Evaluating High-Tech Firm Performance using Hierarchical Balanced Scorecard and Fuzzy Schemes

Chun-hsien Wang
Department of Business Administration, Ming Chuan University, Taipei, Taiwan, R.O.C.
e-mail: absshian@yahoo.com.w
wang@mcu.edu.tw

Chung-Te Ting
Department of Business Administration, Chung Jung Christian University, Tainan, Taiwan, R.O.C.
e-mail: ctting@mail.cjcu.edu.tw

Abstract

A model is developed for measuring the acceptable performance of high tech firms based on the interaction between financial, customers, internal business process, and the learning and growth perspective. The hierarchical balanced scorecard (HBSC) integrated with non-additive fuzzy integral for designing, developing and implementing high technology firms relevant to performance measurement was employed to overcome interaction among the various perspectives. In the light of this empirical evidence, the results provide guidance to high tech firms' performance measurement in both identifying the appropriate metrics and overcoming key implementation obstacles for improving firm-operating efficiency and hence assistance for future strategic adjustment.

Keywords: Performance measurement, balanced scorecard, hierarchical balanced scorecard, fuzzy measure, non-additive fuzzy integral.

1. Introduction

To maintain competitive advantage high tech firms must recognize and emphasize relevant, integrated, strategic, improvement oriented and whole performance measurement systems, doing so by adopting various management philosophies and tools such as benchmarking, total quality management, and business process redesign to help to define goals and performance expectations. High technology firms must integrate and develop appropriate performance metrics to explain and quantitatively analyze the criteria used to measure the effectiveness of the operational system and its numerous interrelated components. Balance scorecard (BSC) [1,2] has been developed to integrate performance measurement system with organizational goal, and aligns production, marketing, organization process, non-financial and traditional functions with firm strategies using performance driver (leading indicators) and outcome measures (lagging indicators). Consequently, the performance measurement system is entire and adopts a multidimensional structure perspective involving the various components which contribute differently to overall high technology firm performance. Constructing and possessing available performance measurement tools not only increases evaluation efficiency but also saves costs. To measure corporate financial and non-financial performance simultaneously, the BSC proves the ability of visible performance measurement approaches in strategy implementation and management control [1]. The essence of BSC lies in seeking a balance between financial and non-financial measures.

To overcome the limitations of financial-based measures, non-financial measures have been recommended owing to

L. Magdalena, M. Ojeda-Aciego, J.L. Verdegay (eds): Proceedings of IPMU'08, pp. 753–760
Torremolinos (Málaga), June 22–27, 2008

them being believed to be leading indicators of financial performance [1, 2]. Notably, practitioners and researchers have recommended increasing non-financial measures that reflect key value-creating activities, namely non-financial value drives [1, 2, 3]. Non-financial information is crucial in the high technology industry, including telecommunications, biotechnology, and software development [4]. On the other hand, because of numerous non-financial indicators are difficult to quantify, including customer satisfaction, total cost control/management capabilities and employee productivities, yet they can significantly impact overall firm performance measurement. This study introduces the subject by arguing about why firms need to assess performance, why they need to link performance measures to strategies or even emphasize financial and non-financial performance of firms without clearly defining the nature of a performance measurement system, and where its virtue resides in terms of management control system. Essentially, non-financial perspectives are leading indicators, derived from establishing a causal link between improved performance in terms of non-financial and financial measures. Employing the HBSC method of measuring high technology firm performance should consider the interactive relationship between different perspectives. Therefore, the first objective of this study is to devise a framework for developing the hierarchical balanced scorecard (HBSC) performance measurement metrics in complex and competitive operational high tech environment. The second objective of this study is to solve the interactive impact through which the non-additive fuzzy integral provides an appropriate approach and process for handling interaction problems; this paper utilizes a properly designed and implemented HBSC structure, which should yield better results than alternative strategies.

The contribution of this study lies in demonstrating the limitations of a “green field” approach in the development of HBSC to help research and practice performance measurement and enhanced management effectiveness and efficiency. The present HBSC performance measurement system is applied to overcome difficulties in performance measurement and focus on aligning the system of measuring high tech firm performance with existing performance measures and parallel initiatives cross-functional performance measures for the particular high tech firm. Recently years, many researchers have been developed and combined BSC, fuzzy AHP, and ANP in order to apply in diverse domains such [5, 6]. However, those approaches still cannot reflect the degree of interaction among performance evaluative perspectives and indicators. Therefore, this study adopts non-additive fuzzy integral method embedded in the HBSC framework to solve the degree of interaction between performance perspectives and their corresponding performance indicators and further relax restrictions for monitoring the deployment of firm strategy.

2. HBSC with fuzzy approach for measuring firm performance

The BSC is designed to help the senior managers/managers to identify the issues of the business that they must be addressed in order to successfully achieve the organizational strategy [7]. It is also highly formalized performance measurement system to integrate organizational strategic indicators and further turns actions related to strategies into tangible and intangible indicators. Our proposed measurement system extends and modifies form [7] in which dealt with indicators is the HBSC that is considered to be an appropriate tool for communicating bridge in a simple and parallel high tech firm strategy. Through comprehensive HBSC framework, strategy implementation (or vision) is easily configurable by way of analysis a series of performance indicators and the contribution of tangible and intangible indicators can be made more explicit and thus more controllable. Furthermore, the primary benefit of HBSC lies in being able to provide a mechanism for managing performance measurement system design process complexity. The four dimensions of criteria for evaluating and selecting high tech firms are derived via literature review and in-depth interviews with scholars focused on high tech management and technology innovation, and with high tech industry experts. Based on the HBSC structure, four selection dimensions were identified, including the financial perspective (FP), customer perspective (CP), internal business processes perspective (IB), and learning and growth perspective (LG).

Regarding the financial perspective (FP), financial performance directly reflects firm structuring profit and efficiency thus most firms use a financial index such as ROA or ROI to represent their performance [8]. Six key financial measures were considered important indicators of performance measurement for high tech firms. This study used traditional finance performance indicators developed by [2]. From the customer perspective (CP), numerous firms now focus on continuously improving products or services to meet changing customer needs, particularly in the extremely competitive high tech industry. The five core measurements include market share, customer retention and loyalty, customer satisfaction, new customer acquisition, and customer profitability. In the internal business processes perspective (IB), the traditional performance measurement system provides no insight into the problems of internal business processes, resulting in firms being unable to determine what is causing and driving their performance. The BSC identifies the interrelated nature of business functional areas and processes. Numerous empirical studies have argued that internal activities influence firm performance, ranging from manufacturing processes [9, 10, 11] to internal organization management activities [9, 11, 12]. Particularly, the evaluation of internal business processes depended not only on the internal organization processes but also on firm relative manufacturing process. Consequently, to measure the processes performance and refer to expert opinions and previous studies, the factor of internal business processes of high tech firm are broadly classified into two groups as follows: (1) Manufacturing processes, including process continuous improvement capability, process innovation capability, conforming rate, improvement in manufacturing cycle capability, and total cost reduction/control capability. (2) Internal organization processes, including regulation and management capability, integrated R&D capability, alignment with customers/suppliers expectations, response time to customer requests. In the learning and growth perspective (LG), Kaplan and Norton argued that learning and growth are the most difficult to measure. In devising the high tech firm learning and growth perspective, the team considered the following three measurements: information system capability, employee capability and motivation, and empowerment alignment. Each of these measurements further contains several sub-criteria. Information system capability indicates information management capability, information acquisition capability, information maintenance capability, and information technology (IT) infrastructure. Figure 1 lists all criteria and sub-criteria.

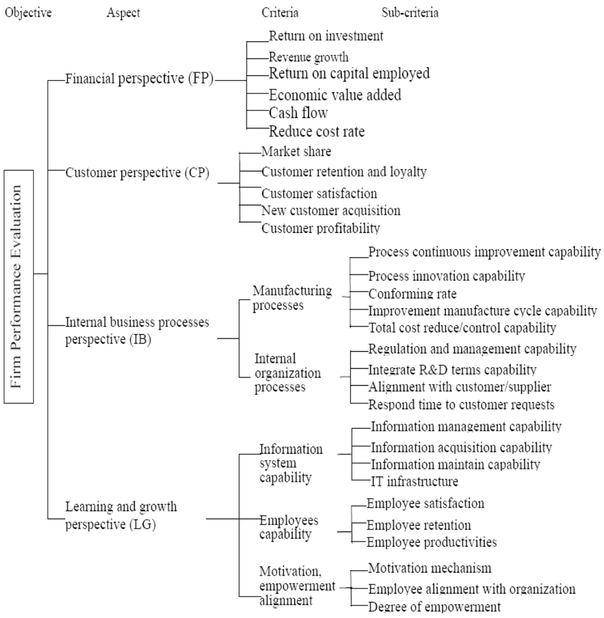

Fig. 1Performance measurement system of HBSC

The original of HBSC is designed through a shared understanding and translation of the organizational strategy into goals and measurable performance indicators in each of the four perspectives. In this study, we argued that such strategic controls could be induced using feedback loop and performance measurement for the same purpose. In other words, strategies are realized through the HBSC performance measurement system. The HBSC framework provides one means of inducing strategies realization via a series of performance indicators. According to expert consensus, previous studies, including [2], encouraged the inclusion of 4-7 measures in each evaluation category. Meanwhile, based on the [13] principles, this study developed the HBSC performance measurement system, which can provide a measurement mechanism and appropriate measurement criteria and eliminate conflicts in the performance measurement system.

3. Method and algorithm for evaluating high tech-firm performance

According to expert consensus the five rating levels for each performance-grade at the lowest level of the HBSC structure are appropriate. The intervals of performance-grade are organized into five rating levels depending on expert consensus. The five numerical intervals, $[0\%, 60\%]$, $[50\%, 70\%]$, $[60\%, 80\%]$, $[70\%, 90\%]$, and $[90\%, 100\%]$ are used to measure high tech firm performance achievement percentage, and are reflected in the triangular fuzzy numbers *VP* to *VG* level, respectively, where *VP* indicates the worst and *VG* indicates the best performance-grade of each performance evaluation criterion. The definitions of the triangular fuzzy numbers of levels *VP* to *VG* are intrinsically similar to the intervals. The performance-grade $\tilde{p}$ can be estimated using the following rating {Very Poor (*VP*), Poor (*P*), Fair (*F*), Good (*G*), and Very Good (*VG*)} and its associate membership function is illustrated in Fig.2, and was used to measure the rating effect of the different evaluation criteria used to assess firm performance.

The rating of importance $\tilde{w}$ can be estimated using the following ratings {Very Low (*VL*), Low (*L*), Medium (*M*), High (*H*), and Very High (*VH*)} and its associate membership function. As shown in Figs. 3 were used to measure the importance of the various criteria.

To determine the overall performance of

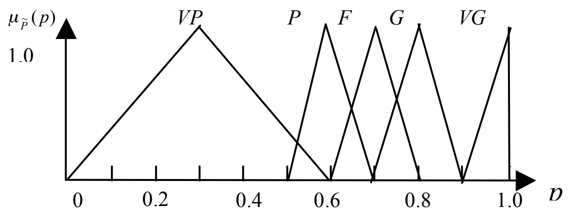

Fig. 2Membership function for five performance-grades

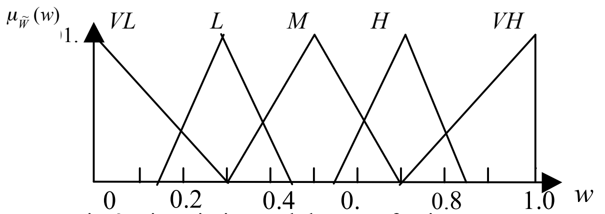

Fig.3 Linguistic model LM_{w2} for importance

particular high tech firms, multiple evaluation criteria are used, and are frequently structured into a multi-level HBSC system (Fig. 2) which accommodates fuzzy set theory to provide evaluator blueprints during the performance evaluation. Given *m* evaluators for example, scholars and expert senior managers, the criteria importance weight, $\tilde{w}_i, i = 1,2, ..., m,$ and the evaluated values (or ratings) of performance-grade metrics, $\tilde{p}_i, i = 1,2, ..., m,$ for a particular high tech firm, can be aggregated, based on the fuzzy arithmetic of [14]Dubois and Prade (1980) to three vertices of triangular fuzzy number and calculated aggregation determined via *m* evaluators using

$$\tilde{\overline{W}}_{ij} = ({}_L\overline{w}_{ij}, {}_M\overline{w}_{ij}, {}_R\overline{w}_{ij}) = ((\sum_{p=1}^{m} w_{ij}^p)/m, (\sum_{p=1}^{m} w_{ij}^p)/m, (\sum_{p=1}^{m} w_{ij}^p)/m), \quad (1)$$

$$\tilde{\overline{P}}_{ij} = ({}_L\overline{p}_{ij}, {}_M\overline{p}_{ij}, {}_R\overline{p}_{ij}) = ((\sum_{p=1}^{m} p_{ij}^p)/m, (\sum_{p=1}^{m} p_{ij}^p)/m, (\sum_{p=1}^{m} p_{ij}^p)/m), \quad (2)$$

where $\tilde{\overline{W}}_{ij} = ({}_L\overline{w}_{ij}, {}_M\overline{w}_{ij}, {}_R\overline{w}_{ij})$ and $\tilde{\overline{P}}_{ij} = ({}_L\overline{p}_{ij}, {}_M\overline{p}_{ij}, {}_R\overline{p}_{ij})$ are triangular fuzzy numbers, and their points on the left, middle and right positions, ${}_L\overline{p}_{ij}$, ${}_M\overline{p}_{ij}$ and ${}_R\overline{p}_{ij}$, represent the overall average ratings of aspect *i,* criteria *j* over *m* evaluators, while both $\tilde{\overline{W}}_{ij}^h$ and $\tilde{\overline{P}}_{ij}^h$, $h = 1, 2, \cdots, m,$ are fuzzy numbers for each evaluator. Meanwhile, the fuzzy aggregation evaluation by each high tech firm yields is a fuzzy number. Therefore, these three fuzzy models are transformed into crisp numbers. For later calculating, it is necessary to transform these fuzzy numbers into crisp numbers. Chen and Klein's [15] defuzzying method is applied to complete it.

4. Fuzzy Schemes for Measuring Firm Synthetic Performance

Sugeno and Terano [16] incorporated the λ- additive axiom to simplify information accumulation. In the fuzzy measure space (X, β, g), let $\lambda \in (-1, \infty)$. If $A \in \beta$, $B \in \beta$ $A \cap B = \phi$, and

$$g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B) \quad (3)$$

hold, then the fuzzy measure *g* is λ- additive. Based on Eq. (3), the fuzzy measure $g(X) = g_\lambda(\{x_1, x_2, \cdots, x_n\})$ can be formulated as follows [13, 17].

$$g_\lambda(\{x_1, x_2, \cdots, x_n\}) = \sum_{i=1}^{n} g_i + \lambda \sum_{i_1=1}^{n-1} \sum_{i_2=i_1+1}^{n} g_{i_1} \cdot g_{i_2} + \cdots + \lambda^{n-1} g_1 \cdot g_2 \cdots g_n$$
$$= \frac{1}{\lambda} | \prod_{i=1}^{n} (1 + \lambda \cdot g_i) - 1 |, \text{ for } -1 \le \lambda < \infty . \quad (4)$$

Based on the boundary conditions in Eq. (4), $g_\lambda(\mathbf{X}) = 1$, λ can be uniquely determined via the following equation,

$$\lambda + 1 = \prod_{i=1}^{n} (1 + \lambda \cdot g_i) . \quad (5)$$

In the case of λ- fuzzy measure identification, fuzzy density g_i, $i = 1, 2, \cdots, k$ and parameter λ must be determined. Since λ- fuzzy measures values, and $A \in \beta(\mathbf{X})$ for a set $\mathbf{X} = \{x_1, x_2, ..., x_k\}$ are subjectively determined, it is difficult to obtain consistent measures values that satisfy fuzzy measurement properties from human experts. For simplicity, the fuzzy measure of the Choquet integral is applied, as follows.

$$(c)\int h dg = h(x_n) g(H_n) + [h(x_{n-1}) - h(x_n)]\ g(H_{n-1}) + \cdots + [h(x_1) - h(x_2)] g(H_1)$$
$$= h(x_n)[g(H_n) - g(H_{n-1})] + h(x_{n-1})[g(H_{n-1}) - g(H_{n-2})] + \cdots + h(x_n) g(H_1) \quad (6)$$

where $H_1 = \{x_1\}, H\{x_1, x_2\}, \cdots, H_n = \{x_1, x_2, \cdots, x_n\} = \mathbf{X}$. In the literature, the fuzzy integral defined by $(c)\int hdg$ is termed a non-additive fuzzy integral. The proposed model using the non-additive fuzzy integral does not require the assumption of the mutual independence of criteria.

5. Outcomes and Conclusions

According to the criteria/sub-criteria of the bottom level, the importance weight scores can be obtained in the case of the HBSC system. This is, from the bottom level, every item comprises an answer to a question and the associated importance weighting. Likewise, internal business processes perspectives (IB) have nine answered questions and the associated importance weight scores. The criteria importance scores are graded using the membership function of importance weight, which depends on the individual subjective perspectives, and professional knowledge background of every individual evaluator. Each evaluator obtains their λ-value using Eq. (5) with corresponding measure density, g_i (fuzzy measure density is apparent hat the degree of importance weight of each criterion). In this study, each evaluator determined the importance weighting of criteria using the triangular fuzzy number and aggregative fuzzy importance weight obtained in Eq. (1). The defuzzifying approach in Chen and Klein (1997) can obtain the crisp importance weight. Furthermore, substituting the crisp number of the importance weight into Eq. (5) can yield the fuzzy λ_i value. In Fig. 4, the aspects FP, CP, IB, and LG generate a λ_T value in level 2 for the evaluator using Eq. (5) based on $g_1, g_2, g_3,$ and g_4 . Moreover, level 2 contains λ_1, λ_2, λ_3, and λ_4 for the evaluator using Eq. (5) based on the importance weight of each criterion in level 3. Additionally, level 3 contains λ_1, λ_2, λ_{31}, λ_{32}, λ_{41}, λ_{42} and λ_{43} for the evaluator based on the importance weight of each criterion of level 4. Consequently, every evaluator possesses ten λ_i values that need to be determined. Moreover, the Choquet integral $(c)\int hdg$ in Eq. (6) is utilized to determine the aggregated value of each criterion based on the sub-criteria (see Fig. 4) and the aggregated value of each aspect based on the criteria (see Fig. 4).

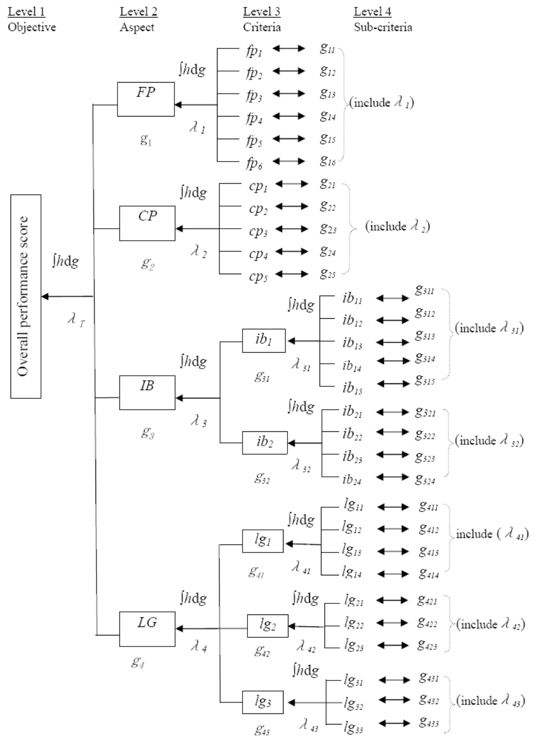

Fig 4. The process of evaluation final synthetic performance

Using Figure 4 and the bottom to top method based on the proposed approach it is possible to easily and efficiently obtain overall high tech firm performance in situations involving interaction among criteria.

Table 3 lists sub-criteria for the importance weight (fuzzy measure g_i) of firm B and aggregated values ($(c)\int h(x_i)dg_\lambda$) of internal business processes perspective (*IB*) based on the evaluation criteria for the HBSC system. Two evaluators exist for each high tech firm, with one being a senior manager and the other being a senior internal auditor. The evaluators were requested to complete a checklist using subjective judgments of the importance weighting of each sub-criterion. The subjective judgments of participants were integrated to employ the fuzzy importance weights the fuzzy measure density g_i is apparent for each criterion as in Eqn. (1) and then the nonfuzzy importance weights were obtained using Chen and Klein [15], as shown in Table 3. In Table 3, the λ-value was determined using Eq. (5) based on the g_i of each sub-criteria and the program was designed using Mathematical 5.0. Table 3 shows that there is a high degree of interactive mutual influence, namely $\lambda-$ values, with the *IB* exceeding -0.95. The $\lambda-$ values close to -1 demonstrated the existence of complete dependent and mutual influence relationships among sub-criteria, and demonstrated the importance of sub-criteria to the interactive effect among the other sub-criteria. Consequently, according to Eq. (6) the Choquet integral $(c)\int h(\bullet)dg_\lambda$ in Eq. (6) can determine the aggregated value of each criteria depending on criteria and the aggregate value of each aspect depending on criteria (see Table 4). Table 3 presents the crisp performance scores $h(\bullet)$ and the importance weighting of $g_i(\bullet)$, which was assessed by the senior manager and senior internal auditor, the λ value of $g_\lambda(\bullet)$, obtained by Eq. (5) and program was designed using Mathematical 5.0 and the aggregated values $(c)\int h(\bullet)dg_\lambda$ obtained by Eq. (6). In Table 3, the aggregated value $(c)\int h(\bullet)dg_\lambda$ represents the overall perceived performance of the evaluator perceptions of the five criteria (ib_1), (ib_2), (ig_1), (ib_2), and (ib_3)'.

Table 3 the fuzzy measure and aggregated values of IB and LG for the firm B

Crit.	Sub-crit.	$h(\bullet)$	$g_i(\bullet)$	$(c)\int h(\bullet)dg_\lambda$ (λ -value)	$g_\lambda(\bullet)$
ib	ib_{11}	0.682	0.591	0.765	$g_\lambda(ib_{11}) = 0.591$
1	ib_{12}	0.682	0.409	(-0.991)	$g_\lambda(ib_{11}, ib_{15}) = 0.838$
					$g_\lambda(ib_{11}, ib_{15}, ib_{12}) = 0.941$
	ib_{13}	0.728	0.695		$g_\lambda(ib_{11}, ib_{15}, ib_{12}, ib_{13}) = 0.991$
	ib_{14}	0.682	0.591		$g_\lambda(ib_{11}, ib_{15}, ib_{12}, ib_{13}, ib_{14}) = 1.0$
	ib_{15}	0.728	0.591		
ib	ib_{21}	0.728	0.591	0.762	$g_\lambda(ib_{24})$ =0.682
2	ib_{22}	0.728	0.591	(-0.974)	$g_\lambda(ib_{24}, ib_{21})$ =0.910,
					$g_\lambda(ib_{24}, ib_{21}, ib_{22})$ =0.977
	ib_{23}	0.728	0.682		$g_\lambda(ib_{24}, ib_{21}, ib_{22}, ib_{23})$ =1.0
	ib_{24}	0.773	0.682		

In Table 4, the λ -value equals -0.98 implying a high degree of interaction among various aspects of HBSC. Furthermore, accuracy information should be obtained during the performance measurement process to examine the overall perspective of particular firms. According to the above approach the operational process is repeated using a bottom-up approach until each type of evidence is obtained.

Table 4 Fuzzy measure and overall performance values for firm B

Firm	Asp.	$h(\bullet)$	$g_i(\bullet)$	$(c)\int h(\bullet)dg_\lambda$ (λ -value)	$g_\lambda(\bullet)$
B	*FP*	0.720	0.682	0.813	$g_\lambda(CP)$ =0.682
				(-0.980)	$g_\lambda(CP, LG)$ =0.877
	CP	0.824	0.682		$g_\lambda(CP, LG, IB)$ =0.960
	IB	0.752	0.591		$g_\lambda(CP, LG, IB, FP)$ =1.00
	LG	0.816	0.591		

To determine the overall performance result, the Choquet integral is utilized again to integrate FP, CP, IB, and LG (Fig. 4). This study constructed the HBSC system capable of providing a reference point and focus for the entire organization. Particularly, the balanced scorecard provides a set of evaluation indicators for monitoring and tracking back the factors that require improvement to ensure that managers and decision-makers remain “in control” and can respond quickly to items that require immediate attention. This study adopted a non-additive fuzzy set function and algorithm procedure to solve the balanced scorecard, difficult to quantify and cause-and-effect relationship among various perspectives. An important advantage of the non-additive measurement approach is that the interaction of the aspects and criteria can be clearly identified and expressed quantitatively. This identification enabled researchers and managers to understand the interaction of aspects will influence the performance evaluation results.

The main benefits of the hierarchical BSC performance evaluation system presented in this study can establish a communication system that bridges the gap between goals established by high-level managers and the employees whose performance is ultimately responsible for achieving organizational goals. Second, adopting the HBSC performance evaluation system with organizational operating enables controllers and managers to more easily establish comprehensive and effective integrating perspectives from different departments of organizations.

References

[1] Kaplan, R. S. and Norton, D. P. 1992. The balanced scorecard-measures that drive performance, Harvard Business Review 70, 71-79.

[2] Kaplan, R. S., and Norton, D. P. 1996. The balanced scorecard: translating strategy into action, Boston: Harvard Business School Press.

[3] Ecceles, R. G., 1991. The performance measurement manifesto, Harvard Business Review 69, 131-137.

[4] Amir, E., and Lev, B., 1996. Value-relevance of non financial information: the wireless communications industry. Journal of Accounting and Economics 22, 3-30.

[5] Ravi, V. Shankar, R. and Tiwari, M. K. 2005. Analyzing alternatives in reverse logistics for end-of-life computers: ANP and balanced scorecard approach, Computers & Industrial Engineering 48, 327-356.

[6] Chan, Y. C. L., 2006. An analytic hierarchy framework for evaluating balanced scorecards of healthcare organizations, Canadian Journal of Administrative Sciences 23, 85-104.

[7] Kaplan, R. S., and Norton, D. P. 2001a. The strategy focused organization how balanced scorecard companies thrive in the new business environment, Boston: Harvard Business School Press.

[8] Chen, M. J., 1996. The applications of fuzzy multiple attribute decision making in stock selection. Journal of Management Science 13, 227-248.

[9] Zirger, B. J., and Hartley, J. L. 1996. The effect of product acceleration techniques on product development time. IEEE Transactions on Engineering Management 43 (2), 143–152

[10] de Ron, Ad J., 1998. Sustainable production: the ultimate result of a continuous improvement. International Journal of Production Economics. 56/57, 99-110.

[11] Evans, J. R., 2004. An exploratory study of performance measurement systems and relationships with performance results. Journal of Operations Management 22, 219–232.

[12] Sattler, L. and Sohoni, V., 1999 Participative management: an empirical study of the semiconductor manufacturing Industry, IEEE Transactions on Engineering Management 46, 387-398.

[13] Keeney, R. L., and Raiffa, H., 1976. Decision with multiple objectives: preferences and value tradeoffs, New York: John Wiley and Sons.

[14] Dubois, D., and Prade, H., 1980. Fuzzy Sets and Systems: Theory and Applications, Academic, Press, New York.

[15] Chen, B. C., and Klein, C. M. 1997. An efficient approach to solving fuzzy MADM problems, Fuzzy Sets and Systems 88, 51–67.

[16] Sugeno, M. and Terano, T., 1977. A model of learning on fuzzy Information, Kybernetes 6, 157–166.

[17] Leszczyński, K. Penczek, P. Grochulski, and Sugeno, W., 1985. Fuzzy measure and fuzzy clustering, Fuzzy Sets and Systems15, 147–158.