Development of the Excel based R&D measurement tool.

This report is a part of the phase 1 with the aim at forming a ground for further development of the R&D measurement methodology and practice (phases 2 and 3).

The workshop held in August 12, 2016 stated the following expectations for the Fingrid Measure 1.0:

- Productivity and cost efficiency of R&D projects can be evaluated.
- Quantitative and qualitative impact of R&D projects on business goals can be estimated.
- Management and realization of R&D projects are improved by evidence based follow up, outcome assessment, and resource allocation.
- Risk management is improved since upfront evaluation will prevent or diminish bad investments.
- Advanced follow up and outcome measures can be applied in international co-projects.
- National economy and clients will get benefits.

The above mentioned expectations and goals have steered the choice of the measurement perspectives, methods and conclusions that are presented in this report.

The report begins by taking a brief look at the-state-of-the-art of R&D measurement. This is followed by the sections that describe some essential background elements of measurement: what is meant by efficiency, how R&D as a whole system can be depicted, how measurement as an operational process is structured, and what the dimension to be taken into account are when choosing the measures. (Sections 2-4).

The next sections introduce the most common measurement approach of key performance indicators and balanced scorecard supplemented by a few more advanced measurement approaches. Then challenges of the service sector measurement and the European measurement frame for electric grid operators are briefly described. (Sections 5-7).

The following section presents four key methodologies of R&D measurement. The section points out that in-depth information of causes and sources of R&D productivity and efficiency can be analyzed only by the most advanced methodologies (Section 8).

The last sections include conclusions and reflections, present an outline for Fingrid's R&D measurement with a fictional example, as well as presents the ways to estimate the impact and value of R&D for Fingrid (Sections 9 and 10).

2. State-of-the-art of R&D measurement

The question of R&D's productivity has been a long lasting challenge. There is far less difficulty measuring productivity and performance in manufacturing and logistics, since a sense of things can be seen just by looking around the production floor or the loading dock. But the R&D department is different. There is no flow of tangible goods through the process, but rather a stream of ideas and concepts that resist the efforts of efficiency experts.

R&D measurement is difficult. Therefore the most companies only use straightforward metrics, e.g. R&D as a percentage of revenue, the ratio of new products to sales, or the time it takes for new products to reach the market. The most common approach takes the ratio of R&D's costs to revenue. This method divides revenue from products developed in the past by what is currently being spent on products for the future. However, for the most companies, this assumption is too pessimistic for investing in future growth and too optimistic when the product pipeline is weakening. Indeed, repeated studies have shown no definite correlation between this R&D ratio and any measure of a company's success.

In the past years the most popular metrics for R&D have practically remained the same. Top five metrics used for R&D are the following: R&D spending as a % of sales, R&D headcount, Current year % sales due to new products released in the past N-years, # Patents filed/pending/awarded/rejected, and # of new products released (Figure 1).

Figure 1. Top 5 R&D product development metrics in 2014 (Goldens 2014)

However, none of these really gives a good idea of how well the R&D function is performing, since the metrics give no information of real efficiency of R&D. Maybe at one time R&D's productivity mattered less. But today, myriad competitive forces drive down R&D budgets, and nearly every company ask the R&D organization to achieve more with the same or fewer resources. While functional requirements, customization needs, and regulatory demands proliferate, the complexity and cost of R&D continue to rise.

The challenge of R&D measurement is common for all companies investing in product or service development. They all struggle with the same problem, how to get more detailed and in-depth information of the real efficiency and productivity of their R&D.

Academic research interest was focused on the BSC and KPI approaches in 1990s, and various sets of metrics were presented at that time. In the 2000s, closer to the present day, more research interest have been woken towards productivity measures instead. However, there are still surprisingly little academic research of internal efficiency measurement of R&D projects. Even if several methods have already been presented for productivity measurement, implementations in companies are still rare. One of the latest advances in business context has been a productivity index presented by McKinsey a few years ago. [1]

3. Efficiency of R&D systems

R&D investments must always compete with other investments within a company. Therefore one of the most critical motives for measuring R&D performance is the argumentation from strategic point of view. The R&D function has to prove its productivity and significance for management, but also for shareholders, partners and clients.

From a practical point of view R&D measurement is focused on efficiency and productivity of the projects. The goal is to bring out knowledge that can be used for both R&D improvement and development of the whole company.

The concept of productivity in the service sector is not always clear, but basically it refers to the relation between output and input. Inputs are the resources used in the production (e.g. labor, materials and services) and outputs are products, services or both.

Productivity of R&D involves two dimensions: internal and external efficiency. Internal efficiency shows how well the work is done and exposes efficiency of project operations: e.g. methods, routines and functions. External efficiency shows what has been achieved. It exposes the results, i.e. financial and other kind of outputs and impacts. Internal efficiency is important for development of R&D functions, and external efficiency is important to motivate R&D investments within a company from strategic and shareholder perspectives. Internal and external measures generally differ, although in some cases they may be overlapping.

Figure 1. Dimensions of project efficiency

[1] Hannon et al 2014

Efficiency is never dependent only on one variable, but instead based on a comprehensive process, or even the system as whole. Accordingly, measurement must cover all the phases of the process and/or elements of the system.

Brown and Svenson (1988) have presented a R&D system that includes the following elements: input, process, output, implementation, and outcome (impact). Also the measurement feedback flows are included in the system as separate entities. Every stage should be covered to grasp the level and elements of efficiency. The detailed description of the system is presented in Figure 2.

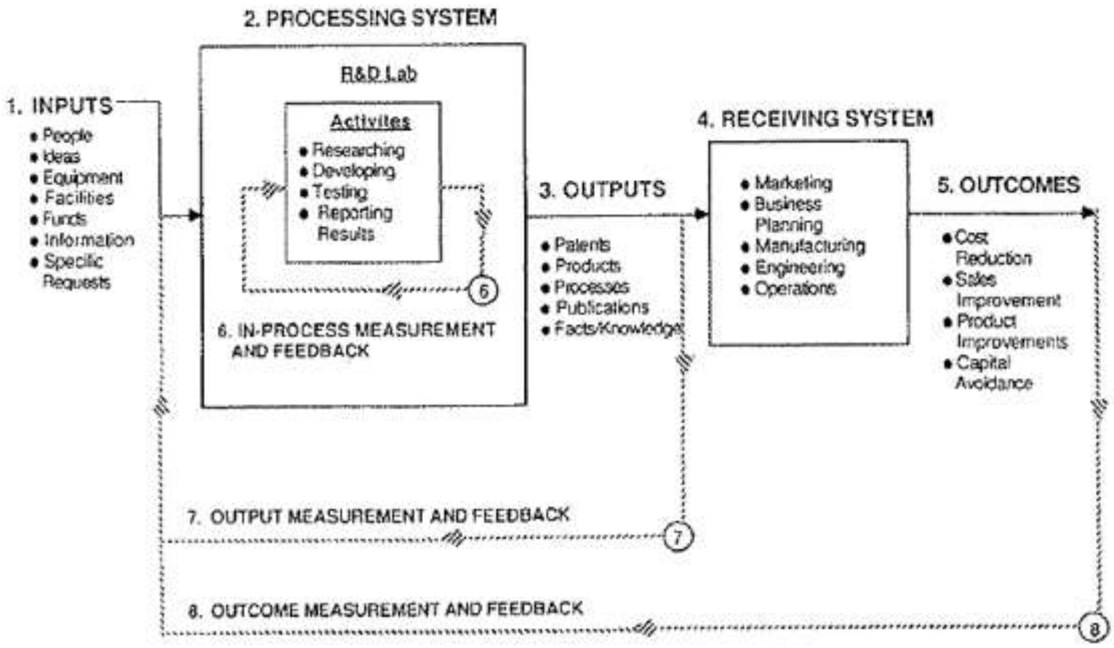


Figure 2. R&D system by Brown & Svenson (1988)

Brown & Svenson (1988) emphasize that R&D measures should be heavily influenced by business strategy. Therefore outputs should always be analyzed together with inputs and strategic goals. Quantitative output measures alone may show that R&D is very productive, even if they were extremely costly and outside of strategic foci. Focus should be on measurement of outcomes and output, not only activities – and these should be measured with emphases on return on investment along three dimensions: quality, quantity and cost.

Engineering utilization, productivity and throughput have also been defined as most important metrics for measuring R&D performance. According to Collett (2011) productivity and utilization directly determine throughput, and therefore he says that throughput (=internal efficiency) is the most important of all R&D performance metrics.

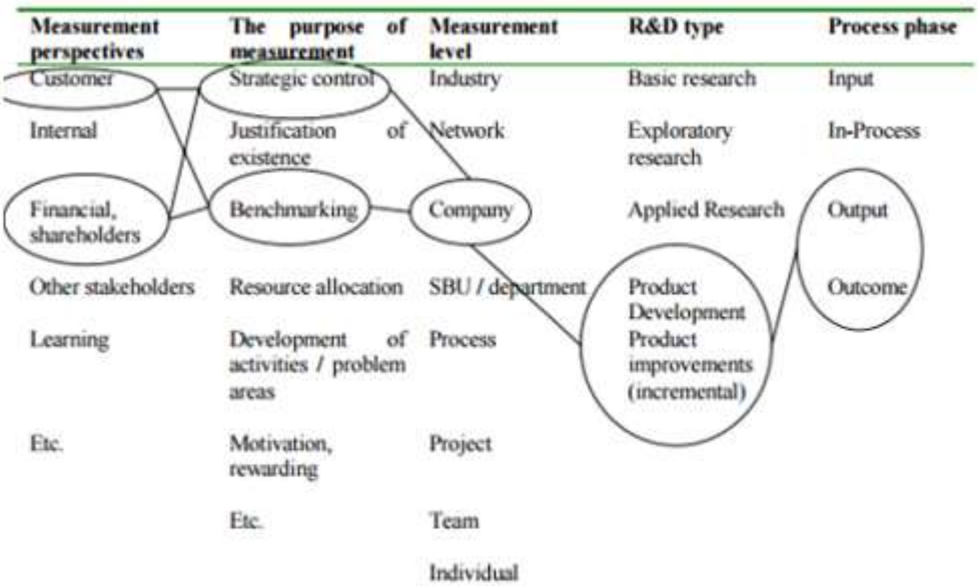
4. Setting the right measures

A universal set of R&D measures does not exist. A set of measures and a method how to treat them is always a company based process depending on the chosen strategy, industry, environment and other special features at a given context and time.

The process starts with recognition and careful consideration of the measurement needs. The strategy of R&D and the strategic company objectives are the bases for all other perspectives that affect not only the choice of measures but also a measurement methodology. Beyond these Ojanen and Vuola (2003)[2] suggest five main dimensions as a basis when choosing a measurement methodology:

- Perspectives of performance analysis
- Purpose of R&D performance analysis
- Measurement level
- Type of R&D
- Phase of a process

Table 1 shows how the dimensions are used by defining a ground for R&D measurement.



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 Product improvements (incremental)	Outcome
Learning	Development of activities / problem areas	Process		
Etc.	Motivation, rewarding	Project		
	Etc.	Team		
		Individual		

Table 1. Example of the dimensions by which to make a selection of measures (Ojanen & Vuola 2003)

A selection of measures is a process where all these dimensions are taken into consideration. The flow chart below demonstrates the process starting with strategic objectives and ending with a set of chosen R&D measures (Figure 3).

[2] Ojanen and Vuola (2003) have made both a comprehensive literature review and survey on the measures and evaluation methods of R&D. Even if the study is made 13 years ago, the main findings are still fully relevant. Useful information also in Ojanen, V. (2003). R&D PERFORMANCE ANALYSIS: Case Studies on the Challenges and Promotion of the Evaluation and Measurement of R&D.

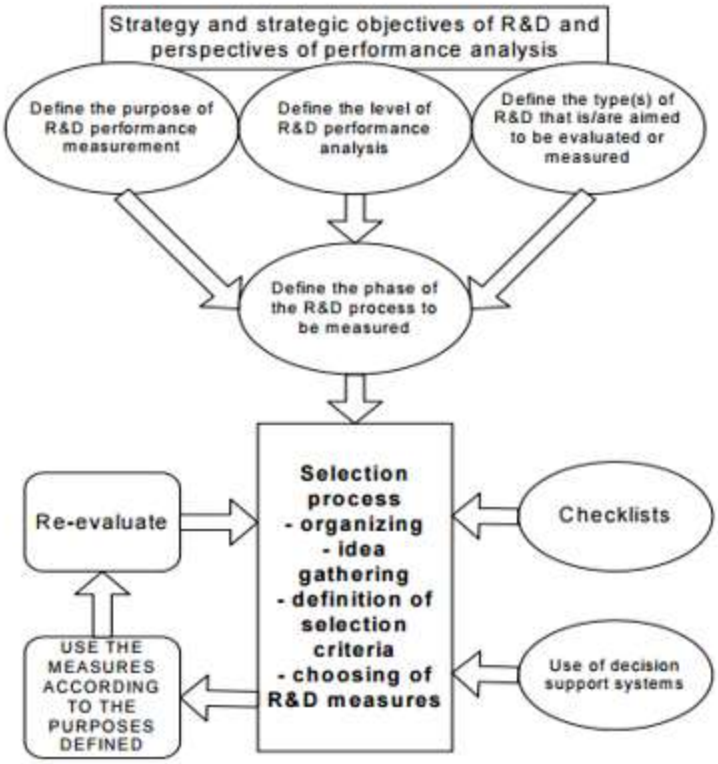


Figure 3. A simplified process of a measure selection for R&D (Ojanen & Vuola 2003)

5. BSC, KPIs and beyond

The basic measurement practices are most often based on Balanced Scorecard (BSC) metrics or other models of key performance indicators (KPI). Indicators form a data set that offers a rough estimation of project efficiency, directly as such or by trend trajectories.

BSC model is created by Kaplan and Norton (1992) and it is widely adopted by companies in the Western world. The critical characteristics of the BSC are a) the focus on the strategic agenda of the organization concerned, b) selection of a small number of data items to monitor, and c) a mix of financial and non-financial data items.

The scorecard designs an approach of four perspectives to identify by which measures to track how strategy is performed. The original four perspectives are:

1. *Financial perspective*
    - Answers the question "How do shareholders see us?"
    - Examples: cash flow, sales growth, operating income, return on equity
2. *Customer perspective*
    - Answers the question "How do customers see us?"
    - Examples: percent of sales from new products, on time delivery, share of important customers' purchases, ranking by important customers
3. *Internal business processes*:
    - Answers the question "What must we excel at?"

- Examples: cycle time, unit cost, yield, new product introductions

4. *Learning and growth*
   - Answers the question "How can we continuously improve, add value and innovate?"
   - Examples: time to develop new generation of products, life cycle to product maturity, time to market versus competition

Table 2 below introduces examples of R&D metrics for the four BSC areas.

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

Table 2. Measures for R&D performance by BSC approach (Kerssens et al 1999)

Even if these kind of direct measures are widely used, they are not sufficient to show the real impact of R&D, neither do they expose efficiency or productivity very well. R&D projects usually bring also unexpected value when various spillover effects are normally linked to the most operations.

Some of the existing methods that are able to expose more refined knowledge both about efficiency of R&D and spillovers are shortly presented below:[3]

The technology flow approach is based on the vertical spillover, which means that research performed in one industry can improve technology in another industry. In the most cases, the increase in inter-

[3] According to Sasidharan 2006

industry spillover decreases the labor and material demand. A number of studies use input-output linkages or technology flow matrices (based on the input-output relationships) to measure the spillover among industries.

Cost Function Approach The cost function approach focuses on cost reduction that is the most common and important beneficial aspect of technology spillover. This line of research utilizes the cost function formulation that is based on output and relative factor prices for variables and quasi-fixed inputs.

The production function approach is based on the influence of technology spillover on productivity and innovation. Empirical studies show that spillovers have a significant impact upon firm's productivity or propensity to innovate. This line of research utilizes econometric models to estimate the effects of spillover on TFP (Total Factor Productivity) or innovation in a knowledge production.

Integrated measures of R&D performance

Werner and Souder (1997a) present an example of integrated method 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%.

$$O = \text{Overall assessment of the value of R\&D} = A + [(C \times B) \times D]$$

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 R&D effectiveness 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.

As a conclusion, BSC/KPI measurement models are too general to expose detailed information of efficiency or productivity of R&D projects. Especially internal efficiency of R&D projects is poorly grasped by the BSC approach. When more sophisticated information and understanding is required, mathematical calculation and further analyses methodologies must be applied.

6. Measurement challenges in the service sector

The service sector has more problems for productivity measurement than the manufacturing sector. Productivity measurement in service is challenging for several reasons. Productivity is hard to define and standardization of heterogeneous inputs and outputs is difficult. The service sector is more labor-intensive and quality is a major part of the product/service itself. The manufacturing sector measures its output by quantity units and increases the amount of production by raising output. Service sector output often has less interest in the quantity aspect and is normally increased by the attempt to provide higher quality services.

Productivity of the service sector can be defined by the following formula [4]

$$\text{Service Productivity} = \frac{\text{Quantity of output and Quality of output}}{\text{Quantity of input and Quality of input}}$$

In this ratio, the quantity aspect of service productivity is the same as the manufacturing productivity, which consists of material, labor, and capital. Quality aspect must be separately defined.

Main difficulties in R&D measurement in the service sector are linked with *intangible elements* of production and products. Normally, output information is presented as revenues by an output index or a price index for each output, but in the service sector also quality is an important output element. Labor input is generally measured in terms of hours worked by the persons engaged in production, however, in the service sector highly skilled workers contribute more to production than unskilled workers. To overcome the problem, new measurement models and formulas that include intangible elements have been presented within the past years.[5]

The measurement of *innovation in services* presents some specific challenges too. It is difficult to measure organizational and process innovations, identifying innovation performance and linking it with firm performance. Important areas for innovation measurement are client interface, service concept, service delivery system and technology. Contrasting with manufacturing firms, it appears that some firms have difficulties to break down their sales by innovative and non-innovative services or to identify the extent to which innovations contribute to the sales performance of the firm.

Temporal factors also appear to be of greater concern in the service sector than for product-oriented firms, particularly with regard to process innovations. It is difficult to quantify the impact of innovation on sales because of the time lags between the introduction of the innovation and the reaping of corresponding benefits. In services sales are not often an appropriate output indicator and do not work as an indicator of economic impact of R&D.

[4] Järvinen, Lehtinen, and Vuorinen 1996
[5] Corrado et al 2005, Lev 2005, Ståhle et al 2015

Ojanen and Vuola (2003) have made an extensive literature review and a large survey of service sector R&D measurement. Based on these they suggest measures for the service sector in the following areas: Timeliness, Business performance, Financial performance, Commercialization, and Innovativeness (Table 3).

Measurement theme	Measure
Timeliness	Proportion of innovations that were first to market/early followers in last *n* years
Business performance	Numbers and value of new customers reached by the innovation and, new market niches entered
Financial performance	Profitability, sales, savings, % of income generated by innovation
Commercialisation	Number of other organisations licensing products/services developed by us
Innovativeness	New products/services introduced in last *n* years relative to market leader

Table 3. Proposed innovation performance measures for business services (Ojanen and Vuola 2003)

7. ENTSO-E approach for European electricity grid operators

European Network of Transmission System Operators for Electricity (ENTSO-E) has published a document for KPI definition for the electricity industry. It defines a set of KPIs that is tailored for the management of the European Electricity Grid Initiative (EEGI) Research and Innovation (R&I) Roadmap 2013-2022.

The main goal of ENTSO-E is to enable evaluation and assessment of the European grid development in a uniform manner by general objectives. It states external strategic goals by chosen indicators in such a way that the output can be explicitly measured.

The framework introduces two categories of KPIs:

1. *Implementation effectiveness KPIs* (external project objectives)
   - measure the progress of research and innovation activities as percentage of completion of a functional objective
   - measure a set of functional objectives within any of the clusters defined in the EEGI Roadmap.

2. *Expected impact KPIs* (external project objectives)
   - estimate the contribution of the new R&I achievements gained within the EEGI Roadmap
   - include overarching, specific and project KPIs:
     - *Overarching KPIs* consist of a limited set of network and system performance indicators which trace clear progress brought by EEGI activities towards its overarching goal. They are intended to provide a very high level understanding of the benefits that would be achieved by European R&I projects and will be evaluated at a system level.
     - *Specific KPIs* provide an overview of other specific technical parameters relevant for network operators in order to reliably achieve their overarching goals. Therefore they are not directly related to overarching goals but to the different innovation Clusters and Functional Objectives of the EEGI Roadmap.

- *Project KPIs* are proposed by each R&I project of the EEGI Roadmap. The results from the Project KPIs will be used to evaluate the Overarching and the Specific KPIs. [6]

The measured KPI values obtained from the R&I activities support deployment decisions of promising innovations. The future steps on the application of this KPIs methodology should be aimed to use the information on the benefits provided by R&I projects and apply it.

All the KPIs in the ENTSO-E are external impact objectives, e.g. cost efficiency, savings, customer satisfaction, and competitive advantage. Thus ENTSO-E focuses to measure external business efficiency and excludes internal project performance measures. ENTSO-E is not a measurement *method* as such, but a set of recommended metrics, and can therefore easily be linked with the BSC metrics.

ENTSO-E is useful in a European scale follow up, but does not offer much operational tools to assess or measure internal R&D efficiency. Instead, the model can be used for strategic planning and evaluation of project outputs (external targets).

8. Key methods for R&D measurement

The aspects of measurement presented in the previous chapters are important to understand when developing R&D measurement within a company. It is essential to define the purpose of the measurement, linkage to the company strategy, relation to the BSC application etc. according to the guidelines presented in the earlier chapters.

In this chapter the *four most important and useful methods* that appear in different forms in the research literature are shortly presented. Every method is disclosed by the following perspectives: Description, When to apply it, Pros and cons, and References.

The simpler the method is the less in-depth information it gives, and vice versa, the more sophisticated calculation a method includes, the more abundant and value added information it offers.

8.1 Balanced Scorecard models

Description

BSC based models are based on simple, straightforward measures for continuous monitoring. BSC methodologies can be applied both for efficiency measurement of internal performance and for evaluation of external impacts.

BSC metrics are used as direct efficiency measures: output, input or output/input ratios. Also comparisons, benchmarks and trends are used as KPIs. Strategic indicators vary by company, but metrics that measure internal efficiency are relatively well established. Normally *input indicators* are based on KLEMS, i.e. investments in capital (K), labor (L), energy (E), materials and resources (M), and services (S). Nowadays these are most often supplemented by intangible capital (N). *Output indicators* vary according to a project type or the branch of industry. Thus the structure of the measurement model is usually the same, but indicators vary according to company and project needs.

[6] For a detailed list of the indicators see ***GRID+*** *(2013)*

BSC is used in R&D measurement in two ways: on one hand R&D projects are included in the corporate BSC, and on the other hand R&D projects can have their individual BSCs. Only individual BSCs of R&D projects can lay ground for R&D in-depth analyses and produce measures for internal efficiency of R&D.

When to apply
BSC is relatively simple to use, since the application is directly based on the plain follow up of the chosen metrics. Well-chosen KPIs are always a necessary basis for all kind of measurement and analyses systems. Therefore BSC is an optimal start in the situations when no culture for a systematic efficiency measurement exists yet.

Pros and cons

- The concept is clear and easy to perceive; none or minor calculations (usually only output/input ratios); simple to follow up and monitor; KPIs form a ground for all more advanced measurement systems (+)
- Connections and dependencies between KPIs are not exposed; causal connections to performance and value creation remain unclear (-).

Important references*:* [7]
Ville Ojanen and Olli Vuola (2006): Coping with the multiple dimensions of R&D performance analysis. International Journal of Technology Management, Volume 33, Issue 2-3. : The study a) discloses the essential factors and dimensions related to R&D performance analysis, and b) depicts the process of choosing metrics of R&D performance for specific needs, context and situations.

Deok Joo Lee, Sung-Joon Park, Kyung-Taek Kim (2013): A Development of Key Performance Indicators for the Public R&D of Energy Technology using Balanced Scorecard Approach. Proceedings of the World Congress on Engineering and Computer Science 2013 Vol II. : The authors present a BSC framework for public energy R&D projects. The model is composed of the four following perspectives: Energy industry, Performance, R&D processes, and Infrastructure. Critical success factors for each perspective and relevant performance indicators are included.

8.2 Composite methods

Description
Composite measurement methods aim at measuring effectiveness of performance and grasping the causes behind. Individual indicators alone do not give enough information of value adding performance, since many variables have casual interdependences and co-effects. Composite methods are able to disclose them to a certain extent.

A composite indicator is created by combining two or more individual metrics into a single indicator. One metric alone does not necessarily provide sufficient information, but together the variables can summarize multiple dimensions of performance.

[7] Other useful sources for the BSC approach: Kaplan and Norton 1992; Hauser and Zettelmeyer 1997; Hauser and Katz 1998; Ojanen and Vuola 2003; Vantrappen and Metz 1994

Composite methods are used in many areas of measurement in science and society, including assessment of intelligence (e.g. intelligence quotient IQ), product ratings (Consumer Reports), and stock market valuation (e.g. the DJI Index / Dow-Jones Industrial Average).

In the *linear* composite method a new indicator is formed by combining two or more metrics that are supposed to have an equal effect on the area of interest. For instance a variable of Customer loyalty can consist equally of Customer satisfaction, Frequency of purchase transaction, and Number of complaints.

In the *nonlinear* composite method a new indicator is formed by combining two or more metrics the effect of which is *not* supposed to be even. This method shows the share of each variable on impacts, and how the variables are dependent on each other.

The more the BSC involves indicators that are formed by composite indicators the more value adding information on performance it gives.

When to apply
To be applied in situations when the measurement foundation by KPIs/BSCs has been established and there is a need for deeper insight of value adding performance and the causes behind.

Pros and cons:

- Exposes structural efficiency components that are more valid than single KPI/BSC metrics since the method discloses the components of internal and external efficiency (*linear composites*); and linkages between efficiency of the components can also be disclosed (*nonlinear composites*) (+).
- Limited to one aspect at a time, several dimensions of nested impact cannot be simultaneously calculated or analyzed (-).

Important references:[8]
Bjorn M. Werner & William E. Souder (1997). Measuring R&D Performance—State of the Art. Research-Technology Management vol 40, issue 2, p.34 -42. : An extensive search of the literature from 1956 to 1995 identified over 90 articles, 12 books and two research reports describing various techniques. Integrated metrics that combine several types of quantitative and qualitative measures were found to be the most effective, but also the most complex and costly to develop and use. The choice of an appropriate R&D measurement metric depends on the user's needs for comprehensiveness of measurement, the type of R&D being measured, the available data, and the amount of effort the user can afford to allocate to it. Guidelines are provided for selecting an appropriate measurement method within these parameters.

Mcgrath, M.E. and Romeri, M.N. (1994). The R&D Effectiveness Index: A Metric for Product Development Performance. The Journal of Product Innovation Management, 11, 3, 213-220. : In this study the R&D Effectiveness Index is introduced to address the need to measure the overall success of product development. It measures effectiveness by comparing the profit from new products to the investment in new product development. The article provides the details for calculating the index along with alternative interpretations. The index was validated through 45 electronic systems companies. A strong relationship between the R&D Effectiveness Index and other performance factors was found. According to the authors the R&D Effectiveness Index can be used to compare performance, measure improvement, and evaluate business units.

[8] Other useful sources: Haner 2002; Li and Prescott 2009

8.3 Production function methodologies

Description

Production is a process of combining various material and immaterial inputs in order to make the output (something for consumption). It is the act of creating output – goods or services – that has value and contributes to the utility of individuals.

Production function (growth accounting) is a mathematical shorthand expression for an input-output process. It aims to answer the question which factors account for the observed growth in the economy and to what extent.

Essentially the production function depicts a process of *physical* transformation of inputs into outputs. The production function can, for example, measure the marginal productivity of a particular factor of production (*i.e.,* the change in output from one additional unit of that factor). It can also be used to determine the maximum output that an organization can attain with the given combinations of production factors (land, labor, capital, and enterprise) in a particular time period with the given technology.

The production function is a mathematical representation of the various technological recipes from which a firm can choose to configure its production process. In particular, the production function tells us the maximum quantity of output the firm can produce given the quantities of the inputs that it might employ.

When to apply:

To be applied in situations where efficiency and economic impact is in focus. Most useful when the detailed economic impact of various individual inputs needs to be exposed.

Pros and cons

- The model can be used to expose the critical KPIs for optimization; the measures for KPIs can be estimated in financial terms; operates both with tangible and intangible variables (+).
- Limited only to one perspective of efficiency at a time: two or more dimensions of efficiency cannot simultaneously be optimized; interdependencies of outputs cannot be analyzed (-).

Important sources [9]

Kristian Uppenberg and Hubert Strauss (2010). Innovation and productivity growth in the EU services sector. Economic and Financial Studies division of the EIB, 2010: The study points to three key ingredients in service sector productivity improvement: tangible fixed investments, intangible capital, and reliance on external knowledge. Service industries tend to innovate in interaction with customers, suppliers and competitors. This greater reliance on external sourcing of new knowledge suggests that cluster formation fostering knowledge transfers and spillovers is an important element in supporting service sector innovations.

Alistair Dieppe and Jan Mutl (2013). International R&D Spillovers, Technology Transfer vs. R&D Synergies. ECB Working Paper Series, No 1504 / January 2013: The article presents a model of

[9] Other relevant sources: Maroto-Sanchez 2010; Lev 2005a; Lev and Radhakrishnan 2004; Corrado et al 2005

international technological spillovers that covers both international and inter-sectoral technology transfer and synergies in R&D. The model also explains the impact of dynamic interaction in total factor productivity (TFP). Relative to the existing literature, the model enables to make a judgment on the relative importance of the channels of international technology transmission.

<u>*Hannon, E., Sander, S. & Weig, F. (2014). Brightening the black box. McKinsey Quarterly, April 2015:*</u> The paper presents a formula that takes a novel approach to measuring R&D outcomes: multiplying a project's total gross contribution by its rate of maturation and then dividing the result by the project's R&D cost. The formula demonstrates several virtues: a) it's a single metric rather than a collection of them, b) it aims to measure the R&D contribution within the sphere of what R&D actually could influence, and c) by measuring productivity both at the project level and across the entire R&D organization it endeavors to speak to the whole company, from the boardroom all the way to the cubicle.

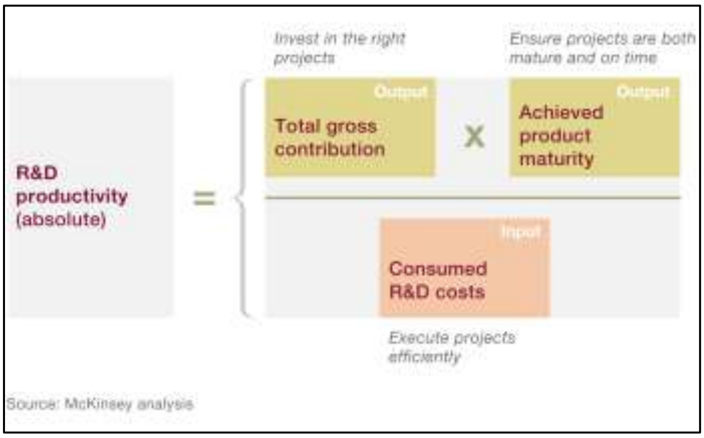


Figure 4. R&D productivity measure by McKinsey

8.4 Data Envelope Analyses DEA

Description

Data Envelopment Analysis (DEA) is a powerful service management and benchmarking technique. Every service organization can benefit from DEA in different ways and the method can be adapted to help improve service productivity.

DEA compares service units considering the resources used and the services provided, and identifies the most efficient units or best practice units (branches, departments, individuals), and the inefficient units in which real efficiency improvements are possible. This is achieved by comparing the mix and volume of services provided and the resources used by each unit compared with those of all the other units.

DEA calculates the amount and type of cost and resource savings that can be achieved by making each inefficient unit as efficient as the most efficient units. Specific changes in the inefficient service units are identified by DEA. The method estimates the amount of additional service an inefficient unit can provide without the need to use additional resources. Management receives information about performance of service units that can be used to help transfer system and managerial expertise from better-managed, relatively efficient units to the inefficient ones. This has resulted in improving the productivity of the inefficient units, reducing operating costs and increasing profitability.

When to apply

To be applied in situations where complex causalities between multiple inputs and outputs must simultaneously be optimized. For instance cost efficiency, project time efficiency, customer satisfaction and number of new customers can be simultaneously optimized.

Pros and cons

- Sources of inefficiency can be analyzed and quantified for every evaluated unit; can be used with any input-output measurements; is good to analyze complex causalities (+).
- Results are sensitive to the selection of inputs and outputs (-).

Important sources [10]

Harel Eilat, Boaz Golany and Avraham Shtub (2008). R&D project evaluation: An integrated DEA and balanced scorecard approach. Science direct, Omega 36 (2008) 895 – 912: The paper presents and demonstrates a multi-criteria approach for evaluating R&D projects in different stages of their life cycle. The method integrates the BSC and data envelopment analysis (DEA) and develops an extended DEA model. The input and output measures for the integrated DEA–BSC models are grouped in "cards" which are associated with a "BSC for R&D projects". The authors illustrate the model with a case study of an industrial research laboratory that selects and executes dozens of R&D projects every year.

Harel Eilat, Boaz Golany and Avraham Shtub (2006). Constructing and evaluating balanced portfolios of R&D projects with interactions: A DEA based methodology. Science direct, European Journal of Operational Research 172 (2006) 1018–1039: The article demonstrates a methodology for the construction and analysis of efficient, effective and balanced portfolios of R&D projects with interactions. The methodology is based on an extended DEA model that quantifies some of the qualitative elements in the BSC approach. The methodology includes a resource allocation scheme, an evaluation of individual projects, screening of projects based on their relative values and on portfolio requirements, and finally a construction and evaluation of portfolios. The DEA–BSC model is employed in two versions, first to evaluate individual R&D projects, and then to evaluate alternative R&D portfolios.

9. What can be reached by R&D measurement

Efficiency of a company's R&D can be measured in several ways, as presented in the previous chapters. The choice of a method is dependent on what kind of needs a company has, but also on a company's capability to utilize measurement outcomes for its R&D and business improvement.

Based on savings, increasing cost efficiency and general efficiency improvement a company can get lots of benefits by using more advanced methodologies. By exploiting the comprehensive set of measurement methods the following outcomes are possible to be reached:

0. *Raw KPI data*
1. *Monetary value for the most KPIs*
2. *Monetary value of project efficiency*

[10] Other interesting sources: Dan Tian, 2013.

3. *Break-even and financial short & long term impacts*
4. *Internal project efficiency with qualitative variables (BSC)*
5. *The most efficient input and process factors*
6. *Projections and simulations of cost and performance optimization*

Different methodologies fit for different purposes. The more in-depth information is required the more advanced method must be used. The raw KPI data is provided by the BSC model, and for all the other outcomes the more advanced methods must be utilized. (Table 4).

Table 4. Applicability of the measurement models (red= not applicable, yellow=applicable to some extent, green=applicable)

How can then Fingrid's measurement goals be reached by these methods? The following expectations have been addressed for the Fingrid Measurement 1.0 project:

- Productivity and cost efficiency of R&D projects can be evaluated.
- Quantitative and qualitative impact of R&D projects on business goals can be estimated.
- Management and realization of R&D projects are improved by evidence based follow up, outcome assessment, and resource allocation.
- Risk management is improved since upfront evaluation would prevent or diminish bad investments.
- Quantity, quality and outcome of partner and client cooperation cab effectively be followed up.
- Recruitments can profoundly be motivated by productivity arguments.
- Advanced follow up and outcome measures can be applied in international co-projects.
- National economy and clients are getting benefits.

All of these expectations can be met, but only by applying the most advanced methodologies like production function and DEA. The case examples presented in the research literature (section 8) include many methods and formulas that can be utilized for Fingrid Measure 1.0. However, because the measurement applications in the literature usually present either a general formula or a limited perspective of a specific need, no one of them can straightforwardly be applied, but instead they need to be modified.

10. Outlines for R&D measurement at Fingrid

10.1 Starting point

The present R&D measurement approach at Fingrid is based on BSC, but it is very general and lacks KPIs for internal efficiency and economic impact. The measurement focus is exclusively on the objectives in terms of budget, schedule and overarching goals.

At Fingrid company level BSC has been more profoundly implemented, and the scorecard has been already several years in use. However, when building up a measurement method for R&D the company BSC cannot be utilized as a model, because the project level data is fundamentally different than the company data. Furthermore, in this case it is important to be aware of the current company BSC data involve clear shortages and imbalance: According to a preliminary review the output indicators are overemphasized compared to the input indicators, soft data are overemphasized compared to hard data, and present monitoring is overemphasized compared to trend exploitation. These aspects are important to take into consideration when building a set of KPIs for R&D measurement in the future.

10.2 KPI data set

The key goal of the Fingrid Measure 1.0 is to measure and optimize efficiency of R&D projects. This is possible by creating a sufficient data set and by utilizing production function methodology. The formula requires both *hard data* (e.g. financial figures, numbers, and exact time measures, i.e. FTE working hours and project duration) as well as *soft data* (e.g. education, experience, quality of equipment). These act as inputs in the production function formula. The output in turn is always dependent of the project; there can either be one overarching target (e.g. increase of customer satisfaction from 3,4 to 3.8) or combination of two or several targets (e.g. to increase both cost effectiveness *and* customer satisfaction).

For internal efficiency the measures can be grounded on the following rather established categories: Tangible Capital, Human Capital, Internal Cooperation, Material and Services, and Extraordinary Expenses. For each of these, the Objects, Items and Indicators must be defined. (See Table 6). The Tangible Capital indicators are relatively constant while the others must be separately set for each project. Furthermore, clear project objectives must always be defined (see Table 7, the first section "Objectives").

Table 6 depicts a rough structure for categories, foci, and indicators for a basic set by which internal efficiency of R&D projects can be measured. The metrics presented in the table are the kind of indicators that must be at hand for calculations by a production function.

The measurement can disclose

- sources of efficiency and inefficiency in project operations
- (economic) impact of each KPI on the outcomes
- KPI dependences and co-effects, and their impact on the outcomes
- the most efficient/inefficient projects as whole.

Based on the comprehensive R&D measurement of R&D projects it is possible to create a specific R&D composite index to be used in the company BSC.

CATEGORY	OBJECT	UNIT	INDICATOR	Data update
TANGIBLE CAPITAL	Plant	Monetary	value/employed	1
	Quality (q)	Years	100 - 5%/year	1
	Property	Monetary	value/employed	1
	q	Years	100 - 5%/year	1
	Equipment	Monetary	value/employed	1
	q	Years	100 - 15%/year	1
To be optimized	*Total expences*	*Monetary*		
HUMAN CAPITAL	Personnel	Number	Benchmark value	2
	FTE hours	Number	Benchmark value	3
	Education (q)	Levels 1 - 7	Benchmark value	2
	Experience (q)	Years	Benchmark value	2
To be optimized	*Total expences*	*Monetary*		
	Time span	*Time*		
INTERNAL CO-OP	Partner units	Number	Benchmark value	2
	FTE Hours	Number	Benchmark value	3
	Number	Number	Benchmark value	2
	Expertise (q)	Levels 1 - 7	Benchmark value	2
To be optimized	*Total expences*	*Monetary*		
	Time span	*Time*		
	Administration	*Monetary*		
MATERIAL AND SERVICES	Outsourced	Monetary	value/employed	3
	Partners	Number	Benchmark value	2
	Customers	Number	Benchmark value	2
	FTE hours	Number	Benchmark value	3
	Expertise (q)	Levels 1 - 7	Benchmark value	2
To be optimized	*Total expences*	*Monetary*		
	Time span	*Time*		
	Administration	*Management*		
	Complexity	*Marketing*		
EXTRAORDINARY EXPENSES	Investments	Monetary	value/employed	3
	Interest value	Number	100 - %/year	2
To be optimized	*Total expences*	*Monetary*		
Data update and use	*1*	*Once a year; valid for all R&D projects*		
	2	*When a project starts or in need of changes*		
	3	*Monthly*		

Table 6. Tentative example of a KPI structure to measure internal efficiency of R&D project

10.3 Measurement report

A fictional example of a possible R&D measurement report is presented in Table 7. It consists of two parts, the first (upper) section includes a project plan with the resource allocation (input), and the second section (lower) includes efficiency analyses for each resource item. The example here shows only the verbal conclusions of the mathematical analyses outcomes without the actual figures.

This example acts as a midterm evaluation of a fictional project and tries to demonstrate how the measurement system could be used – not only for measurement of the outcomes at the end of the project, but also for anticipation and simulation half way the project to optimize the results. The texts in the second section are (fictional) descriptions to be written based on the numeric results produced by the mathematical formulas (production functions and DEA).

These kinds of simulations could also be benefited for scenarios and evaluations of new projects.

The measurement system should be Excel based and simple for a user. Production functions and DEA formulas must be programmed within the system that functions automatically. Only the project based data must be fed in by a user.

10.4 R&D impact

Monetary and other benefits of R&D projects for Fingrid are possible to be estimated or calculated based on a structured set of output targets and a balanced KPI data set.

For monetary *calculation* of project impacts there is no single formula that would cover all kinds of R&D projects. Since R&D projects are various by type and targets, mathematical calculations must be conducted by formulas that are chosen by individual project specifics.

A general model for impact *estimation* can be designed instead. The estimation is rather simple, but requires that the desired project outputs are clearly set and include a structured set of the following valuations: [11]

Decrease/ increase of investments
Decrease/ increase of running costs
Decrease/ increase personnel costs
Decrease/ increase of market share
Decrease/ increase of customer prices

When the values for these variables have been either calculated (when possible) or estimated, monetary values of the impact of R&D project and portfolio can be calculated.

Another way of exposing the value of R&D for Fingrid could take place by benefiting the company BSC. This requires that a simple project based BSC needs to be created, e.g. consisted by five perspectives with one indicator (0-100) in each:

[11] To be located in the Executive report, Section "Objectives", first line, as demonstrated in the Table 7

1. Overall efficiency
2. Time management
3. Use of personnel resources
4. Efficiency of networking and cooperation
5. Success rate

The values for these indicators do not need any extra calculations, since (presumed that the measurement model presented earlier in this chapter is in use) they can automatically be extracted from the production function and DEA based calculations. *In this manner the impact of R&D for all the desired company level BCS metrics could be calculated.* Furthermore, the averages of the R&D projects could be incorporated in the company BSC, which in turn would make the R&D of Fingrid easy and visible to monitor.

Executive report / Project XXX / Follow up No:YY	Date yyyy/mm/dd
Project XXX	
Objectives	
To reduce GRIDYYY-ABC maintenance costs by 2.5 % by year YYYY (and other outputs, see p.23)	Date / DOC
Project planned duration XX months	Date / DOC
Project planned total budget XY MEUR	Date / DOC
Project plan	
Locations and facilities	
Primary units A and B	
Cooperating units C and D	
Personnel	
Units A and B / Persons in total 125	
FTE working hours 70%	
Cooperating units / Internal	
Units C and D / Persons in total 37	
FTE working hours 25%	
Participating customers, subcontractors, partners and experts / External	
5 customers, 3 subcontractors and 1 expert and 0 partners	
Coordination	
Unit A / Persons in total 9	
FTE working hours 25%	
Extraordinary expenses	
Total extraordinary investments XY MEUR / Internal	
Materials and equipment (as expenses) A MEUR	
Total extraordinary expenses Z MEUR / External	
Midterm analysis	ANALYSIS DOC XXX/No:YY.0
Objective: Overall proceeding and success	
Status: The present project results anticipate a decrease of maintenance costs by 1.2% (Success ratio = 48% achieved). Project has used XX months (68% of planned) and 72% of its budget. This indicates that 1) targets will be reached by YY months overdue and 2) at 30-40% higher costs given to some investments that have been made in advance.	
Project plan and structure: Realization / Efficiency of resource allocation and usage	
Locations and facilities	
Analysis 1: Selection of the unit B was not the best possible, because by changing it with another unit with higher quality/cost scores would impact positively in time and budget management (Facility B is not totally well equipped for this project). **Analysis 2**: Selection of two cooperating units was overdoing. The first unit alone contributed ca 85% and the second only 15%. Reducing cooperating units to one would benefit budget management.	
Personnel	
Analysis 1: Personnel competencies are generally ok, but increasing "years in Fingrid" and "years in business" would improve time management 20-30% more than increasing the budget costs by 5-10% (Especially unit B). **Analysis 2**: Project may be over populated as a decrease of personnel with 10% would impact time management only 4% and success ratio only by 3%.	
Cooperating units / Internal	
Analysis 1: Selection of two cooperating units was overdoing. Comparing value-added to project (100%) each unit alone contributed ca 85% and the second only 15%. Reducing cooperating units to one would benefit budget management. **Analysis 2**: Focusing on unit C and increasing FTE from 25% to 30-35% would compensate the dispatching of unit D from the project and secure 100% added-value to project at lower budget costs and no negative impacts on time management.	
Participating customers, subcontractors, partners and experts / External	
Analysis 1: Selecting 5 customers is overdoing increasing only time and budget management challenges. Added value to project (100%) could be achieved with three customers only reducing 1) budget costs, 2) administrative costs and 3) speeding follow up processes, 4) improving time management. **Analysis 2**: Use of expert resources (1) significantly improves time management and project success ratio. Adding this by 1 or one partner would further benefit project timing (10-15%) and success ratio (5-10%) more than increasing budget costs (5%).	
Extraordinary expenses	
Analysis: Extraordinary expenses are balanced and only faster approvals could benefit the project time management positively - up to 10-15%.	
Summary conclusions / Recommendations for the future	
Restructuring the project would improve success ratio with up to 5-10% Restructuring the project would improve time management with up to 20-25% cutting overdue to only 10% Restructuring the project would put the project in line with the present budget within a margin of only 5% increase	

Table 7. Fictional case report of an R&D project: midpoint analyses

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ANNEX

Measurement categories, dimensions and indicators suggested in the literature

Suggested categories

Academic research interest focused on the BSC and KPI approaches in 1990s, and various sets of metrics were presented at that time. In the 2000s, closer to the present day the focus changed towards productivity measures instead and indicators were not any more in the research focus. Therefore the sources below are comparatively old, nevertheless, still relevant.

R&D measures categorized by the purpose of measurement: 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.

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.

R&D measures categorized by the type of R&D: 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.

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.

R&D measures categorized by the process phase: 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.

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.

BSC metrics

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

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.

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 14 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).

Measures for different phases

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

Measures for different industry sectors

Ojanen and Vuola 2003:

18.11 APPENDIX 11: PROPOSED MEASURES FOR BUSINESS SERVICES

Measurement theme	Measure	Supporting evidence	Significance	Feasibility
Timeliness	Proportion of innovations that were first to market/early followers in last *n* years	None found in literature. Recommended on basis of nature of innovation in the sector	High	Literature-based research should offer a way into this data.
Business performance	Numbers and value of new customers reached by the innovation and, new market niches entered	Supported by empirical evidence and literature review	Moderate	Connection between the exploitation and the innovation may not always be clear
Financial performance	Profitability, sales, savings, % of income generated by innovation	Provenance well-established in techno-centric sectors but argued to be insufficient on its own for service sectors		Connection between the innovation and the numbers may not always be clear, but typically financial data are collected
Commercialisation	Number of other organisations licensing products/services developed by us	Based on empirical responses. No evidence found in literature	High. Commercialisation, exploitation, licensing, etc are important indicators for the sector	Data exist but not routinely collected
Innovativeness	New products/services introduced in last *n* years relative to market leader	Counting is a well-established approach (including literature-based counting), also applicable to services	Moderate. In some sub-sectors (e.g. consulting services) it can be difficult to separate new products. Also, may fail to capture organisational innovations	Uncertain as to whether or not data exist due to problem of isolating innovation. Literature-based indicators may be an aid.

18.1 APPENDIX 1: MEASUREMENT CATEGORIES AND INDUSTRY SECTORS

	Aero/Def	Bus Serv	Constr	Creative	Fin Serv	HT Manuf	ICT	Pharma	Pub Sect	Ret & Wholesale	Telecom	Transport
Financial performance	■	■	■	■	■	■	■	■			■	■
Innovativeness		■			■	■	■	■	■	■	■	■
Technological application			■						■	■	■	
Business performance		■			■	■	■					
Process improvement	■		■		■							■
Reputational enhancement				■	■						■	
Knowledge utilisation	■						■					
Market performance								■				■
Product advantage						■		■				
Business model innovation				■							■	

Contd/…

	Aero/Def	Bus Serv	Constr	Creative	Fin Serv	HT Manuf	ICT	Pharma	Pub Sect	Ret & Wholesale	Telecom	Transport
Reinforcement of innovation orientation									■	■		
Strategic importance of innovation						■				■		
Timeliness		■			■							
Commercialisation		■										
Content creation				■								
Exploitation of knowledge stocks over time	■											
Future business value			■									
Innovation collaborations			■									
Innovation index								■				
Knowledge conversion							■					
Outreach									■			
Public impacts									■			
Technology development	■											