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Performance measurement in interdisciplinary innovation processes – Transparency through structural complexity management

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Abstract: Performance measurement and controlling of innovation processes are essential for the successful development and implementation of new products and services. Firms need to understand drivers of success or failure within their innovative performance. Despite the recognized value of innovation controlling, adequate performance measurement in innovation processes is hard to accomplish, particularly in complex interdisciplinary settings and / or for complex product-service systems (instead of pure product offerings). In this paper, we develop and apply matrix-based approaches from structural complexity management to the field of innovation controlling. We use DMMs and a MDM to match economic impacts of interdisciplinary models and methods in the innovation process with strategic business goals and firm performance indicators represented in a Balanced Scorecard. Our approach facilitates the selection of relevant performance indicators, research methods and models for companies trying to achieve their business goals.

Keywords: Innovation controlling, balanced scorecard, process management, structural complexity management

1 Introduction

The development of high-quality products was for a long time the main goal of European and US companies. However, through the challenges of a globalized economic system, such as enhanced price and competitive pressure, these companies nowadays have to offer their customers additional value, as they can hardly compete with the price level of emerging economies (Neely 2007). Companies therefore require a sophisticated management of their innovation processes in order to develop, produce, and provide innovations effectively and efficiently without faults. One particular challenge is adequate performance measurement of innovation processes. Drivers of success or failure in innovation processes are often intangible and hard to measure. This challenge is particularly persistent in interdisciplinary and highly complex settings aiming to provide complex product-service systems (PSS), instead of mere product offerings.

Within this paper, we develop and introduce an approach for the performance measurement of interdisciplinary innovation processes within the context of the Collaborative Research Centre “Managing cycles in innovation processes” (SFB 768)[1]. The SFB 768 aims at facing the described challenges by providing models and methods

[1] http://www.sfb768.de/

to manage and shape innovation processes under consideration of affecting cyclic influences. The variety of models and methods within the SFB 768 include e.g. applications of system dynamics, SysML, structural models and many others. Cycles are defined as recurring patterns of internal and external influencing factors under which companies have to act and react successfully along the innovation process. Besides technical aspects, innovation processes include psychological, sociological and economic aspects. Thus, the different developed models and methods support the management of innovation processes from different viewpoints, e.g., facilitating the development process, analyzing changes, or improving the performance of teams. Each model thereby influences certain aspects of the company, e.g. financial performance, innovative performance, team performance or knowledge. A big challenge, which arises for companies, is the measurement of the overall impact of the different models and methods on the innovation process. Therefore, this paper describes an approach, which is based on the established concept of the Balanced Scorecard (BSC), to measure the 'enhanced' economic influences on the innovation processes ('enhanced' refers to the fact that not all influences can be measured by mere financial value, e.g., knowledge creation or learning processes). By using matrix based approaches the influences of the different models on the identified performance indicators can be analyzed and presented effectively to the different stakeholders.

This paper is structured as follows: In Section 2 the state of the art regarding balanced score card approaches as well as methods for structural complexity management are presented. Section 3 describes the used research methodology in detail and based thereon, the outcomes and findings are described in Section 4. A short discussion of the proposed approach is given in Section 5. Finally, the paper shows the limitations of this research and gives a conclusion as well as suggestions for future research in Section 6.

2 State of the art

2.1 The difficulty of performance measurement for innovation processes

Despite the recognized value of innovation for firm strategy, organizations still struggle with measuring the outcome of innovation processes (Gama et al., 2007; Zizlavsky, 2014). Performance measurement of innovation processes is difficult for various reasons. Outcomes of innovation processes are often intangible (Gama et al., 2007), information is fuzzy and ambiguous (Wang et al., 2010; Zizlavsky, 2014), hard to measure (Eilat et al., 2008). Furthermore, it often needs a long-term business perspective that often conflicts with short-term performance evaluations within firms (Banwet and Deshmukh, 2006; Zizlavsky, 2014). To date, there is no one-size-fits-all approach for performance measurement in innovation processes. Innovation processes are unique – controlling instruments need to account for this uniqueness (Vuolle et al., 2014). Firms need to choose suitable measures according to an organization`s strategy and environment (Ojanen and Vuola, 2003).

2.2 A balanced scorecard approach

A Balanced Scorecard approach has recently been referred to as a promising approach for measuring the returns of R&D processes (Neufeld et al., 2001), by overcoming many of the above mentioned issues (Banwet and Deshmukh, 2006). The Balanced Scorecard (BSC) is an established tool for performance measurement and controlling in the strategic management literature (Kaplan and Norton, 1996, 2007). To date, there are several papers using adapted BSCs to measure innovation processes and R&D outcomes (e.g., Eilat et al., 2008; Garcia-Valderrama et al., 2009).

A BSC offers an established framework for performance measurement closely linked to the strategy of an organization (Kaplan and Norton, 1996). It includes both, financial and non-financial measures (Kaplan and Norton, 1992). These measures are grouped into four perspectives that are hierarchically related to each other. The highest level consists of the financial perspective, consisting of the most important financial indicators for the particular organization. The second layer, the customer perspective aims at analyzing how customers see the organization, including measures such as customer satisfaction or retention. The third layer takes an internal processes perspective, capturing measures on the effectiveness and efficiency of business processes. The lowest layer of the BSC is comprised by measures within the perspective of learning and growth. This perspective is intended to analyze firm capabilities and assets for improving, learning and adapting towards environmental changes (Kaplan and Norton, 1992; Kaplan and Norton, 2007). The four perspectives are assumed to mutually influence each other. By including financial and non-financial measures, the BSC offers a holistic approach to analyze and control drivers for firm performance. The approach is adaptable for various purposes (such as innovation management) and contexts. Within the four perspective framework, organizations chose and weight measures according to their own strategic perspective and environment (Kaplan and Norton, 2007).

Within this paper, we develop an adapted BSC for performance measurement of interdisciplinary innovation processes.

2.3 Multiple-Domain-Matrices for structural complexity management

Performance measurement requires company and case specific indicators to assess innovation processes. Furthermore, an interdisciplinary perspective on innovation is important to respect the different facets and requirements linked to innovation processes. Even though the BSC helps to reduce the complexity by grouping the indicators into four categories, there is still a need for methodical support to describe and analyze the complexity. Therefore, we decided to use structural complexity management because multiple interrelations among the different indicators need to be documented and analyzed. One main advantage of structural complexity management is that it allows linking different objects like components, documents or people (Lindemann 2009). Especially in the context of innovation processes a more holistic or socio-technical perspective is useful.

Structural complexity management is a matrix based approach that comprises three different matrix types: Dependency Structure Matrix (DSM), Domain Mapping Matrix (DMM) and Multiple-Domain Matrix (MDM) (Lindemann 2009). A DSM is an intra-domain matrix, which is squared and maps elements within one domain. The MDM is an intra-domain matrix, which links elements from two different domains and therefore the number of rows and columns is not always the same. The MDM is based on DSMs and DMMs. The creation of a MDM is often the starting point for complexity management because a MDM helps to identify and describe the system in focus and the dependencies between the different domains.

3 Research methodology

In order to measure and document the economic impact of the models and methods developed within the SFB 768, we chose an integrated bottom-up and top-down approach.

The bottom-up approach represents the perspective of the SFB 768 comprising different discipline-specific approaches and viewpoints. As part of the bottom-up approach, we conducted 13 semi-structured interviews with all disciplines in order to identify all existing methods and models of the research groups. Within these interviews, specific performance indicators – so called SFB performance indicators (see Figure 1, abbreviation sI) - enabling the different disciplines to indicate the economic impact of their methods and models, were elaborated.

The top-down approach on the other side represents the firm perspective (in our case specifically the perspective of a PSS provider). We used the BSC framework to adequately cover relevant business goals. Using the four BSC perspectives as a framework, we derived performance indicators of strategic relevance for PSS providers from company goals (see Figure 1, abbreviated as bI). The BSC offered a support tool for exploring the economic impacts of the models and methods developed within the various perspectives of the SFB: Financial perspective, customer perspective (e.g., customer satisfaction), process perspective (e.g., rate of changes), or learning and growth (e.g., knowledge and information management).

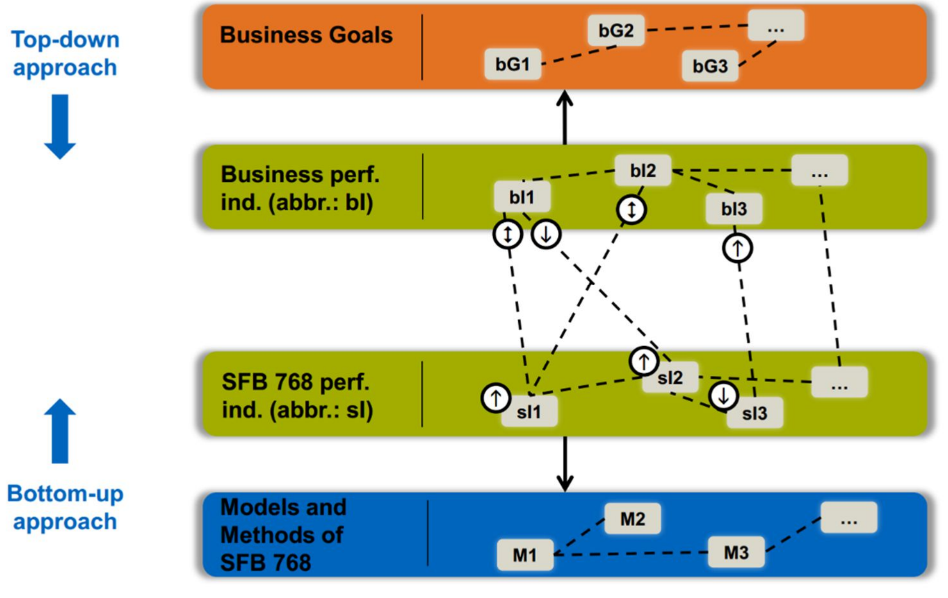

Figure 1. Top-down and bottom-up approach to collect the data

In an interdisciplinary workshop with all disciplines, the bottom-up and the top-down approach were brought together by linking SFB performance indicators (sI) and business performance indicators (bI). Through the integration of the top-down and bottom-up approaches, we merged the perspective of the SFB with the firm perspective.

In order to analyze and visualize the interconnections of the SFB performance indicators and the business goals, the bottom-up and top-down approach were extended by a MDM. The bottom-up and top-down approach as well as their integration are important to make our research findings accessible and useful for practitioners. A comprehensive and user-friendly presentation is an important prerequisite for the applicability in companies. For this purpose, a digital visualization tool was created to facilitate access to the results of the top-down / bottom-up approach.

4 Analysis and results

This paper aims at developing an interdisciplinary approach to capture the relationships among diverse methods designed to manage the innovation process. We focus on the model's influence on performance indicators and their relationships through influencing the same indicators. Therefore, the objective is to contribute to the understanding of the complexity within innovation processes by analyzing dependencies in order to derive implications for research and practice.

The interdisciplinary interviews conducted within the SFB 768 provide a comprehensive description concerning the dependencies between methods/ models and performance indicators, as well as between performance indicators and indicator blocks. The indicator blocks were extracted from literature on performance indicators. The advantage of this data set is that it comprises inputs with respect to innovation management from different disciplines (e.g., psychology, mechanical engineering, computer science, and management). Thus, it takes into account the importance and need of an interdisciplinary perspective on innovation processes. In order to manage the complexity resulting from the interdisciplinary approach of the SFB 768, we decided to analyze the collected data using structural complexity management.

Reading direction	**Model**	**Indicator**	**Indicator Block**
Model	***influences*** (calculated)	***affects*** (interview based)	
Indicator		***influences*** (calculated)	***is assigned to*** (interview based)
Indicator Block			

Figure 2. MDM describing the analyzed domains and relations among the domains

In more detail, we created a MDM with three domains: model (including methods), indicator (performance indicator) and indicator block. The dependencies between the three domains were assessed in the interviews. The MDM is visualized in Figure 2. Our final MDM (dimension: 71 rows and columns) compromises the following information:

34 models, 28 indicators and 9 indicator blocks. To further analyze the data, we split the overall MDM in two DMMs: one DMM capturing the dependencies between models and indicators, and another DMM capturing the dependencies between indicators and indicator blocks. The two DMMs form the basis for following analysis.

4.1 Analysis of the interview data

First, we analyzed the DMM that described the dependencies between the models and the indicators. In total, the DMM included 34 models and 28 indicators as well as 134 dependencies. The analysis showed that

- 16 models / methods influence indicators assigned to the process perspective,
- 15 models / methods affect indicators of the learning and growth perspective,
- 3 methods / models influence the customer perspective.

Further, we found the strongest interconnection of SFB indicators and business goals in the process perspective. On average each model was related to mean = 3.9 (standard deviation = 2.2) indicators and on average each indicator was related to mean = 4.8 (standard deviation = 4.1) models. Models had a maximum and minimum of max = 11 and min = 2 relationships to indicators; and indicators a maximum and minimum of max = 17 and min = 1 relationships to models. Second, we analyzed the DMM by showing the relationships between the indicators and the indicator blocks, which had a total number of 28 indicators and 9 indicator blocks. The descriptive data for the indicators are: mean = 4.8, standard deviation = 4.1, min = 1, max = 17. The models / indicators and indicator blocks with the highest and lowest number of relationships for both DMMs are shown in Figure 3 and Figure 4. The DMMs already provide extensive information on the number of relationships (i.e., degree of interconnectedness) between models, indicators and indicator blocks. We conducted further analyses to investigate the indirect relationships between models and indicators.

	Highest number of relations	***Lowest number of relations***
Model	▪ PSS integration framework ▪ SysML4Mechatronics & engineering change effects ▪ Conceptual traceability reference model for PSS	▪ Generic PSS structure model ▪ Structure based System Dynamics model ▪ Model to assess the risk of a technology ▪ Context model for production change management
Indicator	▪ Planning accuracy ▪ Reaction time ▪ Knowledge concerning engineering change effects	▪ Number of customer inputs ▪ Number of changes within the collaboration ▪ Employee satisfaction

Figure 3. Results of the connectivity analysis of the DMM - Model affects indicator

	Highest number of relations	*Lowest number of relations*
Indicator	▪ Planning accuracy ▪ Reaction time ▪ Knowledge concerning engineering change effects	▪ Number of customer inputs ▪ Number of chances within the collaboration ▪ Employee satisfaction
Indicator Block	▪ Development process ▪ Production of products and services process	▪ Customer perception ▪ Sales and service process

Figure 4. Results of the connectivity analysis of the DMM - Indicator is assigned to indicator block

4.2 Calculation and analysis of indirect dependencies within the domains

The conducted interviews provide data concerning the relations among different domains. However, it is also of great importance for the performance assessment of innovation processes to understand how indicators and models are indirectly related within their domain. This analysis provides information for researchers and practitioner about indirect dependencies of models and thus, the necessity of (interdisciplinary) collaborations and coordination. For the calculation of the indirect dependencies, Equation (1) was used (Lindemann 2009).

$$DSM = DMM \cdot DMM^T \qquad (1)$$

The two DMMs derived from the interviews were transferred into binary DMMs to prepare for the calculation of the indirect dependencies. The outcome of the calculation is a symmetric undirected DSM, which describes how many indirect dependencies exist between the different elements. Overall, the results show that the indicators and the models are highly linked through indirect dependencies. The density of a matrix reveals what percentage of the possible links exists. The results in our case are that the DSM_{Models} has a density of 43.2 % and $DSM_{Indicator}$ has a density of 35.7%. The models and indicators with the highest indirect connections (within domain) are shown in Figure 5.

	Highest number of indirect dependencies	*Lowest number of indirect dependencies*
DSM – Model influences model	▪ PSS integration framework ▪ Process model for production structure adaption ▪ Process model for reconfiguration planning	▪ Context model for production change management ▪ Structure based System Dynamics model ▪ Customer input ontology
DSM – Indicator influences indicator	▪ Planning accuracy ▪ Knowledge concerning engineering change effects ▪ Duration engineering change	▪ Number of chances within the collaboration ▪ Employee satisfaction ▪ Number of variants ▪ Number of customer inputs ▪ Planning accuracy concerning user integration

Figure 5. Results of the analysis of indirect dependencies within the model and indicator domain

5 Discussion and implications

5.1 Discussion of the analysis results

The results that show the direct connectedness between different domains (models and indicators or rather indicator blocks) as well as indirect relationships with domains (models via indicators as well as indicators via models) suggest several implications for managing the innovation process.

When aiming at improving the innovation process by trying to enhance a specific performance indicator (e.g., the planning accuracy) or performance indicator block (e.g., the development process), it is necessary to take into account multiple models that all influence the respective indicator or indicator block. Furthermore, when changing or implementing a model in the innovation process, indirect dependencies to other models have to be considered. The dependent models need to be aligned, in order not to undermine or weaken the other models' effect on an indicator or indicator block. Similarly, when focusing on improving a performance indicator, indirect effects on other indicators need to be considered. Our study provides an approach how the dependencies can be explored, measured and modeled. Ultimately, the approach provides guidance for interdisciplinary collaborations and cooperation within the innovation process, as it is likely that the dependent models and indices are addressed by people of different disciplines and in different phases along the entire innovation process.

5.2 Implications for research

This paper has two important implications for research in the area of performance measurement of interdisciplinary innovation processes.

First, with regard to structural complexity management – We show that matrix-based approaches mainly used in the field of product development, can also be used for other purposes and in other contexts. We apply a matrix based approach in the context of performance measurement of innovation processes. We use a MDM and DMMs to match and integrate performance measurements of interdisciplinary methods and models with a company / practitioner perspective – represented by the adapted BSC.

Second, we contribute to prior literature using the BSC for measuring R&D performance. We add on to this literature by building an adapted BSC to measure performance for innovation processes that are characterized by high complexity within the outcome (integrated PSS instead of mere technical products) and high interdisciplinarity (technical as well as socio-technical perspectives involved). We find that the BSC offers a comprehensive and suitable approach to both merge those different perspectives and to build a framework for exploring different drivers of success or failure of innovation management for PSS.

5.3 Implications for the management of innovation processes

Companies need to identify and measure relevant and evidence-based performance indicators for their innovation controlling in order to be able to initiate changes of business processes, customer-interfaces, people- and culture management activities properly. For this practical purpose, the value of this research is twofold. On the one hand, the integrated

BSC proposes a holistic, interdisciplinary framework for the controlling of innovation processes, mapping well-established and research-based performance indicators with theoretical models and methods that influence these performance indicators. Practitioners could map these results with their own process- and innovation management. They can use this framework to select theoretically and empirically founded performance indicators. Our approach also helps to understand and influence the underlying cycles that occur along the organizational innovation processes of PSS-companies. On the other hand, companies can derive strategic and operational implications for the management of innovation processes by analyzing and understanding relationships between specific performance indicators (e.g., employee satisfaction) or indicator blocks and the related methods and models (e.g., model of management of cycles of teams and complex networks). The information on direct and indirect dependencies between performance indicators, models and methods helps companies to identify and influence hidden mechanisms that might affect the performance within their innovation process. For example, the analysis of the DMM shows that planning accuracies within the PSS innovation process can be influenced by many methods (e.g., PSS integration framework).

6 Conclusion and outlook

In this paper, we developed and applied matrix-based approaches from structural complexity management to the field of innovation controlling. By using DMMs and a MDM to match economic impacts of interdisciplinary models and methods in the innovation process with strategic business goals and firm performance indicators, we provide a first integrative framework for an evidence-based innovation controlling. The approach allows the analysis of direct and indirect linkages and the detection of strongly interconnected methods, models and performance indicators. By applying a Balanced Scorecard (BSC) perspective, we make this research more accessible for the strategic and operational management. It facilitates the selection of relevant performance indicators, research methods and models for companies trying to achieve their business goals. It should be noted that, to date, the linkages are elaborated only in a descriptive manner, while the strength and direction of the individual relationships between all models, methods and performance indicators are not reflected yet. Thus, it is part of future research to close this gap and extend the approach by incorporating these properties comprehensively - in a qualitative and quantitative manner. Future research should also focus on further effects as well as the interdependencies and interactions between the interdisciplinary models, methods and performance indicators. Further possible enhancements include prioritizing and selection of significant performance indicators on both sides (research and industry) to reduce complexity. Future research should also strongly focus on the validation of the framework and its components by field research and collaborations with PSS providers in order to maximize its practical utility.

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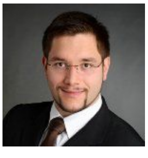

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