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Application of maturity assessment tools in the innovation process: converting system's emergent properties into technological knowledge

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Abstract

This paper aims at establishing a theoretical construction between the concept of learning-by-using and the concepts of Technological Readiness Level (TRL) and System Readiness Level (SRL). The concept of learning-by-using reveals that the technical change that takes place in complex systems is given by the sum of small improvements in many different technological disciplines integrated in a specific configuration of this system. This kind of learning results from the iterative combination of scientific and technological knowledge, which is generated by the extensive use of products and their associated production processes. A stock of this combined knowledge might be required to cope with emergent properties of complex systems. The pattern of complex systems evolution involves the balance of technological and scientific frontiers as well as the fulfillment of customer expectation. Every innovation involves systemic uncertainty, which is positively correlated to the magnitude of the change introduced into the complex system. Maturity level of technological solutions allows organizations to assess pragmatically strategic risk exposure of implementing complex system innovation. The concept of SRL represents a proficuous tool to unveil emergent properties, which consider both the TRL of individual elements and how they are integrated into a complex system.

Keywords: Complexity; Innovation management; Learning-by-using; Systems architecture; Technology maturity

Introduction

Innovation is by nature a complex process, that is to say, a process that comprises a large number of variables of various different kinds. Variables involve not only the natural laws and measurable dimensions (Kline & Rosenberg, 1986), but also abstract or intangible variables such as: a low maturity of various technologies and their inter-relationships; managerial characteristics; and the relationships between the areas involved in the innovation process; and even areas inside and outside the organization not directly involved in the innovation process. Considering this innovation process as a complex system project (Hobday, 2000), it is necessary to consider those that will be affected by the project, and even the system's operational environment (Zandi, 2000). Another aspect that brings more complexity to these highly dynamic projects is the large number of elements involved in the innovation process, which constantly change their characteristics (Sterman, 1992). Thus, it is possible to note that the relationship between complexity and uncertainty of an innovative complex system project brings huge challenges to its decision-making process.

In the classical behavior theory, it is considered that the decision-making process are based entirely on rational principles which seek to optimize processes, i.e., utility maximization,

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but the fact that innovation is complex and uncertain means that it is not possible to achieve maximum return on each activity, so the adoption of the theory of bounded rationality in this case is positive: "However the strong positive case for the classical theory replacing by the model of bounded rationality begins to emerge when we examine their situations involving decision-making under uncertainty and imperfect competition" (Simon, 1978, pp. 349). It is important to consider that the capacity of mental models is limited since it is impossible to understand or analyze all the possibilities in a complex system, thus changing the focus of the decision-making process of utility maximization to the search for satisfactory results to achieve projects main goals, sacrificing or ignoring some aspects of the problem in this process (Simon, 1978).

Despite all the fantastic qualities of a mental model like the flexibility; ability to deal with information of different natures and constantly adapting, their weaknesses are also notable; it is limited. Mental models are not explicit; those cannot be examined or evaluated by others; it is difficult to see their premises; the same phenomenon interpretations may vary by observer; and also contradictions and ambiguities may remain unresolved in these models (Sterman, 1992).

The weaknesses of mental models become even more relevant when one is dealing with complex systems projects. The large number of information requires that of decisions different areas are taken by their respective experts. From this perspective, the need for tangible models that can be evaluated by the group involved in decision-making becomes clear. Therefore the models must overcome the limitations of mental models. Thus they must have the following characteristics: be explicit; its premises should be prone to those involved in the review and revision; and they allow the simultaneous connection between many different factors of the project (Sterman, 1992).

This paper proposes a theoretical construction to bridge the concept of technological maturity (Mankins, 2009) to the chain-linked innovation model (Kline & Rosenberg, 1986). This theoretical construction aims at increasing the ability of managers to understand the nuances and subtleness of the innovation process in order to provide decision-making yardsticks that cope with the uniqueness of complex systems projects.

The need for a better understanding of the innovation in complex systems projects is given by the fact that today the industry and academia expend a lot of resources developing technologies, but just a small fraction of these technologies reach the commercial success incorporated into products (Atkinson, 1999). A great deal of them remains in academia as a scientific demonstration or becoming a commercial failure after a costly process of technological development.

System readiness assessment

The design of an innovative system depends on the evolution of technical knowledge, "The development of new functionalities of a system typically depends on a previous successful advanced technology research and development efforts" (Mankins, 2009, p. 1216). Systemic and rigorous assessment of the understanding level or expertise of the organization in

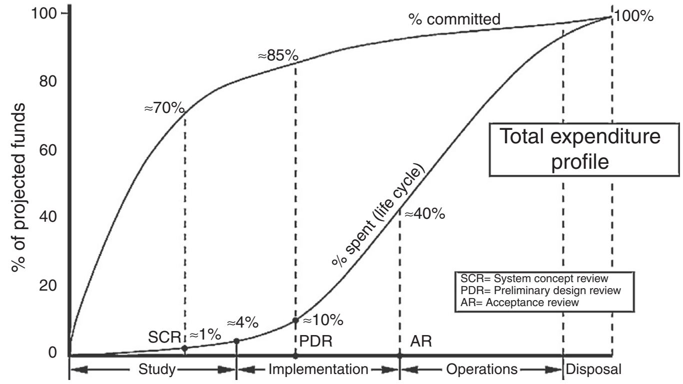

Figure 1. Typical profile of expenses in a project: committed versus spent. Source: Forsberg et al. (2005).

front to a new technology allows risks mitigation in a project, assisting the project manager in prioritizing resources for the development of critical technologies that prove to be immature at an early stage of the project.

If we adopt a low maturity technology that potentially may solve project's problem when it became fully developed, it represents a low cost at that point. But what should be considered is that it represents a high commitment of budget proportion in the later phases of the projects, as show in Figure 1 (Forsberg, Mozz, & Cotterman, 2005), in the early stages of the project, such as the system concept review, the project will have spent around 1% of the total budget, but will have committed approximately 70% of the total. By the time of preliminary design review, 85% of project funds will be committed, changes in the architecture in this stage have a deep impact in the project success given that there is no space in the budget for new developments. Thus, the expenditure profile proposed by Forsberg et al. (2005) show in Figure 1, exposes a major concern in evaluating the maturity of the technologies involved in the project architecture as early as possible to access the risks and, by consequence, the opportunities involved in the project.

To assess the maturity of a technology the TRL (Technology Readiness Level) methodology was developed in the seventies by NASA, which currently consists of a rating of nine levels shown in Table 1. The evaluation is done through a list of requirements that qualify technology to the next level; the level assigned to technology is the highest level that has the requirements met (Mankins, 2009). This methodology is widely accepted and applied, and spread to the most diverse branches of developed economies.

Complex systems depend on the technological evolution in several and concomitant disciplines. These technologies will be integrated in a specific configuration so that these systems achieve its goals through the matching of the features derived from these technologies. However this integration of disciplines cannot generate accidental effects that affect the purpose of the system mission itself "Yet, the emergence of large complex systems created through the integration of diverse technologies has created the need for a more modern maturity metric" (Sauser, Gove, Forbes, & Ramirez-Marques, 2010). These are the emergent properties that comes from the interaction between system's