Integrating hierarchical balanced scorecard with non-additive fuzzy integral for evaluating high technology firm performance

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\textbf{Abstract}

Efficient and accurate performance measurement systems serve as a useful tool enabling managers to control, monitor and improve high technology firm processes, productivity and performance. A model is developed for measuring the acceptable performance of high tech firms based on the interaction financial, customers, internal business process and learning and growth perspective. The HBSC structure 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. Sixteen samples from eight high tech firms are used throughout the study to explain how the execution of the model works. Utilizing the proposed model, the fuzzy assessment of the decision-maker and the interaction among various evaluation criteria can be a focus of the evaluation of the aggregation performance, thus ensuring more effective and accurate performance evaluation and decision-making. In the light of this empirical evidence, the results provide guidance to high tech firms performance measurement in both identification appropriate metrics and overcoming key implementation obstacles for improving firm-operating efficiency and hence assistance for future strategic adjustment.

\textbf{1. Introduction}

In the current extremely competitive global environment, high technology firms have been becoming increasingly reliant on core resources for maintaining long-term competitive advantage. 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 (TQM), and business process redesign (BPR) 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) (Kaplan and Norton, 1992, 1996) 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. Performance measurement is a multidimensional structure involving the various components which contribute differently to overall high technology firm performance. A systematic and efficient approach towards performance measurement is based on constructing a system model which in turn relies on corporate cross-function evaluation of performance. Evaluation methods thus must be applied together with numerous approaches to improve the accuracy of corporate performance measurement. However, performance measurement is difficult and complex and evaluators lack widely recognized performance measurement tools and well-defined criteria for making accurate measurements. Constructing and possessing available performance measurement tools not only increases evaluation efficiency but also saves costs. Traditional corporations generally use financial aspects to measure business performance, for example return on assets (ROA), return on investment (ROI), return on sales (ROS), etc. However, those traditional performance measurements suffer various limitations (Fisher, 1992; Eccles, 1991). The most significant limitation of traditional performance measurements is that they are based on financial perspectives, which emphasize the operational results, but not the internal process would result in ignoring forecasting function and which lacks a long-term orientation.

The financial aspect comprises only part of the firm performance measurement system. Particularly, the new operational
manufacturing environment, global competition, ease of imitation, and the information revolution represent the main reasons for firm managers not only needing to focus on financial performance but also changing their method of assessing overall performance, for example by using measurement of internal operational processes to monitor continuous quality promotion, processes improvement and innovation capabilities. In this environment firms must integrate information on financial and non-financial performance measurement systems to facilitate strategy implementation and further predict long-term performance. 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 (Kaplan and Norton, 1992). The BSC scheme integrates the interests of the key stakeholders, customers and employees on a scoreboard (Kaplan and Norton, 1996). The essence of BSC lies in seeking a balance between financial and non-financial measures.

Traditional financial indicators that use performance measures have been criticized as inadequate for the present rapidly changing business environment, especially when intangible assets rather than tangible assets are the main sources of competitive advantage for high technology firms. These intangible assets include customer satisfaction, process innovation capability, total cost reduction/control capability, etc. To overcome the limitations of financial-based measures, non-financial measures have been recommended owing to them being believed to be leading indicators of financial performance (Kaplan and Norton, 1992, 1996). Notably, practitioners and researchers have recommended increasing non-financial measures that reflect key value-creating activities, namely non-financial value drives (Kaplan and Norton, 1992, 1996; Eccles, 1991). Non-financial information is crucial in the high technology industry, including telecommunications, biotechnology and software development (Amir and Lev, 1996). 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. To overcome the limitations of traditional methods of measuring performance and solve problems involving difficult to quantify non-financial indicators lack sufficient information, and difficult to measure accurately. However, the previous literature seems to lack an objective definition and a consensus of the precise nature of performance measurement systems for high technology firms. 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. 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.

Kaplan and Norton (1996) further contended that in the BSC program a cause-and-effect relationship exists between the financial and non-financial perspectives. BSC combines important practices and concepts from various disciplines and theories into a single performance measurement system to improve financial performance. Essentially, non-financial perspectives are leading indicators, derived from establishing a causal link between improved performance in terms of non-financial and financial measures. Based on BSC, four different perspectives would be accurate the causal linkages between non-financial measures and financial measures, and focusing on improving leading indicator measures should improve the performance in terms of financial measures. Employing the HBSC method of measuring high technology firm performance should consider the interactive relationship between different perspectives. Thus, 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 proposed framework designed by incorporating the HBSC structure with non-addition fuzzy integral to provide an overview of high tech firm performance and prevent local optimization. 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, many researchers have been developed and modified fuzzy analytic hierarchical process (FAHP) and analytic network process (ANP) approach in order to apply in diverse domains. Lee et al. (2008) integrate the fuzzy AHP and BSC to evaluate performance of an information technology department in the manufacturing industry. Ravi et al. (2005) analyzed alternatives in reverse logistics for end-of-life computers by combining of BSC and ANP approaches. The ANP is used to structure the hierarchy and relative weightings of interdependent performance perspectives and indicators. Chan (2006) used the AHP and BSC in implementing healthcare organizations performance assessment. The AHP is applied to calculate the relative weights for each performance assess. However, those approaches still cannot reflect the degree of interaction among performance evaluative perspectives and indicators. Therefore, non-additive fuzzy integral method was designed to solve the degree of interaction between performance perspectives and their corresponding performance indicators within HBSC. The most important component of non-additive fuzzy integral is providing information integration capability within interdependency or interactive characteristics without loss information. The proposed non-additive fuzzy integral incorporate HBSC performance measurement system could specifically design to mathematically represent uncertainty and vagueness and provide formalized tools for dealing with the imprecision intrinsic performance criteria and the degree of interaction. Since fuzziness, vagueness and interaction are coexisting characteristics existing in reality decision-making processes. These coexisting characteristics made the particular way of decision-making approach, for example, non-additive fuzzy integral is need rather general approach apply in the circumstance. Banker et al. (2004) combined a data envelopment analysis (DEA) based method with BSC analysis to assess interrelationships and tradeoff exist among alternative performance dimensions in the US telecommunication. Four quantitative performance indicators are used to adapt the framework of four perspectives of BSC. However, in their studies do not consider qualitative indicators in the model. According to Youngblood and Collins (2003) argued that although the BSC provides valuable feedback on a variety of performance metrics, but those metrics did not consider the relative importance weigh and the issue of interaction and trade-offs between metrics. Unfortunately, those approaches might hold some drawback and pitfalls in the application. First of all, these technique did not consider how to resolve the interdependent existing the quantitative and qualitative indicators. Secondly, with an interactive BSC
framework, they could not determine simultaneously the degree of interaction between the various perspectives and indicators through strict and objective methodology. Thirdly, under the BSC framework, it did not provide performance values to their corresponding quantitative indicators, either for the individual perspectives or for their consolidations (Abran and Buglione, 2003). The BSC framework also does not provide the quantitative and qualitative indicators how much each perspective contributes, even on the relative importance weight for each perspective and its corresponding indicators. This study adopt non-additive fuzzy integral embedded in the HBSC framework that provides the elements need eliminate or decrease the weaknesses of the traditional approaches and further relax restrictions for monitoring the deployment of firm strategy. The remainder of this paper is organized as follows. Section 2 reviews the literature on BSC performance. Next, Section 3 outlines the HBSC structure with the fuzzy approach for measuring firm performance. Section 4 then describes the method and algorithm for evaluating high tech firm performance, after which the performance-grade and importance weighting for each criterion were determined. Subsequently, Section 5 utilizes the fuzzy measures and non-additive fuzzy integral to measure firm synthetic performance. Section 6 then assesses high tech firm performance via the proposed model. Finally, the model results and conclusions are discussed.

2. Balanced scorecard and performance measurement system

In early studies, the measurement of firm performance focuses only on organization financial performance. Watson (1975) proposed a threefold classification of performance measures, namely internal measures, interdependency measures and environmental measures. Similarly, Cameron and Whetten (1983) stated that organizational performance can be assessed in terms of process, response or impact. Moreover, Chakravarthy (1986) studied computer firm operations and found that financial performance measurement is an inadequate indicator of a broader construct. Chakravarthy argued that future-oriented indicators such as investment in R&D, product R&D, process R&D and product quality relative to competitors should also be incorporated into the performance measurement indicators. Moreover, Fisher (1992) studied several high-tech manufacturing plants and demonstrated the non-financial performance measure indicates an attempt to reassert the primacy of operations over financial measures. Fisher found that by using non-financial measures and control systems, managers attempt to track progress on the actionable steps that help firms succeed in the market. Similarly, Amir and Lev (1996) examined the value-relevance problem of technology-based industries, and pointed out that non-financial indicators such as growth ratio and market penetration a measure of operating performance significantly influence value. Amir and Lev also highlighted the complementarities between financial and non-financial data are highlighted. More recently numerous studies have adopted wide aspects for assessing overall firm performance. Atkinson et al. (1997) proposed that performance assessment should be considered by two different sources; internal and external, two different sources of information to assess organizational performance as stakeholders and classify them into two groups the environmental stakeholders (customers, owners and the community) and the process stakeholders (employees and suppliers). Similarly, Eccles (1991) posits high-tech manufacturer recently assumed direct responsibility for including customer satisfaction, quality, market share, information technology and human resources in their formal performance measurement system. However, a broader approach is necessary for measuring firm performance. For example, a broader conceptualization of firm performance measurement would emphasize indicators of operational performance that is, non-financial information as well as indicators of financial performance measures. The BSC measure framework fulfills this broader view.

Original balanced score was developed for performance measurement by Kaplan and Norton (1992), and employs performance metrics from financial, customer and internal business processes, and learning and growth perspectives; BSC provides a bridge linking the financial and non-financial perspectives into an integrated performance measurement system that aligns organization goals and other traditional functional areas with corporate strategy using both leading indicators (performance driver-oriented indicators) and lagging indicators (outcome-based measures indicators) to monitor strategy implementation. The original BSC is an integrated performance measurement framework that helps firms articulate, communicate and translate strategy into action. The BSC framework classifies performance measurement into four perspectives (Kaplan and Norton, 1992): financial, customers, internal business processes, learning and growth performance. The financial perspective involves the question, “To succeed financially, how we should appear to our shareholders?” The customer perspective concerns the question, “To achieve our vision, how should we appear to our customers?” The internal business processes perspective involves the question, “To satisfy our shareholders and customers, at what business processes must we excel?” Finally, the learning and growth perspective concerns the question, “To achieve our vision, how should we sustain our ability to change and improve?” BSC provides key performance measures that go beyond financial matters and consider customers, employees and internal operational processes. By simultaneously aggregating and coordinating information from several various perspectives, managers can acquire the data required to increase decision making efficiency and decision quality. Performance measurement thus is an interactive and continuous process.

Kaplan and Norton (1996) developed original BSC turned business strategies into measurable indicators. Kaplan and Norton argued that the BSC program involves a cause-and-effect relationship among the different measurement in the selected perspective, as illustrated in Fig. 1. Similarly, numerous different scholars have provided empirical evidence supporting the existence of a cause-and-effect relationship among BSC various perspectives (Olve et al., 1997; de Haas and Kleingeld, 1999; Nørreklit, 2003; Niven, 2002; Sandström and Toivanen, 2002; Quezad et al., 2009; Schmidtberger et al., 2009). The relationship reflects the interplay and interdependencies among financial and non-financial measures. While specific high tech firms employed the learning and growth perspective to develop new processes and technologies to reduce costs and increase efficiencies in the internal business processes perspective. Eventually, the result of utilizing the learning and growth perspective provides increased customer value and satisfies customer requirements, and finally significantly enhances financial perspective performance. Consequently, a well-constructed BSC method must consider the interactive relationship among various selected perspectives and their measurement criteria.

The hierarchical balanced scorecard is a tool for translating strategy into action through the performance measures that provides the point of reference and focus for a high tech firm form diagnosing a series of performance criteria to strategic implementation. In line with Niven (2002) argument that the balanced scorecard deploys the organizational strategy, breaking it down into its component parts through objectives, measures, targets and initiatives in each of the four balanced scorecard perspectives. The use of the indicators relates to the balanced scorecard approach, widely used in business strategy (Kaplan and Norton,
The balanced scorecard approach advocates the development of supplementary indicators to measure the performance of strategies, with non-financial and even intangible indicators. In this study, performance indicators were proposed that can help to assess the performance of the implemented strategy for high tech firms. Adopting the proposed hierarchical balanced scorecard as a performance measurement framework for translating the strategy into different set of activities, high tech firm not only diagnose performance and strategy direction but also serves to guide all employees' activities toward the achievement of the acceptable performance level and strategic implementation roadmap. Unfortunately, BSC lacks a method of effectively measuring those impacts. In the decision-making domain the non-additive fuzzy integral method is used to assess interaction between alternatives and their effects on objectives. Applying the non-additive fuzzy integral to the HBSC enables decision-makers to examine the comparison of performance measure with established evaluation standards and better determine the interaction between various performance measures perspectives and criteria. The process of selecting the criteria metrics and HBSC structure is further explained in Section 3.

3. HBSC with fuzzy approach for measuring firm performance

The balanced scorecard 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 (Kaplan and Norton, 2001). It is also a 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 from Kaplan and Norton (2001) in which dealt with indicators is the hierarchical balanced scorecard that is considered to be an appropriate tool for communicating bridge in a simple and parallel high tech firm strategy. The HBSC is explained as a series of measurements that give senior managers a comprehensive and strategic view of the organization including the effects of operational and performance measures rely on four perspectives. The HBSC turns actions related to strategies into tangible and intangible indicators. 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. Performance metrics are designed to conduct measurements throughout the four perspectives of BSC to determine whether the high tech firm requirements reach an acceptable performance level. The performance metrics used in this study reduce subjectivity in measuring the performance of high tech firms by providing a quantitative basis in a complex decision-making process in which the overall performance of the available high technology firms needs to be measured in terms of multiple selection criteria. Complex decision-making problems can divide objectives into hierarchical structures for further evaluation. Based on the four different perspectives of BSC presented by Kaplan and Norton (1996); this study has made significant modifications and extended traditional BSC into a HBSC structure to suit the performance evaluation of high tech firms as shown in Fig. 2. Furthermore, the primary benefit of HBSC lies in being able to provide a mechanism for managing performance measurement system design process complexity. The HBSC provides a framework which is generally used to the assess performance of high tech firms and to help firms turn business strategies into measurable indicators. 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 who are high-level managers with an average of over 7 years of experience in the high technology industry. 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). Four dimensions are used throughout this study. Each dimension consists of a set of performance indicators/criteria that quantitatively express the effectiveness or efficiency or both, of a part of or a whole process, or systems, against a given norm or target (Fortuin, 1988). Performance measurement thus involves measuring activities using a set of performance indicators/criteria where performance indicators/criteria are also known as performance metric. These selection dimensions and their performance criteria are discussed individually below.

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 (Chen, 1996). Six key financial measures were considered important indicators of performance measurement for high tech firms. This study used traditional finance performance indicators developed by Kaplan and Norton (1996).
Financial performance indicators used for these six measures (shown in Fig. 2) determine specific high tech firm financial performance. Senior managers and senior auditor managers assign various weights to the measures for each high tech firm. The performance of each high tech firm in terms of these six indicators of financial performance is combined into a composite financial measure to determine the overall financial performance level of high tech firms. 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. To determine the effectiveness of their efforts, firms must determine objectives for targeted customers that are linked to the overall strategy. Therefore, customer perspective measurements are lagging indicators that indicate to management how well customer objectives are being achieved. 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. By recognizing the performance measurement of internal business processes, firms can understand the effects of their driver indicators in fulfilling target customer objectives and ultimately firm financial objectives. Thus, firms must develop performance measures to track and monitor the pivotal internal process and activities for supporting and achieving customer and firm objectives. Numerous empirical studies have argued that internal activities influence firm performance, ranging from manufacturing processes (Bozarth, 1993; Zirger and Hartley, 1996; de Ron, 1998; Ward and Duray, 2000; Evans, 2004) to internal organization management activities (Zirger and Hartley, 1996; Sattler and Sohoni, 1999; Evans, 2004; Schmidberger et al., 2009). The above activities are involved on the part of firm performance measurement. Particularly, the high tech industries face a reduced product life cycle, and a dynamic and complex competitive environment resulting in high tech firms needing to continuously improve and monitor internal organization activities to achieve long-term survival and competitiveness. Furthermore, the evaluation of internal business processes depended not only on the internal organization processes but also on firm relative manufacturing process. Many processes cut across organization function, or divisions, and require collaboration between individuals in different department. For example, the product development processes needs require employees from R&D, manufacturing and marketing to collaborate to ensure the design, development and marketing of new products which can be manufactured cheaply and efficiently. 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.

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**Fig. 2.** Performance measurement system of HBSC.
contains several sub-criteria. Information system capability indicates information management capability, information acquisition capability, information maintenance capability and information technology (IT) infrastructure. If interdependencies are present within the same level of analysis in a dotted-line rectangle, looped arcs were used to represent such interdependencies (see Fig. 2). The HBSC exist the interactive effect (\(i\)-value) within the same level criteria in which cannot capture interdependencies through conventional fuzzy AHP method. Fig. 2 shows the various interdependencies among the same aspects, criteria and sub-criteria (by means of the arcs and arrows). Therefore, the aspects and criteria are subjective due to which a synthetic score through simple weight method such as fuzzy AHP is difficult to determine the interactive effect (\(i\)-value). These sub-criteria are presented in Fig. 2.

The role of performance measurement under the HBSC framework is to evaluate and monitor processes and outcomes of individual high tech firm. 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 addition, performance measurement has been recognized that can be used to influence behavior and decision-making, thus, affect the strategy (Neely et al., 1994; de Lima et al., 2009; Barclay and Osei-Bryson, 2010). Further, Kaplan and Norton (1996) proposed that strategy may be revised and adjusted accordingly before the next cycle of performance measurement take place, in a process of incremental strategy adjustment by through feedback loop mechanism within BSC. 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. More specifically, in this study we set out to explore the extent to which senior managers of high tech firm seek to influence the realization of their strategies through HBSC performance measurement system, since the performance measures are most important as the primary mechanism to control and adjust strategy implementation. According to expert consensus, previous studies, including Kaplan and Norton (1996), encouraged the inclusion of 4-7 measures in each evaluation category. Furthermore, owing to the limitations of human short-term memory, this study argues that there are no more than seven indicators of each aspect. Meanwhile, Keeney and Raiffa (1976) propose that five properties must be followed during criteria formulation, namely: completeness (the criteria must cover all important aspects of the decision-making problems), operational (the criteria must be meaningful for decision-making analysis), decomposable (the criteria can be decomposed from a higher to a lower hierarchy to simplify the evaluation), nonredundant (there must be no double counting of criteria) and minimum size (the number of criteria should be minimized). Based on these 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.

4. Method and algorithm for evaluating high tech firm performance

To apply the performance measurement system of HBSC to real high tech firms, it is necessary to further identify the measurement indicators used for performance grading and importance weighting. These high tech firms comprised a sample randomly selected from among the Taiwanese high-tech industry specifically from among those firms with one thousand or more regular employees. Individual high tech firms are taken here as the unit of analysis since a single firm can provide a set of performance measurement indicators developed using the checklist of performance measures based on the performance measurement system used by HBSC (see Fig. 2). Researchers distributed the performance measures checklist via e-mail to senior managers and senior auditors of eight high tech firms to measure their overall performance, since the BSC is mainly designed to provide senior managers with an overview for evaluating organizational performance (Ghalayini et al., 1997). Managers in charge of firm strategy have a good understanding of the internal/external operating environment of the business.

As previously mentioned, the entire high tech firm performance evacuation process is complex and imprecise, and relies on subjective evaluator judgments. Managers making a performance evaluation must consider various aspects and criteria, which may include interactive, interdependent, and nonnumerical values. The basic assumptions were significant different between fuzzy AHP and fuzzy measure. The fuzzy AHP methods are directly extension traditional Saaty AHP techniques with fuzzy numbers to the alternative selection and justification problem by using the concepts of fuzzy set theory and hierarchical structure analysis. The main objective of fuzzy AHP is used to accurately capture the importance weights of decision-maker judgment under vagueness and uncertainty of human cognitive processes (Ayag, 2005). A simple additive weighting method was addressed in fuzzy AHP method to aggregating fuzzy arithmetic (Ayag, 2005) and, further, in real MCDM that the criteria are not necessarily mutually independent when we employ the simple additive aggregate method (Chiou and Tzeng, 2002). More importantly, our proposed HBSC framework has an interaction effect among evaluation aspect and criteria based on the initial BSC assumptions introduced by Kaplan and Norton (1992). These assumptions should be carefully made so as to only obtain reliable data that directly affect the attributes of the hierarchical framework. In addition, the non-additive fuzzy integral assumes monotonicity and boundaries property are more general than the conventional additive measures. This is why we used \(i\)-fuzzy measure and the Choquet integral to replace the fuzzy AHP approach.

Traditionally, the probabilities need to assign certain probabilities value to the elements. Unfortunately, the probabilities method is severely limited as it cannot capture any inherent relation through expert’s knowledge and professional background in term of performance scores. This limitation can be overcome by using the fuzzy numbers and non-additive fuzzy integral with respect to a fuzzy measure to aggregate multiple information input without loss any useful information. In fact, there are yet few tools available for aggregation that is well rooted in the theory. The most common aggregation tool which is used today still the weighted arithmetic mean, with all its well-known drawbacks (Grabisch, 1996). However, the weighted and average methods are based on the assumption that the attributes involved are noninteractive and, hence, their weighted effects are viewed as additive (Wang et al., 1998). Wang et al. (1998) also further pointed out that the interactions among the attributes can be incorporated by expressing the importance of the various sets of attributes in terms of an appropriate non-additive measure. Therefore, the fuzzy numbers and probability measures are distinct aggregation tools and, thus, to handle the interactions among the criteria we employ the non-additive set functions as a tool instead of traditional weighted and average methods in the synthetic evaluation process. However, traditional decision making methods such as the multi-criteria decision making (MCDM), and the analytic hierarchy process (AHP) cannot adequately handle the ambiguity and multiplicity of criteria involved the
overall performance assessment. Rephrase Zadeh (1975) introduced the fuzzy set theory to enable uncertain and imprecise real world systems to be captured via linguistic variables. Fuzzy logic thus is a useful tool for dealing with decisions involving complex, ambiguous, and vague phenomena based on the meanings of the linguistic variables. Particularly, human decision making analysis involves obscure, uncertain and imprecise events and factors that have difficulty in assigning a crisp value to subjective judgments (Chen and Hwang, 1992). Linguistics expression provides a useful approach for interpreting the semantics of vague based on the subjective judgments of evaluators. High tech firm performance measurement and evaluation decisions are made mainly on the basis of the opinions of senior auditor managers/senior managers. Linguistic expression can handle ambiguities in assessing data and the vagueness of linguistic expression, in which evaluators can easily describe their measurement and subjective judgments using the evaluation criteria within the framework of fuzzy set theory.

However, the use of performance metrics does not avoid or eliminate the need for human judgment in performance measurement. Subjective evaluator judgments are frequently involved with regard to the importance weighting of criteria, resulting in fuzzy and imprecise data being used, and requiring the application of a fuzzy approach to effectively tackle such decision problems. Senior managers and senior auditor managers conduct subjective judgment and evaluate overall performance using HBSC (see Fig. 2), and the evaluators assess performance-grade and rate importance for each criterion and sub-criterion. These criteria variables of each aspect of performance evaluation, performance-grade and their importance rating can be assessed using fuzzy numbers, which can express linguistic variables. Restated, the triangular fuzzy numbers are used to express linguistic variables and appraise the performance-grade and importance rating of the evaluation criteria.

4.1. Determination of performance-grade

To determine the performance-grade of each criterion, this study invited three scholars and four experts from the high tech industry to assign their own performance-grades. The scholars came from the department of technology management of the university, and the high tech industry experts averaged over 7 years experience in the high tech industry. All participants received a set of performance measurement criteria based on the HBSC structure (see Fig. 2), and then described how the performance measure was calculated and how to divide into different performance-grades.

To objectively grade performance according to consensus among scholars and high tech industry experts and useful data provided by real cases for high tech firm performance measurement. 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 listed in Table 1. The definitions of the triangular fuzzy numbers of levels VP to VG are intrinsically similar to the intervals. For example, consider triangular fuzzy number \( \tilde{A}_k \), where \( k = VP,….VG \) for a particular criterion A. Let \( \tilde{A}_k = (a_k, b_k, c_k) \), \( k=VP, P, F, G \) where \( a_k \), \( b_k \), and \( c_k \) represent three points at the left, medium and right of a particular triangular fuzzy number and the corresponding interval is \([a_k, c_k]\). The most probably value \( b_k \) then can be obtained as \((a_k + c_k)/2\). Fig. 3 shows a membership function diagram for the performance-grade is exemplified. Consequently, the fuzzy numbers for all criteria can be defined and used to obtain the performance-grade of each evaluation criteria at the lowest level of the HBSC structure for measuring firm performance.

To achieve a consistent measurement of performance-grade, five performance-grades, VP to VG, are used to measure the criteria depending on the evaluation criteria of the HBSC structure. The performance-grade \( p \) can be estimated using the following rating (very poor (VP), poor (P), fair (F), food (G) and very good (VG)) and its associate membership function is illustrated in Fig. 3, and was used to measure the rating effect of the different evaluation criteria used to assess firm performance. For each high tech firm requesting that senior managers and senior auditors measure the performance achievement of each criterion using a triangular fuzzy number in the interval \([0, 100%]\) according to the performance-grade. The 0 represents the minimum and 100 denote the maximum performance achieved. Therefore, the evaluators used the linguistic variables to directly assess the impact of various criteria on the firm performance evaluation. On the other hand, the importance of each evaluation criterion should be determined based on the performance evaluation criteria of the HBSC performance measurement system.

4.2. Determining the degree of importance

Numerous techniques exist, including AHP, TOPSIS and SAW, which can be applied to obtain importance weights for various evaluation criteria. However, the use of these techniques for weighting performance has many drawbacks since these techniques do not express the uncertainty associated with presenting evaluator judgments in numerical form and evaluator subjective judgments and background knowledge significantly influence those methods. Restated, importance weights depend on evaluator subjective judgment and cognition. Thus, importance weights and the effect ratings of various criteria assigned by evaluators are

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Membership function</th>
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<tbody>
<tr>
<td>Very poor (VP)</td>
<td>(0.00, 0.30, 0.60)</td>
</tr>
<tr>
<td>Poor (P)</td>
<td>(0.50, 0.60, 0.70)</td>
</tr>
<tr>
<td>Fair (F)</td>
<td>(0.60, 0.70, 0.80)</td>
</tr>
<tr>
<td>Good (G)</td>
<td>(0.70, 0.80, 0.90)</td>
</tr>
<tr>
<td>Very good (VG)</td>
<td>(0.90, 1.00, 1.00)</td>
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</table>

![Fig. 3. Membership function for five performance-grades.](image-url)
expressed in linguistic variables. Linguistic variables are proposed as a means of helping evaluators improve their decisions; moreover, linguistic variables an efficient approach for handling evaluator subjective judgments and situational uncertainty. Additionally, appropriate fuzzy numbers provide an easy means of presenting linguistic variables (Petrovic and Petrovic, 1996; Karsak and Kuzgunkaya, 2002). That is the importance weightings of various criteria can be determined by direct assignment into a fuzzy number by evaluators.

The rating of importance \( \hat{w} \) 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. Figs. 4–6 were used to measure the importance of the various criteria. However, because of possible differences in experiences and knowledge background among evaluators, those evaluators provide the degree of various linguistic weightings for particular performance evaluation criterion. To clarify these differences, different types of linguistic models can exhibit evaluator inclinations regarding each performance evaluation.

The triangular membership functions are overlaps which represent the dependence of the different linguistic models on the evaluator being more professional than other evaluators. Three linguistic models, \( \text{LM}_{w1} \) to \( \text{LM}_{w3} \), represent the degree of importance for particular criteria metrics (see Figs. 4–6 and Table 2). For example, \( \text{LM}_{w3} \) for explaining the grade of importance criteria metrics are the fuzziest among \( \text{LM}_{w1} \) and \( \text{LM}_{w2} \) and are used by the evaluators. The usefulness of the varied linguistic models depends on the ability of the evaluator to clearly distinguish the differences of performance measurement criteria than other.

To determine the overall performance of 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.

### 4.3 Algorithm and procedures of hi-tech firms performance evaluation

During overall fuzzy evaluation, evaluator perceptions of criteria vary, and all have varying valuations of linguistic variables of importance weights. Given \( m \) evaluators for example, scholars and expert senior managers, the criteria importance weight, \( w_i, i = 1, 2, \ldots, m \), and the evaluated values (or ratings) of performance-grade metrics, \( \tilde{p}_{ij}, i = 1, 2, \ldots, m \), for a particular high tech firm, can be aggregated, based on the fuzzy arithmetic of Dubois and Prade (1980) to three vertices of triangular fuzzy number and calculated aggregation determined via \( m \) evaluators using

\[
\overline{W}_{ij} = \left( \tilde{L}_{ij}, \tilde{M}_{ij}, \tilde{H}_{ij} \right) = \left( \left( \sum_{\beta = 1}^{m} w_{\beta} \right) / m, \left( \sum_{\beta = 1}^{m} w_{\beta} \right) / m, \left( \sum_{\beta = 1}^{m} w_{\beta} \right) / m \right),
\]

\[
\overline{P}_{ij} = \left( \tilde{L}_{ij}, \tilde{M}_{ij}, \tilde{H}_{ij} \right) = \left( \left( \sum_{\beta = 1}^{m} p_{ij, \beta} \right) / m, \left( \sum_{\beta = 1}^{m} p_{ij, \beta} \right) / m, \left( \sum_{\beta = 1}^{m} p_{ij, \beta} \right) / m \right),
\]

where \( \overline{W}_{ij} = \left( \tilde{L}_{ij}, \tilde{M}_{ij}, \tilde{H}_{ij} \right) \) and \( \overline{P}_{ij} = \left( \tilde{L}_{ij}, \tilde{M}_{ij}, \tilde{H}_{ij} \right) \) are triangular fuzzy numbers, and their points on the left, middle and right positions, \( \tilde{L}_{ij}, \tilde{M}_{ij}, \text{and} \tilde{H}_{ij} \), represent the overall average ratings of aspect \( i \), criteria \( j \) over \( m \) evaluators, while both \( \overline{W}_{ij} \) and \( \overline{P}_{ij} \), \( h = 1,2, \ldots, m \) are fuzzy numbers for each evaluator.

### Table 2

Linguistic values of performance-grade and grade of importance.

<table>
<thead>
<tr>
<th>Grade of importance ( \text{LM}_{w1} )</th>
<th>Grade of importance ( \text{LM}_{w2} )</th>
<th>Grade of importance ( \text{LM}_{w3} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment</td>
<td>Membership function</td>
<td>Assessment</td>
</tr>
<tr>
<td>Very low (VL)</td>
<td>(0.00, 0.00, 0.25)</td>
<td>Very low (VL)</td>
</tr>
<tr>
<td>Low (L)</td>
<td>(0.20, 0.30, 0.40)</td>
<td>Low (L)</td>
</tr>
<tr>
<td>Medium (M)</td>
<td>(0.35, 0.50, 0.65)</td>
<td>Medium (M)</td>
</tr>
<tr>
<td>High (H)</td>
<td>(0.60, 0.70, 0.80)</td>
<td>High (H)</td>
</tr>
<tr>
<td>Very high (VH)</td>
<td>(0.50, 1.00, 1.00)</td>
<td>Very high (VH)</td>
</tr>
</tbody>
</table>
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. Many defuzzification methods have been developed, including center of sum, center of gravity, mean of maxima, and the z-cut method, for achieving this purpose. The defuzzifying method established by Chen and Klein (1997) is a highly sensitive and effective approach for discrimination during fuzzy ranking by performing many simulated experiments involving the application of various linear or nonlinear fuzzy numbers and various degrees of overlap of fuzzy numbers. Chen and Klein employed a method utilizing fuzzy subtraction of a referential rectangle, \( \bar{R} \) from a fuzzy number, \( \bar{X} \); the rectangle is derived by multiplying the height of the membership function of \( \bar{X} \) by the distance between the two crisp maximizing and minimizing barriers. Here, \( \bar{R} \) can be considered a fuzzy number. Fuzzy subtraction of the referential rectangle, \( \bar{R} \) from the fuzzy number, \( \bar{X} \) can be performed at level \( \xi \) as follows:

\[
\bar{X} _{\xi} = \begin{cases} \bar{R}, & \xi \geq \bar{R} \\ [l_i, r_i] - [c, d] = [l_i - d, r_i - c], & 0 \leq \xi < 1 \end{cases}
\]

(3)

where \( \leq \) and [ ] represent fuzzy subtraction and interval subtraction operators, respectively; \( l_i \) and \( r_i \) denote the left and right loci of \( \bar{R} \), and \( c \) and \( d \) are the left and right barriers, respectively. The defuzzification rating of the fuzzy number is then

\[
D(\bar{X}) = \sum_{\xi=1}^{n} \frac{\sum_{i=1}^{n} (r_i - c)}{\sum_{i=1}^{n} (l_i - d)} \text{ and } n \to \infty,
\]

(4)

where \( n \) denotes the number of \( x \)-cuts; as \( n \) approaches \( \infty \), the sum is the measured area.

In Eq. (4), \( \sum_{i=1}^{n} (r_i - c) \) is positive, \( \sum_{i=1}^{n} (l_i - d) \) is negative and \( 0 \leq D(\bar{X}) \leq 1 \), if \( 0 \leq \xi \leq 1 \). Chen and Klein (1997) demonstrated that their defuzzification method are more efficient and accurate than other methods such as weighted center, area center, total integral value, left and right assigned scores, Huang's ranking and Choobineh and Li's ranking methods. As shown in the experimental results on Chen and Klein (1997), their defuzzification method is a well-defined approach and here can be used to implement the defuzzification processes in this study.

5. Fuzzy measures and non-additive fuzzy integral for measuring firm synthetic performance

To solve the assumption of hierarchical BSC system that not all criteria are completely independent, this study employed fuzzy integrals that were monotonic and non-additive to determine the importance weights for performance evaluation criteria. The original fuzzy integrals were introduced by Sugeno (1974). This study also used ‘importance weight’ to model evaluator subjective judgments and their preference structure. Consequently, a fuzzy measure used in this study can be explained as the subjective importance of evaluator criterion during the evaluation process. Sugeno and Terano (1977) incorporated the \( \lambda \)-additive axiom to simplify information accumulation. In the fuzzy measure space \( (X, \beta, g) \), let \( \lambda \in (-1, \infty) \). If \( A \in \beta \), \( B \in \beta \) \( A \cap B = \phi \), and

\[
g_\lambda(A \cup B) = g_\lambda(A) + g_\lambda(B) + \lambda g_\lambda(A) g_\lambda(B)
\]

(5)

hold, then the fuzzy measure \( g \) is \( \lambda \)-additive. This particular fuzzy measure is termed \( \lambda \)-fuzzy measure because it must satisfy \( \lambda \)-additive, and is also known as the Sugeno measure (Sugeno, 1974). To differentiate this measure from other fuzzy measures, \( \lambda \)-fuzzy measure is denoted by \( g_\lambda \). When \( \lambda = 0 \), the measure is additive. To date, the \( \lambda \)-fuzzy measure has been widely used as a fuzzy measure. Additionally, the \( \lambda \)-fuzzy measure of the finite set can be derived from fuzzy densities, as indicated in the following equation. Based on Eq. (5), the fuzzy measure \( g(X) = g_\lambda(\{X_1, X_2, \ldots, X_n\}) \) can be formulated as follows (Keeney and Raiffa, 1976; Leszczynski et al., 1985):

\[
g_\lambda(\{X_1, X_2, \ldots, X_n\}) = \sum_{i=1}^{n} g_\lambda(1) + \lambda \sum_{i=1}^{n-1} \sum_{j=1}^{n} g_\lambda(1) g_\lambda(1) + \ldots + \lambda^{n-1} g_\lambda(1) g_\lambda(1) \ldots g_\lambda(1)
\]

\[
= \frac{1}{\lambda} \prod_{i=1}^{n} (1 + \lambda g_\lambda(1)) \text{ for } -1 \leq \lambda < \infty.
\]

(6)

Based on the boundary conditions in Eq. (6), \( g_\lambda(X) = 1 \), \( \lambda \) can be uniquely determined via the following equation:

\[
\lambda + 1 = \prod_{i=1}^{n} (1 + \lambda g_\lambda(1)).
\]

(7)

In the case of \( \lambda \)-fuzzy measure identification, fuzzy density \( g_\lambda \), \( i = 1, 2, \ldots, k \) and parameter \( \lambda \) must be determined. Since \( \lambda \)-fuzzy measures values, and \( A \in \beta(X) \) for a set \( X = \{x_1, x_2, \ldots, x_k\} \) are subjectively determined, it is difficult to obtain consistent measures values that satisfy fuzzy measurement properties from human experts.

In a fuzzy measure space \((X, \beta, g)\), let \( h \) denote a measurable function from \( X \) to \([0, 1]\). The fuzzy integral of \( h \) over \( A \) with respect to \( g \) is then defined as

\[
\int_A h(x) dg = \sup \{ \pi : \pi \leq A \cap F_x \},
\]

(8)

where \( F_x = \{x : h(x) \geq \pi \} \) (Wang et al., 1998) and \( A \) represents the domain of a fuzzy integral. When \( A = X \), the fuzzy integral can also be denoted as \( \int h \cdot dg \). For simplicity, consider a fuzzy measure \( g \) of \((X, P(X))\) where \( X \) is a finite set. Let \( h \cdot X \in [0, 1] \) and assume, without loss of generality, that the function \( h(x) \) is monotonically decreasing in \( i \), such that \( h(x_1) \geq h(x_2) \geq \cdots \geq h(x_n) \). Elements in \( X \) then can be renumbered to ensure that Eq. (9) has the following equilibrium:

\[
\int h(x) \cdot dg = \prod_{i=1}^{n} [h(x_i) \cdot g(H_i)],
\]

(9)

where \( H_i = \{x_1, x_2, \ldots, x_i\} \), \( i = 1, 2, \ldots, n \).

In this study, \( h(\cdot) \) can be considered as the performance of a particular criterion of a particular aspect and \( g(\cdot) \) represents the subjective importance weight of each criterion. The fuzzy integral of \( h(\cdot) \) with respect to \( g(\cdot) \) provide an overall assessment of the criterion. For simplicity, the same fuzzy measure of the Choquet integral, rather than the fuzzy integral in Eq. (9), is applied, as follows:

\[
(c) \int h \cdot dg = h(x_0) \cdot g(H_0) + h(x_{n-1}) \cdot g(H_{n-1}) \cdot h(x_{n-1}) \cdot g(H_{n-1}) + \cdots + h(x_0) \cdot g(H_1),
\]

(10)

where \( H_1 = \{x_1\} \), \( H_2 = \{x_1, x_2\} \), \( \ldots \), \( H_n = \{x_1, x_2, \ldots, x_n\} = X \). In the literature, the fuzzy integral defined by (c) \( \int h \cdot dg \) 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. The primary advantage of non-additive fuzzy numbers compared to other integration methods is that it is able to represent certain kind of interaction between criteria, ranging from redundancy (negative interaction) to synergy (positive interaction) (Grabisch, 1996). Based on the argument of Grabisch (1996), there is almost no well established method to deal with interacting criteria except non-additive fuzzy measure, and usually people tend to avoid the problem by constructing independent criteria. The non-additive fuzzy has also
the ability to represent the human preferences in a formal and systematic way (Grabisch, 1995; Marichal and Roubens, 2000). The model can thus be used in nonlinear situations. Even criteria that are objectively and mutually independent are not considered independent of subjective evaluators.

The role of Choquet integral in the area of synthetic evaluation and information fusion have been examined by Onisawa et al. (1986) and Tahani and Keller (1990). In addition, the Choquet integral was used as an important aggregation tool (Tahani and Keller, 1990; Grabisch, 1995, 1996) which is used for aggregating information from multiple information sources with respect to the fuzzy measure (Tahani and Keller, 1990). Information from multiple inputs or sources may agree or conflict with each other. Therefore, the task of information fusion is to search for a maximum degree of agreement between the conflicting supports of an object. In this study, the performance measurement system of HBSC exist inherent interactive among all of strategic aspects and multiple information sources, requiring appropriate tools to aggregate multiple information sources and to handle interactive relationship is needed. The Choquet integral has the ability to handle conflicts in evidence and to make aggregations in the multiple information sources without loss any information. This is why that the Choquet integral employed as our tool to integrate various information sources in this study.

6. Empirical analysis for Taiwan high tech firm performance evaluation

During recent decades, the high tech industry has played a central role in the economic development of Taiwan. The high tech industry has enjoyed average annual growth rate of 18.5% since 1991, and maintained 21.4% annual growth during 2004. In 1991, the contribution of the high tech industry to GDP stood at 11.76%, which increased to 14.07% by 2003 (MOEA, 2004). Restated, the contribution of high tech industry production to GDP has continuously increased and the high tech industry appears to be steadily growing. Moreover, the Taiwanese government also provides favorable conditions such as research subsidies, tax reductions and funding to promote high tech industry competitiveness. As a result, the Taiwanese high tech industry has been becoming increasingly competitive. However, many high tech firms still lack efficient and accurate evaluation methods for measuring their operation performance. To overcome this dilemma, this study designed a HBSC system and fuzzy measure based on non-additive fuzzy integral methods to measure high tech firm operating performance. These methods of fuzzy measurement and non-additive fuzzy integral appear more appropriate for measuring the dependent criteria in a fuzzy environment. Firms can use the proposed method for self-assessment or independent assessment by third parties to identify and audit problems in their practices. This study designed a performance measurement checklist using the hierarchical BSC system. The date acquired for this study was obtained by 16 participants and the performance checklist was sent to senior managers and internal auditors within eight high tech firms, all with more than 6 years of work experience and all specialists in high tech management. The high tech firms are located in the Hsinchu and Taichung science parks in Taiwan. Sixteen participants were asked to evaluate the importance weight and performance-grade of each evaluation criterion according to the practical operating situation of each firm. To increase validity of performance measurement, all high tech firms in our samples have checked whether utilized BSC framework as their performance measurement systems before performance evaluation work carry out. Evaluators were requested to evaluate the importance weighting of criteria depending on the HBSC system using the five fuzzy linguistic weighting variables. Fuzzy sets theory is especially appropriate for expressing subjectivity and objectively, qualitative and quantitative, and ambiguity and precision such as human experiences, overall judgment, human psychology or behavior and human feeling are easy to explain through fuzzy sets theory. Researchers are especially attracted to fuzzy sets theory because it allow researchers to capture domain knowledge quickly using that contain fuzzy domain terms without much restriction such as number of data (Terano et al., 1992). Unlike probability statistical theory, they argued that fuzzy sets theory can expresses the amount of ambiguity under the little data, the total number of the data has no meaning, and the occurrence of events is not clear. In this study, the fuzzy model was chose that widely used in real-case high tech firms performance measurement within BSC performance evaluation system.

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 (see Figs. 4–6) which depends on the individual subjective perspectives and professional knowledge background of every individual evaluator. Each evaluator obtains their $\lambda$-value using Eq. (7) with corresponding measure density, $g_i$ (fuzzy measure density is apparent that 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. (7). The defuzzifying approach in Eq. (6) can obtain the crisp importance weight. Furthermore, substituting the crisp number of the importance weight into Eq. (7) can yield the fuzzy $\hat{z}_i$ value. In Fig. 7, the aspects FP, CP, IB and LG generate a $\gamma$ value in level 2 for the evaluator using Eq. (7) based on $g_1$, $g_2$, $g_3$ and $g_4$. Moreover, level 2 contains $\hat{z}_{11}$, $\hat{z}_{12}$, $\hat{z}_{13}$ and $\hat{z}_{14}$ for the evaluator using Eq. (7) based on the importance weight of each criterion in level 3. Additionally, level 3 contains $\hat{z}_{11}$, $\hat{z}_{12}$, $\hat{z}_{13}$, $\hat{z}_{14}$, $\hat{z}_{15}$, $\hat{z}_{16}$ and $\hat{z}_{17}$ for the evaluator based on the importance weight of each criterion of level 4. Consequently, every evaluator possesses ten $\hat{z}_i$ values that need to be determined. Moreover, the Choquet integral $\Gamma$ of $g_i$ (see Fig. 7) is utilized to determine the aggregated value of each criterion based on the sub-criteria and the aggregated value of each aspect based on the criteria (see Fig. 7).

Using Fig. 7 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 presents sub-criteria for the importance weight (fuzzy measure $g_i$) of firm B and aggregated values $(\Gamma)$ of internal business processes perspective (IB) and learning and growth perspective (LG) 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 Eq. (1) and then the nonfuzzy importance weights were obtained using Eq. (4), as shown in Table 3. In Table 3, the $\lambda$-value was determined using Eq. (7) based on the $g_i$ of each sub-criteria and the program was designed using Mathematical 5.0.
shows that there is a high degree of interactive mutual influence, namely \( \lambda \)-values, with the IB and LG 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 the above approach, the operational process is repeated using a bottom-up approach until each type of evidence value \( h(\bullet) \) and the importance weighting of \( g(\bullet) \), obtained by Eq. (7) and program was designed using Mathematical 5.0 and the aggregated values \( c(\bullet)h(\bullet)dg_c \) obtained by Eq. (10). In Table 3, the aggregated value \( c(\bullet)h(\bullet)dg_c \) represents the overall perceived performance of the evaluator perceptions of the five criteria ‘manufacturing processes \((ib_1)\)', ‘internal organization processes \((ib_2)\)', ‘information system capability \((ig_1)\)', ‘employee capability \((ib_2)\)' and ‘motivation and empowerment alignment \((ib_3)\)’.

From Table 3, the Choquet integral values \( c(\bullet)h(\bullet)dg_c \) of each sub-criterion can further employed to determine the next evidence value \( h(\bullet) \) of each criterion (see Table 4). Table 4 also shows \( h(\bullet) \) and \( g(\bullet) \) as assessed by the senior manager and senior internal auditor, as well as the \( \lambda \)-value of \( g(\bullet) \) and \( c(\bullet)h(\bullet)dg_c \) for the four aspects, financial perspective, customer perspective, internal business processes perspective and learning and growth perspective based on the HBSC structure for the performance evaluation of firm B.

Similarly, from Table 4, the Choquet integral values \( c(\bullet)h(\bullet)dg_c \) can further obtain the overall performance value for firm B, which is shown in Table 5, where the overall performance for firm B is 0.813 (81.3%). In Table 5, the \( \lambda \)-value equals \(-0.98\) (which is extremely close to \(-1\) and indicated complete dependence) 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...
the high-tech firms by their

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

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Sub-criteria</th>
<th>$h(*)$</th>
<th>$g(*)$</th>
<th>$(c)/h(*)/dg, (\lambda$-value)</th>
<th>$g,(*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$ib_1$</td>
<td>$ib_{11}$</td>
<td>0.682</td>
<td>0.591</td>
<td>0.765 (−0.991)</td>
<td>$g,(ib_{11})=0.591$</td>
</tr>
<tr>
<td>$ib_{12}$</td>
<td>0.682</td>
<td>0.409</td>
<td></td>
<td></td>
<td>$g,(ib_{12})=0.838$</td>
</tr>
<tr>
<td>$ib_{13}$</td>
<td>0.728</td>
<td>0.695</td>
<td></td>
<td></td>
<td>$g,(ib_{13})=0.941$</td>
</tr>
<tr>
<td>$ib_{14}$</td>
<td>0.682</td>
<td>0.591</td>
<td></td>
<td></td>
<td>$g,(ib_{14})=0.991$</td>
</tr>
<tr>
<td>$ib_{15}$</td>
<td>0.728</td>
<td>0.591</td>
<td></td>
<td></td>
<td>$g,(ib_{15})=1.000$</td>
</tr>
<tr>
<td>$ib_2$</td>
<td>$ib_{21}$</td>
<td>0.728</td>
<td>0.591</td>
<td>0.762 (−0.974)</td>
<td>$g,(ib_{21})=0.682$</td>
</tr>
<tr>
<td>$ib_{22}$</td>
<td>0.728</td>
<td>0.591</td>
<td></td>
<td></td>
<td>$g,(ib_{22})=0.910$</td>
</tr>
<tr>
<td>$ib_{23}$</td>
<td>0.728</td>
<td>0.682</td>
<td></td>
<td></td>
<td>$g,(ib_{23})=0.977$</td>
</tr>
<tr>
<td>$ib_{24}$</td>
<td>0.773</td>
<td>0.682</td>
<td></td>
<td></td>
<td>$g,(ib_{24})=1.000$</td>
</tr>
<tr>
<td>$lg_1$</td>
<td>$lg_{11}$</td>
<td>0.773</td>
<td>0.591</td>
<td>0.818 (−0.980)</td>
<td>$g,(lg_{11})=0.682$</td>
</tr>
<tr>
<td>$lg_{12}$</td>
<td>0.773</td>
<td>0.682</td>
<td></td>
<td></td>
<td>$g,(lg_{12})=0.878$</td>
</tr>
<tr>
<td>$lg_{13}$</td>
<td>0.773</td>
<td>0.591</td>
<td></td>
<td></td>
<td>$g,(lg_{13})=0.973$</td>
</tr>
<tr>
<td>$lg_{14}$</td>
<td>0.839</td>
<td>0.682</td>
<td></td>
<td></td>
<td>$g,(lg_{14})=1.000$</td>
</tr>
<tr>
<td>$lg_2$</td>
<td>$lg_{21}$</td>
<td>0.773</td>
<td>0.591</td>
<td>0.805 (−0.924)</td>
<td>$g,(lg_{21})=0.591$</td>
</tr>
<tr>
<td>$lg_{22}$</td>
<td>0.728</td>
<td>0.682</td>
<td></td>
<td></td>
<td>$g,(lg_{22})=0.859$</td>
</tr>
<tr>
<td>$lg_{23}$</td>
<td>0.839</td>
<td>0.591</td>
<td></td>
<td></td>
<td>$g,(lg_{23})=1.000$</td>
</tr>
<tr>
<td>$lg_3$</td>
<td>$lg_{31}$</td>
<td>0.728</td>
<td>0.591</td>
<td>0.818 (−0.976)</td>
<td>$g,(lg_{31})=0.591$</td>
</tr>
<tr>
<td>$lg_{32}$</td>
<td>0.794</td>
<td>0.889</td>
<td></td>
<td></td>
<td>$g,(lg_{32})=0.967$</td>
</tr>
<tr>
<td>$lg_{33}$</td>
<td>0.839</td>
<td>0.591</td>
<td></td>
<td></td>
<td>$g,(lg_{33})=1.000$</td>
</tr>
</tbody>
</table>

Table 4
Fuzzy measure and aggregated values of IB and LG for the firm B.

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Criteria</th>
<th>$h(*)$</th>
<th>$g(*)$</th>
<th>$(c)/h(*)/dg, (\lambda$-value)</th>
<th>$g,(*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$FP$</td>
<td>$fp_1$</td>
<td>0.728</td>
<td>0.591</td>
<td>0.720 (−0.981)</td>
<td>$g,(fp_{1})=0.409$</td>
</tr>
<tr>
<td></td>
<td>$fp_{2}$</td>
<td>0.728</td>
<td>0.409</td>
<td></td>
<td>$g,(fp_{2})=0.839$</td>
</tr>
<tr>
<td></td>
<td>$fp_{3}$</td>
<td>0.728</td>
<td>0.591</td>
<td></td>
<td>$g,(fp_{3})=0.906$</td>
</tr>
<tr>
<td></td>
<td>$fp_{4}$</td>
<td>0.682</td>
<td>0.409</td>
<td></td>
<td>$g,(fp_{4})=0.966$</td>
</tr>
<tr>
<td></td>
<td>$fp_{5}$</td>
<td>0.682</td>
<td>0.318</td>
<td></td>
<td>$g,(fp_{5})=0.980$</td>
</tr>
<tr>
<td></td>
<td>$fp_{6}$</td>
<td>0.728</td>
<td>0.591</td>
<td></td>
<td>$g,(fp_{6})=1.000$</td>
</tr>
<tr>
<td>$CP$</td>
<td>$cp_1$</td>
<td>0.682</td>
<td>0.409</td>
<td>0.824 (−0.969)</td>
<td>$g,(cp_{1})=0.786$</td>
</tr>
<tr>
<td></td>
<td>$cp_{2}$</td>
<td>0.839</td>
<td>0.500</td>
<td></td>
<td>$g,(cp_{2})=0.905$</td>
</tr>
<tr>
<td></td>
<td>$cp_{3}$</td>
<td>0.839</td>
<td>0.786</td>
<td></td>
<td>$g,(cp_{3})=0.955$</td>
</tr>
<tr>
<td></td>
<td>$cp_{4}$</td>
<td>0.682</td>
<td>0.318</td>
<td></td>
<td>$g,(cp_{4})=0.979$</td>
</tr>
<tr>
<td></td>
<td>$cp_{5}$</td>
<td>0.682</td>
<td>0.409</td>
<td></td>
<td>$g,(cp_{5})=1.000$</td>
</tr>
<tr>
<td>$IB$</td>
<td>$ib_1$</td>
<td>0.765</td>
<td>0.591</td>
<td>0.752 (−0.811)</td>
<td>$g,(ib_{1})=0.786$</td>
</tr>
<tr>
<td></td>
<td>$ib_{2}$</td>
<td>0.765</td>
<td>0.786</td>
<td></td>
<td>$g,(ib_{2})=1.000$</td>
</tr>
<tr>
<td>$LG$</td>
<td>$lg_1$</td>
<td>0.818</td>
<td>0.682</td>
<td>0.816 (−0.944)</td>
<td>$g,(lg_{1})=0.682$</td>
</tr>
<tr>
<td></td>
<td>$lg_{2}$</td>
<td>0.805</td>
<td>0.591</td>
<td></td>
<td>$g,(lg_{2})=0.925$</td>
</tr>
<tr>
<td></td>
<td>$lg_{3}$</td>
<td>0.818</td>
<td>0.682</td>
<td></td>
<td>$g,(lg_{3})=1.000$</td>
</tr>
</tbody>
</table>

Table 5
Fuzzy measure and overall performance values for the firm B.

<table>
<thead>
<tr>
<th>Firm</th>
<th>Aspect</th>
<th>$h(*)$</th>
<th>$g(*)$</th>
<th>$(c)/h(*)/dg, (\lambda$-value)</th>
<th>$g,(*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>B</td>
<td>FP</td>
<td>0.720</td>
<td>0.682</td>
<td>0.813 (−0.980)</td>
<td>$g,(FP)=0.682$</td>
</tr>
<tr>
<td></td>
<td>CP</td>
<td>0.824</td>
<td>0.682</td>
<td></td>
<td>$g,(CP)=0.877$</td>
</tr>
<tr>
<td></td>
<td>IB</td>
<td>0.752</td>
<td>0.591</td>
<td></td>
<td>$g,(IB)=0.960$</td>
</tr>
<tr>
<td></td>
<td>LG</td>
<td>0.816</td>
<td>0.591</td>
<td></td>
<td>$g,(LG)=1.000$</td>
</tr>
</tbody>
</table>

is obtained. To determine the overall performance result, the
Choquet integral is utilized again to integrate FP, CP, IB and LG
(see Fig. 6).

The different aspect performance values and overall performance
scores are determined by analyzing all sets of performance
evaluation criteria (see Fig. 7) for various high tech firms by their
senior managers and senior internal auditors depending on the HBSC
system and proposed evaluation method. Therefore, adopting the
similar evaluation procedure and proposed approach can obtain
overall performance scores for selecting hi-tech firms. The individual
aspect scores and global performance evaluation scores of each high
tech firm are provided in Table 6. To clearly understand the
performance scores for the different firms under the HBSC four
different aspects, the performance scores for each of eight cases are
also listed in Table 6.

From Table 6, for the global perceived performance score
(or the value of $(c)/h(*)/dg,\lambda$) of eight hi-tech firms only one firm
scored over 90%. Through analyzing and evaluating all sets of
performance criteria evaluated by senior manager and senior
auditor based on the HBSC performance measurement system
(see Fig. 1) each firm can determine the performance-grade from
various perspective. The evaluation results can provide decision-
makers with a deep understanding of organizational advantages
and disadvantages during strategy development. Although firm D
achieved the highest global performance score, its score was not
highest in all aspects. Table 6 shows the performance values for
each aspect and the corresponding priority of alternatives. Clearly,
firms D has the best performance score for the four aspects respectively, based on the HBSC performance measurement system. However, the perceived performance score of the internal business processes perspective for firm D only reaches 0.792, meaning the performance may falls short of requirements. This result indicates that managers must track back the manufacturing processes and relevant departments to examine areas such as continuous process improvement capability, conforming rate, total cost reduction/control capability, etc., to improve IB perspective performance.

7. Conclusions

Balanced scorecard is a tool for translating strategy into action via various sets of performance measurement indicators. Numerous studies and publications have designed procedures for evaluating performance measurements/indicators. However, few such studies use standard-settings of measures in performance-grade in which is still problematic for high tech firms. Thus, this study identifies the performance-grade setting depending on expert consensus opinions from experts working in high tech industry. Furthermore, this study also 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 application of the non-additive measurement model to evaluate the performance of various high tech firms demonstrates that the effects of multi aspects on performance can be aggregated into a global perceived performance score. Moreover, the proposed performance measurement methods can provide firm self-auditing and third-party expert evaluations based on HBSC. In this study, the performance measurement is only tend to the inside perspective such as senior managers within an organization but may ignore outside aspects. Nevertheless, the pitfalls of this philosophy can improve accordingly to propose HBSC framework. Through this framework, the outside experts such as scholars or third parties can measure the high tech firms’ operational performance to reduce the gaps and cognition between inside and outside performance measurement perspectives. In subsequent research, there is a need to focus on the outside information source within which the organization is set, rather than just being concerned with internal performance measurement. Decision-makers look increasingly outside information to improve performance measurement accurately and then plan to move the firm’s strategic adjustment accordingly. 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. By gathering and processing information from existing organizations it is possible to understand the manner in which these organizations operate based on the HBSC performance evaluation system; HBSC determines whether the organization is achieving its goals and assigns a grade together with a quantitative assessment that manager and employees can use to assess whether the organization is making progress. 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. Consequently, successful organization performance measurement systems can effectively integrate the information flow within various organization functions and between business processes, and then can cooperate and manage enterprise operation practices, including R&D, finances, manufacturing, marketing, service and human resource management. Complete performance measurement systems are implemented to identify and validate existing organization performance evaluations and help an organization to further increase its competitive advantage.

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References


