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Enhanced Six Sigma Business Scorecard and Application Research Based on Entropy Weight and Relative Approach Degree

[1]Weimin Ye, [1]Deyong Zhao, [1]Woye Liu, [2]Jingzhong Li, [1]Xiao Chen and [1]Yu Bai
[1]Department of Management Engineering,
[2]Department of Training, College of Mechanical Engineering,
Shijiazhuang, 050003, People's Republic of China

Abstract: In order to improve the accuracy and operability of Six Sigma Business Scorecard (SSBS) method, the model of enhanced SSBS based on entropy weight and relative approach degree was proposed. For overcoming the lack of specific method in determining the indexes weight, entropy weight theory was introduced to modify the subjective weight which improved the accuracy of the index weight determination process in SSBS. Moreover, approach degree theory was also introduced to figure out the sigma value and relative approach degree between two levels based on vector standardization which enhanced the evaluation value determination method of six sigma business scorecard. Lastly, a demonstration example was analyzed the validity of this method is proved.

Key words: Performance evaluation, six sigma business scorecard, entropy weight, relative approach degree

INTRODUCTION

SSBS comes into existence along with the development of enterprise performance evaluation system and six sigma management. Performance evaluation system is an organic combination of a series of rules, indexes, methods, standards and institutions related to performance. As a breakthrough, DuPont financial analysis system became popular all over the world soon after its appearance, but it simply focuses on finance and internal management instead of the influence of external market upon the enterprise. In view of this, balanced scorecard is jointly developed by Robert Kaplan and David Norton to keep concerns balanced in view of finance, customer, internal process, learning and growth so as to provide a full assessment to the development of the organization. However, balanced scorecard is mainly used in high strategic level of the organization (Yao, 2008).

Members of American Society of Quality and six sigma black belt masters Praveen Gupta make a perfect combination of six sigma method with balanced scorecard to create an efficient evaluation system-SSBS (Xiong, 2011; Gupta, 2005). Integrating six sigma management with balanced scorecard, SSBS achieves maximized profitability and growth via a complete set of strategies, accelerate organization growth, specify duties of a leader as well as encourage employees' active participation. When receiving growing attention from scholars, it provides organization with a new approach not only for performance evaluation but also for project analysis and evaluation that accord with sigma level during lean six sigma strategy improvement.

However, from a general point of view, there is a shortage of studies on six sigma scorecard and in-depth discussions on six sigma scorecard evaluation. In particular, scientific methods are badly needed in view of the weight of indexes classification and performance ratio determination. For this reason, this paper introduces entropy weight theory and relative approach degree into SSBS in order to improve scientific and practical application of SSBS.

FUNDAMENTALS OF SSBS

SSBS combines six sigma method that can significantly improve customer satisfaction with balanced scorecard that focuses on the pursuit of financial goals (Feng, 2013), aiming to provide an efficient enterprise performance evaluation system so that enterprises can strike a balance between profitability and growth. In view of cost, revenue, improvement and innovation, SSBS divides index measurement into seven parts as shown in Fig. 1.

Corresponding Author: Weimin Ye, Department of Management Engineering, College of Mechanical Engineering, Shijiazhuang, 050003, People's Republic of China

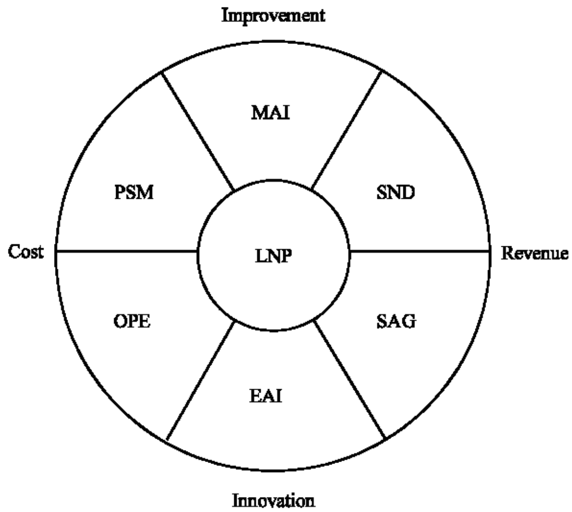

Fig. 1: Components of SSBS

These seven components are Leadership and Profitability (LNP), Management and Improvement (MAI), Employees and Innovation (EAI), Purchasing and Supplier Management (PSM), Operational Execution (OPE), Sales and Distribution (SND) and Service and Growth (SAG), each of can be supplemented with subdivided index restricted with limited applicable scope. Their goals are to evaluate effectiveness of key operations that may impose great impact upon organization health and profit, analyze fields necessary to be improved and determine the direction for lean six sigma project operation.

Combining the advantages of balanced scorecard, SSBS measures organization performance with business performance index (BPIn), merits and demerits of each index category, as well as overall sigma level. Basic ideas of SSBS-based organization performance evaluation and lean six sigma project selection are that after determination of evaluation objective and index system, category acronyms (which categories the index belongs to) shall be determined to work out index contribution and sigma level of BPIn and organization on the basis of category importance and performance ratio.

Operations are listed as follows (Tang, 2006; He and Gao, 2009):

- Analyze the chosen index x_i which are subordinated to the category x'_j, among which i = 1, 2,…, m, m is the number of indexes and j = 1, 2,…, 7
- Set the weight of x'_j in the chosen index system
- Determine performance ratio μ_i through calculating the ratio between actual performance and planned performance
- Work out weighted value of the indexes and organization BPIn

$$BPIn=\sum_{i=1}^{n}\omega_j\mu_i \quad (1)$$

- Work out defects per unit (defect per unit, DPU):

$$DPU=-\ln\left(\frac{BPIn}{100}\right)=\frac{\text{No. of defects in a certain process}}{\text{No. of products in a certain departments}} \quad (2)$$

- Work out organization defects per million opportunities (defect per million opportunities, DPMO):

$$DPMO=\frac{DPU\times 10^6}{\text{No. of managers(departments)}}=\frac{\text{No. of defects in a certain process}\times 10^6}{\text{Total No. of defects opportunities}} \quad (3)$$

- After getting DPMO, organization sigma level *Z* can be consulted or obtained through the following formula in MATLAB:

$$Z=\text{norminv}\left(1-\frac{DPMO}{10^6}\right)+1.5 \quad (4)$$

Herein 1.5 is added when center drifting value (Tao and Chen, 2005) is considered.

SSBS BASED ON ENTROPY WEIGHT AND RELATIVE APPROACH DEGREE

Weight determining method of indexes classification based on entropy: Traditional SSBS fail to put forward appropriate methods for determining importance degree of the seven index categories. Generally speaking, scholars refer to index weights recorded as in (Gupta, 2005) rather than give considerations to the greatly different index weights resulting from various practical demands of enterprises and organizations of kinds.

SSBS determination and index category importance degree can be improved in accurate weight analysis through entropy weight theories and expert decisions.

First, set judgment matrix $(U'_{ab})_{n\times n}$ of index category $X' = (x'_1, x'_2,\ldots, x'_n)$ based on expert decision assignment and supplement judgment matrix according to category of the index $X = (x_1, x_2,\ldots, x_m)$ chosen and determine the value of new element in the new judgment matrix $(U_{i1i2})_{m\times m}$ in line with the following rules.

$$u_{i_1i_2}=\begin{cases}1, & i_1=i_2;\\ u_{j_1j_1}=1, & x_{i_1}\text{ belongs to }x'_{j_1}\text{, and }x_{i_2}\text{ belongs to }x'_{j_1};\\ u'_{j_1j_2}, & x_{i_1}\text{ belongs to }x'_{j_1}\text{, but }x_{i_2}\text{ belongs to }x'_{j_2}\end{cases} \quad (5)$$

Based on consistency check, work out maximum characteristic root λ_{max} and corresponding eigenvector η of the judgment matrix $(U_{i1i2})_{m\times m}$ and make eigenvector components the weight $\eta = (\eta_1, \eta_2,\ldots, \eta_m)$ of each corresponding index category.

Then use entropy technology (Wang, 2010; You and Yang, 2012) to correct weights as follows:

Step 1: Normalize all column vectors in view of the established $(U_{i1i2})_{m\times m}$ to get standard matrix $V = \{V_{i1i2}\}_{m\times m}$ and work out the output entropy value of index x_{i2}

$$E_{i_2} = -K\sum_{i_2=1}^{m} v_{i_1 i_2} \ln v_{i_1 i_2} \quad (i_2 = 1, 2, \cdots, m) \tag{6}$$

Wherein constant $K = (\ln n)^{-1}$ and it can be verified that $0 \le E_{i2} \le 1$.

Step 2: Work out the degree of deviation D_{i2} of index x_{i2}:

$$D_{i2} = 1 - E_{i2} \; (i_2 = 1, 2,\ldots, m) \tag{7}$$

Step 3: Work out the information weight ξ_{i2} of index x_{i2}:

$$\xi_{i_2} = \frac{D_{i_2}}{\sum_{i_2=1}^{m} D_{i_2}} (i_2 = 1, 2, \cdots, m) \tag{8}$$

Step 4: Use information weight ξ_{i2} to correct weight vector η obtained through expert decision making:

$$\omega_{i_2} = \frac{\xi_{i_2}\eta_{i_2}}{\sum_{i_2=1}^{m} \xi_{i_2}\eta_{i_2}} \quad (i_2 = 1, 2, \cdots, m) \tag{9}$$

Finally, Then the index weight vector is:

$$\omega = (\omega_1, \omega_2,\ldots, \omega_{i2},\ldots \omega_m) \tag{10}$$

Evaluation value conversion method based on relative approach degree: Traditional SSBS sees planned performance as the reference which is unfavorable for direct comparison between organization performance and excellent industry performance for the purpose of endeavoring to the top level in the industry. The use of absolute value ratio of performance as the evaluation index value makes it difficult to measure the relative level of organization performance in the industry. Based on (Song, 2004), SSBS based computation of two performance contrast ratio can determine evaluation index values by introducing relative approach degree and specific reference standards.

Also known as distance comprehensive evaluation, relative approach degree combines relevancy in grey system theory with fuzzy mathematics and adopts the index of "relative approach degree" to sequence and compare various decision schemes. With advantages of wide application scope, no special requirements on sample size, small amount of calculation, direct geometrical significance and small information distortion, relative approach degree is often used in comprehensive comparison of economic benefit, especially numeric index analysis.

First, determine maximum and minimum index values in feasible region, together with the best reference point and the worst reference point.

Make data collection and analysis on the chosen indexes $X = (x_1, x_2,\ldots, x_m)$ to determine performance value range $[d_{i1}, d_{i2}]$ of the similar-sized industry peers, thus scop-min = $(d_{11}, d_{21},\ldots, d_{m1})$ and synchronously scop-max = $(d_{11}, d_{2},\ldots, d_{m2})$. Among which d_{i2} is the maximum performance level of index x_i within the feasible region. When x_i is benefit index, optimal performance level is reached and while x_i is cost index, the worst performance level is reached. d_{i1} is the minimum performance level of x_i within the feasible region. When x_i is benefit index, the worst performance level is reached and while x_i is cost index, the optimal performance level is reached. Therefore, we get excellent performance index (best reference point) $\bar{M} = (\bar{M}_1, \bar{M}_2, \cdots, \bar{M}_m)$ and the worst performance index (worst reference point) of the industry $\underline{M} = (\underline{M}_1, \underline{M}_2, \cdots, \underline{M}_m)$. If x_i is benefit index, $\bar{M}_i = \max(d_{i1}, d_{i2})$ and $\underline{M}_i = \min(d_{i1}, d_{i2})$ or if x_i is cost index, $\bar{M}_i = \min(d_{i1}, d_{i2})$ and $\underline{M}_i = \max(d_{i1}, d_{i2})$.

Then, standardize indexes and vectors.

Traditional SSBS fails to process indexes. Evaluation based on absolute value of actual value cannot accord with industry level and evaluation values of performance levels are typically greater. Based on value range of each index, this paper carries out standardization transformation of indexes and standardized processing of corresponding vectors.

Conduct standardized conversion on index, we get:

$$y_i = \frac{x_i - \underline{M}_i}{\bar{M}_i - \underline{M}_i} \tag{11}$$

In view of such vector standardization, any vector $X = (x_1, x_2,\ldots, x_m)$ $(d_{i1} \le x_i \le d_{i2}$ $i = 1, 2,\ldots, m)$ then can be called:

$$Ref\_x = \left(\frac{x_1 - \underline{M}_1}{\bar{M}_1 - \underline{M}_1}, \frac{x_2 - \underline{M}_2}{\bar{M}_2 - \underline{M}_2}, \ldots, \frac{x_m - \underline{M}_m}{\bar{M}_m - \underline{M}_m}\right)$$

as standardized vector of vector x. Standardized vectors of the best reference point $\bar{M} = (\bar{M}_1, \bar{M}_2, \cdots, \bar{M}_m)$ and the worst reference point $\underline{M} = (\underline{M}_1, \underline{M}_2, \cdots, \underline{M}_m)$ are Ref_max = (1, 1..., 1) and Ref_min = (1, 1..., 1), respectively.

Then, work out the weighted distance between standardized vectors and the best reference point and the worst reference point.

Based on weights from Eq. 10 and standardization from Eq. 11, weighted distance g_1 between standardized vector and the best reference point as well as weighted distance g_2 between standardized vector and the worst reference point can be work out:

$$g_1(x) = \sqrt{\sum_{i=1}^{m} \omega_i (y_i - 1)^2}$$

$$g_2(x) = \sqrt{\sum_{i=1}^{m} \omega_i (y_i - 0)^2} \quad (12)$$

Finally, work out the relative approach degree c with the best reference point:

$$c(x) = \frac{g_2(x)}{g_1(x) + g_2(x)} \quad (13)$$

Obviously, when c(x) is greater, it means the target vector gets closer to the best reference point which means organization performance level gets closer to the industry's excellent performance level. With c(x) expressing organization BPIn level, a series of subsequent operations then give organization sigma level.

PRACTICAL EXAMPLE

A common equipment maintenance factory is an important land forces ordnance equipment maintenance bases in China, with 11 functional departments such as sub-service factories, machining factories and logistics branches. Lean six sigma strategy quality improvement decides SSBS for analysis on organization performance so as to determine organization performance level and carry out key projects.

As shown in Table 1, after data collection and analysis by referring the indexes $X = (x_1, x_2, \ldots, x_m)$ as in (Gupta, 2005), the indexes value of the actual performance of the factory can be gained as x = (78, 0.17, 0.39, 1.11, 0.82, 0.52, 11, 0.26, 0.39, 0.79) and then industry performance indexes value range can be shown as:

$$[d_{11}, d_{12}] = [2., 91], [d_{21}, d_{22}] = [0.02, 0.24]$$

$$[d_{31}, d_{32}] = [0.08, 0.46], [d_{41}, d_{42}] = [0.41, 1.71]$$

$$[d_{61}, d_{62}] = [0.11, 0.73], [d_{51}, d_{52}] = [0.57, 1.02]$$

$$[d_{71}, d_{72}] = [8, 23], [d_{81}, d_{82}] = [0.12, 0.77]$$

$$[d_{91}, d_{92}] = [0.13, 0.54] \text{ and } [d_{101}, d_{102} = [58, 96]$$

Then, $\underline{M} = (24, 0.02, 0.08, 0.41, 1.02, 0.73, 23, 0.77, 0.13, 58)$ and $\overline{M} = (91, 0.24, 0.46, 1.71, 0.57, 0.11, 8, 0.12, 0.54, 96)$.

Based on expert decision-making assignment, opinions from leaderships, experts, suppliers and military representatives, as well as expanded judgment matrix from expert decisions, entropy technology is used to correct and obtain the final weight vector ω = (0.1547, 0.1547, 0.199, 0.096, 0.052, 0.052, 0.047, 0.047, 0.086, 0.107)^T.

With relative approach degree and MATLAB mentioned in this study, we get the standardized vector of measured value y = (0.8060, 0.6818, 0.8158, 0.5385, 0.4444, 0.3387, 0.8000, 0.7846, 0.6341, 0.5526) and synchronously $g_1(x) = 0.3533$, $g_2(x) = 0.6912$, $c(x) = 0.6618$. When BPIn is taken as relative approach degree, we finally, get DPU = 0.4128, DPMO = 37531 and Z = 3.2801. All the data is cleared up and shown in Table 1.

Table 1: Improved SSBS of one common equipment maintenance factory

Indexes	Acronym	Weight	Worst ref.	Best ref.	Actual value	Standardized value
Approbation	LNP	0.154	24.00	91.00	78.00	0.8060
Profit	LNP	0.154	0.02	0.24	0.17	0.6818
Improvement rate	MAI	0.201	0.08	0.46	0.39	0.8158
Proposal per person	EAI	0.096	0.41	1.71	1.11	0.5385
Total expense/Total sales	PSM	0.052	1.02	0.57	0.82	0.4444
Supplier defect rate	PSM	0.052	0.73	0.11	0.52	0.3387
Operating cycle	OPE	0.047	23.00	8.00	11.00	0.8000
Process defect rate	OPE	0.047	0.77	0.12	0.26	0.7846
New revenue/Total revenue	SND	0.093	0.13	0.54	0.39	0.6341
Customer satisfaction	SAG	0.104	58.00	96.00	79.00	0.5526
Relative approach degree/BPIn	0.6618					
DPU						0.4128
DPMO						37531
Sigma level						3.2801

Then we get BPIn of 0.6618 and sigma level of 3.2801 which are only passable values, indicating there is still space for improvement for organization performance to catch up with industry excellent performance. Analysis on standardized vector y suggests that satisfactory y_1 (recognition of employees), y_3 (improvement rate), y_7 (operating cycle) and unsatisfactory performance in $y_5 = 0.3387$ (total expense/total sales) and y_6 (supplier defect rate). $y_5 = 0.3387$ which is far behind from excellent performance level, so it can be made a key direction of lean six sigma quality improvement that is to be specifically analyzed in the next step.

CONCLUSION

This study aims to improve SSBS method by introducing entropy weight theory and relative approach degree. Weight from entropy corrected expert decisions can better solve index category assignment. New performance comparison standards and measurement methods are introduced. Based on vector standardization, this paper uses weighted distance between actual value and ideal point & negative ideal point to calculate relative approach degree and sigma level between organization performance and excellent performance. This method makes SSBS more scientific, practicable and maneuverable so that the evaluation process is more scientific and reasonable which provides organization performance evaluation with a new and effective way. In view of the deepening practical applications, index setting and diversified evaluation of performance comparison standards are still open to further research.

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