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General and specific formalization approach for a Balanced Scorecard: An expert system with application in health care

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ABSTRACT

The Balanced Scorecard (BSC) presents the essentials of strategic and performance management in clear, straightforward manner which is also usable in health care. If a BSC for a clinical department is an agreement, the first question to consider is the method by which it can be ascertained whether a strategy has been accomplished. There are many different techniques like AHP (analytic hierarchy process) and fuzzy systems to calculate indices.

However, how does a formalized mathematical groundwork looks like that integrates current approaches and is still general enough to incorporate future expert systems with applications?

The purpose of this paper is the formalization of BSC evaluation by respecting current research. The formalized expert system was implemented in an information system for health care management.

1. Introduction and motivation

Any hospital is confronted by substantial society changes due to a variety of factors such as increasing life expectancy and population ageing, economical pressure and competition, limited resources as well as shrinking and tight budgets, new governmental deregulations and liberalization. In order to cope with the changing nature of this environment, which is also aggravated by deep structural reorganization, it is important to accomplish success goals with a tool of strategic management such as a Balanced Scorecard.

In order to support strategy and performance management, Robert Kaplan and David Norton's "Balanced Scorecard" concept (Kaplan, 1992) may be used. It is a tool of strategic management, strategic communication and performance management, providing frequently measured performance and regular reviewing and refinement strategy with an ongoing evaluation process of clinical indicators. A BSC design and implementation process can be separated into four stages: (1) translating the vision and gaining consensus; (2) communicating the objectives, setting the goals, and linking strategies; (3) setting targets, allocating resources, and establishing milestones; (4) and feedback and learning (Stewart & Bestor, 2000). Types of performance indicators and factors are termed as "perspectives". These perspectives as in the original definition are differentiated into a financial, a customer, and a process and innovation perspective. The simply monitoring of key financial indicators, which have often been historical in nature and concentrated almost exclusively on lagging indicators are hiding the key drivers.

Examples of Balanced Scorecards in health care can be found for a burn centre (Wachtel, Hartford, & Hughes, 1999), a kidney transplant (Colaneri, 1999), an ambulant treatment (Curtright, Stolp-Smith, & Edell, 2000), an electronic patient record (Gordon & Geiger, 1999), a children's hospital (Meliones, 2000), dialysis (Peters, 1999), anesthesiology (Zbinden, 2002), cardiology (Chang, 2002), behaviour therapy (Santiago, 1999), information strategy of Canadian NHS (Protti, 2002), and indicator system for Dutch health system (Asbroek et al., 2004). These articles give a brief overview about BSCs and their development and application in healthcare management.

Strategic management is an externally oriented philosophy of managing an organization that links strategic thinking and analysis to organizational action (Ginter, Swayne, & Duncan, 2002). The strategic process can be presented as a model where key elements include an environment scanning, strategy formulation, strategic implementation as well as a strategic evaluation (Wheelen & Hunger, 2004). The following points should be noted in connection with the practical implementation of clinical Balanced Scorecards:

1. *Which indicators are relevant for the clinical Balanced Scorecard*? The proposed strategic management system should enable hospital managers, not just to be informed about financial indicators but also about specific requirements that are relevant to health care. Indicators consist of various measures that may

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be expressed or implied. Not all the indicators are of equal importance and the healthcare manager has to seek so to classify them according to their importance. However, this is beyond the scope of this paper which focuses on the evaluation.

2. *How to evaluate indicators of a clinical Balanced Scorecard*? The main focus of this study is how to present the multitude of indicators in an adequate way for managing purposes. First of all, it is necessary to answer the utilization of each individual indicator. This means to which degree is a specific target for an indicator accomplished. Secondly, how can these indicators be aggregated in a general way on the foundation of an appropriate metric into a single performance index for each perspective and on BSC level these perspective indices into one entire BSC index. Although many publications (Asbroek et al., 2004; Colaneri, 1999; Curtright et al., 2000; Chang, 2002; Gordon & Geiger, 1999; Meliones, 2000; Peters, 1999; Protti, 2002; Santiago, 1999; Wachtel et al., 1999; Zbinden, 2002) describe Balanced Scorecards in health care only few like (Tarantino, 2003; Griffith & White, 2005) show how an overall index can be computed. This study therefore aims to formalize the computation of an index both for entire BSC and for each perspective. Therefore it uses concepts of decision theory that give a profound base for formalization.

The method part of this paper shows a general definition of an indicator system for each perspective in a BSC for a clinical application and how a utility function can be defined. In addition to utility functions a formalization of a general approach as utility values can be aggregated into an index for a perspective and an entire BSC. The definition is general and implies no assumptions of the implemented utility functions and aggregation. Unlike, the general definition the result section of this paper explicitly defines a specific set of utilization functions and the manner of aggregation. With regard to the formalization an implementation was made with cooperation with an orthopedics department.

2. Theory and methods

The formalization of the Balanced Scorecard presented here is in part based on decision theory. Decision theory is the product of the joint efforts of economists, mathematicians, philosophers, social scientists, and statisticians toward making sense of how individuals and groups make or should make decisions (Resnik, 1987). Decision theory provides a formal framework for making logical choices in the face of uncertainty. Given a set of alternatives, a set of consequences, and a correspondence between those sets, decision theory offers conceptually simple procedures for choice (Parmigiani & Inoue, 2009). It is thus usual to divide decision theory into two main branches: normative (or prescriptive) decision theory and descriptive decision theory (Resnik, 1987). The basic assumption is that decision functions are based on preferences. A function or representation of preferences is regarded to be a utility function or evaluation function if each alternative can be associated with a real number (Resnik, 1987).

2.1. General formalization

The functional criterion for evaluation of indicators for a clinical balanced scorecard needs an appropriate metric for an afterwards or *ex post* consideration. For each perspective j exist a set of n_j disjoint indicator x_{i_j}, which can be combined to an indicator vector $\vec{x}_j = (x_{1_j}, \ldots, x_{n_j})^T; x_{i_j} \in \mathbb{R}$.

2.1.1. Utility functions

An indicator vector of a perspective is an element of an n_j-dimensional real number space. An indicator vector $\vec{x}_j$ can be assigned with a vector function $\vec{\Phi}_j(\vec{x}_j)$ to an evaluation vector. The vector function $\vec{\Phi}_j(\vec{x}_j)$ contains a number of n_j one-dimensional functions $\Phi_{i_j}(x_{i_j})$ that assigns each component to a single utility value.

2.1.2. Aggregation functions

The resulting vector of $\vec{\Phi}_j(\vec{x}_j)$ can be assigned to a single scalar P_j. This can be interpreted as aggregation function or index for a perspective P_j. Function $\Gamma_j\left(\vec{\Phi}_j(\vec{x}_j)\right)$ incorporates the mathematical method of transferring the utility vector into a single real value.

$$P_j = \Gamma_j\left(\vec{\Phi}_j(\vec{x}_j)\right). \tag{1}$$

For a classical Balanced Scorecard with a financial, customer-, process- and innovation perspective let the number of perspective be $m = 4$. The aggregation function of the entire BSC for disjoint perspective evaluations P_j with $j \in \{1, \ldots, m\}$ is:

$$B = \Lambda(P_1, \ldots, P_m) = \Lambda\left(\Gamma_1\left(\vec{\Phi}_1(\vec{x}_1)\right), \ldots, \Gamma_m\left(\vec{\Phi}_m(\vec{x}_m)\right)\right). \tag{2}$$

The functions Φ, Γ und Λ incorporate preferences with weighting values. How this weighting is performed in a concrete situation is still undefined and left to the special definition. Fig. 1 show how the hierarchy level looks like. This hierarchy is general and abstract. Specific utilization and aggregation at this point are still left to individual definition.

2.1.3. Decision rule

Coming to a decision rule it is useful to know before and therefore *ex ante* how prospective changes can be evaluated. The underlying assumption is that the decision maker is rational in a way that he wants to increase the entire score B of a BSC throughout different time period. Thus, each period t has one and only one entire evaluation B_t. If the decision rule from time period t to time period $(t + 1)$ is to increase the score then the necessary condition is $B_t \leqslant B_{t+1}$. However, the decision maker does not only want to increase the score in successive time periods but also to maximize it. His sufficient condition is therefore to select one alternative that leads to a maximum value. Let A_j be the set of result from activities that are accomplishable. A rational decision maker would choose for a perspective P_j that alternative $\vec{a}$ which is the maximum:

$$(\forall \vec{b} : \Gamma(\vec{a}) \geqslant \Gamma(\vec{b})) \wedge \vec{a}, \vec{b} \in A_j. \tag{3}$$

It is possible that there exist more than one indicator vector that satisfies the requirement. In this case the decision maker is indifferent to these alternatives. These indifferent indicator vectors belong to one equivalence class that results by the homomorphism of the function.

3. Results

The results are classified into utility functions, techniques to aggregation, an approach to fast computation and examples of an application of an expert system.

3.1. Special formalization

The above general formalization establishes certain requirements that must be satisfied before the exact scope of a utility function and aggregation can come into play. A special formalization precisely defines calculation principles that can be imple-