ANALYZING TRADE-OFF ISSUES AMONG KEY PERFORMANCE INDICATORS USING FUZZY COGNITIVE MAPS

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ABSTRACT

Continued improvement of performance has become a real challenge for most companies and organization. This paper presents a framework using Fuzzy Cognitive Maps (FCM) method to quantitatively analyze the influence and relationship among the KPIs used to monitor performance. The proposed method can help the top management and decision-makers to identify the improvement behavior of one Key Performance Indicator (KPI) target on the whole Performance Management System (PMS). A deferent scenario was conducted in one of the organizations to analyze the interconnections between the KPIs and the impact of changing the targets.

Keyword: KPIs; fuzzy cognitive maps; PMS; trade-off.

INTRODUCTION

Key Performance Indicators (KPIs) is an important management tool in a complex and competitive business environment which is designed to measure the organization's defined strategic objectives and whether the objectives have been achieved (accomplished) or otherwise. However, according to management experts, a real performance not only seeks to achieve the defined target but to extend those targets within a reasonable time frame and accomplish them.

Intensive study has been conducted regarding Performance Measurement System (PMS), and KPIs defined within the PMS. Despite the importance and the popularity of the KPIs in any organization and firm's performance measurement, there are still critical issues requiring further research. One of the critical issues identified from the literature is the trade-off and relationships that exist among the KPIs. In this research, the relationships among the KPIs are addressed where the method of Fuzzy Cognitive Maps (FCMs) was used to compute and analyze the relationships that exist among the KPIs. Organizations and performance measurement experts often ignore or do not take into consideration the cause-and-effect or interdependencies among those KPIs. Only a few researches have been penetrative enough and able to identify the relationships that exist among the KPIs. Alisha (2003) for example, used Multi-Attribute Utility (MAU) to identify the trade-off between performances metrics defined within the PMS. However, it is important to realize that the use of MAU and correlation in the analysis is limiting since it considers pairs of KPIs instead of analyzing all the KPIs at the same time. Kung et al. (2007) employed grey relation analysis and grey decision-making to evaluate financial performance and its relationship with the company attributes. In addition, Deshmukh et al. (2006) proposed the Interpretive Structural Modeling (ISM) and Analytical Network Process (ANP) to link the relationship between measures and the strategic objectives. The aim of this paper is to use FCM to analyze trade-off issues among KPIs.

TRADE-OFF AND RELATIONSHIP OF KPIs

In practice, once the PMS has been created, they are kept unchanged for a long period of time and the system is considered as static. In fact however, the measurement system is dynamic, especially the KPIs which can get outdated since the business environment changes rapidly. It is important for the organization to continuously update and change the strategic objectives to cope with the business environment. To clarify, many decision-makers face difficulties in figuring out ways of dealing with such a situation since the KPIs often correlate and have tangled trade-off interplays (Klejinen & Smits 2003). Indeed, occasionally improving one KPI might subvert performance of other KPIs. In other words, the interdependence and influences among KPIs may lead to conflict in-between those KPIs; in this case, accomplishment of one KPI may cause extra cost, effort, or even damage to other KPIs. For instance, efforts to accomplish the KPI target for 'manufacturing costs' will usually lead to extra efforts/cost for KPI of accomplishing 'customer satisfaction'. Furthermore, in some other scenario improvement of one KPI may lead to good performance improvement for many other KPIs. In essence, we believe that there is an optimum point of performance (where KPI is to be increased/decreased) that would positively affect other KPIs. Under the circumstances mentioned above, the FCM is proposed to handle this vagueness as management often faces difficulty in identifying optimization of performance improvement.

FUZZY COGNITIVE MAPs

Fuzzy cognitive maps are an intelligent computing tool which is considered a combination of neural network and fuzzy logic. FCMs were introduced by Bart Kosko in 1986 and since then FCMs have been used in a variety of domains such as engineering, planning and management, decision analysis, and psychology.

Simply explained, FCM is a fuzzy diagram that illustrates the complex system behavior in terms of cause-and-effect relationship existing between the nodes/concepts. FCMs consist of nodes/concepts and edges/arcs where the nodes/concepts are connected with each other by direct connection or by path and the edges/arcs represent the causal relationship between the nodes/concepts. The nodes/concepts may stand for goals, events, variables, actions, etc. In our case, the concept is a KPI. Each edge is accompanied by a weight to identify the causality among the concepts. The sign of the weight indicates whether it is a positive or negative causality while zero denotes that there is no causality. The FCM concepts can be formed as $C=\{C_1, C_2, \ldots, C_n\}$. Additionally, the edges among the concepts are written as (Cj,Ci) which are oriented to represent how the concept C_j causes the concept C_i. The weights of edges are gathered in a weight value matrix $E_{n.n}$, where each element of the matrix e_{ij} ranges in the interval [-1, 1]. Thus,

- $e_{ij} > 0$ represent positive causality that indicates increase/decrease in the value of C_j leading to increase/decrease in the value of C_i (direct causality).

- e_{ij} <0 represent negative causality that indicates increase/decrease in the value of C_j leading to decrease/increase in the value of C_i (inverse causality)
- e_{ij} =0 indicates no causality relationship.

When the FCM system runs, each concept takes its initial value. Then the value A_i of each concept C_i is calculated for each iteration step; the influence of the interconnected concept can be calculated by:

$$A_i^{(k+1)} = f\left(A_i^{(k)} + \sum_{\substack{j \neq i \\ j=1}}^{N} \mathrm{A}_\mathrm{j}^{(\mathrm{k})} . \mathrm{e}_{\mathrm{ji}} \right). \quad (1)$$

where $\mathrm{A}_\mathrm{i}^{(\mathrm{k+1})}$ is a value of the effect of the concept C_i on concept C_j at the iteration step $k+1$, and $A_i^{(k)}$ is a value of C_j in the iteration step k, e_{ij} is the value (weight) of the cause-effect link between the concepts (C_j,C_i), and f is the threshold function.

$f(x_i) = -1, \quad x_i \leq -0.5$

$f(x_i) = 0, \quad -0.5 \leq x_i < 0.5$

$f(x_i) = 1, \quad x_i \geq 0.5$

The threshold function of "trivalent" (Miao and Liu 2000) is used in our work since the value of the concepts under study are [-1, 0, +1] which is equivalent to negative effect, no effect, and positive effect respectively.

Assigning Linguistic Variables and Numerical Weights:

A group of experts were pooled together for constructing accurate and precise FCM. Through the knowledge and brainstorming sessions of the participating experts, the structure could be acquired. In addition, the experts were also asked to articulate the causal relationship among the concepts. Figure 1 illustrates the result of this procedure, in which the FCM is structured to simulate the company (market competitiveness) in terms of other factors (KPIs) that may positively or negatively affect the behavior of the company's competitiveness. As shown in Figure 1, the company's competitiveness in the market is affected directly by several factors such as turnaround time rate, turnaround time hit, staff productivity, etc. These factors positively affect the company's competitiveness in the market and are represented as black arcs. Similarly, some other factors directly and negatively influence the competitiveness of company in the market, for example backlog which is represented by red dashed arcs.

Another important step that required more attention in order to construct an accurate FCM is the degree of the relation within the concepts (fuzzy logic). Here the experts were also asked to state the degree of causality among the concepts by using linguistic expression such as "negatively strong", "positively strong", "negatively weak", positively weak", etc. Figure 2 describes the linguistic variable used to grade the influence within the concepts in Figure 1.

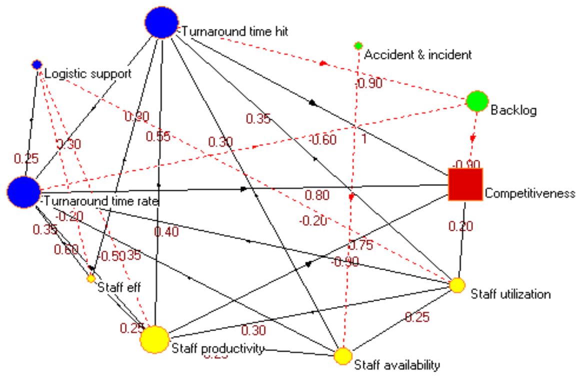

FIGURE 1 FCM model with initial linguistic labels of influence

Once the FCM structure and all the relationships of the concepts have been identified, then the behavior of FCM and how changes on the level of one concept contribute to changes in other concepts whether positively or negatively (improving or undermining
the performance) were explored. The KPIs under study are compiled from company
(A). The top management of Job-Shop for aircraft component Maintenance Repair and Overhaul or MRO in (A) monitors the performance of the business using a set of KPIs

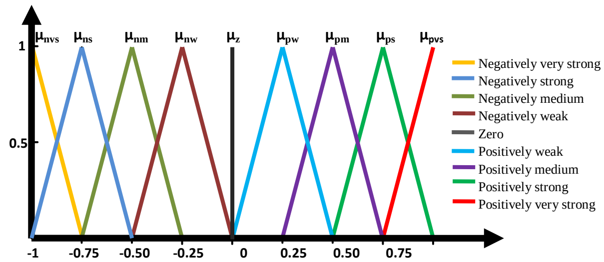

FIGURE 2 Linguistic scales of influence between the variables

to ensure competitiveness in the market. Let us suppose that in normal circumstances, the targets of each KPI are as depicted in the table below.

TABLE 1 The average level for each KPI

KPIs	Target Level	FCM Level
Staff efficiency	76 %	50
Staff utilization	76 %	50
Staff productivity	75 %	50
Staff availability	92 %	50
Accident & incident	< 2	50
Turnaround time hit	< 5 days	50
Turnaround time rate	7 days per unit	50
Backlog	<95 unit per week	50
Logistic support	85 %	50
Competitiveness	-- %	50

RESULT AND DISCUSSION

For FCM, we set the level to fifty as an average level for all KPIs. We simulated the FCM and after a few iterations, the simulation was stopped when the result showed no change, so that what we expect since all the level is the same. Next, we changed the level of one, KPI which is staff availability for two scenarios, below the normal level (40) and above the normal level (60). As can be seen in Figure 3, when the staff availability KPI is set below the target (92), the performance of other KPIs decreased, and the backlog increased. However, after twenty two iterations the convergence of the system was reached, which indicated that it would negatively affect the performance of the MRO Job-Shop to some point, and at that point, the decline in the performance will stop.

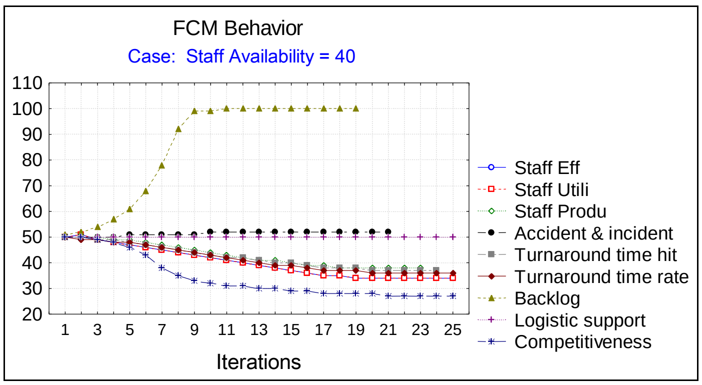

FIGURE 3 The effect of one KPI on other KPIs (below normal)

Similarly, next we increased the level of staff availability to sixty. Figure 4 shows the effect on all the other KPIs when the availability of the staff is set at a high level, in this case sixty.

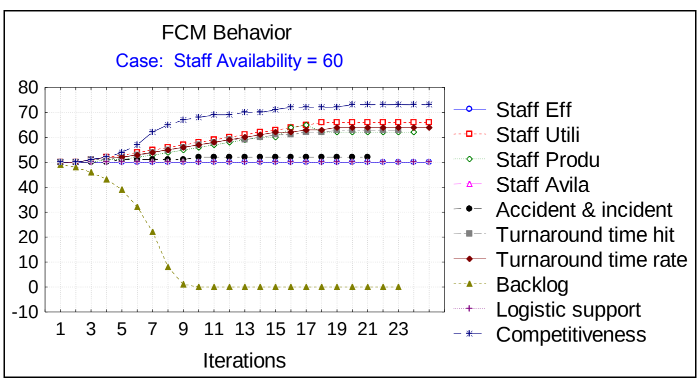

FIGURE 4 The effect of one KPI on other KPIs (above normal)

In another scenario, market competitiveness is increased and set at 54 to see its effect on other KPIs. The illustration in Figure 5 shows the effect of this scenario and the improvements that would need to be performed on all the other KPIs.

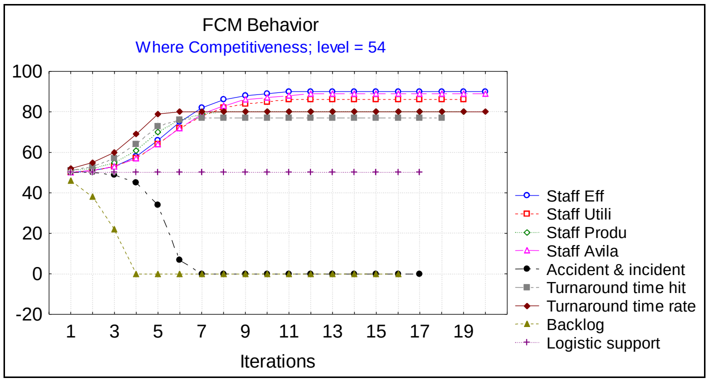

FIGURE 5 The effect of increasing market competitiveness on other KPIs

CONCLUSION

This article presents a soft computing method of FCM that is used to evaluate the performance measurement system. The trade-off analysis showed how an effective PMS can be developed. One of the main benefits from this research is the fact that the if-then scenario can be carried out before a real change to the organization's targets is implemented. Furthermore, the estimation on the cost of improving one KPI on other KPIs can be computed in a systemic manner and additionally, how the changes made to one KPI could lead to improvements of other KPIs can be modeled and previewed beforehand.

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