A MULTIDIMENSIONAL MEASUREMENT SYSTEM WITH BALANCED SCORECARD

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ABSTRACT

This paper aims at proposing a multidimensional measurement system with balanced scorecard (BSC), in which Fuzzy Structural Modeling is applied to build up structural models of perspectives by multi-evaluators, and a multiattribute decision making based on Choquet integral for weighting and integrating the evaluation values of perspectives. Furthermore, we introduce fuzzy inference mechanism to obtain the integrated value through inferring individual linkages among the outcome measures and drivers. From doing this, the system provides evaluators with a mechanism to incorporate subjective understanding or insight to evaluation process, and the evaluation can be conducted under consideration of decision-makers' differences on values, beliefs, attitudes, and understandings for the given problem set logically and analytically. In order to show how the system works and inspect its effectiveness, an example is illustrated.

KEYWORDS

Balanced scorecard, Fuzzy inference mechanism, Multiattribute decision making, Multidimensional measurement system

INTRODUCTION

In today's competitive business environment characterized by globalization, short product life cycles, open systems architecture and diversity of customers' preferences, a lot of managerial innovations have been deployed such as just-in-time inventory management; total quality management; six sigma quality; supply chain integration; customer-supplier partnerships; business process reengineering; and many more. Since the complexity and pace of change in business increased, we have owned a common recognition of keeping eyes on our customers to find what we should do not only for today, more important, for the future.

Usually, the ability of an organization to execute its strategy is directly proportional to its ability to understand and communicate the strategy. Balanced scorecard (BSC) is one of the most successful tools to articulate, implement, and manage strategy, which was first articulated in 1992 as a comprehensive framework [11] for translating a company's strategy objectives into a coherent set of performance measures to help leaders define and rapidly implement strategy. As a methodology, BSC [12] [13] [14] [15] was proposed to complement financial analysis with analysis of other domains such as customer, internal process, and learning and growth to examine performance using non-financial data such as customer satisfaction and retention; production and innovation; as well as employee satisfaction and retention and information system performance and so on. Nowadays, it has gained global acceptance and been already adopted as a strategic management system [13] in organizations. There are many successful stories [20] [23] known from practical areas such as business, hospital, and autonomy in many countries.

Generally, building a balanced scorecard involves the processes below [14]: (a) recognizing organization architecture; (b) defining strategy objectives; and (c) selecting measures, and (d) building implementation plan. We call (b) and (c) BSC design process, also see it as a core decision-making process during the whole building process, because in the design process, strategy and vision are understood, articulated, and translated into a set of financial and non-financial measures under cause-and-effect relationship. Clearly, how to reflect the decision-makers (executives/managers/staffs)' subjective understanding or insight rationally for the given problem, and how to evaluate the relations among the measures (outcome measures/drivers) effectively and efficiently should be essential and indispensable subject, but they are often ignored somewhat for balancing the complexity and apperception, in other words, people in practice often keep away from evaluation of intangible substance such as human insight, beliefs, or understandings.

In order to cope with the problem with respect to human behavior such as human judgment, insight and intuition, several methodologies have been studied in game theoretic, social psychological and political science frameworks [19]. For instance, such the multivariable analysis of statistical methodology as principal components analysis and cluster analysis and so on are exploited to solve considerable practical problems in several areas [25]. And also some qualitative techniques such as Brainstorming [9], NGT (Nominal Group Techniques) [5] [6], Delphi method [18], LENS (Leadership Effectiveness and New Strategy) [3] have been employed for creating an alternative space from which meaningful and distinct alternatives are likely to be identified.

Of the methodologies used in arranging system elements in a hierarchy, ISM (Interpretive Structural Modeling) [26], DEMATEL (Decision Making Trial & Evaluation Laboratory) [7] and FSM (Fuzzy Structural Modeling) [1][24] are popular ones. The major advantage of those methodologies is intuitive appeal of the graphical picture to decision makers. ISM, DEMATEL and FSM are based on graph theory to portray system hierarchy with contextual relations among elements such as "purpose and means", "cause and effect". The relations among system elements modeled by ISM through a pairwise comparison, are intuitively and empirically given with binary relation {0 or 1} to indicate whether or not the element is relative to the other under an assumption that the relations are transitive, that is, if A is relative to B and B relative to C, then A is relative to C, which assumes transitivity inference works in usual while human beings make decision. On the other hand, FSM uses binary fuzzy relation given within the closed interval of [0, 1] to represent the subordination relations among the elements [17], and relaxes the transitivity constraint in contrast to ISM. Different from ISM and FSM, DEMATEL structures system elements by ranking the degree to give effect and the degree to get effect between them, which is predefined given on "cause and effect" relations with four grade values in order to incline strong relations to evaluate. Although DEMATEL does not assume that the relations own transitivity property, the decision makers are strongly required having high quality of knowledge background, so-called expert of the area, for achieving the effectiveness of weighting.

In this paper, we aim to propose a multidimensional measurement system with BSC for solving the evaluation subject described above. In the proposed system, we apply FSM to obtain structural models of perspectives from multi-evaluators. For evaluating and integrating the scores of BSC, a multiattribute decision making method based on Choquet integral [8][21] is proposed for weighting and integrating the evaluation values of perspective structural models. Moreover, in order to derive the evaluation value logically and analytically, we introduce fuzzy inference mechanism to obtain the integrated value through inferring individual linkages between the outcome measures and drivers. From doing this, the evaluation can be conducted under consideration of decision-makers' differences on values, beliefs, attitudes, and understandings for the given problem set. In consequence, the system we propose provides evaluators with a mechanism to incorporate subjective understanding or insight to evaluation process, and also offers a flexible support such changes with environment or organizational structure. For showing how the system works and inspect its effectiveness, an example is illustrated.

THE METHODS

BSC also is a decision-making approach to performance measurement from multiple perspectives: financial, customer, internal process and learning/growth. In order to balance the traditional financial performance measurement system, the measures on the BSC involve several groups of performance measures: short-term and long-term, internal and external, and current and future. To translate vision and strategy, objectives and targets are set and the measures and initiatives are designed and assigned by teamwork such as interview, workshop and meeting. Figure 1 shows the typical processes of building BSC [13], where the processes dotted by line are called the design process in this paper.

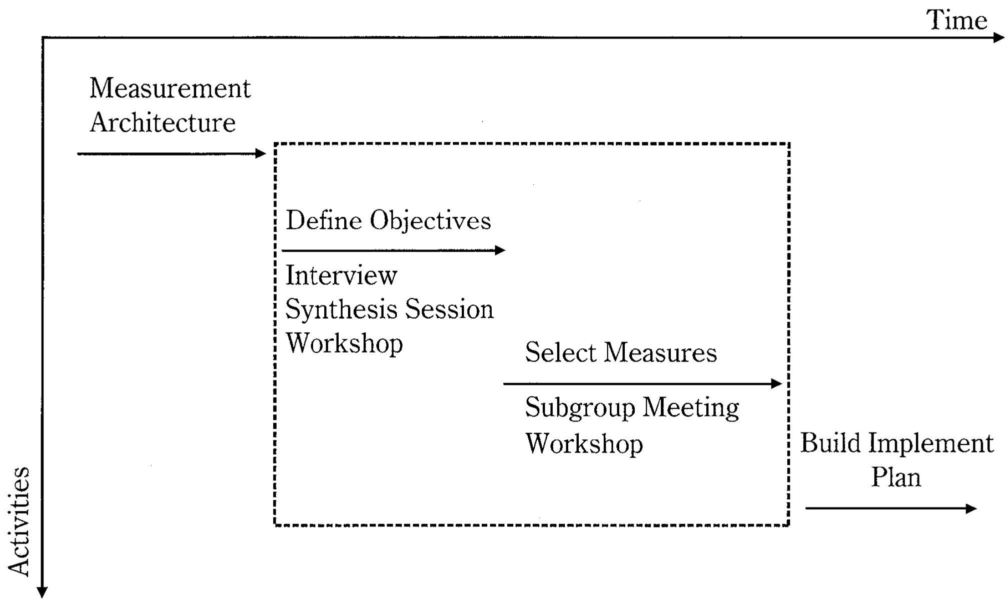

Figure 1 The typical processes of building BSC

Herein, in order to present the methods we propose in the latter section, we give an example of scorecard of customer, and learning and growth perspectives (see figure 2). On the scorecard, the relations between measures and drivers are assumed as cause-and-effect, or called means-and-propose relationship arrowed from driver measure to outcome measure. As shown in figure 2, the outcome measures are sub-divided into driver measures. For instance, since claim response time and on-time delivery are critical to satisfy customers, the scorecard says that the decreasing of on-time delivery rate and claim response time bring customer satisfaction in customer perspective. Also, it says that if employee quit rate is high and rate of sufficiency on employee requirement is low, then employee are not satisfied from the standpoint of organizational learning. Meanwhile, clearly the scorecard can be seen as a set of cause-and-effect relations, which also can be interpreted as a set of if-then rules. Here, how to evaluate each relation among measures and drivers to obtain an integrated evaluation value (score) should be considered.

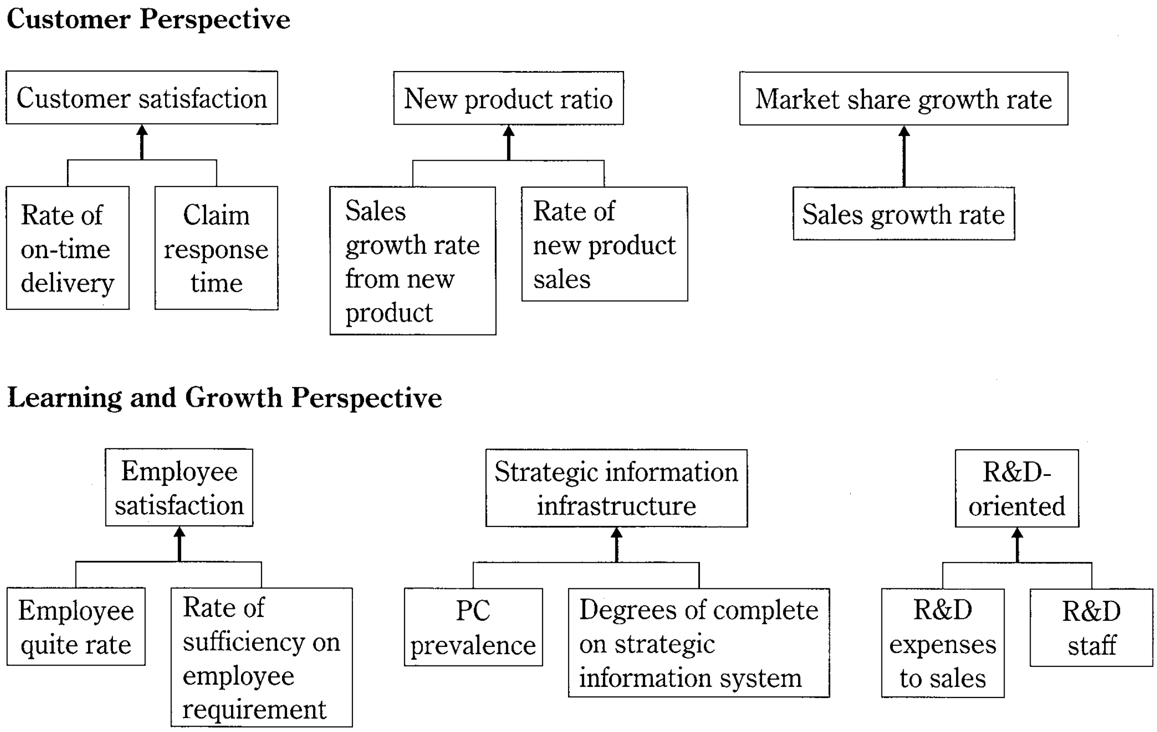

Figure 2 An example of a scorecard from customer and learning/growth perspective

Fuzzy inference mechanism

Fuzzy inference [16] [17] [22] is the process of formulating the mapping from a given input to an output using fuzzy logic. Then the mapping provides a basis for which decisions can be made, or patterns discerned. Here, fuzzy inference is prepared as a vehicle to evaluate the perspective models which are structured by applying FSM. In this paper, fuzzy inference focuses on how to reflect the evaluators' understanding or know-how on the integrating process under the consideration of the changes of social and business environment, which is the characteristic of the proposed system mentioned in the section above. Therefore, although the evaluators have no theoretical understanding on the overall BSC methodology, they are able to conduct the measurement performance through applying the system proposed in this paper. Generally, fuzzy inference rules are expressed as follows:
Assume a collection of n fuzzy rules of the form

$$IF\ x\ is\ A_i\ and\ y\ is\ B_i\ THEN\ z\ is\ C_i \tag{1}$$

Denote (1) symbolically by A_i and $B_i \rightarrow C_i$, where A_i, B_i and C_i, ($i=1, \cdots, n$), are fuzzy sets [2] [24] in the universes U, V, W respectively. That is, if a proposition " X is A and Y is B" is given, then the value of C inferred from the complete collection of the n rules is equivalent to the aggregated value derived from the individual rules, that is,

$$
\begin{array}{l}
IF\ x\ is\ A_1\ and\ y\ is\ B_1\ THEN\ z\ is\ C_1\ else \\
\quad ......\ IF\ x\ is\ A_i\ and\ y\ is\ B_i\ THEN\ z\ is\ C_i\ else \\
\qquad ......\ IF\ x\ is\ A_n\ and\ y\ is\ B_n\ THEN\ z\ is\ C_n\ else \\
\qquad\qquad x\ is\ A'\ and\ y\ is\ B' \\
\qquad\qquad z\ is\ C'
\end{array}
\tag{2}
$$

where 'else' is recognized as 'or ($\cup$)' on the basis of Mamdani's notation. Then we express (2) by the following equation.

$$
\begin{aligned}
C' &= (A' \cap B')\ o\ [(A_1 \cap B_1 \to C_1) \cup \cdots \cup (A_n \cap B_n \to C_n)] \\
&= [(A' \cap B')\ o\ (A_1 \cap B_1 \to C_1) \cup \cdots \cup (A' \cap B')\ o\ (A_n \cap B_n \to C_n)] \\
&= C_1' \cup \cdots \cup C_n'
\end{aligned}
\tag{3}
$$

where 'o' is the max-min composition. Now let $\mu_{A_i}(u)$, $\mu_{A'}(u)$, $\mu_{B_i}(v)$, $\mu_{B'}(v)$, $\mu_{C_i}(w)$, and $\mu_{C'}(w)$, $(i=1, 2, \cdots, n)$ are membership function of A_i, A', B_i, B', C_i, and C', $(i=1, 2, \cdots, n)$, respectively.

Here, (3) is expressed as follows:

$$
\begin{aligned}
\mu_{C_i'}(w) &= \mu_{(A' \cap B')\ o\ (A_n \cap B_n \to C_n)}(w) \\
&= max\{\mu_{(A' \cap B')}(u, v) \wedge \mu_{A_i \cap B_i \to C_i}(u, v, w)\} \\
&= max\{\mu_{A'}(u) \wedge \mu_{A_i}(u)\} \wedge max\{\mu_{B'}(v) \wedge \mu_{B_i}(v)\} \wedge \mu_{C_i}(w)
\end{aligned}
\tag{4}
$$

and $\mu_{C'}(w)$ is also rewritten according to $C' = C_{1'} \cup C_{2'} \cup \cdots \cup C_{n'}$ as follows:

$$
\mu_{C'}(w) = \mu_{C_1'}(w) \vee \mu_{C_2'}(w) \vee \cdots \vee \mu_{C_n'}(w)
\tag{5}
$$

In this paper, each relation in BSC is given by a membership function which indicates the degree of cause-and-effect. The integrated evaluation value can be determined by aggregating the outputs of inference of the individual relation (see (4), (5)). Therefore, no matter whether the evaluators have the whole knowledge background of performance measurement, they are able to measure the performance according to the following procedure.

The procedure

Step 1 Identify the structural model which represents cause-and-effect relations among measures for the perspective.

Step 2 Formulate the membership functions for each relation in the structural model built up in step 1.

Step 3 Create inference rules on basis of evaluators' experience and/or knowledge for the perspective.

Step 4 Carry out the inference based on the membership function and the inference rules created in step 2 and 3.

The procedure described above is carried out for each perspective of BSC to obtain the evaluation value of the perspective. Furthermore, according to the inference mechanism, the total evaluation value can be computed by integrating each value of perspective.

Multiattribute decision making based on Chquet integral

We describe a method to integrate evaluation values from the four perspectives based on Choquet integral for the multiattribute decision making (MADM) [8][21].

Now let D_i, $(i = 1, 2, ..., n)$, c_j, $(j = 1, 2, ..., m)$, w_{ij}, $(i = 1, 2, ..., n; j = 1, 2, ..., m)$ and u_{ij}, $(i = 1, 2, ..., n; j = 1, 2, ..., m)$, and u_{ij}, $(j = 1, 2, ..., m)$, be decision makers, perspectives, weighting factors, and evaluation values respectively. And let u_{ij}, $(i = 1, 2, ..., n; j = 1, 2, ..., m)$ be the evaluation value determined by D_i for c_j. Fuzzy Choquet integral is expressed by

$$(c)\int \mu_{ij}^{k} \cdot w_{ij} \tag{6}$$

where $(c)\int$ denotes a symbol of fuzzy Choquet integral. Then the algorithm of Choquet integral is described as follows:

Algorithm

Step 1 Sort u_{ij}, $(j = 1, 2, ..., m)$ in descending order.
Step 2 Sort w_{ij}, $(j = 1, 2, ..., m)$ corresponding to u_{ij} $(j = 1, 2, ..., m)$ sorted in Step 1.
Step 3 Find the distribution functions $H_i(c_j)$, $(j = 1, 2, ..., m)$ from the following equations.

$$H_i(c_1) \underline{\underline{\Delta}} w_{i1} \tag{7}$$

$$H_i(c_j) = w_{ij} + H_i(c_{j-1}) + \lambda w_{ij} * H_i(c_{j-1}),\ j = 2, ..., m \tag{8}$$

Step 4 Find the integrated evaluation value $s_j(y_i)$ from the perspectives c_j, $(j = 1, 2, ..., m)$, as follows:

$$s(y_j) = \sum_{j=1}^{m} \mu_j (H_i(c_j) - H_i(c_{j-1})) \tag{9}$$

Here the algorithm described above is performed by D_i, $(i = 1, 2, ..., n)$

The procedure

Step 1 Identify the structural perspective model of BSC.

Step 2 Set up the matrix showing the relations among measures and drivers in the structural model identified in step 1, where the relations among the elements of matrix are given in the closed interval [0, 1].

Step 3 Compute the eigen value and the eigen vector for the matrix obtained in the step 2. Here, the eigen vector is recognized as the weight of the specified evaluation factor.

Step 4 Measure the driver measures of the perspective.

Step 5 Compute the evaluation value by applying MADM based on Choquet integral.

According to each evaluation value obtained from each perspective, an integrated evaluation can be conducted by applying the multiattributes decision making based on Choquet integral.

THE MULTIDIMENSIONAL PERFORMANCE MEASUREMENT SYSTEM

The system of performance measurement should act flexibly while the social and business environment changes. In this section, a multidimensional measurement system with BSC is proposed as figure 3 shows:

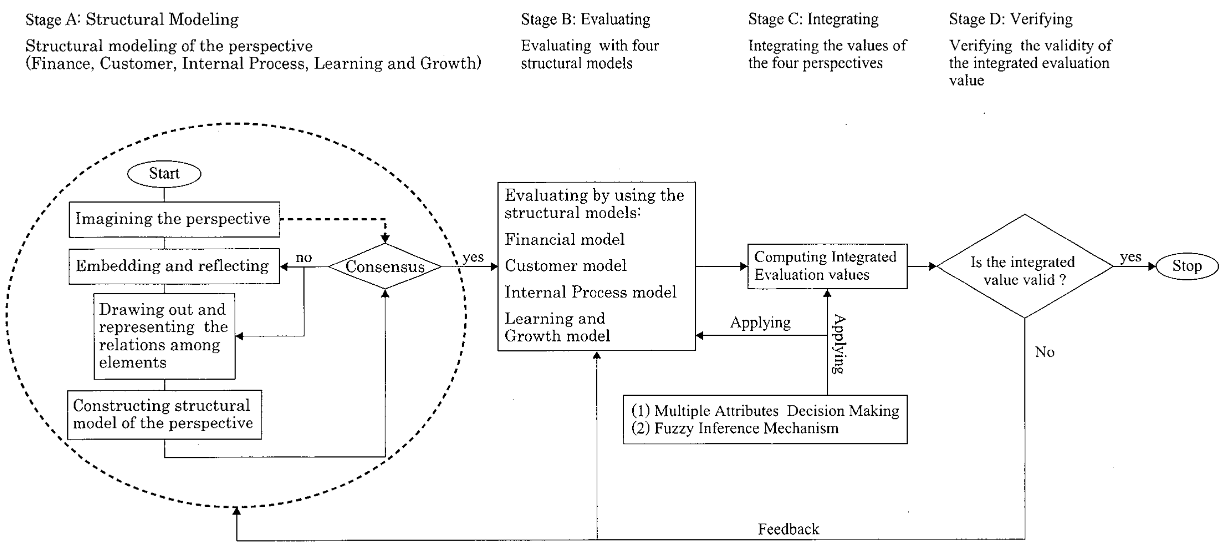

Figure 3 The Multidimensional measurement system with BSC

It starts from the initial stage, termed structural modeling, at which four perspective models (financial, customer, internal business process, and organization learning) are built up respectively through the processes encircled within the dotted line in the left side of figure 3. We also see it as multi-dimensional system analysis. For obtaining a concrete model of the respective perspective, we apply fuzzy structural modeling method to portray an intuitive graphical hierarchy with well-preserved contextual relations among measurement elements. Firstly, executives/managers' mental model (imagination) on the given problem are embedded and reflected on a structural model. Here, the measurement elements are specified by techniques such as nominal group techniques, questionnaire or interview according to the operational conditions. Then, the contextual relations among the elements are examined and represented based on the assumption of cause-and-effect. And the hierarchy of measurement system is constructed and drawn as an interpretive structural model. Furthermore, In order to compare the structural model with the mental model, a feedback for learning will be conducted by group members (evaluators). If an agreement among evaluators is obtained, then the process goes up to the next stage, and the result is set as the outcome of stage A. Otherwise, the modeling process restarts from the embedding process or from drawing out and representing the evaluating elements process. Then the process goes as same as illustrated in figure 3 until a consenting structural model is obtained.

As the outcome of stage A, we have the models of perspectives, which are evaluated respectively so as to obtain each evaluation value of each perspective model. Further, an integrated value is computed at stage C. At both of evaluating and integrating stage, multiattributes decision making method and/or fuzzy inference mechanism can be introduced for achieving the simultaneous optimization of multiple elements of system for determination of a satisfying solution to a given problem. If the integrated evaluation value is valid, the process goes to the end. Otherwise, a feedback will be conducted at stage D, back to the stage B or A, performed until a consenting integrated value is derived. In order to inspect the effectiveness of the proposed system, an example is illustrated by using the numerical data in the following section.

SIMULATION

In this section, the effectiveness of the performance measurement methods with BSC is inspected according to the procedure of the proposed system. In the procedure, an evaluation from the financial perspective is carried out on the basis of the multiple attributes decision making based on choquet integral. The other evaluations from the customer, the internal process and the organization learning perspective are respectively computed by making use of fuzzy inference mechanism. Further, a total evaluation value is found by integrating the four evaluation values obtained from the four perspective models through fuzzy inference mechanism. On account of the limited space of paper, we only illustrate the procedure to obtain a computational result of the performance measurement from the customer perspective.

Illustrative example

According to annual report of valued securities from 2005/4 to2006/3, a set of financial data of A corporation is given below, and other relative figures are shown as follows:

Financial perspective	
Stability	
Current ratio	
Quick ratio	252.1%
Cash flow	23.7billion yen
Fixed ratio	
Fixed assets to fixed liability and equity	80.1%
Capital ratio	81.5%
Profitability	
Current profit on capital employed (ROI)	
Return on equity	6.3%
Operating profit on operating capital	8.0%
Ratio of current profit to sales	
Ratio of gross profit to sales	22.9%
Ratio of operating profit to sales	8.4%
Capital employed turnover	36%, 34.4%
Growth	
Sales grows	
Rate of profit increase	
Rate of current profit increase	102.6%
Productivity	
Value added for each person	18,450,000yen
Return on capital investment	187.0%
Capital-labor ratio (54)	9,646,000yen
Ratio of value added to sales	48.7%
Customer perspective	
Customer satisfaction	
Rate of on-time delivery	80%
Claim response time	4hours
New product ratio	
Sales growth rate for new product	65%
Sales rate for new product	25%
Market share growth rate	15%

Internal business process perspective	
Kaizen activities	
Lead time shortening	35%
Production cost reduction	7%
Participating rate of QC	75%
Fulfillment on an incentive system	
Organizational efficiency	
Number of organizational hierarchy	7 levels
Learning and growth perspective	
Employee satisfaction	
Employee quit rate	20%
Satisfaction of employee expectation	75%
Strategic information infrastructure	
PC prevalence	70%
Completion of strategic information system	15%
R&D oriented	
R&D expenses to sales	4%
R&D staff	7%

Stage A Structural modeling

The structural models are built up by applying FSM in multiparticipant decision-making. The results of this stage, which are the backbone of evaluation, termed perspective structural models, are shown as hierarchical graphs in figure 4 to 7.

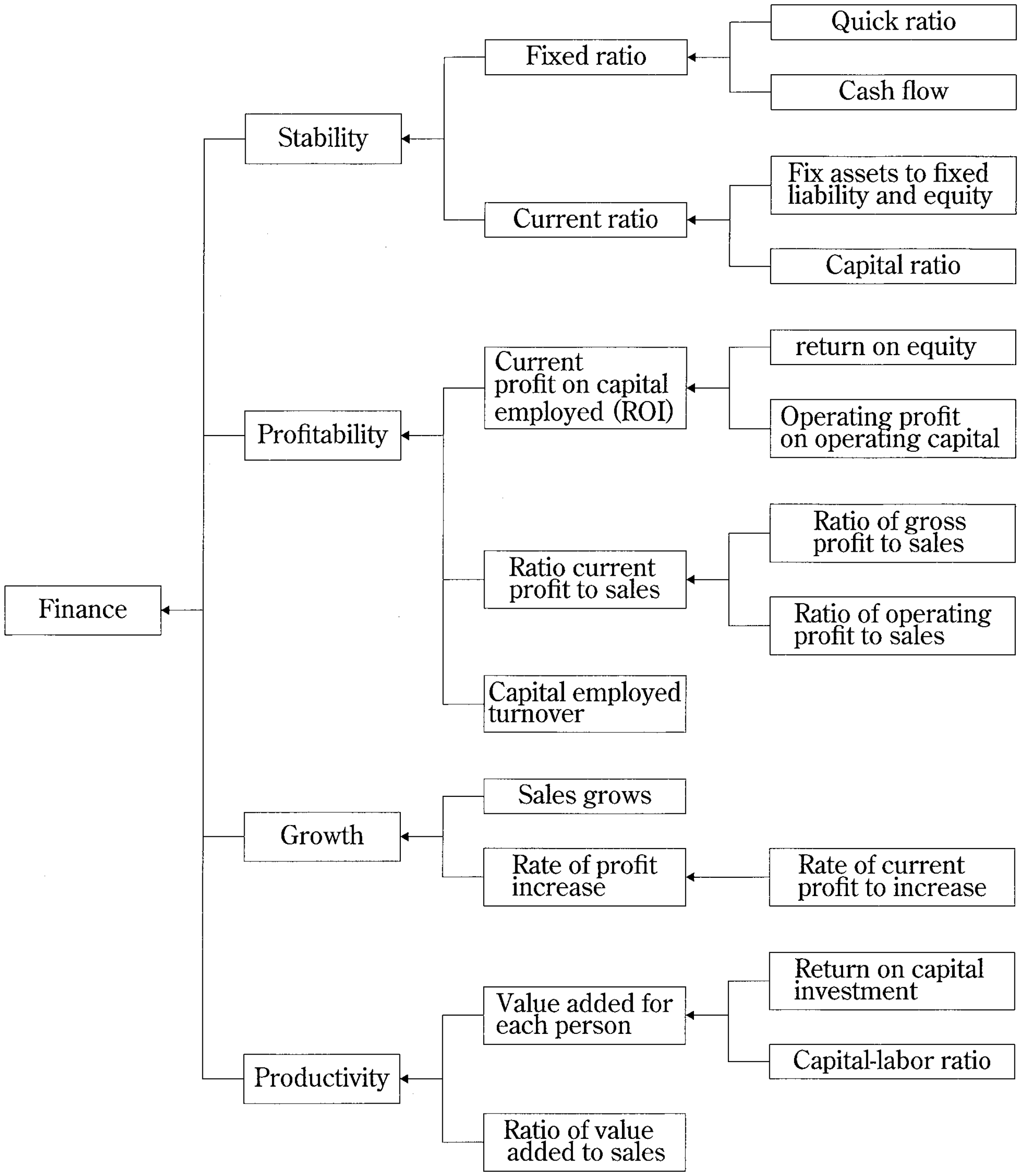

Figure 4 The financial perspective structural model

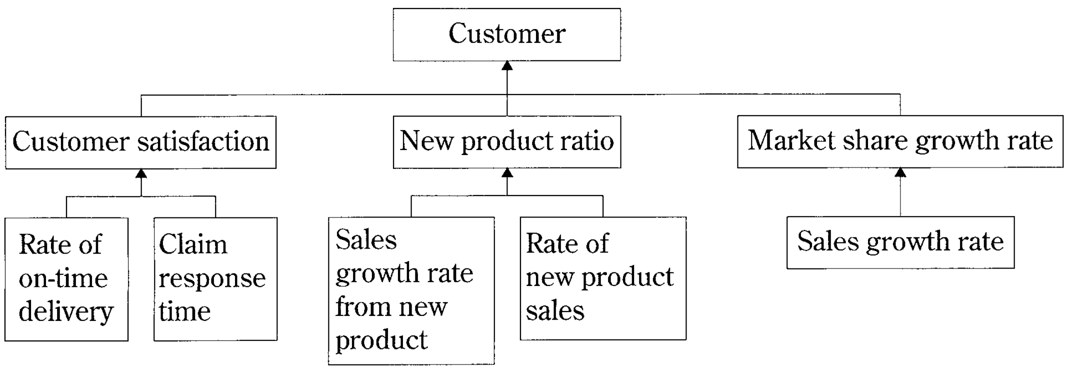

Figure 5 The customer perspective structural model

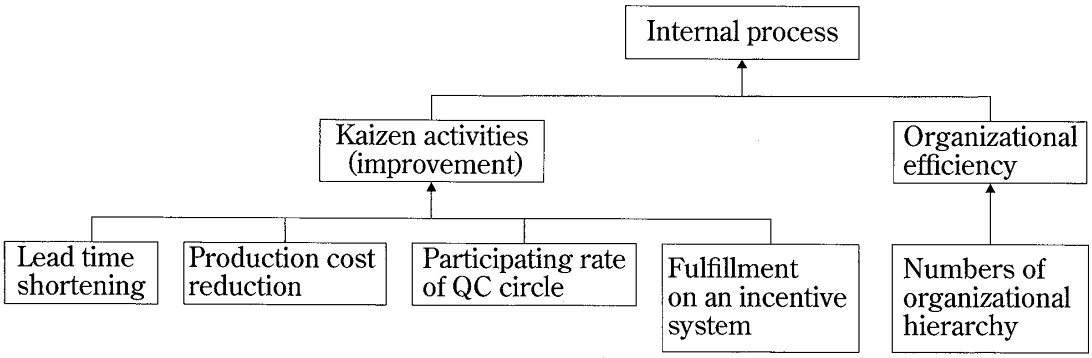

Figure 6 The internal process perspective structural model

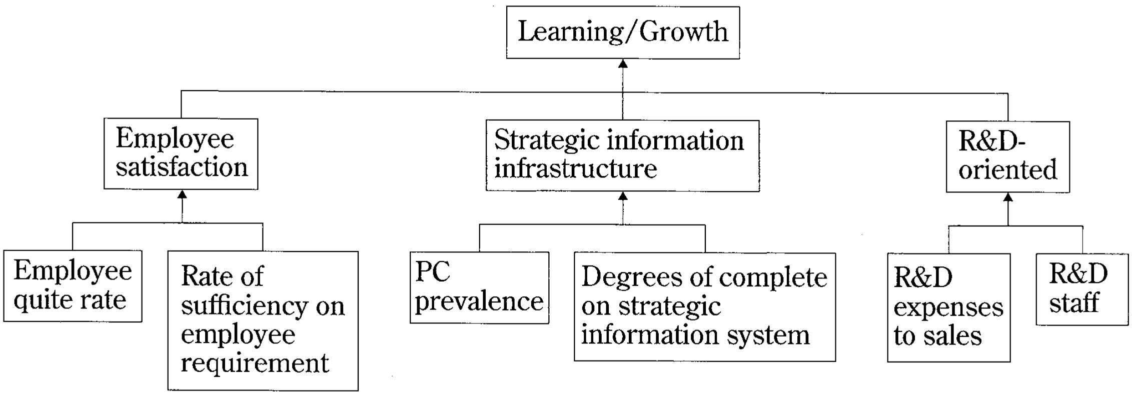

Figure 7 The learning and growth perspective structural model

Stage B Evaluating with structural models

Financial perspective:

Stability	Fs
Current ratio (%)	Cr
Quick ratio (%)	Qr
Cash flow (yen)	Cf
Fixed (assets) ratio (%)	Fr
Fixed assets to fixed liability and equity (%)	Le
Capital ratio (%)	Ca
Profitability	Fp
Current profit on capital employed (%)	ROI
Return on equity (%)	Rq
Operating profit on operating capital (%)	Op
Ratio of current profit to sales (%)	Cs
Ratio of gross profit to sales (%)	Rg

Ratio of operating profit to sales (%)	Os
Capital employed turn over (%)	Ce
Growth	Fg
Sales growth (%)	Sg
Rate of profit increase (%)	Pi
Rate of current profit increase (%)	Cp
Productivity	Pr
Value added for each person (yen)	Va
Return on capital investment (%)	Ci
Capital-labor ratio (%)	Cr
Ratio of value added to sales (%)	Vs

According to the algorithm described in the previous section, the evaluation value of financial perspective is obtained as follows:

Step 1 Apply the structural model of financial perspective built up in the stage 1.

Step 2 Set up the matrices showing the relations among the measures in the financial perspective structural model. The element of matrix, a_{ij}, shows the degree of preferring the measure a_i to the measure a_j and satisfies $0 \leq a_{ij} \leq 1$.

1' Functional perspective

	Fs	Fp	Fg	Pr
Fs	-	0.4	0.7	0.62
Fp	0.6	-	0.7	0.62
Fg	0.3	0.3	-	0.45
Pr	0.7	0.6	0.55	-

2' Stability

	Cr	Fr
Cr	-	0.6
Fr	0.4	-

3' Current ratio

	Qr	Cf
Qr	-	0.3
Cf	0.7	-

4' Fixed asset ratio

	Le	Ca
Le	-	0.6
Ca	0.4	-

5' ROI

	Rq	Op
Rq	-	0.4
Op	0.6	-

6' Ratio of current profit to sales

	Rg	Os
Rg	-	0.6
Os	0.4	-

7' Profitability

	ROI	Cs	Ce
ROI	-	0.6	0.3
Cs	0.4	-	0.4
Ce	0.7		

8' Growth

	Sg	Pi
Sg	-	0.3
Pi	0.7	-

9' Productivity

	Va	Vs
Va	-	0.4
Vs	0.6	-

10' Value added per person

	Ci	Cr
Ci	-	0.6
Cr	0.4	-

Step 3 Compute the eigen value and the eigen vector of matrix.

Let λ be eigen value, and Λ be eigen vector. Then the maximum λ of eigen values and the eigen vectors of matrix 1' are respectively computed as follows:

$\lambda = 1.44$

$\Lambda = [0.27,\ 0.30,\ 0.19,\ 0.23]$

where the element of Λ are recognized as the weights which are used to obtain the evaluation value of the financial perspective. The weights of the stability, the profitability, the growth and the productivity are respectively 0.27, 0.30, 0.19 and 0.23. In this case, it says that the evaluator takes profitability measures into account in the financial perspective model. As the similar way, the weights for the current profit on capital employed (ROI), the ratio of current profit to sales, and the capital employed turnover are also obtained by computing the eigen value and the eigen vector of matrix 7'. The computational result says that capital employed turnover taken account of as follows:

$\lambda = 0.97$

$\Lambda = [0.30,\ 0.29,\ 0.40]$

$\triangleq$ [ROI, Ratio of current profit to sales, Capital employed turnover]

Step 4 Evaluate the financial performance based on MADM

Evaluate the lowest level measures (drivers) {Qr, Cf, Le, Ca, Rq, Op, Rg, Os, Ce, Sg, Cp, Ci, Cr, Vs} (see Table 1) in the financial perspective structural model shown in figure 4. Here, assume that on the basis of the financial indexes described in the given data, the financial performance of the corporation was empirically evaluated by decision-makers in advance as follows:

Qr=1.0 Cf=0.65 Le=0.8 Ca=0.7 Rq=0.4 Op=0.5 Rg=0.6

Os=0.7 Ce=0.3 Sg=0.35 Cp=0.4 Ci=0.7 Cr=0.4 Vs=0.7

Table 1　Weighting for measures in financial perspective

Measure	Weight	Measure	Weight	Measures	Weight
Fs	0.27	Cr	0.16	Qr	0.05
				Cf	0.11
		Fr	0.11	Le	0.07
				Ca	0.04
Fp	0.30	ROI	0.09	Rq	0.04
				Op	0.05
		Cs	0.09	Rg	0.05
				Os	0.04
		Ce	0.12		
Fg	0.19	Sg	0.06		
		Pi	0.13	Cp	0.13
Pr	0.23	Va	0.09	Ci	0.05
				Cr	0.04
		Vs	0.14		

* The measures in gray cells are evaluated by MADM.

Step 5　Compute the evaluation value

Here we apply the fuzzy Choquet integral prepared in the former section, defined by the following equation.

$$g(X \cup Y) = g(X) + g(Y) + \lambda g(X) g(Y), \quad \text{where } -1 < \lambda < \infty$$

Assume the measure with $\lambda = 0$. Then the evaluation value Fi of the financial perspective is computed with a linear combination of the measures as follows:

$$\begin{aligned} Fi &= W_{Qr}Qr + W_{Cf}Cf + W_{Le}Le + W_{Ca}Ca + W_{Rq}Rq + W_{Op}Op + W_{Rg}Rg \\ &\quad + W_{Os}Os + W_{Ce}Ce + W_{Sg}Sg + W_{Cp}Cp + W_{Ci}Ci + W_{Cb}Cb + W_{Vs}Vs \\ &= 0.887 \end{aligned}$$

where $W_{\bullet}$ means the weight of "•" which denotes the specified measure.

Customer perspective:

Step 1　Apply the customer perspective structural model shown in figure 5 to build up the inference models for the customer perspective. Make the input and output of inference clear.

Step 2　Formulate membership functions for each measure.

Based on the inference model obtained from step 1, The input/output membership functions for measures are initialized by making use of triangular, trapezoidal and/or Gaussian types.

Step 3 Create the inference rules

Let H be a set of {high, high a little, standard, low a little, low}, and $R_j, (j = 1, 2, ..., n)$ be a inference rule. Then the inference rules for customer perspective model are defined according to the figures in table 2 as follows:

The inference rule for the measure of customer

R_i: IF Cs is K_{i1}, Nr is K_{i2} and Ms is K_{i3}, THEN the evaluation value is h_i, where $K_{ij} \in H$, $(j = 1, 2, 3)$, $h_i \in H$, $(i = 1, 2, ..., 125)$, and Cs, Nr and Ms are referred to table 2.

The inference rules for customer satisfaction

R_i: IF Dd is K_{i1} and Cr is K_{i2}, THEN the evaluating value is h_i, where $K_{ij} \in H$, $(j = 1, 2)$, $h_i \in H$, $(i = 1, 2, ..., 25)$, and Dd and Cr are referred to table 2.

The inference rules for new product ratio

R_i: IF Ns is K_{i1} and Np is K_{i2}, THEN the evaluating value is h_i, where $K_{ij} \in H$, $(j = 1, 2)$, $h_i \in H$, $(i = 1, 2, ..., 25)$, and Ns and Np are referred to table 2.

Table 2 Characteristics of the customer perspective

Perspective	Measure	Weight	Measure	Best	Worst
Customer	Customer satisfaction (Cs)	La	Rate of on-time delivery (Dd)	100%	80%
			Claim response time (Cr)	Less than 3hours	More than 24hours
	New product ratio (Nr)	St	Sales growth rate for new product (Ns)	100%	30%
			Sales rate of new product (Np)	30%	0%
	Market sharegrowth rate (Ms)	Lo	Sales growth rate (Sg)	30%	0%

*La stands for low a little, St for standard, and Lo for low

Step 4 Inference and compute the evaluation value

The results of inference based on the rules created in step 3 are shown in table 3 and figure 8 to 10. It says that if Dd=80% (low) and Cr=4 hours (high a little), then Cs=0.577, and if Ns=60% (Standard) and Np=20% (high a little), then Nr=0.716. Further, when Cs=0.577, Nr=0.716 and the market share growth rate (Ms)=0.50, then the evaluation value from the customer perspective is 0.675 (high a little).

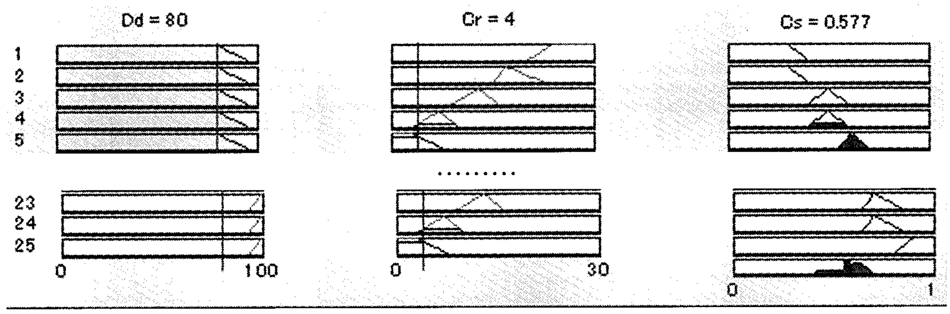

Figure 8 Rule viewer of customer satisfaction

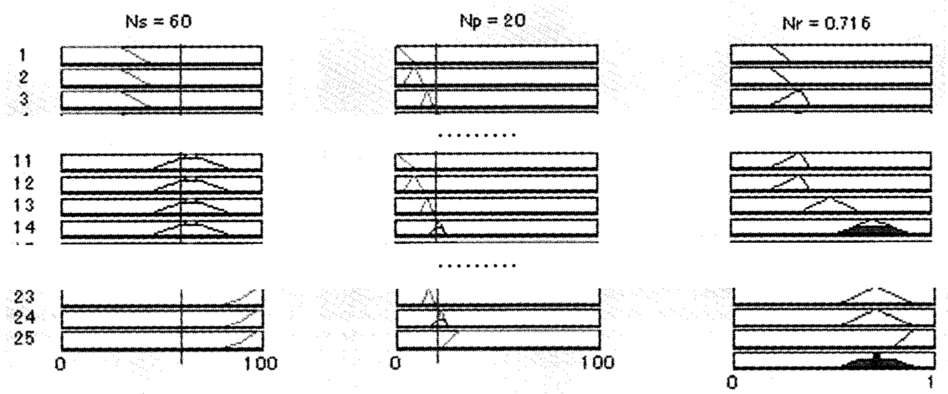

Figure 9 Rule viewer of the new product ratio

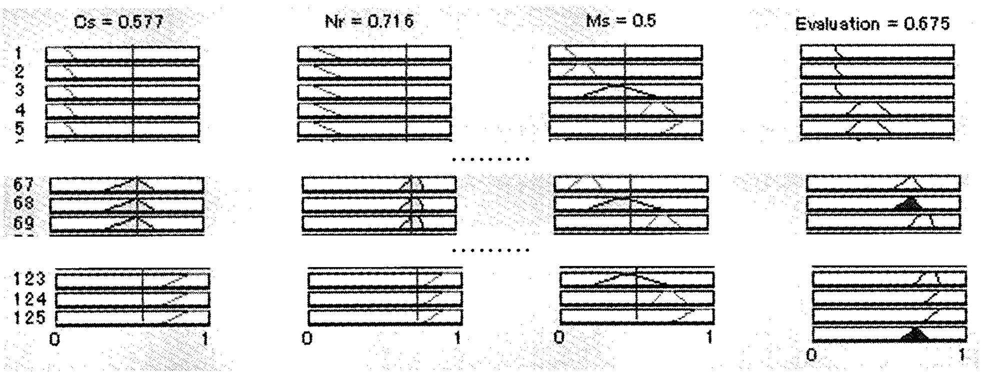

Figure 10 Rule viewer of the customer perspective

Table 3 Inference result from the customer perspective

Perspective	Result	Measure	Sub result	Measure	Given data
Customer	0.675	Customer satisfaction (Cs)	0.577	Rate of on-time delivery (Dd)	80% (Low)
				Claim response time (Cr)	4hours (High a little)
		New product ratio (Nr)	0.716	Sales growth rate for new product (Ns)	60% (Standard)
				Sales rate of new product (Np)	20% (High a little)
		Market share growth rate (Ms)	0.500	Sales growth rate (Sg)	15% (Standard)

The following tables of 5 and 7 show the results of other perspective model evaluations obtained by conducting the same method described above on the basis of the characteristics of given figures of each perspective (see tables 4, 6).

Internal Process Perspective:

Table 4 Characteristics of the internal process perspective

Perspective	Measure	Weight	Measure	Best	Worst
Internal process	Kaizen activities (Ka)	La	Lead time shortening (Ls)	50%	0%
			Production cost reduction (Pc)	10%	0%
			Participating rate of QC (Qc)	80%	20%
			Fulfillment on an incentive system (Is)	12	2
	Organizational efficiency (Of)	St	Number of organizational hierarchy (Oh)	4-6	Less 3 or more 7

*La stands for low a little, St for standard.

Table 5 Inference result of internal process

Perspective	Result	Measure	Sub result	Measure	Given data
Internal process	0.574	Kaizen activities (Ka)	0.603	Lead time shortening (Ls)	35% (High a little)
				Production cost reduction (Pc)	7% (High a little)
				Participating rate of QC (Qc)	75% (High)
				Fulfillment on an incentive system (Is)	6 (Standard)
		Organizational efficiency (Of)	–	Number of organizational hierarchy (Oh)	7 level (Low)

Learning and growth perspective:

Table 6 Characteristics of the learning and growth perspective

Perspective	Measure	Weight	Measure	Best	Worst
learning and growth	Employee satisfaction (Es)	LO	Employee quit rate (Eq)	10%	30%
			Satisfaction of employee expectation (Se)	80%	30%
	strategic information infrastructure (Si)	St	PC prevalence	70%	20%
			Completion of strategic information system (Is)	80%	10%
	R&D oriented (Ro)	La	R&D expenses to sales (Re)	10%	1%
			R&D staff (Rs)	10%	2%

*La stands for low a little, St for standard, and Lo for low

Table 7 Inference result of learning and growth

Perspective	Result	Measure	Weight	Measure	Given data
learning and growth	0.499	Employee satisfaction (Es)	0.626	Employee quit rate (Eq)	20% (Standard)
				Satisfaction of employee expectation (Se)	75% (High)
		strategic information infrastructure (Si)	0.478	PC prevalence	70% (High)
				Completion of strategic information system (Is)	15% (Low)
		R&D oriented (Ro)	0.373	R&D expenses to sales (Re)	4% (Low a little)
				R&D staff (Rs)	7% (High a little)

Stage C Integration of Four Evaluation Values

Here, fuzzy inference is introduced to integrate the four evaluation values computed in the stage B for the total evaluation as figure 11 shows.

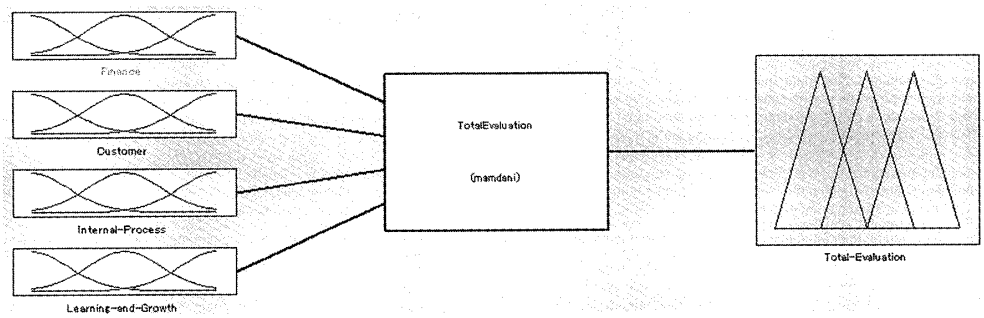

Figure 11 The measurement model from four perspectives

Let H be the set of 5 evaluation values denoted as follows:

H= {high, high a little, standard, low a little, low}

Inference rules for the integration of four perspective evaluations denoted by R_i, $(i = 1, 2, ..., 625)$, that is, R_i : IF finance is K_{i1}, customer is K_{i2}, internal process is K_{i3} and learning and growth is K_{i4}, THEN the integrated evaluation value is h_i, where $K_{ij} \in H$, $(j = 1, 2, 3, 4)$, $h_i \in H$, $(i = 1, 2, ..., 625)$. For instance, IF Finance is high, customer is standard, internal process is standard and learning and growth is high a little, THEN the evaluation value is high.

As figure 11 shows, the system consists of 4 inputs, termed finance, customer, internal-process, and learning-and-growth. The evaluation of finance is carried out on the basis of MADM, and others of customer, internal-process, and learning-and-growth are based on the fuzzy inference in previous stages. The output of the system is performed by fuzzy inference to integrate the four evaluation values. Figures 12 gives the results computed by integrating the four values.

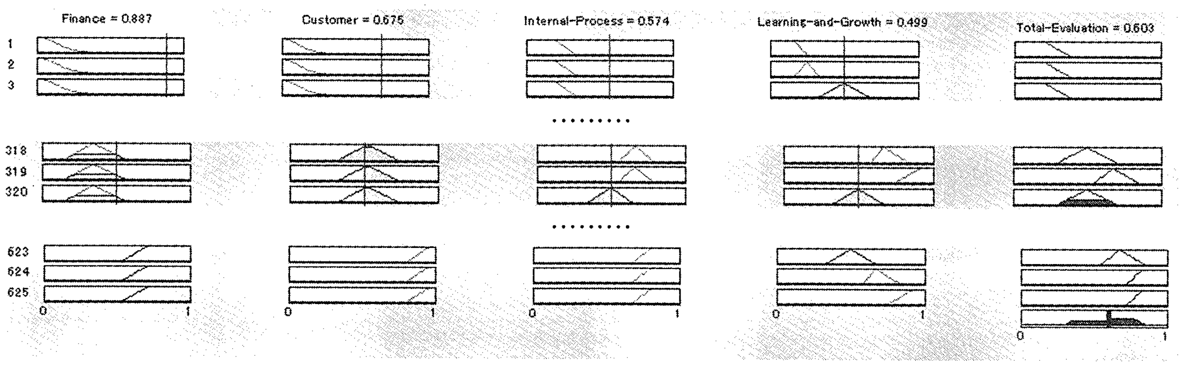

Figure 12 **Computational result of integration of four perspectives**

As the results shown in figure 12, says, when Finance=0.887 (standard), Customer=0.675 (high a little), Internal-Process=0.574 (standard), and Learn-and-Growth=0.499 (standard), the integrated evaluation value for the corporation is 0.603. It says that the performance of the corporation is able to be expressed in a semantic form, such as "standard" or "high a little".

CONCLUSION

In this paper, a multidimensional measurement system with BSC was proposed for solving the subject on the evaluation of financial and nonfinancial measures in BSC. In order to arranging the measures in a hierarchy rationally, we applied FSM to build up structural models of perspectives in multi-participant decision making, which are the backbone of evaluation conducted in this paper. For evaluating and integrating the scores, a multiattribute decision making based on Choquet integral was proposed. Moreover, we introduced fuzzy inference mechanism to obtain the total integrated value through inferring individual linkage among the outcome measures and drivers. From doing this, the evaluation can be conducted logically and analytically under consideration of decision-makers' differences on values, beliefs, attitudes, and understandings for the given problem set. As the results of the illustrative example, the following points are cleared.

(1) The proposed system offers a flexible support such changes from social and business environment or team-based organizational structure,

(2) and provides evaluators with a mechanism to incorporate subjective understanding or insight to evaluation process.

(3) It is possible that an evaluation value can be derived through a feedback which is iterated within the proposed system rationally through drawing out evaluating elements and constructing the structural perspective models.

(4) We focus on the formulation of membership function and rules for measuring and integrating the rational evaluation value. However, several simulation issues need to be solved in the future.

We used MATLAB 7.0 for conducting the fuzzy rule-based inference in this paper.

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