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A model for R&D performance measurement

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ABSTRACT

R&D activities are increasingly costly and risky and, as a consequence, measuring their performance and contribution to value becomes critical. This paper illustrates a formal model for measuring R&D performance, based upon a balanced and synthetic evaluation of quantitative indicators from five different perspectives of performance: financial, customer, innovation and learning, internal business, alliances, and networks. The model is built in coherence with the suggestions coming from the theory of measurement in soft systems, which gives relevant guidelines for ensuring validity, objectivity and inter-subjectivity of the model. Then, an application in a real R&D setting is described, which helps to understand the model and to enlighten its main advantages and limits.

1. Introduction

Measuring performance and contribution to value of Research & Development (R&D) has become a fundamental concern for R&D managers and executives in the last decades (Kerssen-van Drongelen and Bilderbeek, 1999). Since the 1990s, several phenomena have encouraged the development and adoption of specific methodologies and techniques for assessing the performance of R&D. First of all, the technological and competitive environment has dramatically changed. Market arenas have become more turbulent and dynamic, with customer needs, competitors and business models changing over time with a frequency much higher than ever (Wolf, 2006; Mohr et al., 2005). New knowledge has been developed and applied to products and services faster and faster (Bayus, 1998; Wind and Mahajan, 1997). Consequently, life-cycles have shortened in some product categories (Nevens et al., 1990), a higher number of new products and services have been introduced over time and the time between subsequent innovations has decreased. Moreover, radical innovations have often come out from the confluence of technologies belonging to traditionally separate disciplines (Kodama, 1995) and the complexity, costs and variety of technical and scientific knowledge incorporated into products and services have raised (Tidd et al., 2005).

This paradigmatic change has significantly amplified the importance of R&D to the firm's competitiveness, especially in technology-intensive industries (Germeraad, 2001). However it is still acknowledged that the measurement of R&D performance is a challenging task, since effort levels may not be easily observable, success is uncertain and influenced by uncontrollable factors, and it can be usually assessed only after long delays. The definition itself of the property under measurement – 'R&D performance' – is usually loose and very context dependent. As a consequence, in the last years many studies have been written aimed at discussing the subject and suggesting possible approaches in the performance measurement, innovation and R&D management literature (Pappas and Remer, 1985; Brown and Svenson, 1988; Sivathanu and Srinivasa, 1996; Werner and Souder, 1997; Hauser, 1998; Driva and Pawar, 1999; Loch and Tapper, 2002; Godener and Soderquist, 2004; Ojanen and Vuola, 2006; Jimenez-Zarco et al., 2006; Kunz, 2010; Molina-Castillo and Munuera-Aleman, 2009; Chiesa et al., 2008, 2009; Bassani et al., 2010; Merschmann and Thonemann, 2011) and in the practitioners' contribution as well. In spite of the huge amount of work in the field, the problem of defining a rigorous model for measuring R&D performance has not been solved yet, although some notable and interesting attempts have been recently published (Tohumcu and Karasakal, 2010; Carayannis and Provance, 2008).

Relevant insight can be drawn from the literature on measurement in soft systems, an increasingly important subject in Measurement Science (Finkelstein, 2003; Finkelstein, 2005; Cecconi et al., 2006). The underlying hypothesis is that, although in these situations physical sensors cannot be exploited as data acquisition devices (or however the measurand, R&D performance, cannot be measured by means of a physical effect of transduction), some lessons learned in designing and performing "hard measurement" processes (in terms of, e.g., modeling of the relation between measurand and influence quantities, calibration and traceability to standards, repeatability and stability, etc.) can be exported to soft systems, thus emphasizing the structure of the process instead of its implementation details.

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This paper aims at contributing to this growing body of knowledge, focusing on the definition of a model for R&D performance measurement. The paper is organized as follows. The next section introduces some basics of measurement in soft systems, in view of interpreting them in the case of that specific non-physical quantity, which is R&D performance. Section 3 presents the proposed model of R&D performance measurement, and that in Section 4 is applied to an exemplary case. Section 5 synthesizes the highlights of this work, outlines some of its limitations, and suggests some directions for future research.

2. Measurement in soft systems

An increasingly important subject of research in Measurement Science is the analysis of measurability conditions (Rossi, 2007; Mari, 2007; Mari et al., 2009) for non-physical properties, to which physical transducers cannot be applied, by transferring to such "soft" properties what have been learned in measurement of physical quantities in many centuries of scientific and technological development. In the current literature this borderline field of analysis is termed "measurement in soft systems", or sometimes (more appropriately) "measurement of soft quantities", or even simply "soft measurement". Recently, an authoritative contribution to the analysis of measurement in soft systems has come from the "Guide to the expression of uncertainty in measurement" (GUM) (BIPM, 1995), which has thrown some new light on the classical distinction between "direct" and "derived" (or "indirect") measurement. The basic hypothesis is that the property intended to be measured, called in this context the "measurand", must be characterized by a suitable model describing, in particular, the relations between the measurand itself and other properties, generically called "input quantities to the measurement model" and including in particular all relevant influence quantities that could affect the measurand value. Hence, it is acknowledged that several components generally contribute to the measurand value and uncertainty, so that any measurement in which such components must be combined should be dealt with as an indirect process that includes an information processing stage. The considered measurand is indeed the output quantity obtained by processing one or more input quantities by a functional relationship that the GUM calls the (mathematical) measurement model.

In principle, such measurement models have thus the same structure for both hard and soft systems: what makes the difference is the lack of a generally agreed theory embedding a system of relations among soft quantities, analogous to the International System of Quantities (ISO, IEC, 2007) for physical quantities. That is why measurement in soft systems is mainly concerned with the problem of suitably selecting input quantities (in this context usually called "indicators", plausibly to emphasize their role of co-determining the measurand) and algorithmically combining them to obtain a value for the searched quantity, i.e., the measurand. In this context the fundamental issue arises of how to characterize measurement with respect to generic assignment of numerical values to quantities, as it could be performed by, e.g., estimation, guess, etc., so to guarantee the epistemic significance of the results. Accordingly, our attempt here is to apply some general principles of measurement in soft systems to R&D, in order to identify a model able to give as much as possible a robust and reliable measurement to R&D performance. Such a model should be able to operatively support the identification of the conditions for an objective and inter-subjective numeric characterization of R&D performance, such as they are required to consider it a "proper case" of measurement (see, e.g., (Mari, 2003, 2007):

– *Objectivity*: measurement results should convey information on the considered system and not the surrounding environment (which typically includes the subject who is measuring). In physical measurement systems objectivity is obtained by guaranteeing a sufficient stability and selectivity of the system, so to make its output invariant to the effects of the environment, i.e., to the variations of the influence quantities. Hence, objectivity is a condition of reliability for the information produced by the evaluation process.
– *Inter-subjectivity*: measurement results should be interpreted in the same way by different subjects. In physical measurement systems inter-subjectivity is obtained by calibration, that makes the system output traceable to a standard, so that different systems traced to the same standard produce comparable results. Hence, inter-subjectivity is a condition of public interpretability for the information produced by the evaluation process.

Furthermore, the problem of characterizing measurement is made complex by its polysemy, as the following diagram highlights (see Fig. 1).

A data acquisition process (1) applied to an empirical object, i.e., the system under measurement (s), produces an information entity (x), which is in turn processed (2) leading to a further information entity (y). Hence, the concept of (physical) measurement can be recognized as twofold:

– measurement as data acquisition (1): this is traditionally called *fundamental* (or also: direct) *measurement*;
– measurement as data acquisition+data processing (1+2): this is called *derived* (or also: indirect) *measurement*.

Furthermore, when taking into account some, usually non-physical, quantities a third meaning is adopted:

– measurement as data processing (2), to obtain the value (y) for a property of the object of interest (s) from some raw data (x), under the hypothesis that such raw data actually were obtained from that object in some reliable way.

R&D performance is not generally considered a physical property, so that no physical transducers sensitive to performance can be exploited. Some analysis on the concept of derived measurement can be useful at this regards, also aimed at identifying the structural elements on which objectivity and inter-subjectivity could be obtained in this case.

According to a black box model, measurement processes can be formalized as represented in Fig. 2, i.e., the measurand is thought of as an entity that allows mapping system states to symbolic values, $p: S \rightarrow X$, so that measurement results are interpreted as measurand values. The case of derived measurement is just a specialization of this general model (as presented in Fig. 3), where thus $p_i: S \rightarrow X_i$ and $f: X_1 \times \ldots \times X_n \rightarrow Y$.

Accordingly, the measurement of the measurand Y implies that a value to all input quantities X_i has been previously assigned. Since this is generally a demanding requirement, redundancies in the argument of the model f are avoided, , the quantities X_i are chosen so to be empirically independent and thus reduce the information

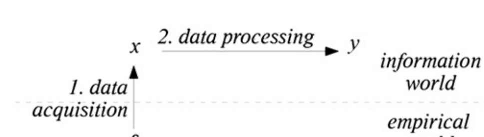

Fig. 1. Measurement as data acquisition and possibly data processing.