Balanced Scorecard with Fuzzy Inference Mechanism as A Strategic Management System

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1. Introduction

To meet the diversified challenge in today, companies have to survive around intense global competition. The winner needs to make timely and accurate decision to respond the changes confronting with business environment. Executives understand that acquiring adequate information affects performance measurement for shaping their strategy. However, most measures are being inadequate for expressing today's business performance with continuous improvement and innovation.

Traditional financial accounting measures like return on investment and residual income used to be measured for performance measurement in US manufacturing companies. These measures worked well for assessing physical assets to help managers understand profit return in industrial era, but in 1980s, it pointed out that financial measures were inadequate under the situation in which US companies battled against foreign competitions especially from Japanese companies. Thus, several comparative researches on why we couldn't be more competitive and where the Japan's success comes from have been conducted.

As a result, the traditional measurement system keeping eyes on the short-term performance in the top-down organization was inappropriate to translate future strategy. It has not worked well for information era with the diversified competitive situations which are unlike in industrial era. Therefore, the critical factor to become a successful business today is how to shift the performance from focusing on equipment investment for profit return to additionally enhancement of employee skills and enrich of organizational culture for being a knowledgeable organization. That is, the ability to exploit intangible assets has become more decisive than the ability to invest and manage the physical assets. Needless to say, companies should be measured by a comprehensive measurement system from not only financial assessing, but also the other perspectives—customer, internal business process and learning and growth. For doing this, Balanced Scorecard was proposed as a methodology to complement financial measures with operational measures based on non-financial information.

BSC was first articulated in 1992 as a comprehensive framework that translates a company's strategy objectives into a coherent set of performance measures (Kaplan and Norton 1992). Then for doing this, BSC was proposed as a methodology to complement financial measures with operational measures based on non-financial information (Matsuo 2005).

Several companies have already adopted it as a strategic management system. There are several successful stories known in practical area from such companies as Motorola and Ricoh (Kaplan and Norton 1993; Matsuo 2005). Recently, although there has many researches in practical and academic area, practical studies tend to run ahead academic research. In this situation that theory and practical research are isolated, action research has been applied as an initiative to grope in both areas.

In this paper, we aim to attempt a new approach of performance measurement based on BSC framework. In the approach, a fuzzy inference mechanism is introduced to reflect experience and knowledge decision makers have. From this, we can conduct the performance measurement in conformity with reality.

2. The balanced scorecard and the measures

2. 1 Balanced scorecard overview

Balanced scorecard is a tool to structure measures from four perspectives for giving managers a comprehensive view of the business－short-term and long-term, financial and non-financial, as well as current and future to formulate vision and strategy. Its focus is on how to link the measures with strategic activities from financial, customer, internal business process and organization learning perspective. Figure 1 shows the four perspectives of balanced scorecard.

It assumes that a linkage exist among the four perspectives which are not independent or parallel while translating vision and strategy. Generally, financial measures are the sole indicators of the company's performance such as ROE and ROI. However, to raise profit return needs to enrich customer satisfaction and loyalty, and to improve production process and shorten the time of delivery. For doing this, employees' skills need to be enhanced from learning and growth perspective. Therefore, the perspectives are seen in a cause-effect relation called vertical linkage.

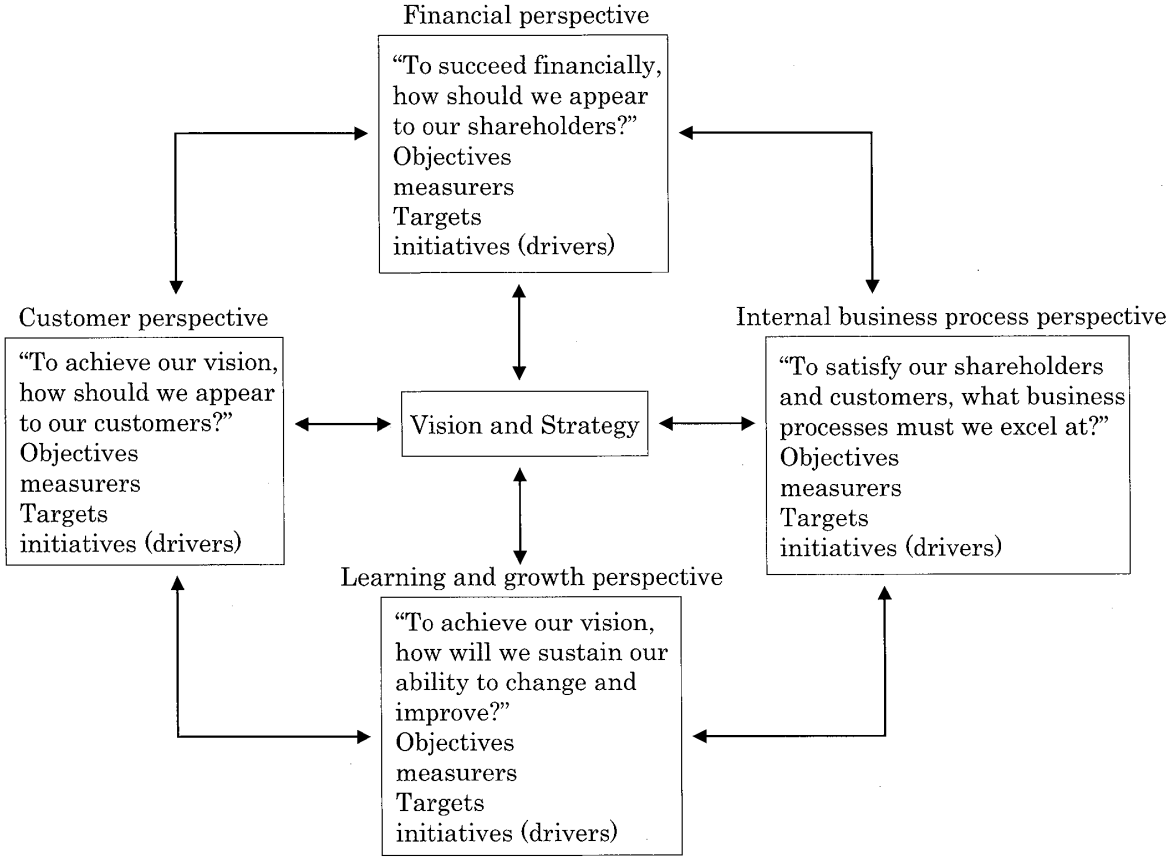


Figure 1 Balanced scorecard: four perspectives (Kaplan and Norton 1996)

As shown in Figure 1, in order to translate vision and strategy, objectives and targets are set and the measures and initiatives are designed and aligned. Herein, the designed measures and aligned initiatives interrelate each other in a relation called horizontal linkage. (see Figure 2)

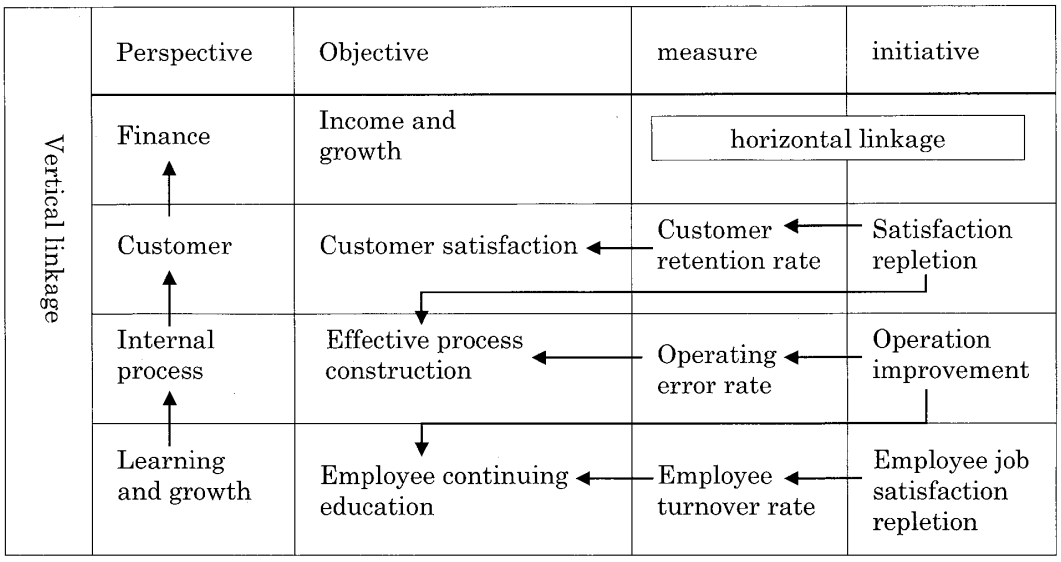


Figure 2 The vertical and horizontal linkage in BSC

2．2　A measurement framework of the paper

In this paper, we attempt to present a suggestion of a measurement system based on BSC with introducing fuzzy inference. The relations among measures of each perspective consist of as the followings:

Financial perspective: the measures and initiatives

In financial measurement, we see return on asset as a measure, and sales rate, total capital turnover rate and sales growth rate as the initiative. The relations among them are illustrated in Figure 3.

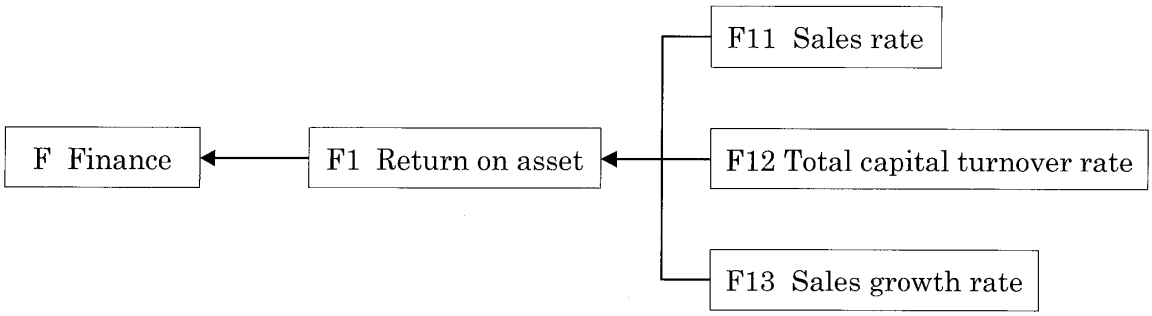


Figure 3　Financial perspective: the measures and initiatives

Customer perspective: the measures and initiatives

According to customers' concern, customer satisfaction and new product ratio can be designed as the measures. Since claim response time is critical to satisfy customer, it is aligned under the customer satisfaction measure as an initiative. Meanwhile, sales growth rate and introducing number of new product are designed as initiatives for new product ratio measure. (see Figure 4)

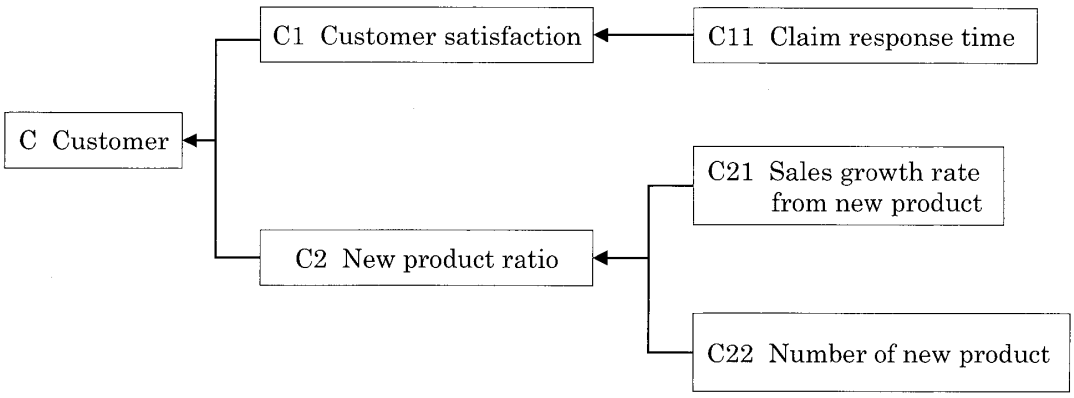


Figure 4　Customer perspective: the measures and initiatives

Internal business process: the measures and initiatives

To satisfy customers' expectation demands to improve internal business process through shortening lead time, reducing operating error rate and cutting product cost. Furthermore, to shorten operating wait time and defect repair time lead to shorten lead time. And the shortening of QC circle time and operation study time are aligned to link lowering operating error rate. Meanwhile, reducing labor cost and expenses is essential to achieve product cost reduction, and operating time shortening causes cutting labor cost. Therefore, as figure 5 shows, Lead time shortening, operating error rate reduction and production cost reduction are drawn out as measures from internal process perspective. As the initiatives of each measure, operating wait time shortening and defect repair time shortening are aligned to the measure of lead time shortening. Meanwhile, the shortening of QC circle time and operation study time are set for measuring operating error rate reduction. Then Operating time shortening is seen as an initiative of labor cost reduction, and the reduction of labor cost and expenses are aligned under the measure of product cost reduction.

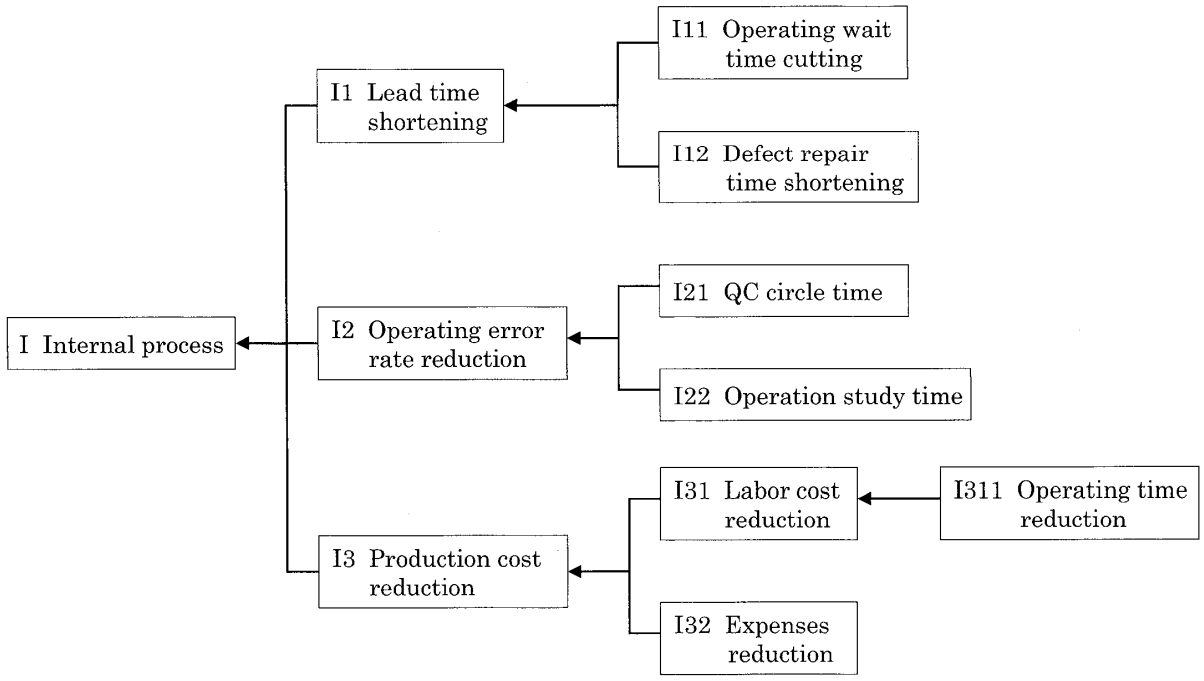


Figure 5 Internal business process: the measures and initiatives

Learning and growth perspective: the measures and initiatives

Figure 6 illustrates the measures and initiatives designed from organization learning perspective. In order to improve internal process continuously, companies are required to keep training employee, as well as secure internal infrastructure. For doing this, they need to examine

employee job satisfaction, enhance infrastructure, research and development for long run, also raise employee competence. Therefore, we draw out employee job satisfaction, strategic information infrastructure rate, and expense rate of research and development as organizational learning measures. Then, according to assumption of an existing cause-effect relation, several initiatives are aligned with each relative measure. As figure 6 shows, employee job repletion is set for examining employee job satisfaction. The initiatives of the rate of strategic information infrastructure are seen as PC prevalence and IT certification coverage. Increasing the number of patent and research staff affects long-term research and development, and the number of patent on file can be aligned as an initiative with patent number. Finally, the number of seminar and course and employee skill-holding number are linked with the measure of employee competence.

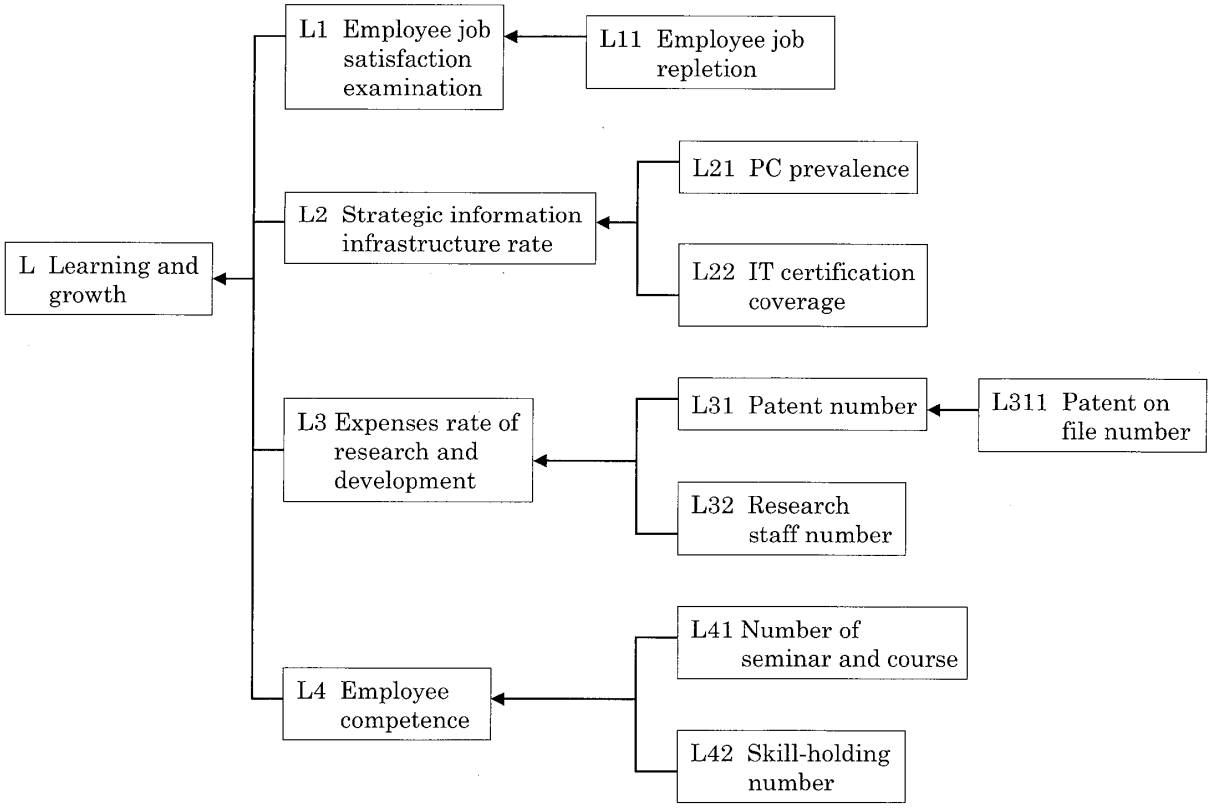


Figure 6 Learning and growth perspective: the measures and initiatives

2. 3 Relations among measures from four perspectives based on BSC

The focus of this paper is on relations among the four perspectives and measures. We attempt to introduce fuzzy inference for reflecting evaluators' experience or knowledge naturally while measuring performance. For simplicity, assume that there is one measure and one initiative for each perspective as table 1 shows:

Table 1 the measures and initiatives for four perspective

	Four perspectives		Measures		Initiatives
F	Finance	F1	Return on asset	F11	Sales rate
C	Customer	C1	Improvement of customer satisfaction	C11	Reduction of claim-happening
I	Internal Process	I1	Reduction of operating error	I11	Number of Improvement proposal
L	Learning and growth	L1	Enhancement of employee skill	L11	Number of seminar participant

Then, suppose that a relation exists between measures and initiatives with regard to each perspective, which is that to boost measure needs to increase initiative, as the direction of arrow drawn in figure 7. For example, the arrow drawn from initiative C11 to measure C1 can be interpreted that increasing customer satisfaction needs to reduce claim-happening. Similarly, satisfying customers' need leads to the rise of sales rate. Also, in order to raise return on asset, customer satisfaction is required from customer perspective, likewise, it demands the reduction of operating error rate from internal business process perspective. Consequently, employee skills should be enhanced for lowering operating error rate of internal process measure.

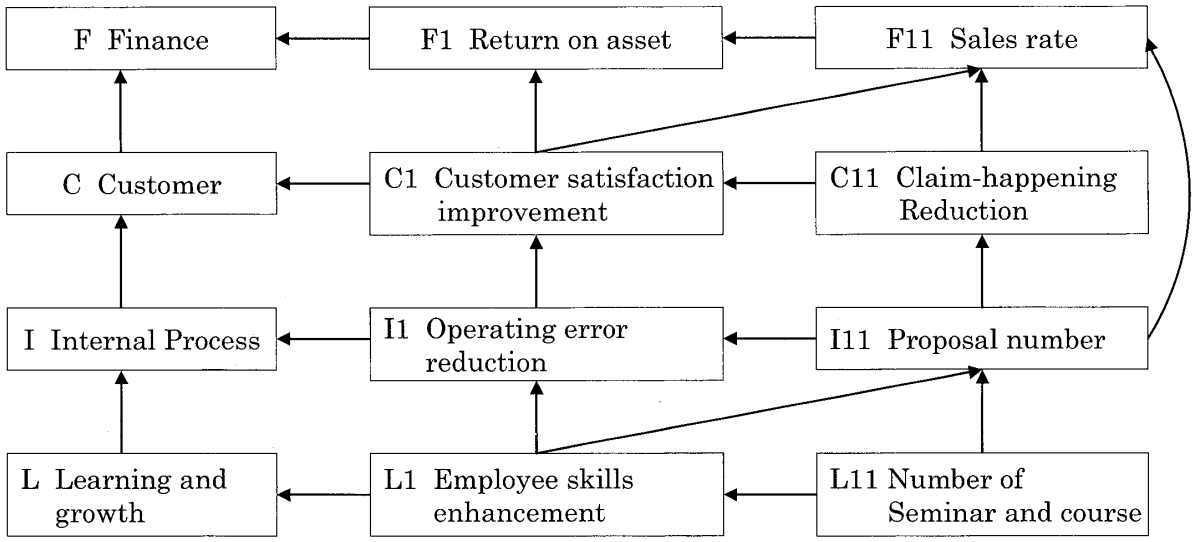


Figure 7 Strategy map of horizontal and vertical relations among each perspective and measure

Firstly, we introduce fuzzy inference mechanism to construct each perspective model for performance measurement according to the horizontal linkage between measures. (see Figure 8)

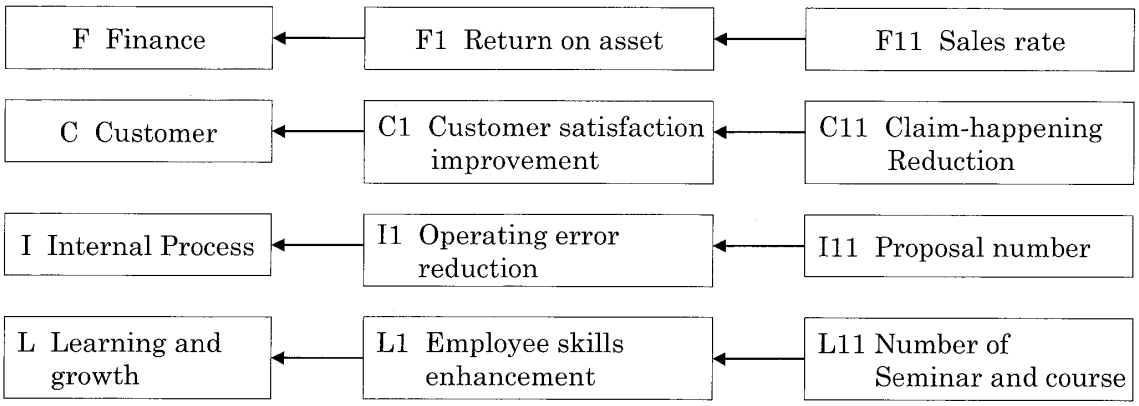


Figure 8 Strategy map of horizontal relations among each perspective and measures

3. Performance measurement system

The system of performance measurement should be flexible for the changes happening in social and business environment. The measuring system of performance is constructed in this paper from two processes: the process to reflect evaluators' intelligence to each perspective models—finance, customer, internal business process and organization learning; the process to integrate the evaluation values derived from the perspective model. (see Figure 9)

As figure 9 shows, the modeling process starts from the initial stage of system analysis—embedding structural model to reflect evaluators' relevant intelligence and represent their own evaluation imagination as a structure of evaluation system. At this stage, the measuring elements are drawn out and specified by Nominal Group Techniques (NGT). Then, the relations among the elements are studied and the hierarchy of measuring system is constructed. Furthermore, a feedback is conducted for helping evaluators compare the constructed result with the one they own. If it is consistent with their evaluation imagination, then the modeling process goes to the end, and the result is set as the outcome of the measuring system.

Otherwise, the modeling process restarts from the embedding process or from drawing out and representing the evaluating elements. Then the process goes as same as the process described above goes until a structural model of measuring system is consistent with the evaluating imagination of the evaluators. (see the right-side of Figure 9)

This evaluating process is applied to structure models respectively from finance, customer, internal process and organization learning perspective for constructing a optimal perspective model for performance measurement.

Further, an integral evaluation value is derived through integrating the perspective models. Herein, fuzzy inference is adopted to integrate the perspective models to derive an integral evaluation value. We call it multi-dimensional measurement system of performance.

In order to discuss the validity of the proposed system, we simulate it using the detail data

and compare it with the traditional methodology. If it is shown effective, it will be applied to solve practical problem. Otherwise, the evaluating process is conducted iteratively until the optimal outcome is derived.

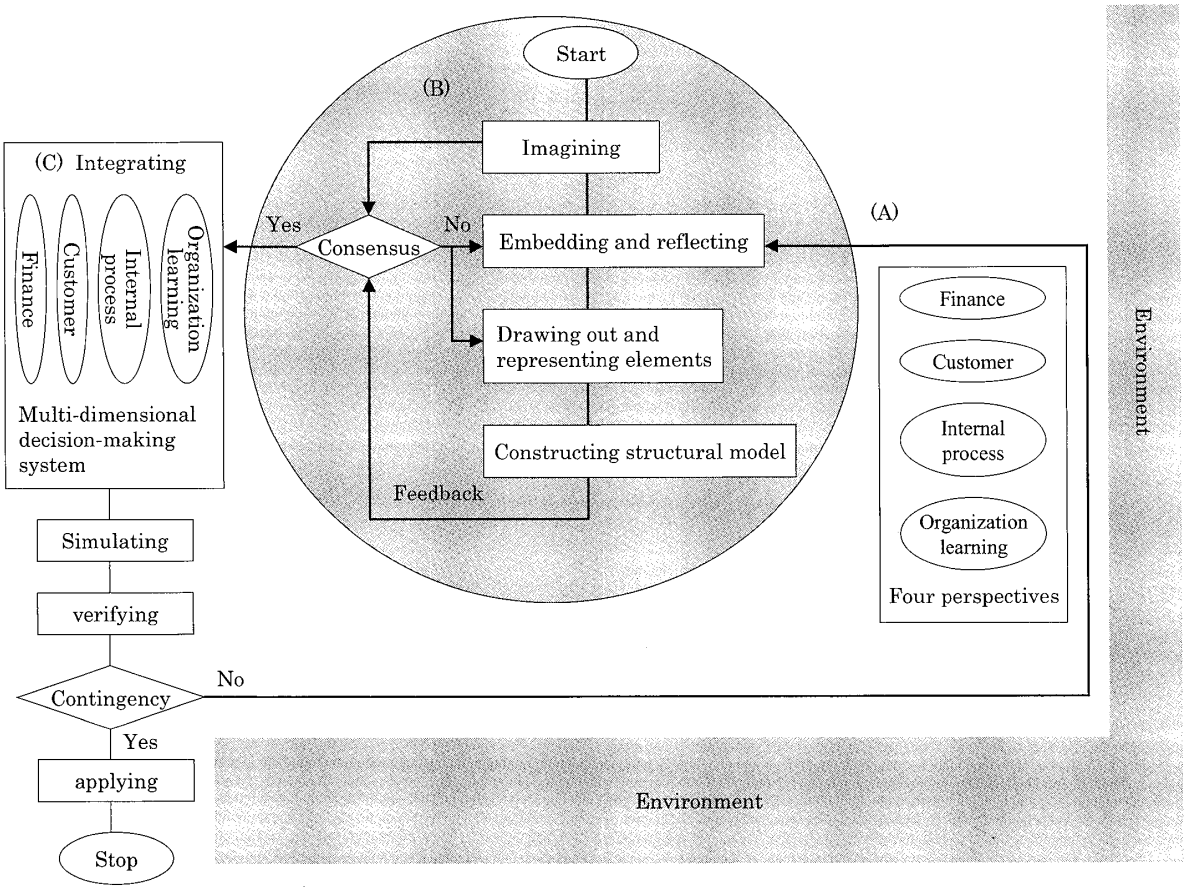


Figure 9 Multi-dimensional measurement system of performance

4. Inference process

Here, fuzzy inference is prepared for Multi-dimensional measurement system of performance. The system is proposed to integrate the perspective models to obtain an integral value of evaluation. The important subject in the proposed system is how to reflect the understanding or know-how the evaluators have to the integrating process under the consideration of the changes happening in social and business environment, which is the characteristic of the proposed system. Therefore, although the evaluators have no theoretical understanding on the performance measurement, they are able to measure the performance specialist-likely through applying the system proposed in this paper.

4. 1 Fuzzy inference mechanism

Generally, the fuzzy inference rule is expressed as the follows:

「IF x is A_1 and y is B_1 THEN z is C_1 else IF x is A_2 and y is B_2 THEN z is C_2 else ...
... IF x is A_n and y is B_n THEN z is C_n else IF x is A' and y is B' THEN z is C'」

where each of A_1, ..., A_n, A' is subset of universe of discourse U, and B_1, ..., B_n, B' fuzzy subset of universe of discourse V; C_1, ..., C_n, C' subset of universe of discourse W.

「IF x is A_1 and y is B_1」 is expressed by membership function $\mu_{A_i \cap B_i}(u, v) = \mu_{A_i}(u) \wedge \mu_{B_i}(v)$. Then $A_i \cap B_I \rightarrow Ci$ is expressed as follows: $\mu_{A_i \cap B_i \rightarrow C_i}(u, v, w) = [\mu_{A_i}(u) \wedge \mu_{B_i}(v)] \rightarrow \mu_{C_i}(w)$.

'else' is recognized as 'or' on the basis of Mandani notation.

$$C' = (A' \cap B') o [A_1 \text{“} B_I' C_1) \cup \ldots \cup (A_n \text{“} B_n' C_n)]$$
$$= (A' \text{“} B') o [A_1 \text{“} B_I' C_1) \cup \ldots \cup (A' \text{“} B') o (A_n \text{“} B_n' C_n)]$$
$$= C_1' \cup \ldots \cup C_n'$$

C_i is expressed by making use of max-min composition as follows:

$\mu_{C_i}'(w) = \mu_{(A' \text{“} B') o (A_n \text{“} B_n' C_n)}(w) = max \{\mu_{(A' \cap B')}(u, v) \wedge \mu_{A_i \text{“} B_i' C_i}(u, v, w)\} = \mu_{A' o (A_i \rightarrow C_i)}(w) \wedge \mu_{B' o (B_i' C_i)}(w)$.

$\mu_{C_i}'(w)$ is also rewritten as follows: $\mu_{C_i}'(w) = max \{\mu_{A'}(u) \wedge \mu_{A_i}(v)\} \wedge max \{\mu_{B'}(v) \wedge \mu_{B_i}(v)\}_{\mu C_i(w)}$

Therefore $C' = C_1 \cup C_2 \cup \text{“} \ldots \cup C_n$ $\mu_{C_i}(w) = \mu C_1'(w) \vee \mu_{C_2'}(w) \vee \ldots \vee \mu_{C_n'}(w)$

4. 2 Fuzzy number

There are several types of fuzzy number. Here, we concentrate on the common types: triangular and trapezoidal fuzzy number.

4. 2. 1 Triangular fuzzy number

Let A be a triangular fuzzy number with properties of continuity, converxity and normality, denoted by $A = (A_L, A_C, A_R)_L$. Moreover, use $A = (A_L, A_C, A_R)$ expressing A clearly, herein, A_C is the modal value, A_R and A_L are the lower and upper of bounds. Then let $\mu_A(x)$ denote membership function of A as follows:

$$\mu_A(x) = L(x) = \begin{cases} L_1(x) : x \in [A_C, A_R] \\ L_2(x) : x \in [A_L, A_C] \end{cases}$$

where the membership function of $L(x)$ has the following properties:

$L(A_C) = 1$

$L(A_R) = L(A_L) = 0$

$L_1(x)$ is linearly-increasing on interval $[A_L, A_C]$, and $L_2(x)$ nonincreasing function on interval $[A_C, A_R]$ (see Figure 10)

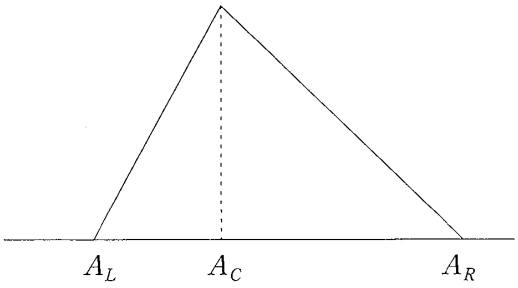


Figure 10 Triangular fuzzy number

Furthermore, the triangular fuzzy number A defined above can be expressed by linear formula as follows:

$L_1(x) = [1-(x-A_C/W_r)]$ $\quad x \in [A_C, A_R]$

$L_2(x) = [(x-A_L/W_l)]$ $\quad x \in [A_L, A_C]$

then according to the above formula, obtain $A = (A_C, W_l, W_r)_L$, where Ac is the modal value, W_r is right bound and W_l is left bound. Specially, if $W_r = W_l = W$, then A also can be expressed as the following formula:

$A = (A_C, W)_L$

which is commonly used.

4. 2. 2 Trapezoidal fuzzy number

Let A be a trapezoidal fuzzy number of the extension of triangular fuzzy number denoted by $A = (a_1, a_2, a_3, a_4)$ and membership function of A be $\mu_A(x)$. (see Figure 12)

$$\mu_A(x) = \begin{cases} 0 & x < a_1 \\ (x-a_1)/(a_2-a_1) & a_1 \le x \le a_2 \\ 1 & a_2 \le x \le a_3 \\ (a_4-x)/(a_4-a_3) & a_3 \le x \le a_4 \\ 0 & x > a_4 \end{cases}$$

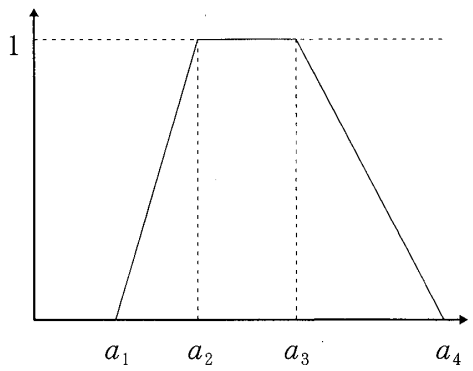


Figure 11 Trapezoidal fuzzy number

As shown in figure 11, when $a_2 = a_3$, A is expressed by triangular fuzzy number.

In this paper, we mainly use triangular and trapezoidal fuzzy number, but partially also use Gaussian function depending on the given problem.

5. Balanced scorecard with fuzzy inference

Fuzzy inference rules for performance measurement are constituted on the knowledge of relative specialists or evaluators. Therefore, no matter the evaluator is specialist of performance measurement or not, they enable to conduct measurement of performance specialists-likely.

Here, balanced scorecard is constructed by introducing fuzzy inference.

(1) Rules and membership function for financial perspective

(a) Sale rate: Sb

(b) Sale growth rate: Sg

(c) Capital turnover rate: Ct

G_1 is the set of 5 evaluation values for Sb and Sg denoted as follows:

G_1 = {high, high a little, standard, low a little, low}

G_2 is the set of 5 evaluation values for Ct denoted as follows:

G_2 = {fast, fast a little, standard, slow a little, slow}

H is the set of 5 evaluation values for financial mesures denoted as follows:

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

(d) Fuzzy inference rule denoted R_i, $i = 1, 2, \ldots, 125$.

R_i: IF Sb is K_{i1}, Sg is K_{i2}, Ct is K_{i3} THEN the evaluation value from financial perspective is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2$, $K_{i3} \in G_2$, $h_i \in H$, $i = 1, 2, \ldots, 125$.

(e) Membership function

The membership functions for Sb, Sg and Ct are initialized as triangular, trapezoidal number or Gaussian type.

For instance, rule 10 is decided as follows: R_{10}: IF Sb is high, Sg is standard, and Ct is low, THEN the evaluation value from financial perspective is low. The evaluators no matter who relative specialists are or not enable to infer specialist-likely as the rules they use reflect know-how of relative experts on the given problem.

(2) Rules and membership function for customer perspective

(a) On time delivery: Dd

(b) New product introduction number: Np

(c) Sales growth rate from new product: Ns

(d) Claim response time: Cr

G_1 is the set of 5 values for Dd, Np and Cr denoted as follows:

G_1 = {high, high a little, standard, low a little, low}

G_2 is the set of 5 evaluation values for Cr denoted as follows:

G_2 = {fast, fast a little, standard, slow a little, slow}

H is the set of 5 values for customer satisfaction denoted as follows:

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

(e) Inference rule denoted R_i, $i = 1, 2, \ldots, 625$.

R_i: IF Dd is K_{i1}, Np is K_{i2}, Ns is K_{i3}, and Cr is K_{i4}, THEN the evaluating value for customer satisfaction is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2, 3$, $K_{i4} \in G_2$, $h_i \in H$, $i = 1, 2, \ldots, 625$.

(f) Membership function

The membership functions for Dd, Np, Ns and Cr are initialized as triangular, trapezoid number.

For instance, rule 10 is decided as follows: R_{10}: IF Dd is high, Np is standard, Ns is low, and Cr is low, THEN the customer satisfaction is low. In rule 10, relative specialists' knowledge is reflected.

(3) Rules and membership function for internal process perspective

(a) lead time shortening: Lh

(i) Operating wait time cutting: Wr

(ii) Defect Repair time shortening: Ir

G_1 is the set of 5 values for Wr and Ir denoted as follows:

G_1 = {high, high a little, standard, low a little, low}

H is the set of 5 values for lead time reduction denoted as follows:

H = {fast, fast a little, standard, slow a little, slow}

(iii) Inference rule denoted R_i, $i = 1, 2, \ldots, 25$.

R_i: IF Wr is K_{i1} and Ir is K_{i2}, THEN the evaluating value for lead time reduction is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2$, $h_i \in H$, $i = 1, 2, \ldots, 25$.

(iv) Membership function

The membership functions for Wr and Ir are initialized as triangular, trapezoidal number and Gaussian type.

For instance, rule 10 is decided as follows: R_{10}: IF Wr is high and Ir is standard, THEN the lead time reduction is evaluated highly a little. In rule 10, relative specialists' knowledge is reflected.

(b) Operational error rate reduction: Mr

(i) QC circle time: Qt

(ii) Operation study time: Wt

G_1 is the set of 5 values for Qt and Wt denoted as follows:

G_1 = {much, much a little, standard, less a little, less}

H is the set of 5 values for operation error rate reduction denoted as follows:

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

(iii) Inference rule denoted R_i, $i = 1, 2, \ldots, 25$.

R_i: IF Qt is K_{i1} and Wt is K_{i2}, THEN the evaluating value for operation error rate reduction is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2, 3$, $K_{i4} \in G_2$ $h_i \in H$, $i = 1, 2, \ldots, 25$.

(iv) Membership function

The membership functions for Qt and Wt are initialized as triangular, trapezoid number and gauss type.

For instance, rule 10 is decided as follows: R_{10}: IF Qt is high and Wt is standard, THEN the evaluation of operation error rate reduction is evaluated high. In rule 10, relative specialists' knowledge is reflected.

(c) Production cost reduction: Pc

(i) Labor cost reduction: Lc

(ii) Operating time shortening: Lt

(iii) Expenses reduction: Rc

G_1 is the set of 5 values for Lc, Lt and Rc denoted as follows:

G_1 = {high, high a little, standard, low a little, low}

H is the set of 5 values for production cost reduction denoted as follows:

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

(iv) Inference rule denoted R_i, $i = 1, 2, \ldots, 125$.

R_i: IF Lc is K_{i1} and Lt is K_{i2}, and Rc is K_{i3}, THEN the evaluating value for production cost reduction is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2, 3$, $h_i \in H$, $i = 1, 2, \ldots, 125$.

(v) Membership function

The membership functions for Qt and Wt are initialized as triangular, trapezoidal number and Gaussian type.

For instance, rule 10 is decided as follows: R_{10}: IF Lc is high, Lt is standard and Rc is low, THEN the evaluation of operation error rate reduction is standard level. In rule 10, relative specialists' knowledge is reflected.

Furthermore, the values of evaluation for (a), (b) and (c) from internal process perspective are integrated by the rules indicated as follows:

Rules for integration from internal process perspective:

(a) lead time shortening: Lh

(b) Operational error rate reduction: Mr

(c) Production cost reduction: Pc

G_1 is the set of 5 values for Lh, Mr and Pc denoted as follows:

G_1 = {high, high a little, standard, low a little, low}

H is the set of 5 values for internal process denoted as follows:

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

(iv) Inference rule denoted R_i, $i = 1, 2, \ldots, 125$.

R_i : IF Lh is K_{i1}, Mr is K_{i2}, and Pc is K_{i3}, THEN the evaluation for internal process is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2, 3$, $h_i \in H$, $i = 1, 2, \ldots, 125$.

(d) Membership function

The membership functions for Lh, Mr and Pc are initialized as triangular, trapezoidal number and Gaussian type.

For instance, rule 10 is decided as follows: R_{10} : IF Lh is high, Mr is standard and Pc is low, THEN the evaluation of internal process is standard level. In rule 10, relative specialists' knowledge is reflected.

(4) Rules and membership function for organization learning perspective

(a) Employee job satisfaction: Es

(i) Proposal number: Pn

(ii) Proposal adoption number: An

G_1 is the set of 5 values for Pn and An denoted as follows:

G_1 = {many, many a little, standard, a little, little}

H is the set of 5 values for employee job satisfaction denoted as follows:

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

(iii) Inference rule denoted R_i, $i = 1, 2, \ldots, 25$.

R_i : IF Pn is K_{i1} and An is K_{i2}, THEN the evaluating value for employee job satisfaction is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2$, $h_i \in H$, $i = 1, 2, \ldots, 25$.

(iv) Membership function

The membership functions for Pn and An are initialized as triangular, trapezoidal number and Gaussian type.

For instance, rule 10 is decided as follows: R_{10} : IF Pn is many and An is standard, THEN the employee job satisfaction is evaluated highly a little. In rule 10, relative specialists' knowledge is reflected.

(b) Strategic information infrastructure rate: Si

(i) PC prevalence: Pw

(ii) IT certification coverage: Pq

G_1 is the set of 5 values for Pw and Pq denoted as follows:

G_1 = {high, high a little, standard, low a little, low}

H is the set of 5 values for Strategic information infrastructure rate denoted as follows:

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

(iii) Inference rule denoted R_i, $i = 1, 2, \ldots, 25$.

R_i : IF Pw is K_{i1} and Pq is K_{i2}, THEN the evaluating value for Strategic information infrastructure rate is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2$, $h_i \in H$, $i = 1, 2, \ldots, 25$.

(iv) Membership function

The membership functions for Pw and Pq are initialized as triangular, trapezoidal fuzzy number and Gaussian type.

For instance, rule 10 is decided as follows: R_{10} : IF Pw is high and Pq is standard, THEN the Strategic information infrastructure rate is evaluated high a little. In rule 10, relative specialists' knowledge is reflected.

(c) Research and development: Rd

(i) Patent number: Pg

(ii) Patent on file number: Pa

(iii) Research staff number: Rn

G_1 is the set of 5 values for Pg, Pa and Rn denoted as follows:

G_1 = {many, many a little, standard, a few, few}

H is the set of 5 values for research and development denoted as follows:

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

(iv) Inference rule denoted R_i, $i = 1, 2, \ldots, 125$.

R_i : IF Pg is K_{i1}, Pa is K_{i2}, and Rn is K_{i3}, THEN the evaluating value for research and development is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2, 3$, $h_i \in H$, $i = 1, 2, \ldots, 125$.

(v) Membership function

The membership functions for Pg, Pa and Wt are initialized as triangular, trapezoidal fuzzy number and Gaussian type.

For instance, rule 10 is decided as follows: R_{10} : IF Pg is many, Pa is standard and Rn is a few, THEN the evaluation of research and development is standard level. In rule 10, relative specialists' knowledge is reflected.

(d) Employee competence: Ec

(i) certification course number: Qp

(ii) Skill-holding number: Fa

G_1 is the set of 5 values for Qp and Fa denoted as follows:

G_1 = {many, many a little, standard, a few, few}

H is the set of 5 values for employee competence denoted as follows:

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

(iii) Inference rule denoted R_i, $i = 1, 2, \ldots, 25$.

R_i: IF Qp is K_{i1} and Fa is K_{i2}, THEN the evaluating value for employee competence is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2$, $h_i \in H$, $i = 1, 2, \ldots, 25$.

(iv) Membership function

The membership functions for Qp and Fa are initialized as triangular, trapezoidal fuzzy number and Gaussian type. For instance, rule 10 is decided as follows: R_{10}: IF Pg is many, Pa is standard and Rn is a few, THEN the evaluation of research and development is standard level. In rule 10, relative specialists' knowledge is reflected.

Furthermore, the values of evaluation for (a), (b), (c) and (d) from learning and growth perspective are integrated by the rules indicated as follows:

Rules for integration from organization learning and growth perspective:

(a) Employee job satisfaction: Es

(b) Strategic information infrastructure rate: Si

(c) Research and development: Rd

(d) Employee competence: Ec

G_1 is the set of 5 values for Es, Si, Rd and Ec denoted as follows:

G_1 = {high, high a little, standard, low a little, low}

H is the set of 5 values for learning and growth denoted as follows:

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

(e) Inference rule denoted R_i , $i = 1, 2, \ldots, 625$.

R_i: IF Es is K_{i1}, Si is K_{i2}, Rd is K_{i3} and Ec is K_{i4}, THEN the evaluation for organization learning and growth is h_i.

Here, $K_{ij} \in G_1$, $j = 1, 2, 3, 4$, $h_i \in H$, $i = 1, 2, \ldots, 625$.

(f) Membership function

The membership functions for Es, Si, Rd and Ec are initialized as triangular, trapezoidal fuzzy number and Gaussian type.

For instance, rule 10 is decided as follows: R_{10}: IF Es is high, Si is standard, Rd is low and Ec is low, THEN the evaluation of learning and growth is low a little. In rule 10, relative

specialists' knowledge is reflected.

The relations among each perspective in the system are shown in figure 12.

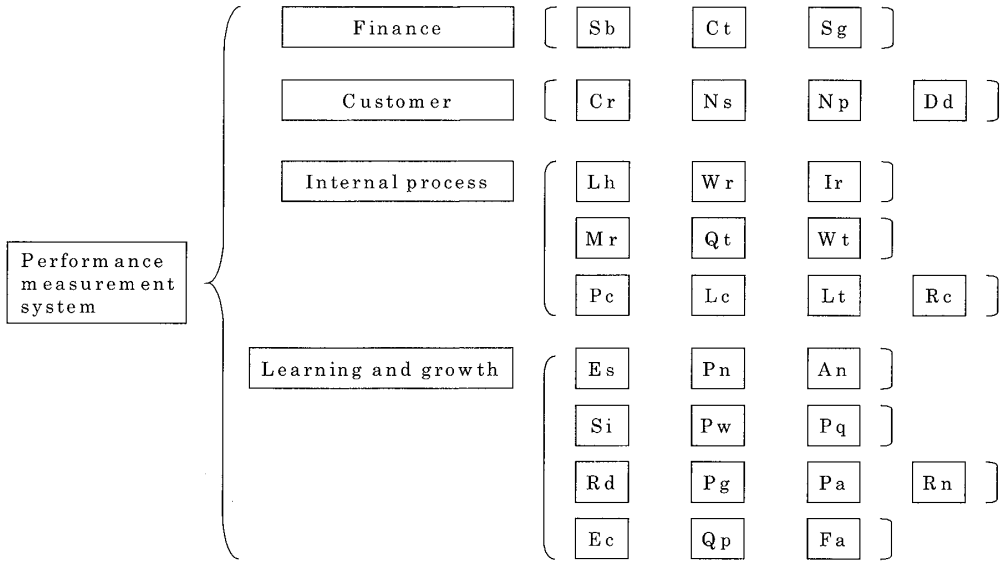


Figure 12 Performance measurement system by Balanced scorecard

6. Illustrative example

(1) Measurement from financial perspective

Membership function and rule are contributed based on the model shown in figure 13.

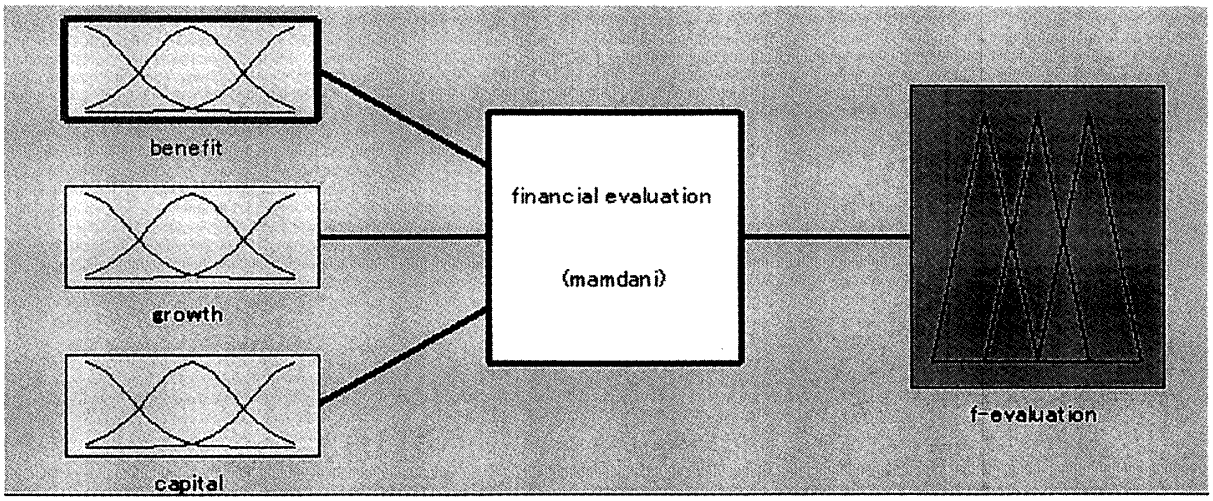


Figure 13 Measurement model of financial perspective

(a) Membership function

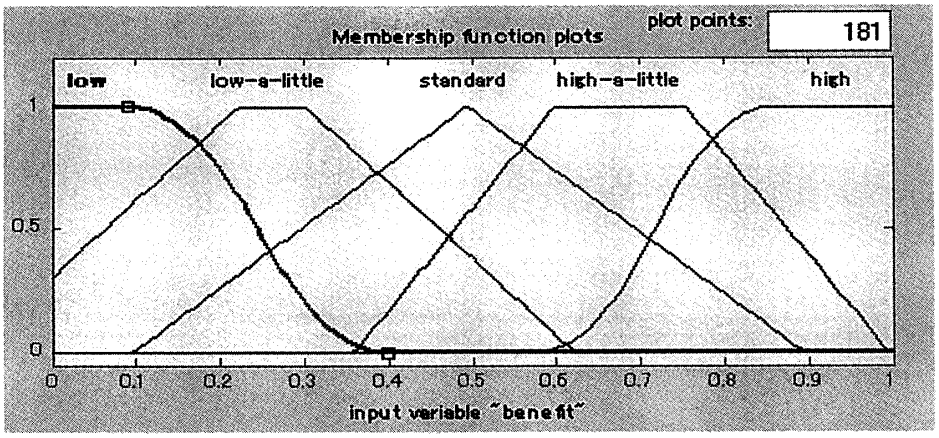


Figure 14 Membership function of sales rate

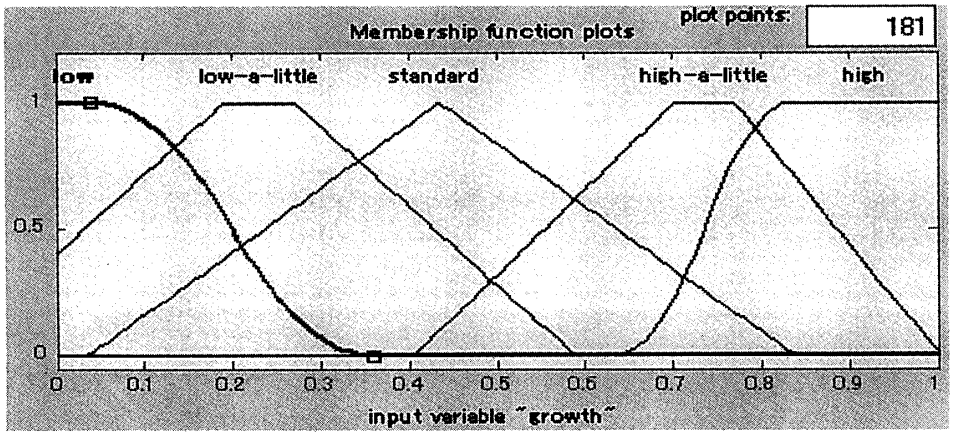


Figure 15 Membership function of sales growth rate

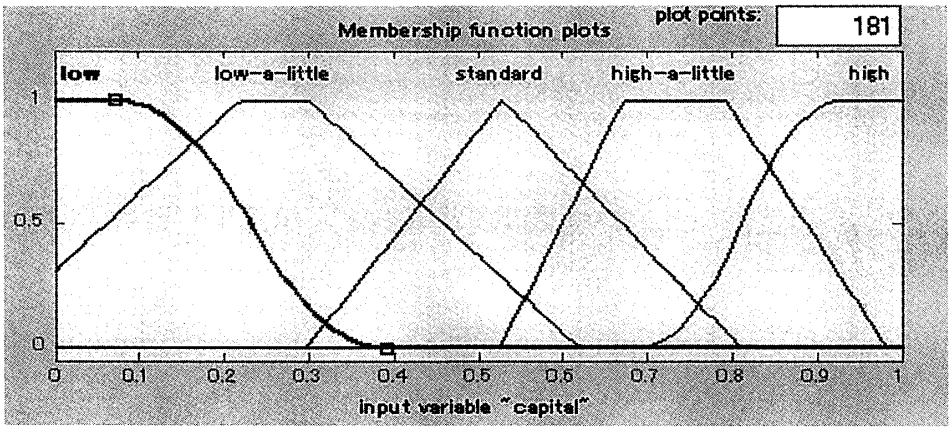


Figure 16 Membership function of capital turnover rate

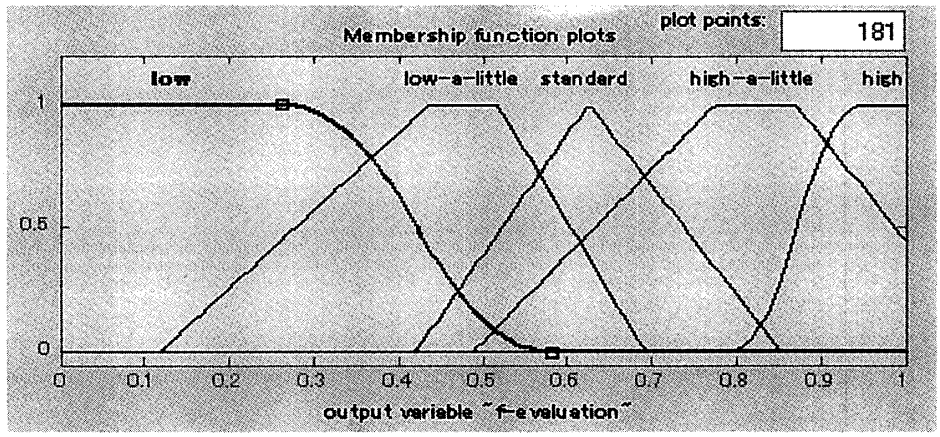


Figure 17 Membership function of financial perspective

(b) Inference rule (partially):

1. If (benefit is low) and (growth is low) and (capital is low) then (f-evaluation is low) (1)
2. If (benefit is low) and (growth is low) and (capital is low-a-little) then (f-evaluation is low) (1)
3. If (benefit is low) and (growth is low) and (capital is standard) then (f-evaluation is low) (1)
4. If (benefit is low) and (growth is low) and (capital is high-a-little) then (f-evaluation is low-a-little) (1)
5. If (benefit is low) and (growth is low) and (capital is high) then (f-evaluation is low-a-little) (1)

30. If (benefit is low-a-little) and (growth is low) and (capital is high) then (f-evaluation is low-a-little) (1)
31. If (benefit is low-a-little) and (growth is low-a-little) and (capital is low) then (f-evaluation is low) (1)
32. If (benefit is low-a-little) and (growth is low-a-little) and (capital is low-a-little) then (f-evaluation is low-a-little) (1)
33. If (benefit is low-a-little) and (growth is low-a-little) and (capital is standard) then (f-evaluation is standard) (1)
34. If (benefit is low-a-little) and (growth is low-a-little) and (capital is high-a-little) then (f-evaluation is standard) (1)

60. If (benefit is standard) and (growth is low-a-little) and (capital is high) then (f-evaluation is standard) (1)
61. If (benefit is standard) and (growth is standard) and (capital is low) then (f-evaluation is low-a-little) (1)
62. If (benefit is standard) and (growth is standard) and (capital is low-a-little) then (f-evaluation is low-a-little) (1)
63. If (benefit is standard) and (growth is standard) and (capital is standard) then (f-evaluation is standard) (1)
64. If (benefit is standard) and (growth is standard) and (capital is high-a-little) then (f-evaluation is high-a-little) (1)

120. If (benefit is high) and (growth is high-a-little) and (capital is high) then (f-evaluation is high) (1)
121. If (benefit is high) and (growth is high) and (capital is low) then (f-evaluation is low-a-little) (1)
122. If (benefit is high) and (growth is high) and (capital is low-a-little) then (f-evaluation is standard) (1)
123. If (benefit is high) and (growth is high) and (capital is standard) then (f-evaluation is high-a-little) (1)
124. If (benefit is high) and (growth is high) and (capital is high-a-little) then (f-evaluation is high) (1)
125. If (benefit is high) and (growth is high) and (capital is high) then (f-evaluation is high) (1)

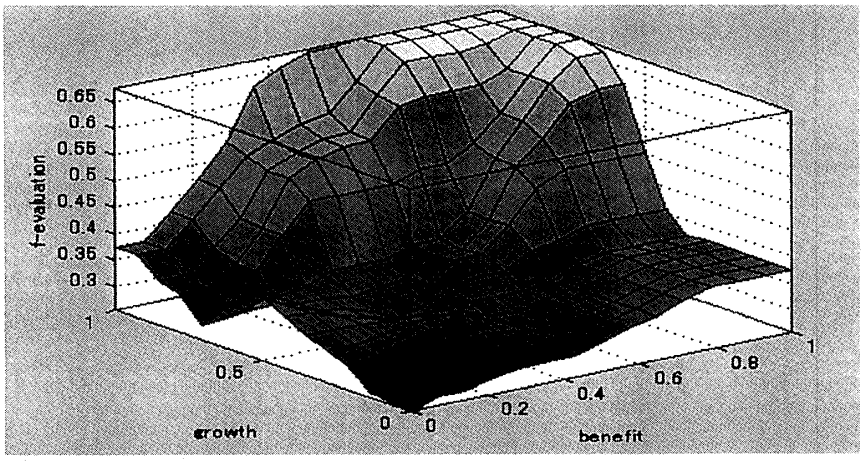
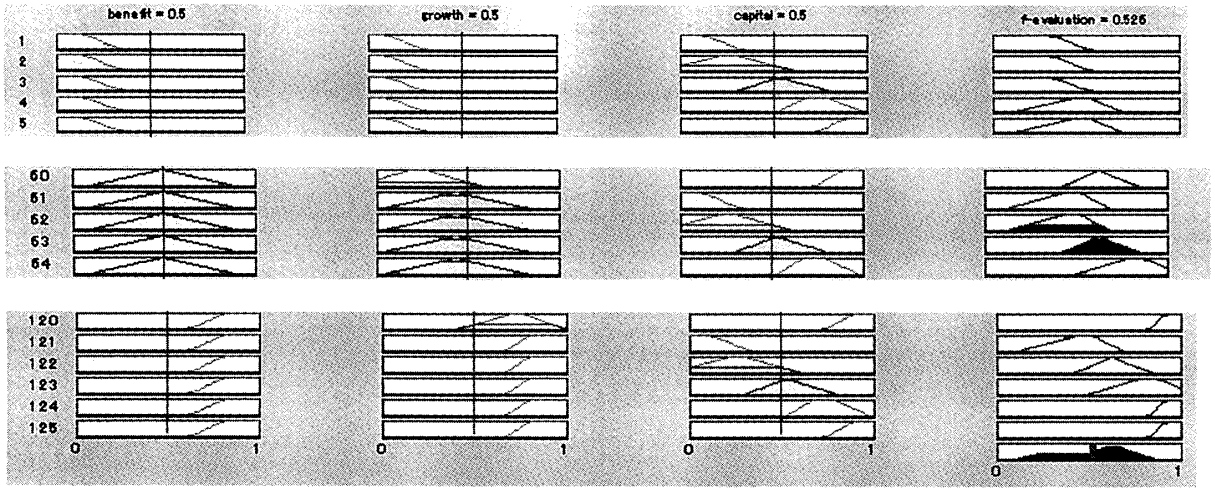


Figure 18 3D for measurement from financial perspective

An example: financial perspective

Sales rate=0.5 Sales growth rate=0.5 Capital turnover rate=0.5 Value=0.526



(2) Measurement from customer perspective

Membership function and rule are contributed based on the model shown in figure 3

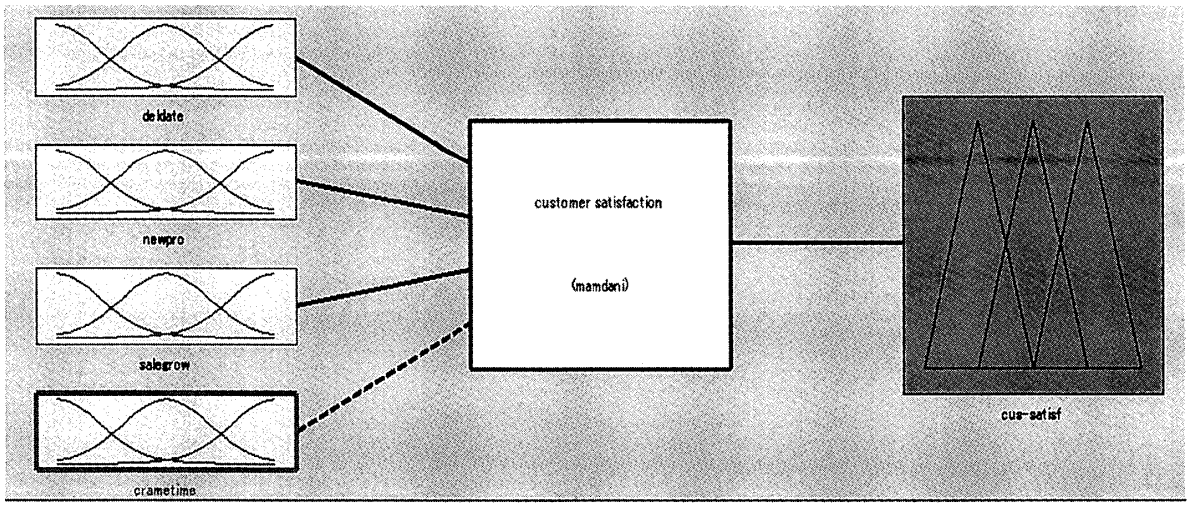


Figure 19 Measurement model of customer perspective

(a) Membership function

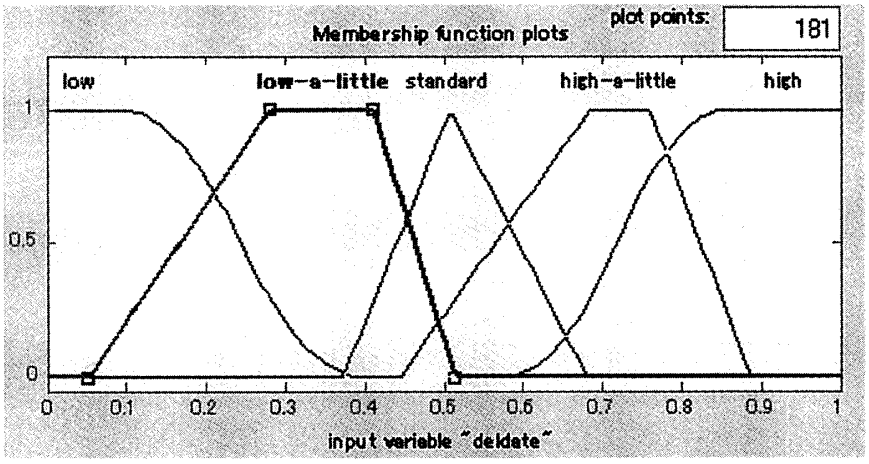


Figure 20 Membership function of on time delivery

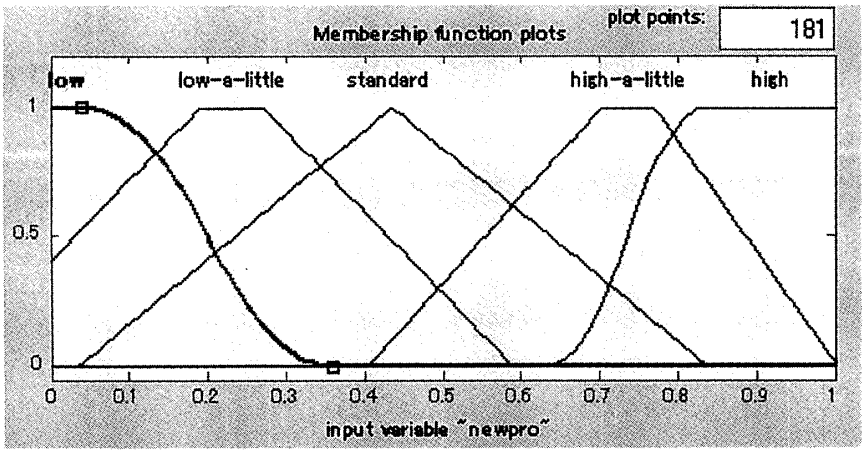


Figure 21 Membership function of new product introduction rate

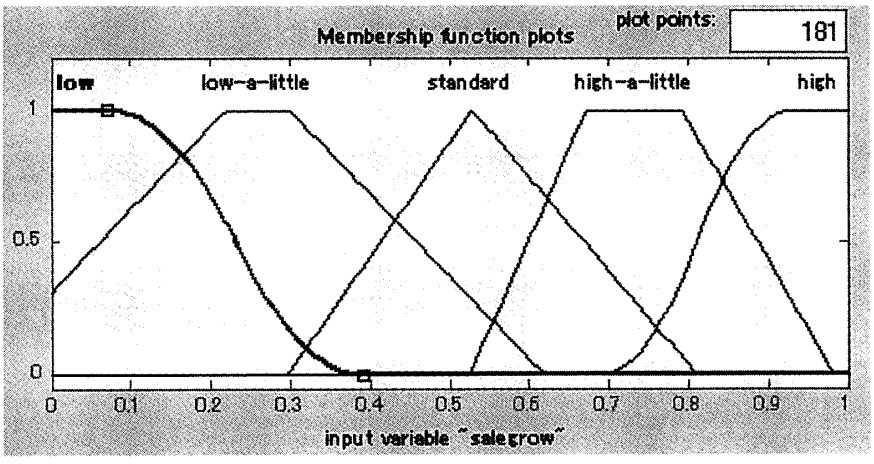


Figure 22 Membership function of sales growth rate from new product

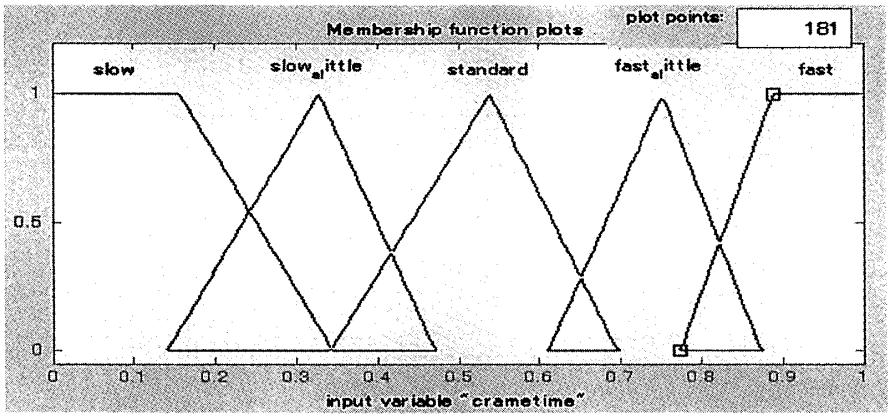


Figure 23 Membership function of claim response time

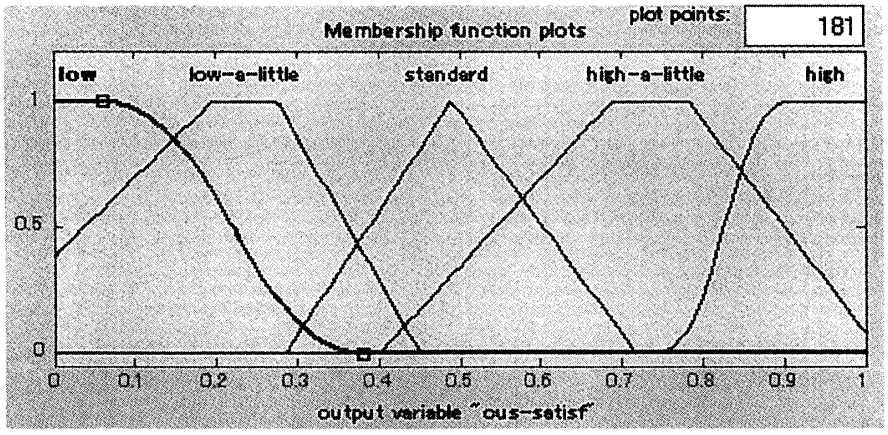


Figure 24 Membership function of customer perspective

(b) Inference rule (partially):

1. If (deldate is low) and (newpro is low) and (salegrow is low) and (crametime is slow) then (cus-satisf is low) (1)
2. If (deldate is low) and (newpro is low) and (salegrow is low) and (crametime is slow a little) then (cus-satisf is low) (1)
3. If (deldate is low) and (newpro is low) and (salegrow is low) and (crametime is standard) then (cus-satisf is low) (1)
4. If (deldate is low) and (newpro is low) and (salegrow is low) and (crametime is fast a little) then (cus-satisf is low) (1)
5. If (deldate is low) and (newpro is low) and (salegrow is low) and (crametime is fast) then (cus-satisf is low) (1)

...

200. If (deldate is low-a-little) and (newpro is standard) and (salegrow is high) and (crametime is fast) then (cus-satisf is high a little) (1)
201. If (deldate is low-a-little) and (newpro is high a little) and (salegrow is low) and (crametime is slow) then (cus-satisf is low a little) (1)
202. If (deldate is low-a-little) and (newpro is high a little) and (salegrow is low) and (crametime is slow a little) then (cus-satisf is low a little) (1)
203. If (deldate is low-a-little) and (newpro is high a little) and (salegrow is low) and (crametime is standard) then (cus-satisf is low a little) (1)
204. If (deldate is low-a-little) and (newpro is high a little) and (salegrow is low) and (crametime is fast a little) then (cus-satisf is low a little) (1)

400. If (deldate is high-a-little) and (newpro is low a little) and (salegrow is low) and (crametime is slow) then (cus-satisf is low a little) (1)
401. If (deldate is high-a-little) and (newpro is low a little) and (salegrow is low) and (crametime is slow a little) then (cus-satisf is low a little) (1)
402. If (deldate is high-a-little) and (newpro is low a little) and (salegrow is low) and (crametime is standard) then (cus-satisf is low a little) (1)
403. If (deldate is high-a-little) and (newpro is low a little) and (salegrow is low) and (crametime is fast a little) then (cus-satisf is standard) (1)
404. If (deldate is high-a-little) and (newpro is low a little) and (salegrow is low) and (crametime is fast) then (cus-satisf is standard) (1)

...

620. If (deldate is high) and (newpro is high) and (salegrow is standard) and (crametime is slow) then (cus-satisf is standard) (1)
621. If (deldate is high) and (newpro is high) and (salegrow is high) and (crametime is slow) then (cus-satisf is high a little) (1)
622. If (deldate is high) and (newpro is high) and (salegrow is high) and (crametime is slow a little) then (cus-satisf is high a little) (1)
623. If (deldate is high) and (newpro is high) and (salegrow is high) and (crametime is standard) then (cus-satisf is high) (1)
624. If (deldate is high) and (newpro is high) and (salegrow is high) and (crametime is fast a little) then (cus-satisf is high) (1)
625. If (deldate is high) and (newpro is high) and (salegrow is high) and (crametime is fast) then (cus-satisf is high) (1)

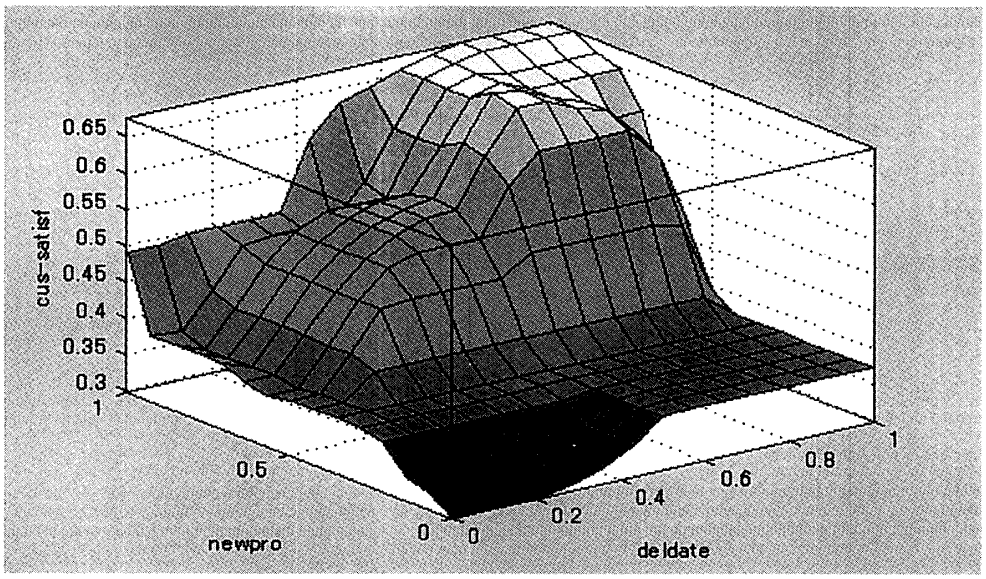


Figure 25 3D for measurement from customer perspective

An example: customer perspective

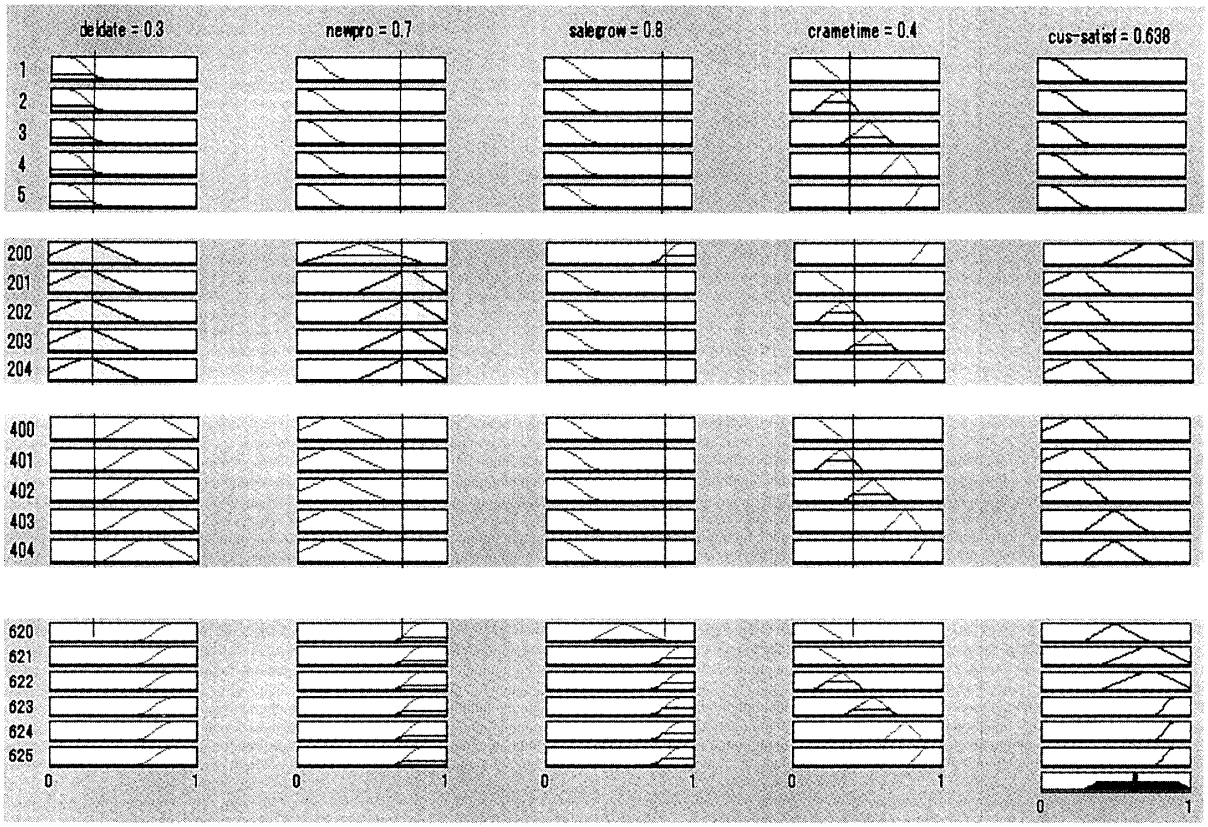
On time delivery=0.3

New product introduction rate=0.7

Sales growth rate from new product=0.8

Claim response time=0.4

Value=0.526



(3) Measurement from internal process perspective

Membership function and rule are contributed based on the model shown in figure 4

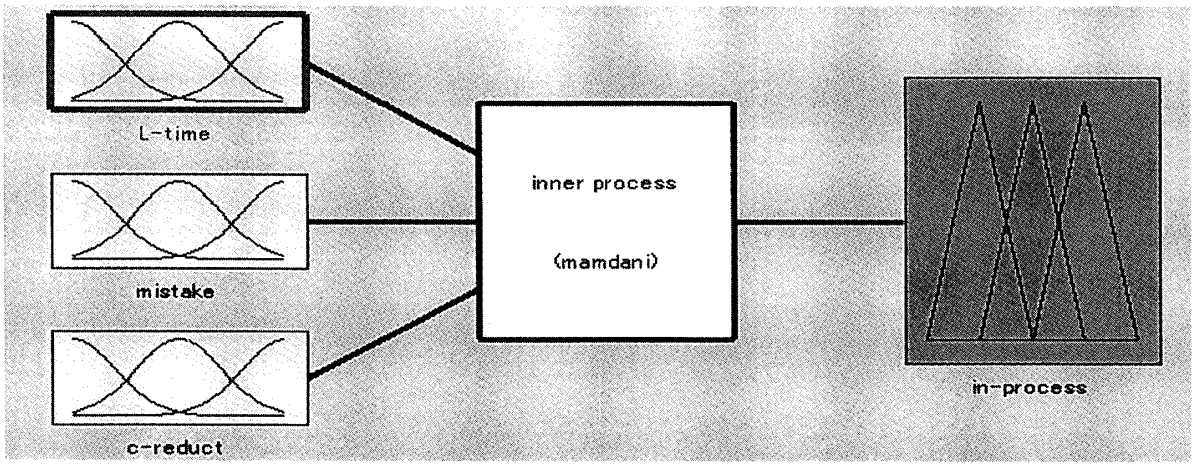


Figure 26 Measurement model of internal process perspective

(a) Membership function

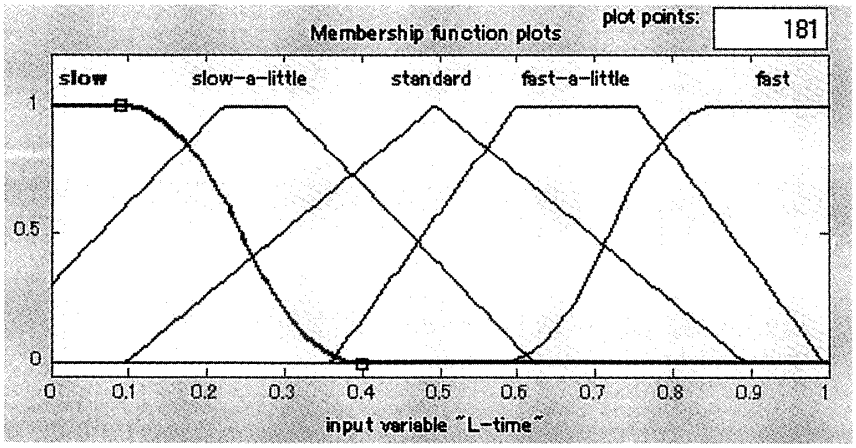


Figure 27 Membership function of lead time reduction

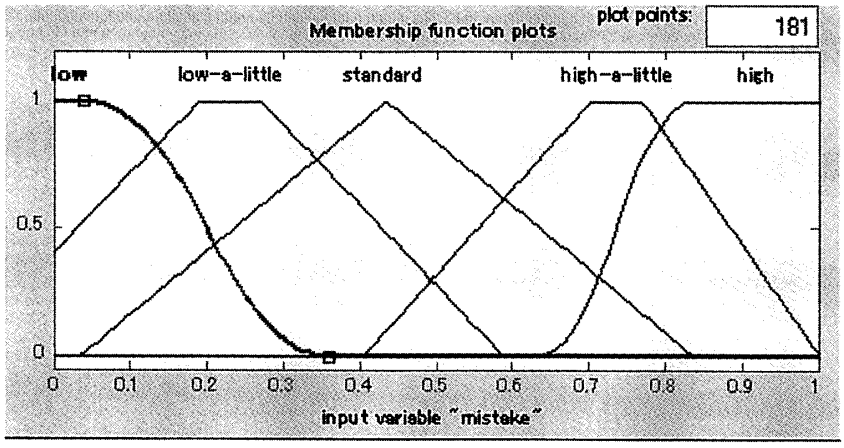


Figure 28 Membership function of operating error reduction

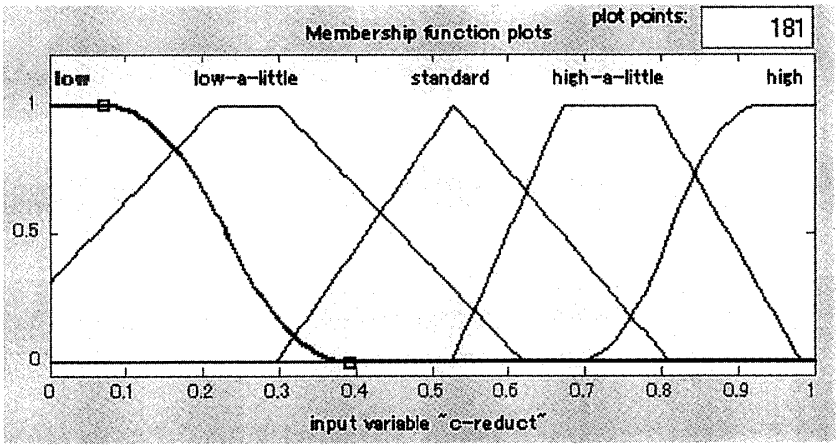


Figure 29 Membership function of production cost reduction

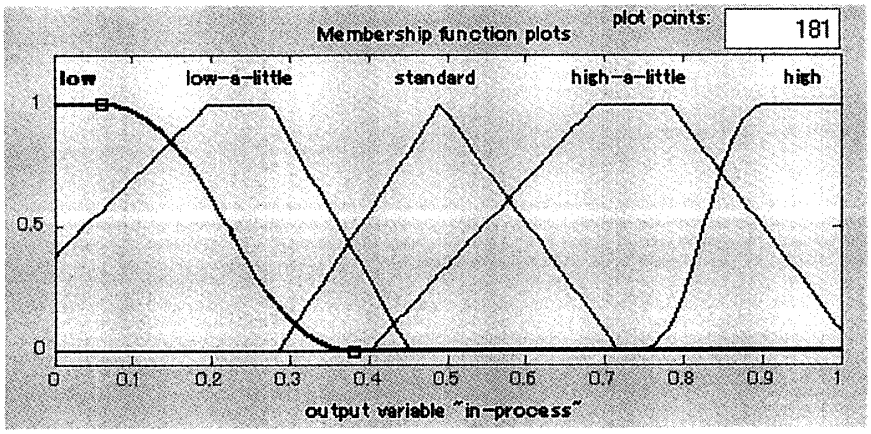


Figure 30 Membership function of internal process perspective

(b) Inference rule (partially):

1. If (L-time is slow) and (mistake is low) and (c-reduct is low) then (in-process is low) (1)
2. If (L-time is slow) and (mistake is low) and (c-reduct is low a little) then (in-process is low) (1)
3. If (L-time is slow) and (mistake is low) and (c-reduct is standard) then (in-process is low) (1)
4. If (L-time is slow) and (mistake is low) and (c-reduct is high a little) then (in-process is low a little) (1)
5. If (L-time is slow) and (mistake is low) and (c-reduct is high) then (in-process is low a little) (1) . . .

60. If (L-time is standard) and (mistake is low a little) and (c-reduct is high) then (in-process is standard) (1)
61. If (L-time is standard) and (mistake is standard) and (c-reduct is low) then (in-process is low a little) (1)
62. If (L-time is standard) and (mistake is standard) and (c-reduct is low a little) then (in-process is low a little) (1)
63. If (L-time is standard) and (mistake is standard) and (c-reduct is standard) then (in-process is standard) (1)
64. If (L-time is standard) and (mistake is standard) and (c-reduct is high a little) then (in-process is high a little) (1)

120. If (L-time is fast) and (mistake is high a little) and (c-reduct is high) then (in-process is high) (1)
121. If (L-time is fast) and (mistake is high) and (c-reduct is low) then (in-process is low a little) (1)
122. If (L-time is fast) and (mistake is high) and (c-reduct is low a little) then (in-process is standard) (1)
123. If (L-time is fast) and (mistake is high) and (c-reduct is standard) then (in-process is high a little) (1)
124. If (L-time is fast) and (mistake is high) and (c-reduct is high a little) then (in-process is high) (1)
125. If (L-time is fast) and (mistake is high) and (c-reduct is high) then (in-process is high) (1)

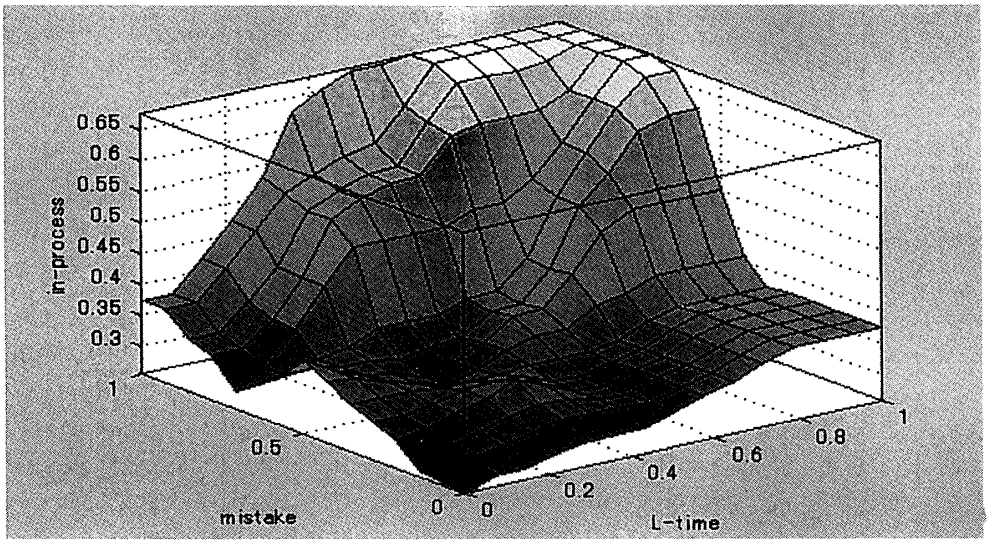


Figure 31 3D for measurement from internal process perspective

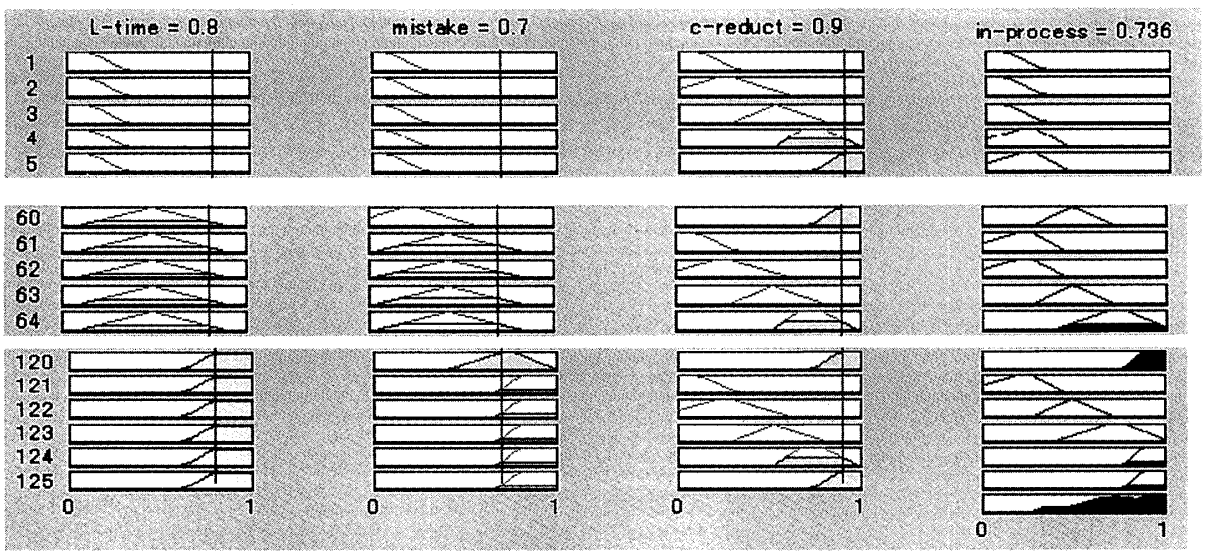
An example: internal process perspective

Lead time reduction=0.8

Operating error reduction=0.7

Production cost reduction=0.9

Value=0.736



(4) Measurement from organization learning perspective

Membership function and rule are contributed based on the model shown in figure 6

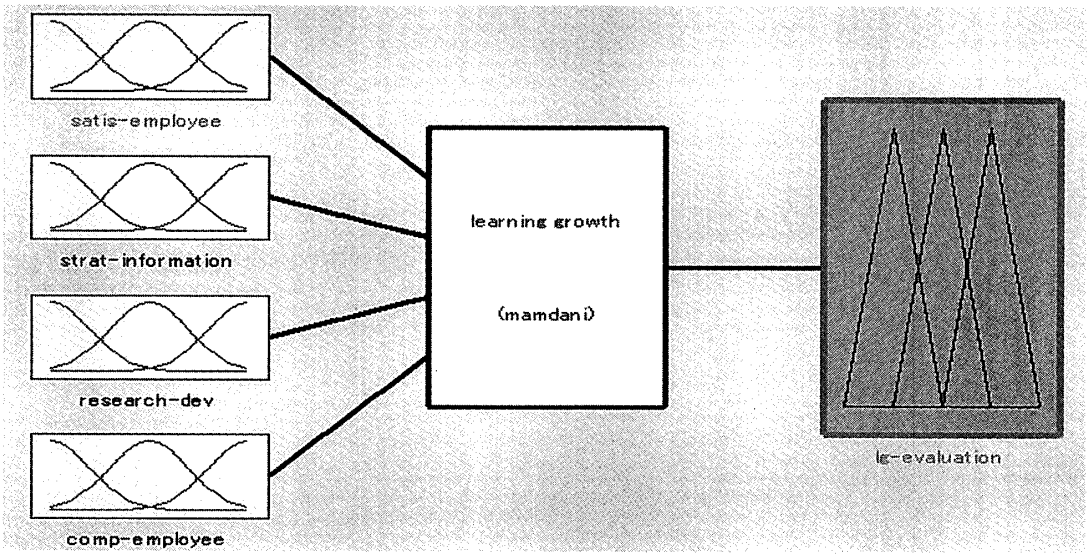


Figure 32 Measurement model of organization learning perspective

(a) Membership function

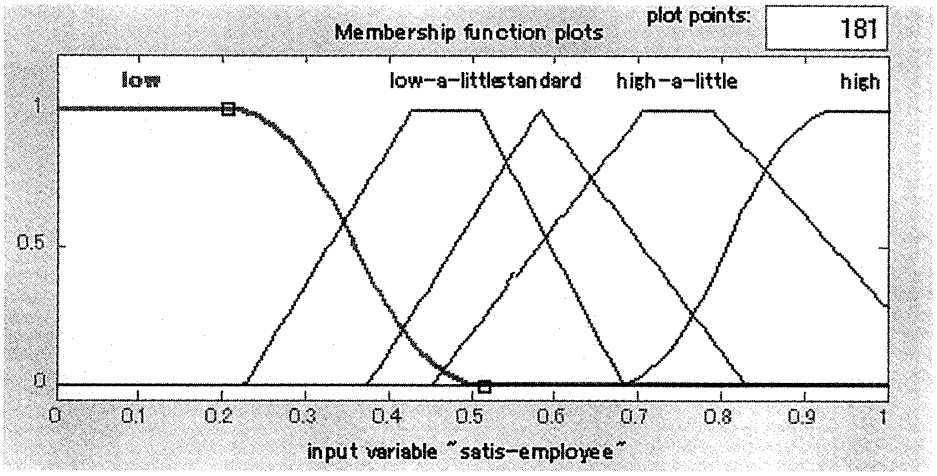


Figure 33 Membership function of employee job satisfaction

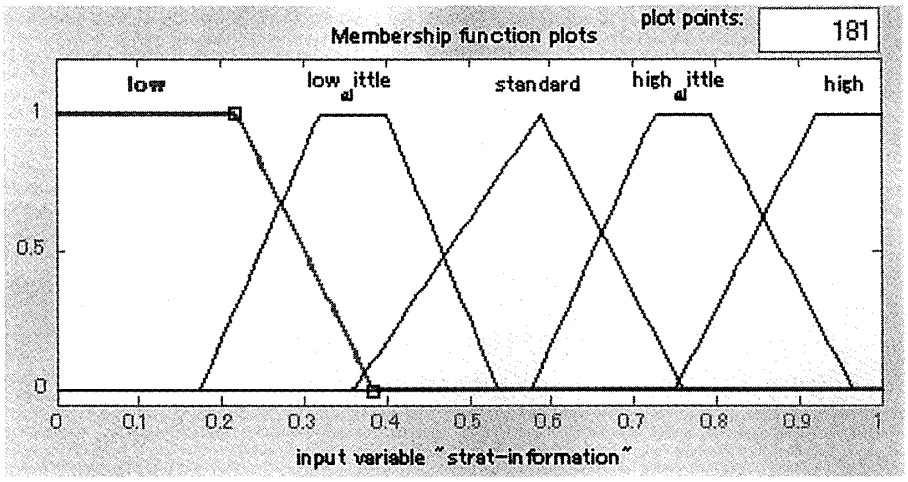


Figure 34 Membership function of strategic information infrastructure rate

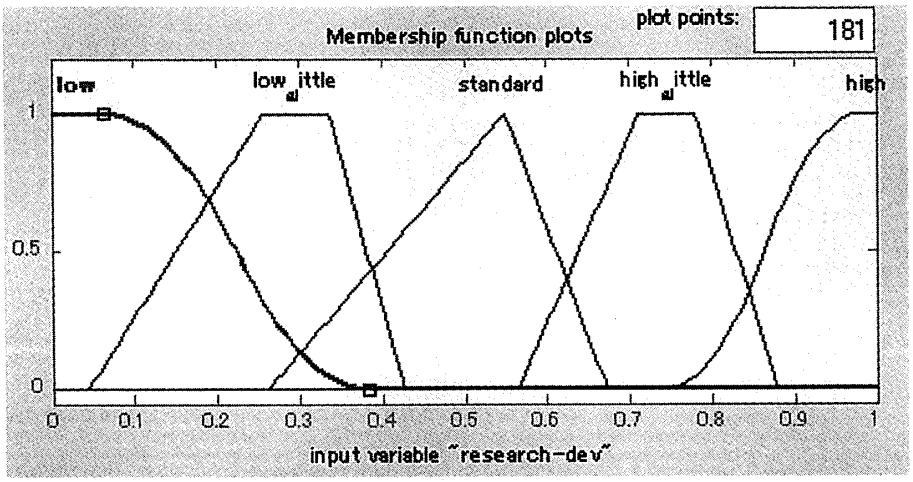


Figure 35 Membership function of research and development

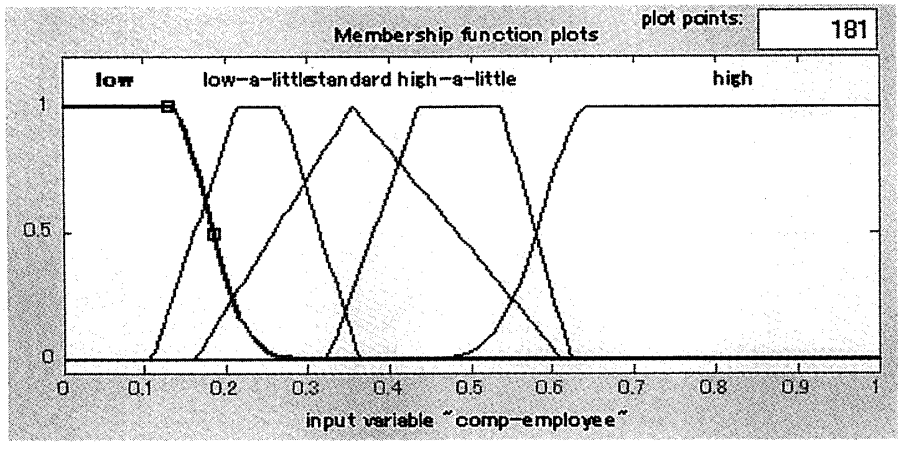


Figure 36 Membership function of claim response time

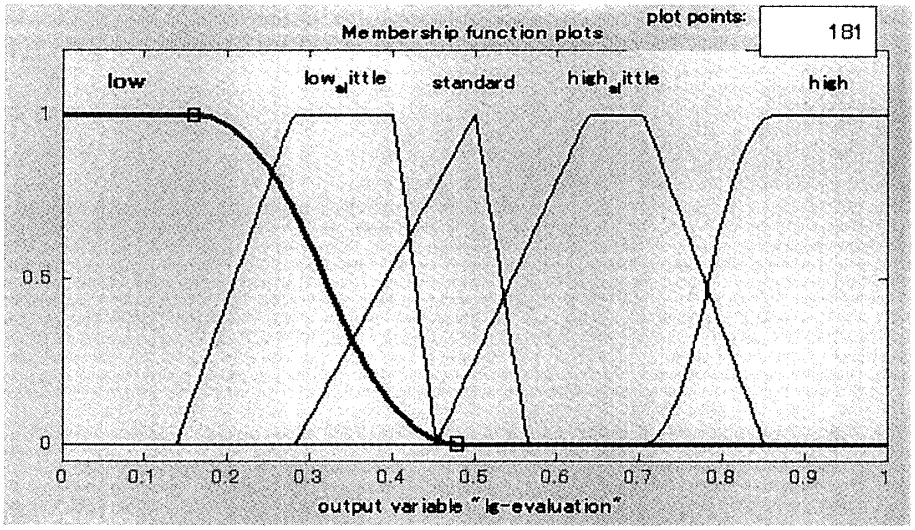


Figure 37 Membership function of organization learning perspective

(b) Inference rule (partially):

1. If (satis-employee is low) and (strat-information is low) and (research-dev is low) and (comp-employee is low) then (lg-evaluation is low) (1)
2. If (satis-employee is low) and (strat-information is low) and (research-dev is low) and (comp-employee is low-a-little) then (lg-evaluation is low) (1)
3. If (satis-employee is low) and (strat-information is low) and (research-dev is low) and (comp-employee is standard) then (lg-evaluation is low) (1)
4. If (satis-employee is low) and (strat-information is low) and (research-dev is low) and (comp-employee is high-a-little) then (lg-evaluation is low) (1)
5. If (satis-employee is low) and (strat-information is low) and (research-dev is low) and (comp-employee is high) then (lg-evaluation is low) (1)

...

200. If (satis-employee is low-a-little) and (strat-information is standard) and (research-dev is high) and (comp-employee is high) then (lg-evaluation is high) (1)
201. If (satis-employee is low-a-little) and (strat-information is high a little) and (research-dev is low) and (comp-employee is low) then (lg-evaluation is low) (1)
202. If (satis-employee is low-a-little) and (strat-information is high a little) and (research-dev is low) and (comp-employee is low-a-little) then (lg-evaluation is low a little) (1)
203. If (satis-employee is low-a-little) and (strat-information is high a little) and (research-dev is low) and (comp-employee is standard) then (lg-evaluation is low a little) (1)
204. If (satis-employee is low-a-little) and (strat-information is high a little) and (research-dev is low) and (comp-employee is high-a-little) then (lg-evaluation is low a little) (1)

400. If (satis-employee is high-a-little) and (strat-information is low) and (research-dev is high) and (comp-employee is high) then (lg-evaluation is high) (1)
401. If (satis-employee is high-a-little) and (strat-information is low a little) and (research-dev is low) and (comp-employee is low) then (lg-evaluation is low) (1)
402. If (satis-employee is high-a-little) and (strat-information is low a little) and (research-dev is low) and (comp-employee is low-a-little) then (lg-evaluation is low) (1)
403. If (satis-employee is high-a-little) and (strat-information is low a little) and (research-dev is low) and (comp-employee is standard) then (lg-evaluation is low) (1)
404. If (satis-employee is high-a-little) and (strat-information is low a little) and (research-dev is low) and (comp-employee is high-a-little) then (lg-evaluation is low a little) (1)

620. If (satis-employee is high) and (strat-information is high) and (research-dev is high a little) and (comp-employee is high) then (lg-evaluation is high) (1)
621. If (satis-employee is high) and (strat-information is high) and (research-dev is high) and (comp-employee is low) then (lg-evaluation is high) (1)
622. If (satis-employee is high) and (strat-information is high) and (research-dev is high) and (comp-employee is low-a-little) then (lg-evaluation is high a little) (1)
623. If (satis-employee is high) and (strat-information is high) and (research-dev is high) and (comp-employee is standard) then (lg-evaluation is high) (1)
624. If (satis-employee is high) and (strat-information is high) and (research-dev is high) and (comp-employee is high-a-little) then (lg-evaluation is high) (1)
625. If (satis-employee is high) and (strat-information is high) and (research-dev is high) and (comp-employee is high) then (lg-evaluation is high) (1)

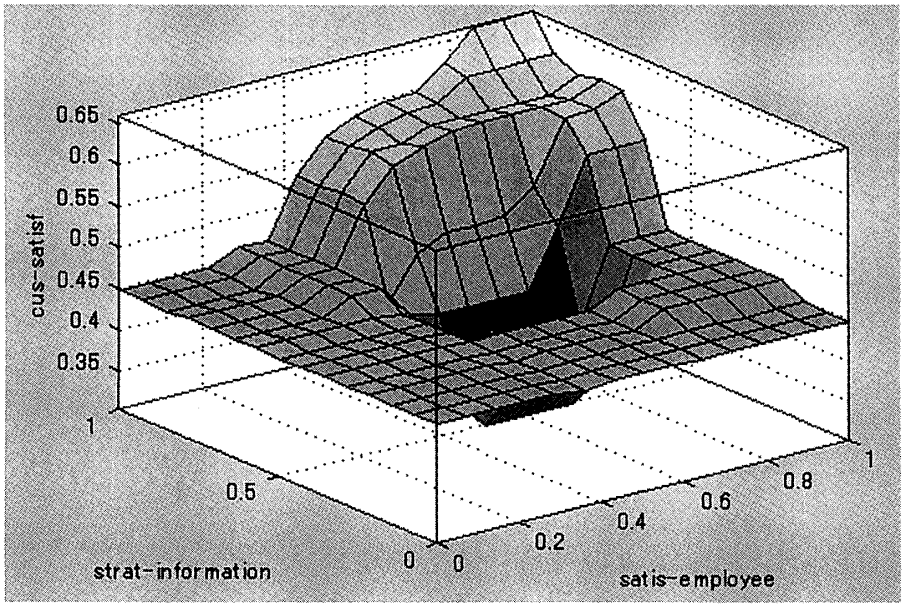


Figure 38 3D for measurement from organization learning perspective

An example: organization learning perspective

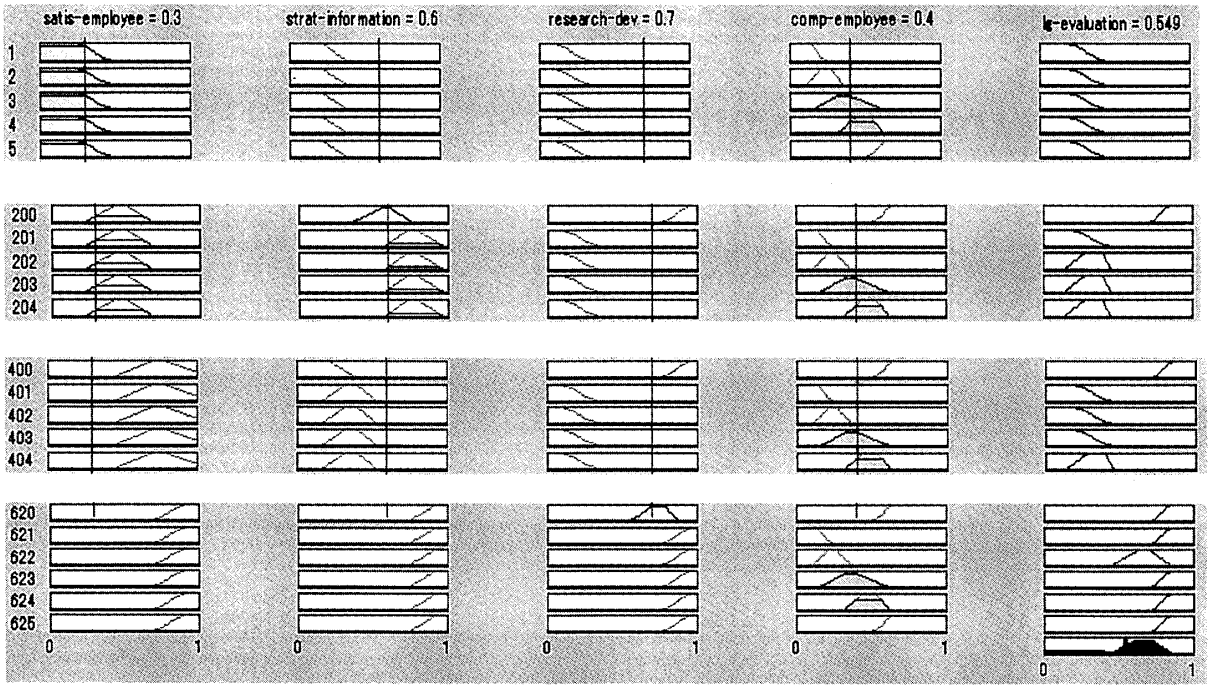
Employee job satisfaction=0.3

Strategic information infrastructure rate=0.6

Research and development=0.7

Employee competence=0.4

Value=0.549



(5) Measurement from four perspectives

Membership function and rule are contributed based on the model shown in figure 13

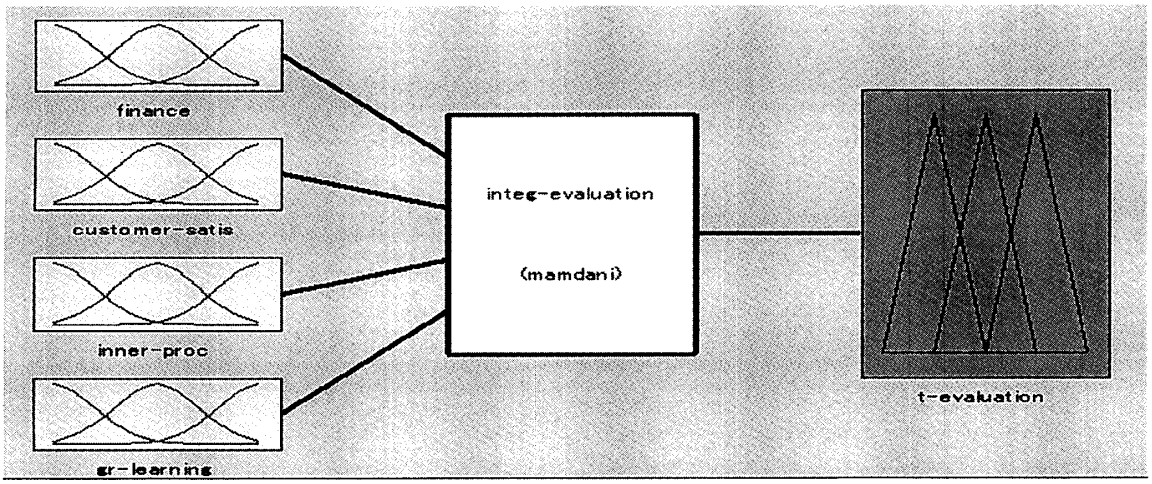


Figure 39 Measurement model of four perspectives

(a) Membership function

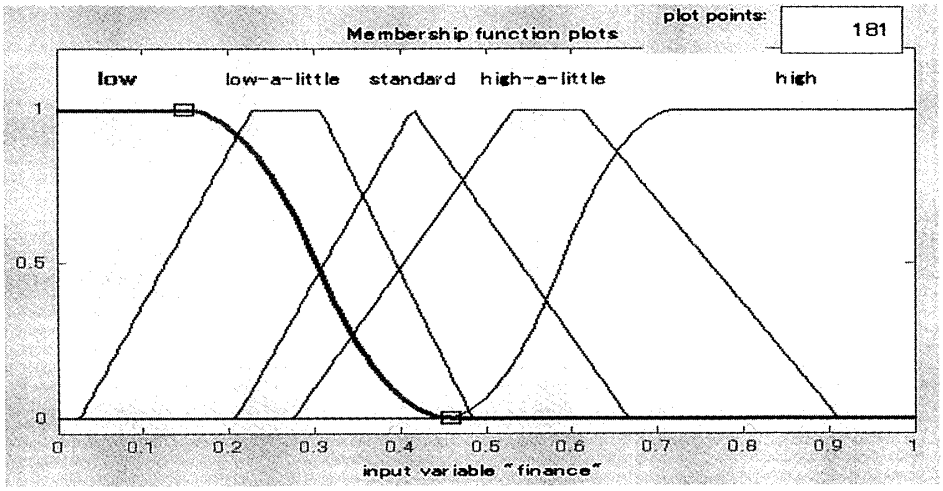


Figure 40 Membership function of financial perspective

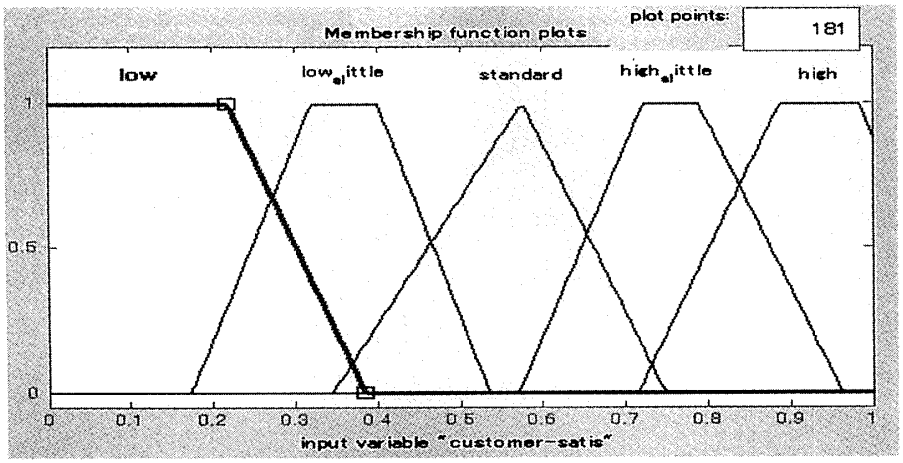


Figure 41 Membership function of customer perspective

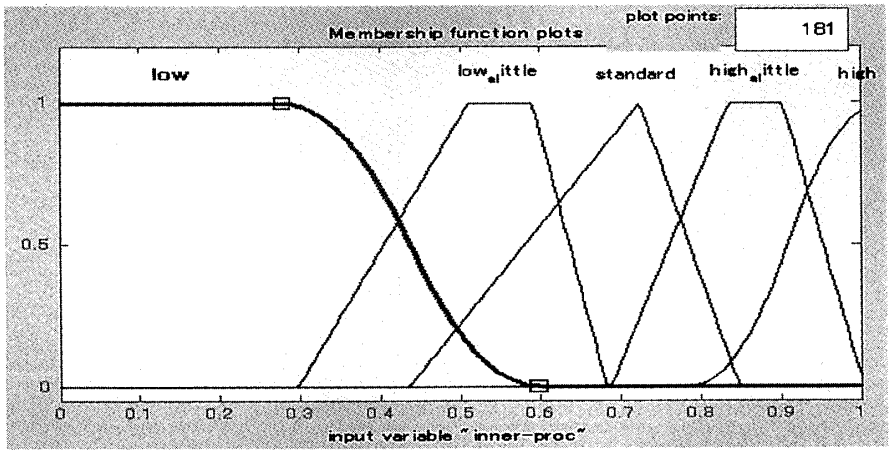


Figure 42 Membership function of internal process perspective

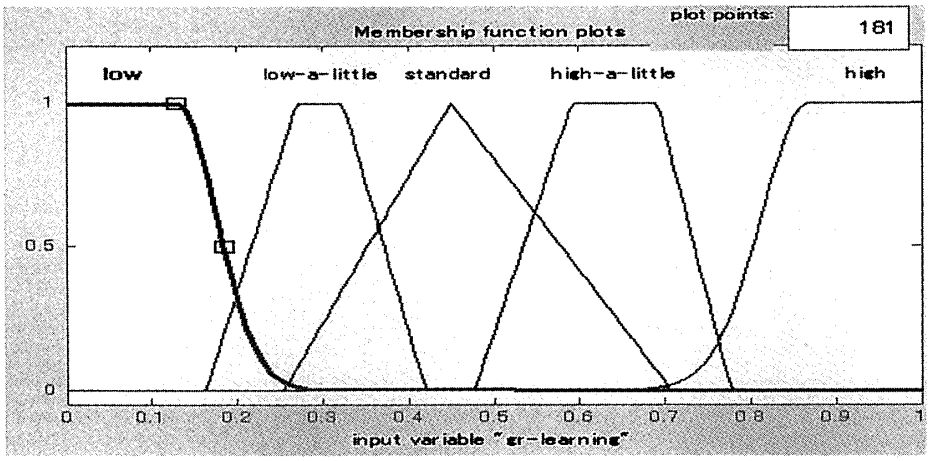


Figure 43 Membership function of learning and growth perspective

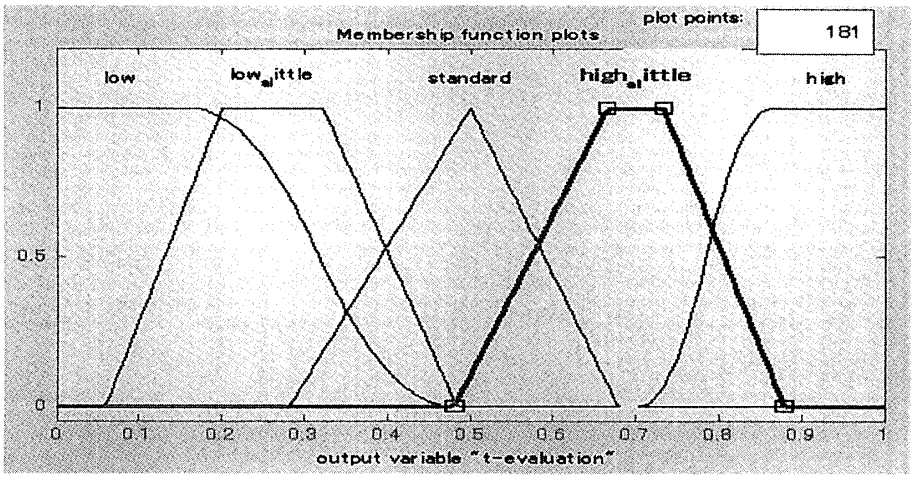


Figure 44 Membership function of four perspectives

(b) Inference rule (partially):

1. If (finance is low) and (customer-satis is low) and (inner-proc is low) and (gr-learning is low) then (t-evaluation is low) (1)
2. If (finance is low) and (customer-satis is low) and (inner-proc is low) and (gr-learning is low-a-little) then (t-evaluation is low) (1)
3. If (finance is low) and (customer-satis is low) and (inner-proc is low) and (gr-learning is standard) then (t-evaluation is low) (1)
4. If (finance is low) and (customer-satis is low) and (inner-proc is low) and (gr-learning is high-a-little) then (t-evaluation is low) (1)
5. If (finance is low) and (customer-satis is low) and (inner-proc is low) and (gr-learning is high) then (t-evaluation is low) (1)

200. If (finance is low-a-little) and (customer-satis is standard) and (inner-proc is high) and (gr-learning is high) then (t-evaluation is high) (1)
201. If (finance is low-a-little) and (customer-satis is high a little) and (inner-proc is low) and (gr-learning is low) then (t-evaluation is low) (1)
202. If (finance is low-a-little) and (customer-satis is high a little) and (inner-proc is low) and (gr-learning is low-a-little) then (t-evaluation is low a little) (1)
203. If (finance is low-a-little) and (customer-satis is high a little) and (inner-proc is low) and (gr-learning is standard) then (t-evaluation is low a little) (1)
204. If (finance is low-a-little) and (customer-satis is high a little) and (inner-proc is low) and (gr-learning is high-a-little) then (t-evaluation is low a little) (1)

400. If (finance is high-a-little) and (customer-satis is low) and (inner-proc is high) and (gr-learning is high) then (t-evaluation is high) (1)
401. If (finance is high-a-little) and (customer-satis is low a little) and (inner-proc is low) and (gr-learning is low) then (t-evaluation is low) (1)
402. If (finance is high-a-little) and (customer-satis is low a little) and (inner-proc is low) and (gr-learning is low-a-little) then (t-evaluation is low) (1)
403. If (finance is high-a-little) and (customer-satis is low a little) and (inner-proc is low) and (gr-learning is standard) then (t-evaluation is low) (1)
404. If (finance is high-a-little) and (customer-satis is low a little) and (inner-proc is low) and (gr-learning is high-a-little) then (t-evaluation is low a little) (1)

620. If (finance is high) and (customer-satis is high) and (inner-proc is high a little) and (gr-learning is high) then (t-evaluation is high) (1)
621. If (finance is high) and (customer-satis is high) and (inner-proc is high) and (gr-learning is low) then (t-evaluation is high) (1)
622. If (finance is high) and (customer-satis is high) and (inner-proc is high) and (gr-learning is low-a-little) then (t-evaluation is high a little) (1)
623. If (finance is high) and (customer-satis is high) and (inner-proc is high) and (gr-learning is standard) then (t-evaluation is high) (1)
624. If (finance is high) and (customer-satis is high) and (inner-proc is high) and (gr-learning is high-a-little) then (t-evaluation is high) (1)
625. If (finance is high) and (customer-satis is high) and (inner-proc is high) and (gr-learning is high) then (t-evaluation is high) (1)

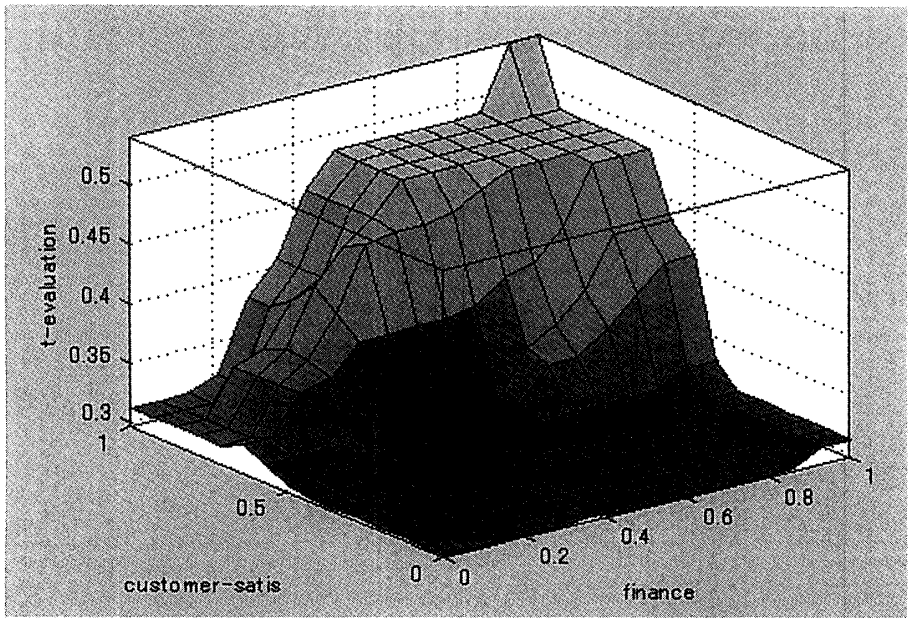


Figure 45 3D for measurement from four perspectives

An example: customer perspective

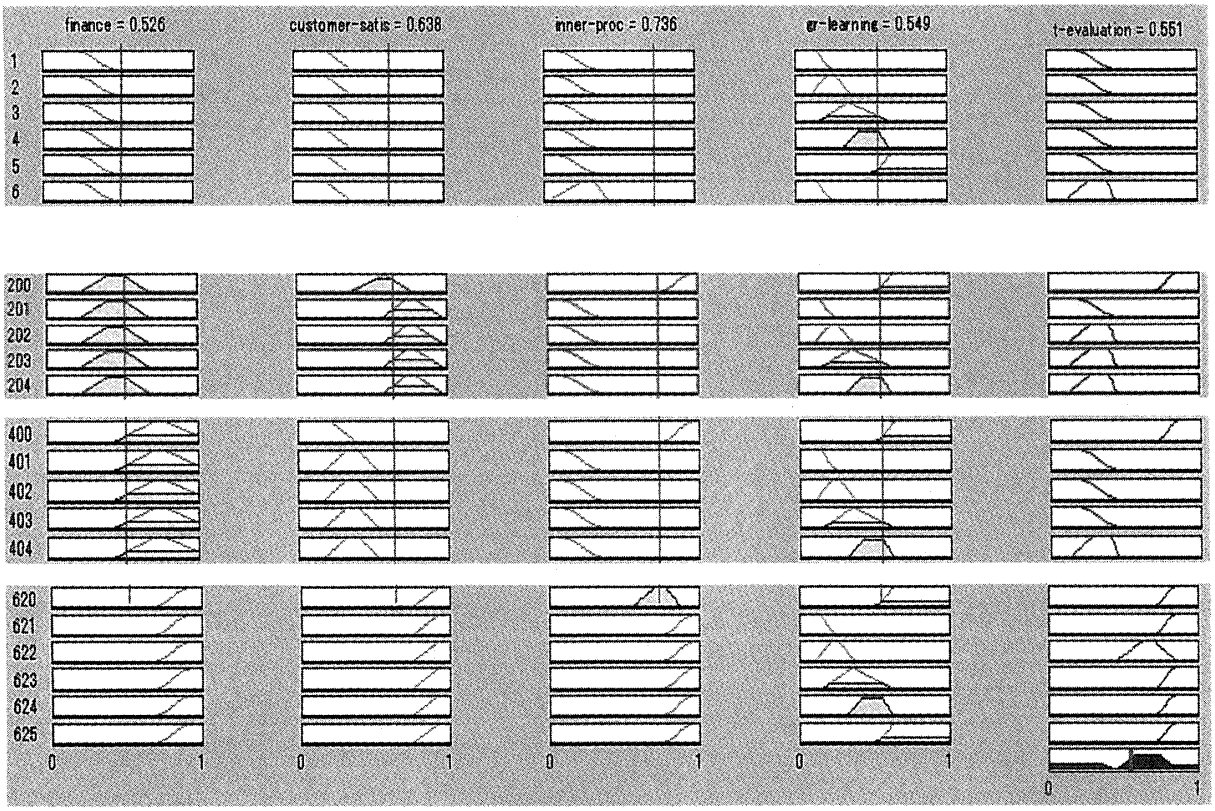
Finance=0.526

Customer=0.638

Internal process=0.736

Organization learning=0.549

Value=0.551



7. Conclusion

In this paper, the following points are indicated:

(1) We propose a method to integrate each perspective structural model based on balanced scorecard – finance, customer, internal business and learning and growth perspective to achieve an integral value for performance measurement. And the validity of the proposed method is discussed.

(2) Each perspective structural model constructed in the paper enable to response flexibly with dynamic environment and evaluators.

(3) The characteristic of multi-dimensional measurement system of performance is the processes to reflect the understanding or know-how relative evaluators have to integrate the each perspective evaluation value effectively under the dynamic social and business environment.

(4) The evaluators no matter who even do not understand the context of the given measurement problem theoretically enable to measure performance specialist-likely.

(5) We focus on the configuration of membership function and rules for measuring and integrating the rational value for performance measurement. However, several simulation issues need to be done in the following research.

(6) It is possible that the rational measuring value can be derived through a feedback which is iterated within multi-dimensional decision-making system (see Figure 9) for drawing out evaluating elements and constructing structural models, which is an important subject in the paper.

We used MATLAB to construct the performance measurement system based on BSC with the fuzzy inference.

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