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CRITICAL SUCCESS FACTORS OF SIX-SIGMA IMPLEMENTATION: AN ANALYTIC HIERARCHY PROCESS BASED STUDY

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Six-Sigma is a well-established and one of the most recognized approaches in manufacturing strategy development. Companies who have adopted and successfully implemented such a methodology were found to be more innovative which led to increased customer satisfaction and an improved bottom line. The aim of this study is to identify factors for successful Six-Sigma implementation by using the Analytic Hierarchy Process (AHP). The study involves four phases, which include: (1) assessment of potential factors and performance measures in Six-Sigma implementation (2) development of the problem structure and building the AHP model (3) soliciting and compilation of opinion on preferences through expert interviews, and (4) determination of critical success factors. Twenty-one experts, consisting of three-project champions and eighteen-black belts from five multinational companies located in Thailand, were interviewed. Expert Choice® software was used to compute the normalized and unique priority weights. The results of the data analysis determined the relative importance of individual factors, and in turn identified the critical factors on which organizations should consolidate their efforts in the process of implementing Six-Sigma methodology.

Keywords: Analytic hierarchy process (AHP); critical factors; multinational company; Six-Sigma; Thailand.

1. Introduction

Six-Sigma is a well-established and one of the most recognized manufacturing strategies, and is gaining wide acceptance in the industry. Many large and small companies have successfully implemented this strategy. For example, in 1999 General Electric spent about half a billion in Six-Sigma initiatives and received over two billion in benefits for that fiscal year [Pande *et al.* (2000)]. Other companies such as Texas Instruments, Honeywell, and Johnson and Johnson have gained substantial benefits from Six-Sigma implementations [Kwak and Anbari (2004)]. It takes a holistic and multidimensional systems approach towards understanding and providing solutions for problems, and thus develops close links between organizational competitiveness, customer satisfactions, and continual improvement. By implementing the Six-Sigma strategy, organizations could achieve breakthrough improvement with a dramatic impact not only on financial benefits but also customer satisfaction and manufacturing capability [Harry and Schroeder (2000)].

While the Six-Sigma strategy has made a substantial impact on industry, academic research in this area is lacking, particularly research regarding what makes a successful Six-Sigma implementation. The purpose of this study is to identify factors for successful Six-Sigma implementation by employing the Analytic Hierarchy Process (AHP) approach. This method allows us to define those success factors in a hierarchical structure of factors, evaluate factors in pairs, and quantify the relative importance of each factor to the successful implementation. This study utilizes preference data from selected experts involved in Six-Sigma projects. The following section reviews relevant literature in the field and identifies the factors for successful Six-Sigma strategy implementation. A detailed discussion on research methodology is given in Sec. 3, while data analysis and findings are shown in Sec. 4. Finally, managerial implications are discussed in Sec. 5.

2. Literature Review

2.1. *Brief history of Six-Sigma*

Six-Sigma is an approach to quality management that originated at Motorola Inc. in the 1980s [Antony (2002)]. It was a way for Motorola to express its quality goal where a defect opportunity is a process failure that is critical to the customer. This provided a focus on the improvement rate that considered simply ‘better’ may not be sufficient. It was concluded that it is important to become sufficiently better expeditiously. Six-Sigma clearly focused on resources at Motorola, including human effort that reduced variation in all processes including manufacturing and management. The rationale for the name choice was that ‘Sigma’ is a statistical measure related to the capability of the process or its ability to produce non-defective products/units/parts. In statistical term, sigma is a measure of process variation referred to as the standard deviation and ‘Six-Sigma’ generally implies occurrence of defects at a rate of 3.4 defects per million opportunities (DPMO) for defects to arise [Antony and Fergusson (2004)]. Note that this almost certainly implies more than 3.4 defective units per one million units, since typically any given unit is sufficiently complex so as to allow multiple opportunities for defects to occur.

It is generally possible to calibrate the ‘cost of quality’ or the ‘cost of poor quality’ with the sigma level at which processes perform. Six-Sigma performance levels are considered to be world class with the cost of poor quality being less than 1 percent of sales. By contrast, sigma levels of three, four, and five produce DPMO rates of 66807, 6210, and 233, and the corresponding costs of poor quality ranges from 25–40 percent, 15–25 percent, and 5–15 percent respectively [Antony and Banuelas (2002); Banuelas and Antony (2002)]. These numbers substantiate the importance of reducing process variation across all key primary and support processes in an organization as well as variation of that obtained from suppliers.

2.2. *Factors for successful Six-Sigma implementation*

In order to identify the factors for successful Six-Sigma implementation, a large body of literature was searched. This led to the identification of six factors. A brief discussion on the rationale for each factor is given below.

2.2.1. *Management leadership, involvement and commitment*

The literature suggests that management leadership, involvement, and commitment is an important factor in Six-Sigma implementation since it improves performance by influencing other factors including total quality management (TQM) practices [Banuelas and Antony (2002, 2003)]. Successful implementation of Six-Sigma requires effective change in organizational culture, and it is almost impossible to change an organization without a concerted effort by management aimed at encouraging continuous improvement, involvement among people within the organization, and cooperation throughout the supply chain [Breyfogle *et al.* (2001); Pande and Holpp (2002)].

2.2.2. *Training and understanding the Six-Sigma methodology, tools and techniques*

Employee training has been identified as a critical component of workforce management when implementing significant changes in an organization [Dale (2000); Choo *et al.* (2003)]. If it is to be effective — by, for example, transforming employees into creative problem solvers — training in quality-related aspects should emphasize both tools and techniques in problem solving, effective communication, and statistical process control [Choo *et al.* (2003)]. Workforce training in tools and techniques must be continuously carried out if the improvement effort is to be sustained, as an ongoing training program will help employees discover innovative ways to improve the organization and shoulder more of the responsibility for effecting improvements [Eckes (2000); Halliday (2001); Ingle and Roe (2001)].

2.2.3. *Linking Six-Sigma to business strategy*

Six-Sigma must not be treated as another stand-alone activity. It requires adherence to whole philosophy rather than just the usage of a few tools and techniques of quality improvement [Dale (2000)]. Top management needs to be clear as to how

Six-Sigma strategy and other business strategy are linked to each other and enhance the over competitiveness of the organization [Pande *et al.* (2000)]. Since the competitiveness of most organization is to maximize profits, Six-Sigma strategy could be considered in order to make business process profitable while attacking variability which leads to high scrap rate, high rework rate, low productivity [Sanders and Hild (2000); Banuelas and Antony (2002)].

2.2.4. *Linking Six-Sigma to customers*

The literature suggests that one of the most important factors for successful Six-Sigma implementation is the ability to link this strategy to customers [Harry and Schroeder (2000)]. Six-Sigma should be started and ended with the customer. Projects should begin with the determination of customer needs, requirements, and expectations [Pande *et al.* (2000)]. Therefore, the process of linking this strategy to the customer could be divided into two steps: (a) identifying the core process, defining the key inputs-outputs of these processes, and defining how much cost or profits could be reduced or increased; (b) identifying and defining the customer needs, requirements, and expectation [Banuelas and Antony (2002)].

2.2.5. *Project prioritization, selection and project management skills*

The prioritization and selection of projects for product/process evaluation and improvement is critical for successful Six-Sigma implementation [Sandholm and Sorqvist (2002)]. The selection and definition of projects in an effective manner leads to delays and results in a great deal of frustration [Pande *et al.* (2000)]. Also, previous studies demonstrate that it is important for project team leaders and members to learn tools and techniques of effective project management within the black belt training program [Eckes (2000)]. Since Six-Sigma is a project driven-based strategy, it requires for the team members to have project management skills to meet the various deadlines or milestones during the course of the project [Antony and Banuelas (2002)].

2.2.6. *Linking Six-Sigma to suppliers*

Linking the continual improvement process to suppliers is important for adopting this strategy. It could be facilitated by long-term cooperative relationships with as few suppliers as possible to ensure that the quality materials and/or services would be provided. Maintaining a small number of suppliers improves product quality and productivity of buyers by encouraging enhanced supplier commitment to both the customer responsiveness and quality improvement [Harry (1998); Harry and Schroeder (2000)]. Additionally, Henderson and Evans [2000] suggest that linking Six-Sigma strategy to a small number of suppliers facilitates the solution of quality and delivery problems. Successful linkage encourage suppliers to become involved in the buying firm's design of products, and give them a chance to offer suggestions regarding product and/or component simplification and improvement. They can also help purchasers procure the materials and parts that can be used most

Table 1. Description of Six-Sigma implementation factors.

Factors	Descriptions
Factor 1: Management leadership, involvement and commitment	• Providing adequate financial support; • Involving in project progress review meeting; • Communicating customer needs, requirements, and expectation throughout the organization
Factor 2: Training and understanding the Six-Sigma methodology, tools and techniques	• Providing training budgets; • Establishing the formal training programs; • Evaluating the understanding of all training courses
Factor 3: Linking Six-Sigma to business strategy	• Establishing business/functional strategies; • Determining the linkage among business/functional strategies; • Communicating business/functional strategies to all level of the organization
Factor 4: Linking Six-Sigma to customers	• Determining customer needs, requirements, and expectations; • Communicating the common goal/objective to all level in the organization and customer
Factor 5: Project Selection, prioritization and project management	• Determining project timeframe; • Determining authority and responsibility for each stage of project management; • Follow-up the progress periodically
Factor 6: Linking Six-Sigma to suppliers	• Determining all capable suppliers who involve in continuous improvement activities; • Communicating business and functional strategies to suppliers

efficiently [Hendricks and Kelbaugh (1998); Sandholm and Sorqvist (2002)]. The six factors for successful Six-Sigma implementation and their purposes have been summarized in Table 1.

3. The AHP Methodology

In order to ascertain the managers understanding on factors that affect the successful Six-Sigma implementation at firm level, this study conducted an in-depth research in the Thai electronics components manufacturing industry using the AHP approach [Saaty (1980)].

AHP is a decision-making approach which integrates simultaneously qualitative and quantitative information for prioritizing alternatives when multiple criteria must be considered. According to Saaty (1982), a decision making approach should have the following characteristics:

- be simple in structure,
- be adaptable to both group and individual decision making environments,
- be natural to human intuition and general thinking,
- encourage compromise and consensus, and
- not require inordinate specialization to master and communicate.

The decision making process of the AHP is consistent with these characteristics. After comparing five different utility models for determining priorities, Schoemaker and Waid (1982) concluded that the AHP was the easiest to use and produced the most credible results.

AHP enables decision makers to assign a relative weight to each factor through pair-wise comparison. The modeling process of the AHP is supported by four axioms:

Axiom 1: *Reciprocal condition*: The decision maker can make comparisons and state the strength of his preferences. The intensity of these preferences must satisfy the reciprocal condition: If X is n times preferred to Y, then Y is $1/n$ times preferred to X.

Axiom 2: *Homogeneity*: The preferences are represented by means of a bounded scale. This axiom deals with the idea that comparisons are meaningful only if the criteria or alternatives are comparable.

Axiom 3: *Independence*: The relative importance of a criterion at any level of the hierarchy is independent of the criteria/alternatives included at the lower level.

Axiom 4: *Expectations*: For the purpose of making a decision, the hierarchic structure is assumed to be complete.

3.1. *The modeling process of the AHP*

The modeling process involves four steps:

(1) assessment of success factors in Six-Sigma implementation,
(2) structuring the problem as a hierarchy and building the AHP model,
(3) collection and compilation of experts' opinions and application of the prioritisation procedure, and
(4) determination of critical factors through the synthesis of normalized priority weights.

The first step involves identification of key factors that influence the successful Six-Sigma implementation. Identification and classification of these factors was accomplished using the literature review and is given above in Table 1.

The structuring step consists of breaking down any complex multiple criteria decision-making problem into a series of hierarchies or set of integrated levels. Generally, the problems are structured in at least three levels given in Table 2.

Criteria and decision alternatives are located at levels two and three respectively of the hierarchy. Criteria can be split into sub-criteria, and as sub sub-criteria, thus extending the hierarchy beyond three levels. While structuring a complex problem into different levels of hierarchies, it is important that axiom 4 is observed; that is, the decision makers must make sure that all relevant criteria and/or alternatives are included in the hierarchies. Absence of any necessary criterion and/or alternative will make the decision flawed. Structuring any decision problem as a hierarchy is an effective way of dealing with complexity and of identifying important criteria and/or alternatives to achieve the overall objective of the problem. Saaty [1980] suggested limiting the hierarchy to seven levels and seven items per level. This is based on the psychological finding that humans can consider seven $\pm$ two items for

Table 2. Problem structure and definition.

Level		Generic definition	In the study
1	Goal	The overall objective of the decision making process which is placed at the apex of the hierarchy	The goal is to identify the appropriate strategy based on the level of criticality of each of the factors
2	Criteria	Bases on which the alternatives are evaluated	Performance measures such as financial benefits (profit), customer satisfaction, and process capability
3	Alternatives	The outcomes of the evaluation process	Actual priority weights of the six factors

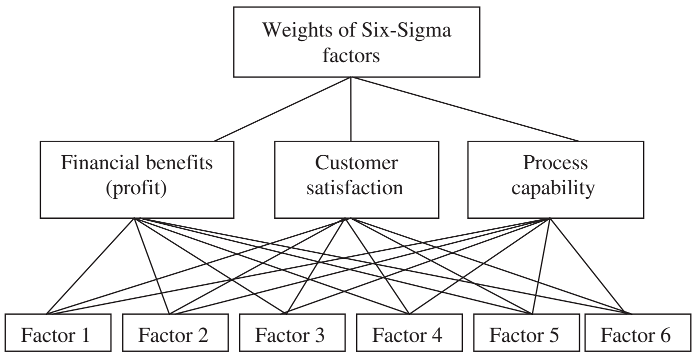

Fig. 1. Structure of the AHP model.

simultaneous comparison [Miller (1956)]. In cases where too many criteria (more than seven) appear on a given level it is possible to cluster them into sub categories, thus creating additional levels. Similarly, if there are many alternatives (more than seven) that need to be evaluated, it may be impractical to carry out consistent pair wise comparisons for all alternatives. One way to resolve this problem is to use a rating scale referred to as the intensity mode of AHP. The structure of the problem is given in Fig. 1.

The next step is the application of the prioritization procedure to determine the relative importance of the criteria and/or alternatives in each level. Criteria in each level are compared pair-wise in terms of their importance to a criterion in the next higher level. Starting at the top of the hierarchy and working down, a number of preference (square) matrices are generated in the process of comparing criteria at a given level. A generic matrix is as follows:

$$\mathbf{A} = (a_{ij}) = \begin{bmatrix} w_1/w_1 & w_1/w_2 & \dots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \dots & w_2/w_n \\ \vdots & \vdots & \dots & \vdots \\ w_n/w_1 & w_n/w_2 & \dots & w_n/w_n \end{bmatrix}, \quad (1)$$

where rows indicate ratios of weights of each factor with respect to all other factors.

Table 3. Scale of preferences between two factors — one-to-nine scale.

Value	Judgment	Description
1	Equal	Two alternatives shares the same level of importance
3	Moderate	Experience and judgment slightly favors one alternative
5	Strong	Experience and judgment strongly favors one attribute over another
7	Very strong	Experience and judgment tell that one alternative is much more important than the other
9	Extreme	The difference of importance is extreme
2, 4, 6, 8	Intermediate values between the two adjacent judgments	Used if more precision is needed

The scale used for pair-wise comparisons in AHP is called a one-to-nine scale (see Table 3). This scale has often been used whenever the hierarchical approach could be followed, and found to be quite reliable. To further simplify, the scale is built based on five attributes:

- equal;
- moderate;
- strong;
- very strong;
- extreme.

For example, if the decision maker strongly believes that criterion X is more important than criterion Y, then this judgment is represented by a 5. It is assumed that the decision maker has sufficient knowledge about the relative values of the criteria being compared whose ratio is ≥ 1, and that the numerical ratios formed are nearest-integer approximations scaled in such a way that the highest ratio corresponds to nine.

For a set of n criteria and/or alternatives in a matrix, $(n^2 - n)/2$ judgments are needed because there are 1's on the diagonal (comparing criteria with themselves) and the remaining judgments are reciprocals ($a_{ji} = 1/a_{ij}$). Thus the comparisons of criteria using the suggested scale, and generation of preference matrices are guided by axioms 1 (reciprocal condition) and 2 (comparable or homogeneous criteria).

The fourth and final step of AHP is the determination and synthesis of normalized weights. The normalized weights can be determined using either the eigenvector method or the simple row average method. The preference matrices generated in step three are translated into largest eigenvalue problems and solved to find unique and normalized vectors of weight to criteria in each level of hierarchy. When matrix A (Eq. (1)) is multiplied by the transpose of the vector of weights w, we get the resulting vector in nw,

$$\mathbf{A}w = nw, \tag{2}$$

where $w = (w_1; w_2; \ldots; w_n)^{\mathrm{T}}$ and n is the number of rows or columns. Further, Eq. (2) could be rewritten as:

$$(\mathbf{A} - n\mathbf{I})w = 0, \tag{3}$$

where n is also the largest eigenvalue, $\lambda_{\max}$, or trace of matrix **A** and **I** is the identity matrix of size n. For a further mathematical discussion of this method, see Saaty and Vargas [1982].

The overall weights of the decision alternatives are determined by aggregating the weights throughout the hierarchy. This is done by following a path from the top of the hierarchy to each alternative at the lowest level and multiplying the weights along each segment of the path and the best alternative is chosen for the decision purpose. Axiom 3 governs this synthesis.

The AHP offers not only a methodology to rank alternative courses of action but also provides a direct measure of consistency of judgment elicited by the decision-makers. Saaty [1977] demonstrated that $\lambda_{\max} = n$ is a necessary and sufficient condition for consistency. Inconsistency may arise when $\lambda_{\max}$ deviates from n due to inconsistent responses in pair-wise comparisons. Therefore, the matrix **A** should be tested for consistency using the formula:

$$\mathbf{CI} = (\lambda_{\max} - n)/(n - 1), \tag{4}$$

$$\mathbf{CR} = \mathbf{CI}/\mathbf{RI} \tag{5}$$

where **CI** is the consistency index, **RI** is random index generated for a random matrix of order n, and **CR** is the inconsistency ratio. The **CR** refers to the degree to which decision-makers adhere to the rank order specified and measures the extent to which an established preference is kept. A $\mathbf{CR} \leq 0.1$ is recommended as acceptable [Saaty and Kearns, (1985)]. If $\mathbf{CR} > 0.1$, it is suggested that the decision-makers reevaluate their judgments. Homogeneity of factors within each group, smaller number of factors in the group, and better understanding of the decision problem would improve the consistency index [Saaty (1993)].

4. Analysis and Findings

4.1. *Determination of weights of the performance criteria*

Twenty-one experts, consisting of three-project champions and eighteen-black belts from five multinational companies (Singaporean, Japanese, and USA) located in Thailand, were interviewed. In order to determine the priority weight of each factor, judgment matrices were translated into the largest eigenvalue problems, and then calculated the normalized and unique priority vectors of weights by using the Expert Choice® Software [DSS (1995)]. The overall inconsistency index of judgments was then calculated for performance measures and success factors.

The results of the analysis are shown in Table 4 and a graphical representation of the summary result is shown in Fig. 2. The results indicate that the main objective of implementing Six-Sigma processes is to maximize financial benefits (profit) (weight = 0.569), followed by process capability improvement (weight = 0.264), and increased customer satisfaction (weight = 0.167). The inconsistency ratio = 0.023,

Table 4. Weights of performance measures.

Expert	Profits	Customer satisfaction	Process capability	CR
1	0.540	0.163	0.297	0.01
2	0.540	0.163	0.297	0.01
3	0.648	0.122	0.230	0.05
4	0.648	0.122	0.230	0.00
5	0.625	0.136	0.238	0.02
6	0.571	0.143	0.286	0.00
7	0.443	0.169	0.387	0.02
8	0.625	0.136	0.238	0.02
9	0.657	0.196	0.147	0.05
10	0.493	0.196	0.311	0.05
11	0.701	0.106	0.193	0.00
12	0.500	0.250	0.250	0.00
13	0.600	0.200	0.200	0.00
14	0.540	0.163	0.297	0.09
15	0.500	0.250	0.250	0.00
16	0.500	0.250	0.250	0.00
17	0.540	0.163	0.297	0.01
18	0.540	0.163	0.297	0.07
19	0.571	0.143	0.286	0.00
20	0.540	0.163	0.297	0.02
21	0.614	0.117	0.268	0.07
Average	0.568	0.167	0.265	0.02
Ranking	1	3	2	0.02

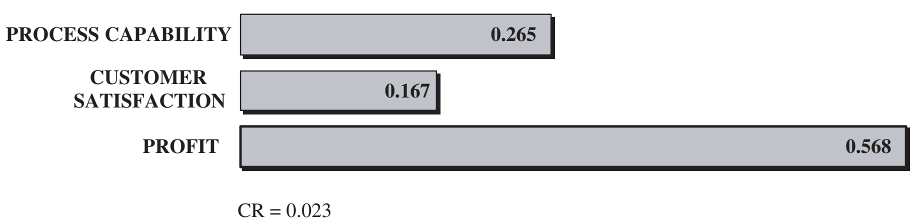

Fig. 2. Weights of the three performance measures.

is within the acceptable level. All calculations were done based on the eigenvector method and using the Expert Choice® software [DSS (1995)].

Note that the weights of criteria at level two add up to one. The distribution of weights indicates that the maximizing profitability is judged by the experts to be 3.4 times (i.e. 0.568/0.167) more important than customer satisfaction, and 2.15 times (i.e. 0.568/0.264) more important than process capability.

4.2. *Determination of weights of the six factors based on performance criteria*

4.2.1. *Performance criterion: profit*

In order to determine the weights of the factors (F1 to F6), experts were subjected to the following question: which factor is preferred most with respect to the

Table 5. Weights of the factors based on profit as the performance criterion.

Expert	Factor 1	Factor 2	Factor 3	Factor 4	Factor 5	Factor 6	IR
1	0.254	0.237	0.115	0.115	0.227	0.052	0.02
2	0.297	0.208	0.165	0.159	0.129	0.042	0.03
3	0.263	0.226	0.156	0.076	0.238	0.041	0.05
4	0.250	0.240	0.118	0.115	0.222	0.056	0.01
5	0.285	0.184	0.139	0.101	0.237	0.055	0.02
6	0.202	0.194	0.169	0.109	0.202	0.124	0.04
7	0.238	0.249	0.109	0.103	0.238	0.064	0.01
8	0.303	0.173	0.157	0.113	0.190	0.063	0.04
9	0.228	0.256	0.075	0.216	0.173	0.052	0.04
10	0.270	0.277	0.100	0.091	0.183	0.079	0.04
11	0.262	0.218	0.107	0.173	0.174	0.065	0.08
12	0.282	0.271	0.105	0.069	0.183	0.091	0.04
13	0.205	0.205	0.177	0.165	0.160	0.089	0.08
14	0.272	0.206	0.120	0.137	0.195	0.071	0.02
15	0.261	0.189	0.103	0.200	0.200	0.047	0.03
16	0.315	0.179	0.102	0.188	0.163	0.053	0.06
17	0.258	0.239	0.112	0.102	0.193	0.096	0.05
18	0.241	0.189	0.166	0.108	0.216	0.080	0.04
19	0.242	0.228	0.148	0.082	0.215	0.085	0.02
20	0.276	0.244	0.138	0.197	0.089	0.056	0.02
21	0.252	0.262	0.132	0.102	0.182	0.067	0.04
Average	0.260	0.223	0.129	0.130	0.191	0.068	0.04
Ranking	1	2	5	4	3	6	

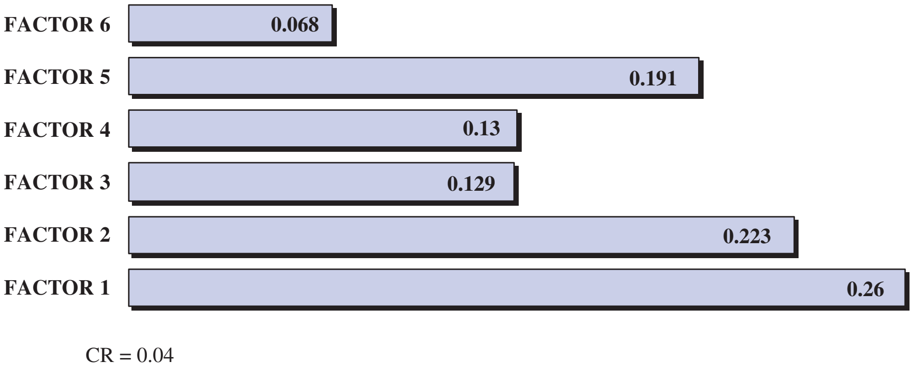

Fig. 3. Weighs of the six factors based on profit as the performance criterion.

performance criterion profit and how strongly? Results are shown in Table 5 and Fig. 3. The weights calculated are 0.260, 0.223, 0.129, 0.130, 0.191, and 0.068 for Factor 1, Factor 2, Factor 3, Factor 4, Factor 5 and Factor 6 respectively. The inconsistency ratio (CR) was found to be 0.04. This indicates that all judgments were within acceptable limits. The results indicate that Factor 1: 'Management leadership, involvement and commitment' is considered to be the most important factor when the success of Six-Sigma implementation is assessed based on the profit criterion, and Factor 6: 'Linking Six-Sigma to suppliers' is found be least important.

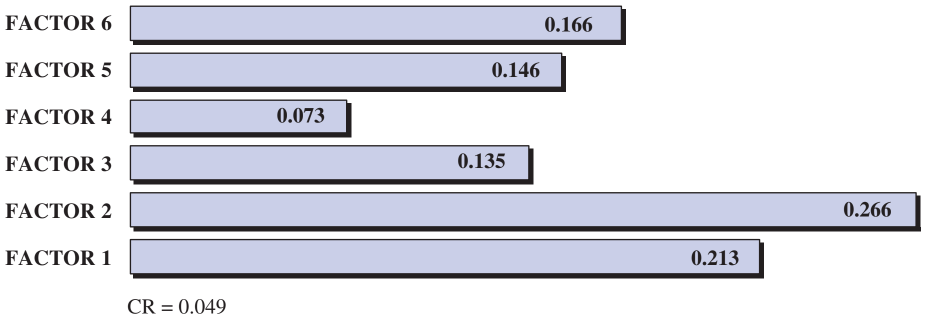

Fig. 4. Weights of the six factors based on process capability as the criterion.

4.2.2. *Performance criterion*: *process capability*

Experts were subjected to the following question: which factor is preferred most with respect to the performance criterion process capability and how strongly? Figure 4 shows the summary result of the analysis. The weights calculated are 0.213. 0.266, 0.135, 0.073, 0.146, and 0.166 for Factor 1, Factor 2, Factor 3, Factor 4, Factor 5 and Factor 6 respectively. The inconsistency ratio (CR) was found to be 0.049 which is within the acceptable limit. The results indicate that Factor 2: 'Training and understanding the Six-Sigma methodology, tools and techniques' is considered to be the most important factor when the success of Six-Sigma implementation is assessed based on the process capability criterion and Factor 4: 'Linking Six-Sigma to customers' is considered by the experts as the least important factor.

4.2.3. *Performance criterion*: *customer satisfaction*

Weights for the six factors were determined based on the criterion customer satisfaction. Experts were asked the following question: which factor is preferred most with respect to the performance criterion customer satisfaction and how strongly? Figure 5 shows the summary result of the analysis. The weights calculated are

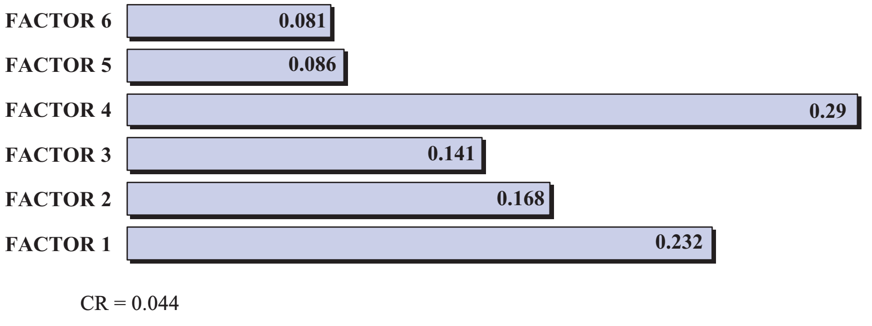

Fig. 5. Weights of the six factors based on customer satisfaction as the criterion.

Table 6. Weights and rankings of the factors.

Success factors	Performance measures (Weight, Ranking)					
	Profit (0.568, 1)		Customer satisfaction (0.167, 3)		Process capability (0.265, 2)	
	Weight	Ranking	Weight	Ranking	Weight	Ranking
Factor 1	0.260	1	0.232	2	0.213	2
Factor 2	0.223	2	0.168	3	0.266	1
Factor 3	0.129	5	0.141	4	0.135	5
Factor 4	0.130	4	0.290	1	0.073	6
Factor 5	0.191	3	0.086	5	0.146	4
Factor 6	0.068	6	0.081	6	0.166	3
CR	0.040		0.044		0.049	

0.232, 0.168, 0.141, 0.290, 0.086, and 0.081 for Factor 1, Factor 2, Factor 3, Factor 4, Factor 5 and Factor 6 respectively. The inconsistency ratio (CR) was found to be 0.044 which is within the limit. The results indicate that experts considered Factor 4: 'Linking Six-Sigma to customers' as the most important factor and Factor 6: 'Linking Six-Sigma to suppliers' as the least preferred factor when the success of Six-Sigma implementation is assessed based on the customer satisfaction criterion.

The weights and rankings of the six success factors are compared in Table 6. Factors such as 'Factor 1: Management leadership, involvement and commitment', and 'Factor 2: Training in Six-Sigma methodology' were found to be the two most important factors when the success of Six-Sigma implementation was assessed based on both profit and process capability criteria. Whereas, factor such as 'Factor 6: Linking Six-Sigma to suppliers' was found to be least important when success of Six-Sigma implementation was assessed based on profit and customer satisfaction.

4.3. *Degree of importance of the factors in successful Six-Sigma implementation based on overall performance measure*

The overall weights of the factors were calculated by taking into account weights of the performance measures and weights of the factors with respect to these measures. The results are shown in Fig. 6. The weights calculated are 0.243. 0.225, 0.133, 0.142, 0.159, and 0.098 for Factor 1, Factor 2, Factor 3, Factor 4, Factor 5 and Factor 6 respectively. The inconsistency ratio (CR) was found to be 0.034 which is within the acceptable limit. The results indicate that 'Factor 1: Management leadership, involvement and commitment' is the most important factor and 'Factor 6: Linking Six-Sigma to suppliers' is the least important factor for successful Six-Sigma implementation. The distribution of weights indicates that Factor 1 is judged by the experts to be 2.5 times (i.e. 0.243/0.09) more important than Factor 6, and 1.83 times (i.e. 0.243/0.133) more important than Factor 3.

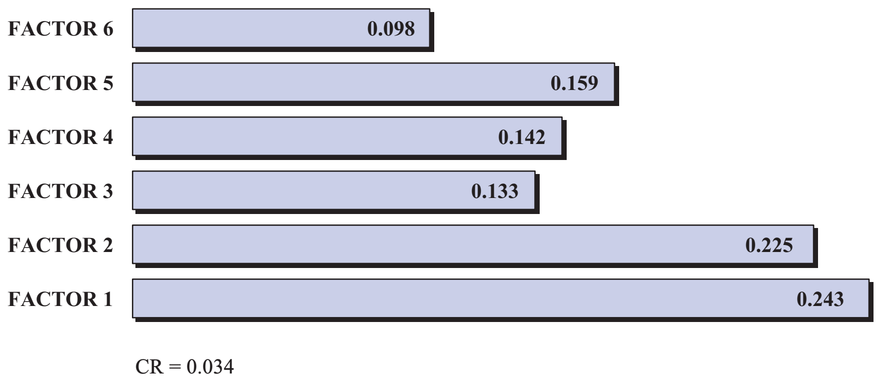

Fig. 6. Overall weights of success factors.

5. Managerial Implications

Six-Sigma is a well-established methodology that simultaneous seeks to achieve triple bottom-line such as improve process capability, increase customer satisfaction, and enhance profit. It is claimed and demonstrated that the Six-Sigma program provides competitive advantages to companies that implement it. However, to achieve competitiveness Six-Sigma program needs to be implemented strategically. This paper not only identifies critical success factors for Six-Sigma implementation, but also the level of criticality of these factors. The following managerial implications can be drawn from the results of this study.

5.1. *Management leadership, involvement and commitment*

This study suggests that the most important factor for successful Six-Sigma implementation is management leadership. Successful implementation requires effective change in organizational culture, and it is almost impossible to change an organization without a concerted effort by management aimed at encouraging continuous improvement, involvement among people within the organization, and cooperation throughout the supply chain. Top management must demonstrate leadership and commitment in term of setting up the visible policy, providing financial support, and following-up the progress towards to a selected project. These aspects of leadership are well demonstrated in companies such as GE and AlliedSignal [Snee and Hoerl (2003)]. In both companies top leaders personally drove the implementation process. Top management:

- ensured that their leadership team was truly on board and there was a well thought out plan for Six-Sigma implementation.
- provided resources to appropriately and adequately support the Six-Sigma effort.
- expected and demanded results from the effort.
- were willing to change internal policies and procedures to support implementation.

Recent studies in Six-Sigma supports this view. For example, conducting research in software industry, and SMEs in UK, Antony and Fergusson [2004], Antony and Kumar [2005] revealed that the top management commitment and involvement is the most critical factor for successful Six-Sigma implementation.

5.2. *Training and understanding the Six-Sigma methodology, tools and techniques*

The second most important critical factor for Six-Sigma implementation identified in this study is the understanding of Six-Sigma methodology and training of tools and techniques of Six-Sigma. This finding is consistent with other studies [Snee and Hoerl (2003)]. Employee training has been identified as a critical component of workforce management when implementing significant changes in an organization [Dale (2000); Choo *et al.* (2003)]. If it is to be effective — by, for example, transforming employees into creative problem solvers — training should emphasize both tools and techniques in problem solving, effective communication, and statistical process control [Choo *et al.* (2003)]. Snee and Hoerl [2003] identified 'top talent', which can be achieved through training, as one of the three factors for successful Six-Sigma deployment.

Training must also be continuously carried out if the improvement effort is to be sustained. The fundamental principle of Six-Sigma strategy is to take an organization to an improved level through the rigorous application of statistical methods [Antony *et al.* (2003)]. Six-Sigma project team members (i.e. process owner, blackbelt) must be trained continuously in tools and techniques such as design of experiments, measurement system analysis, failure mode and effect analysis, statistical process control, quality function deployment, and hypothesis testing [Eckes (2000); Halliday (2001); Ingle and Roe (2001)].

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