

Total Quality Management,
Vol. 15, No. 9–10, 1217–1229, November–December 2004



Applying Six-Sigma to Supplier Development

FU-KWUN WANG*, TIMON C. DU** & ELDON Y. LI†

**Department of Industrial Engineering and Management, National Taipei University of Technology, Taiwan, **Department of Decision Sciences and Managerial Economics, The Chinese University of Hong Kong, Hong Kong, †Department of Information Management, Yuan Ze University, Taiwan*

ABSTRACT *Supply chain management (SCM) adopts a systematic and integrative approach to managing the operations and relationships among different parties in supply chains. To implement SCM successfully involves a lot of issues. One of the major issues is supplier development. On the other hand, studies have investigated how quality management can be employed in SCM to improve the performance of various issues in the whole supply network. This study will develop an application guideline for the assessment, improvement, and control of quality in SCM using Six-Sigma improvement methodology. Improvements in the quality of all supply chain processes lead to cost reductions as well as service enhancements. In our approach, supplier evaluation is conducted by principal component analysis. The measurement data from 25 suppliers of a PC manufacturer in Taiwan, including two major input variables and three major output variables, will be used for demonstration.*

KEY WORDS: Principal component analysis, Six-Sigma, supplier evaluation, supply chain management

Introduction

Supply chain management (SCM) is a concept that integrates all parties over the value chain into one whole system and manages them as the assets of an extended enterprise (Simchi-Levi *et al.*, 2000). It involves the removal of barriers between trading partners to facilitate the synchronization of information. It involves not only logistic activities (e.g. inventory management, transportation, warehousing, and order processing, etc), but also other business processes (e.g. customer relationship management, demand management, order fulfilment, procurement, and product development and commercialization, etc). SCM adopts a systematic and integrative approach to managing the operations and relationships among the different parties in supply chains. It is aimed at building trust, exchanging information on market needs, developing new products, and reducing the supplier base to release management resources for developing long-term, mutual-benefited relationships. The high quality of products and services from each level of the

Correspondence Address: Timon C. Du, Department of Decision Sciences and Managerial Economics, The Chinese University of Hong Kong, Shatin, NT, Hong Kong, People's Republic of China. Email: timon@cuhk.edu.hk

1478-3363 Print/ 1478-3371 Online/04/09-101217-13 © 2004 Taylor & Francis Ltd
DOI: 10.1080/1478336042000255596

1218 F.-K. Wang et al.

supplier network is an essential part of successful SCM (Choi & Rungtusanatham, 1999). Improving the quality of all supply chain processes leads to cost reductions, improved resource utilization, and improved process efficiency (Beamon & Ware, 1998). Some research studies have investigated how quality management can be employed in SCM to improve the performance of the whole supply network. For example, Forker *et al.* (1997) demonstrate that Total Quality Management (TQM) can influence the quality performance in the supply chain by combining nonlinear (Data Envelopment Analysis) and linear regression analyses. Their results suggest that manufacturers should continue to promote TQM practices throughout the supply chain. Wong & Fung (1999) present an in-depth case study of the TQM system of a construction company in Hong Kong. They examined the strategy, structure, and tasks for managing the supplier–subcontractor relationships that form an integral part of total quality pursuits. Matthews *et al.* (2000) showed that the concepts of quality management systems and partnering could be effectively incorporated into the construction supply chain. This is because the closer working relationships and the increased technology transfers provide organizations with the opportunity to obtain expert skills from their partners with limited resources. Houshmand & Rakotobe-Joel (2000-2001) developed an integrated supply chain structural analysis method to identify the priorities for a blood processing centre operations improvement. In the model, all channel members appeared to be in cohesion with their next line in the process. The distribution centre (H16) with the most connections means that it is the important element that makes the supply chain work. Romano & Vinelli (2001) discussed how quality can be managed from a supply chain perspective. Their case study indicated that the whole supply network could improve its ability to meet the expectations in quality of the final customer through the joint definition and co-management of quality practices and procedures. Sohn & Choi (2001) develop a fuzzy Quality Function Deployment (QFD) model to explain the fuzzy relationship between customers' needs and design specifications for reliability of supply chain management.

The continuous improvement concepts established by Deming, Juran, Feigenbaum and Crosby have provided insight into the measurement of supply chain management. Recently, the Six-Sigma improvement methodology has become extremely popular. The Six-Sigma methodology is a structured tool with techniques of quality management, and it can achieve strategic business results through its applications on a project basis. Numerous books and articles are available to provide the basic concepts of Six-Sigma, such as those by Harry & Schroeder (2000), Hahn *et al.* (2000), Breyfogle (1999) and Hoerl (1998). A review of literature shows that Six-Sigma has recently been deployed in areas like human resource function (Wyper & Harrison, 2000) and supplier development (Avery, 2001), and others. It is our belief that the Six-Sigma can be used to develop a model for assessing, improving, and controlling quality in the supply chain network. Note that improvement in the quality of all supply chain processes leads to the simultaneous reduction of costs and enhancement of service. This study will use the Six-Sigma methodology to improve the quality of the process of supplier development.

This article structured as follows. The next section reviews the development

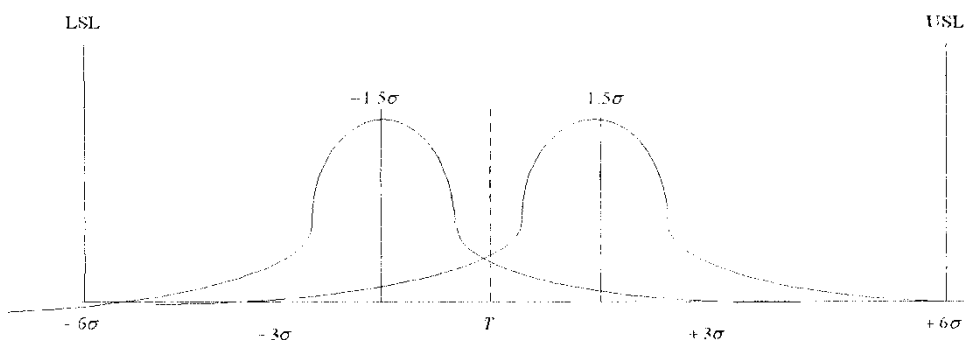
Applying Six-Sigma to Supplier Development 1219

and application of Six-Sigma, and the section after discusses our application guidelines. The fourth section applies the methodology to supplier development, and the final section presents conclusions.

Six-Sigma

Six-Sigma is a logical and systematic approach to achieving continuous process improvements. This process improvement methodology was developed in the 1980s in Motorola's high volume manufacturing environment (Breyfogle, 1999). Note that a sigma quality level offers an indicator of how often defects are likely to occur, whereby higher sigma quality levels indicate a process that is less likely to create defects. Originally, Six-Sigma was so named because the process mean will produce 3.4 defects per million opportunities (DPMO) and is shifted 1.5 standard deviations from the target mean that has six standard deviations on each side of the specified limit (see Figure 1). Recently, Six-Sigma has been successfully implemented in both manufacturing and service industries. For example, as reported by Harry & Schroeder (2000), Motorola saved US\$2.2 billion in the first 5 years of adoption. Honeywell saved in excess of US\$2 billion since implementing Six-Sigma in 1994. General Electronics initiated Six-Sigma in 1996 and generated more than US\$2 billion of revenue in 1999. Black & Decker's savings rose to approximately US\$75 million in 2000, which was more

Normal distribution with the mean shifted by $\pm 1.5\sigma$ from the target



Specification limit	Inside specification	ppm defective
$\pm \sigma$	30.23%	697700
$\pm 2\sigma$	69.13%	608700
$\pm 3\sigma$	93.32%	66810
$\pm 4\sigma$	99.3790%	6210
$\pm 5\sigma$	99.97670%	233
$\pm 6\sigma$	99.999660%	3.4

Figure 1. The original concept of Six-Sigma

1220 *F.-K. Wang et al.*

than double the savings of the previous year, and accumulated over US\$110 million since 1997. The implementation of Six-Sigma is not a short-term, quick fix improvement process. A committed and charismatic leadership is essential in coaching and guiding the adoption of this holistic, long-term, and continuous improvement methodology. Blakeslee (1999) suggested the following seven key principles to ensure companies can reap benefits from Six-Sigma:

- (1) A committed leader is needed to ensure a successful Six-Sigma implementation.
- (2) Six-Sigma efforts must be integrated with existing business strategies and key performance measures.
- (3) The framework of business process must support successful Six-Sigma efforts.
- (4) Six-Sigma requires disciplined customers and market intelligence.
- (5) Six-Sigma projects must produce real savings or revenue.
- (6) Well-trained full-time team leaders, who are known as Champions, Master Black Belts, Black Belts, and Green Belts, must lead six-Sigma projects. A Champion is a quality leader in the organization and is responsible for developing and implementing strategy, setting objectives, allocating resources, and monitoring progress. Master Black Belts have a more managerial role, in that they are often responsible for all Six-Sigma work in a particular area or function. Black Belts are operational roles. In most cases, a Black Belt is the leader of a team that is working on a problem. For those people who are trained and committed to a Six-Sigma project as part of their regular jobs, they are referred as Green Belts (Hoerl, 2001).
- (7) Six-Sigma projects must be supported by the continuous reinforcement and reward of leaders.

Application Guidelines

The basic framework of the Six-Sigma improvement technology in the supply chain network we proposed is given in Figure 2. The framework consists of five integrated modules: Define, Measure, Analyse, Improve, and Control.

Module 1: Define (prioritize)—This module defines the processes that have the highest priority for improvement, i.e. the key process that will enable maximum leverage and customer satisfaction. Module 1 defines the required activities and the key process output variables that are used to count defects and calculate the cost of poor quality. Graphical tools such as flowcharts, flow process charts, Gantt charts, and relation diagrams are useful in determining the tasks that are performed in the supply chain (Breyfogle, 1999). After the activities are identified, they are assigned to process improvement. These processes may include inbound and outbound transport, warehousing, production planning/inventory control, order processing, and customer service.

Module 2: Measure—This module measures the capability of the process. The purpose of this module is to identify performance measures such as cost, productivity, and service levels. Moreover, this measure can help to identify the deviations of current measurements. The goals of SCM should be consistent

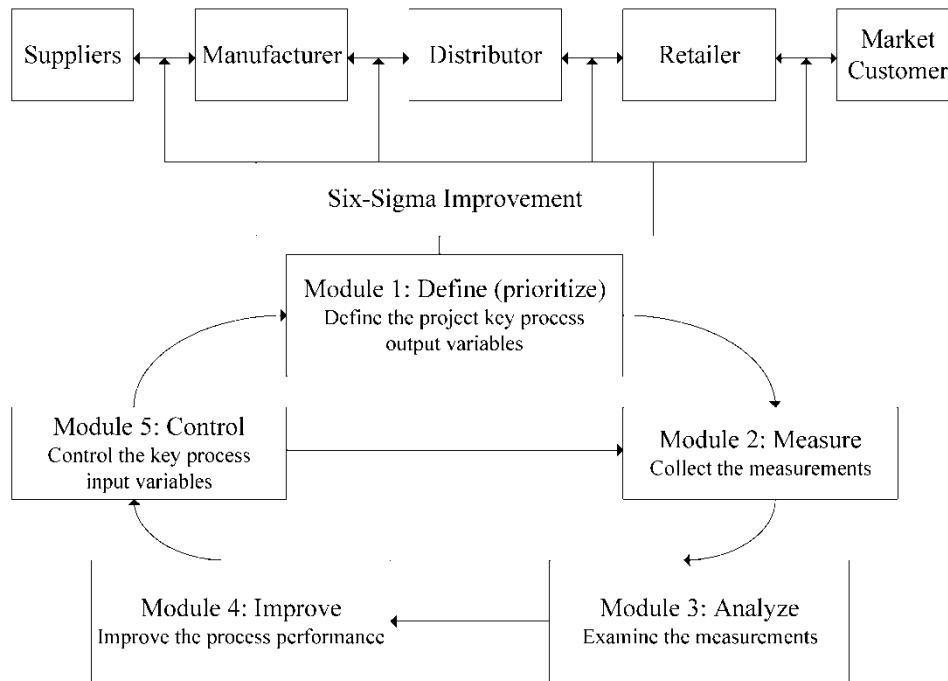


Figure 2. The framework of the Six-Sigma model in the supply chain network

with organizational goals. This module helps to create an understanding of the types of quality measures that are currently employed. First, the deviations that are associated with the various supply chain management and customer requirements are identified. Then, the deviations that are associated with the quality factors for the process are identified. Numerous quality factors can be used as measures in SCM (Simchi-Levi *et al.*, 2000). Some of the major metrics are: (1) Reliability—concerns about the failure to deliver products; (2) Order accuracy—concerns about the probability of the correct orders arriving at or departing from the warehouse on time; (3) Worker standards—concerns about engineering standards for workers inside the warehouse; (4) Customer satisfaction—concerns about whether internal or external customers are satisfied with the service that is provided; (5) Worker quality—concerns about such things as safety and damaged goods, etc; and (6) Cost—concerns about the cost that is incurred in a supply chain.

Module 3: Analyse—This module analyses when and where defects occur. The purpose is to evaluate current performance and re-evaluate the standards for cost, productivity, and service objectives. The best-in-class standards, e.g. supply-material days of cover (<5 days) and customer service level (>98%), are used to examine the measurements that are collected in Module 2. A control chart can be employed to detect whether or not the process is in control. Note that a process is considered as in control when there are no occurrences of special

1222 *F.-K. Wang et al.*

causes of variations. For example, a special variation in a supply chain process may be that a truck arrives late due to inclement weather. Once the process is in control, current data can be used to evaluate the process performance. Multivariate charts, regression analysis, analysis of variance, and multivariate statistical analysis can also be used in this module.

Module 4: Improve—This module focuses on how Six-Sigma improvement technology can be developed, and identifies the critical factors that arise from the control process. The purpose is to identify and implement changes so that the overall supply chain process performance can be improved. The first step in this module consists of identifying and prioritizing improvement areas. Once these areas have been prioritized, the areas that must receive immediate attention, considering time and cost restrictions, are identified. The purpose of continuous improvement is to reduce the amount of common-cause variations in the supply chain process. In planning this improvement, hypotheses must be made. Once the causes of variations are identified, a plan is implemented to eliminate them. The plan is then tested to determine whether the solution is able to reduce variations. After this testing, the improvement should be implemented throughout the process. The process should be tested again to determine whether it is in control. If the process is in control, the standards of cost, productivity, and service are set to those of the improved process. The process variability reduction can be improved by the experimental design or Taguchi methods.

Module 5: Control—This module identifies the controls that must be in place to sustain the benefit of the new process. The purpose is to control and monitor productivity and service performance to ensure that the process meets the identified standards. There are numerous quality tools that can be used in this step. Some are given as follows:

- (1) control charts, such as exponentially weighted moving average (EWMA) charts or engineering process control (EPC) charts, for variability analysis;
- (2) cause and effect diagrams for troubleshooting analysis;
- (3) Failure Model Effects Analysis (FMEA) for failure analysis;
- (4) histograms for variable frequency analysis;
- (5) scatter diagrams for variable relationship analysis; or
- (6) run charts for trend analysis.

In fact, Six-Sigma improvement projects can be considered as the driving force for cost reduction and service improvement in SCM. Figure 3 indicates the benefits of a Six-Sigma improvement project. In a Six-Sigma project, the potential value of the project must be first acknowledged by the Six-Sigma Black Belt (team leader), the project sponsor (Champion), and the relevant people from various departments in the organization. Once the definition of the defect in the SCM is agreed upon and data of the existing process are acquired, a preliminary analysis of possible benefits, such as improvements in the level of service and cost reduction etc, can be developed. Throughout the Improve and Control phases of the Six-Sigma project, the results are compared with industry benchmarks such as the average and the best in class. This identifies the

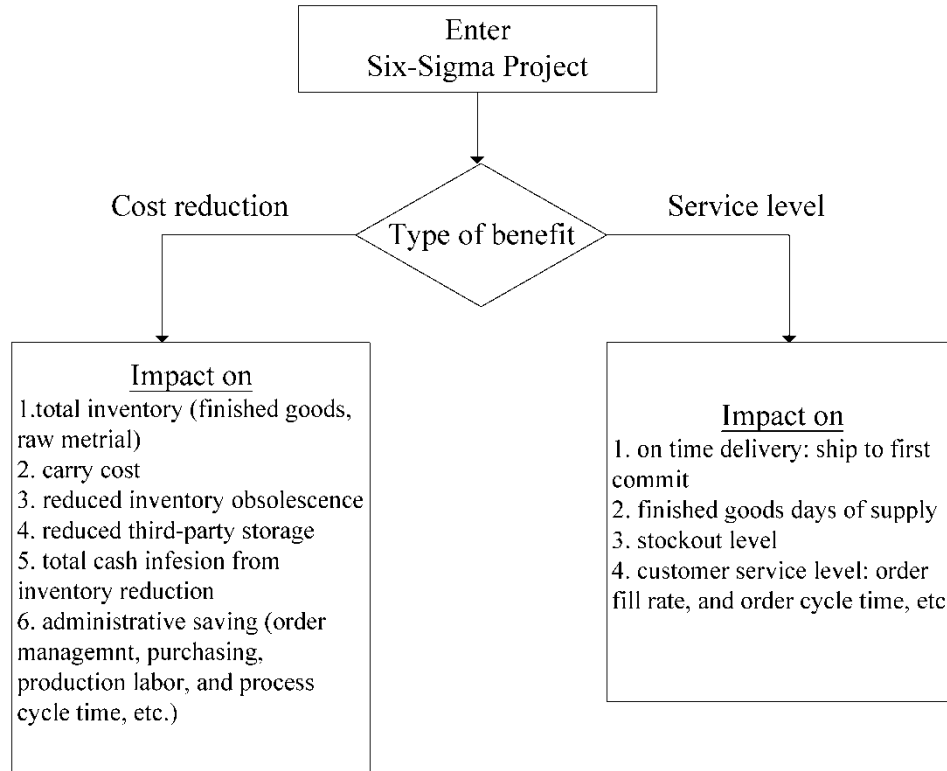


Figure 3. The flow chart of the project benefits

company's advantages as well as opportunities to improve its supply chain performance.

Applying Six-Sigma to supplier development

It is well known that the long replenishment lead-time, large order lots, expected shortage of products, fluctuated product, and limited information sharing are the major obstacles to supply chain coordination. However, one key factor influencing the performance of supply chain relationship is trust. Through the high degree of mutual trust, supply chain partners can develop a strategy to maximize supply chain benefits collaboratively. The development of trust requires a lot of effort, such as the partners' need to value the relationship, identify correct roles, agree with effective contracts, and be willing to resolve the conflict. Then, through a long period of cooperation, the trust can be gradually built up. Therefore, it is clear that the supplier development is a major task in supply chain management (Avery, 2001). Supplier development involves a long-term cooperative effort between a buying firm (e.g. a manufacturer) and its suppliers (i.e. its material providers), and is aimed at creating and maintaining a network of competent suppliers. The development activities include supplier selection and monitoring,

1224 F.-K. Wang et al.

supplier assistance and training, the provision of incentives for continuous improvements, and supplier organizational integration. The ultimate objectives of supplier development are supplier base reduction, concurrent engineering, reductions in cycle time, reductions in inventories, and increases in customer satisfaction (Hahn *et al.*, 1990). Grieco (1989) suggests that there should have five steps in the supplier certification process: preliminary evaluation, product design and quality certification, a review of the supply process, performance monitoring, and certification. Raytheon Corp. has applied Six-Sigma to improving its supplier development activities (Avery, 2001). The Raytheon process for supplier development has six steps: the identification of supplier candidates for projects, the definition of objectives and resources, the identification of baseline opportunities (which do not have to focus on cost-cutting) and rank, the analysis of selected opportunities, the implementation of projects, and the documentation and realization of improvements. Raytheon's Night Vision camera, which is available on certain Cadillac automobiles, shows how Six-Sigma was used to transform a piece of defence technology into a small, cost-effective, and durable commercial product.

In the Six-Sigma improvement process for supplier development, the main purpose is constantly and carefully to evaluate the supplier's performance. For this purpose, an accurate rating system is needed. This rating system can maintain competitive pressure on suppliers by monitoring and comparing their improvement over time. In addition, an accurate rating process with multi-dimensional criteria can reduce the risk of encountering 'contractual hazards' in buyer-specific investments. To demonstrate how statistical tools can evaluate the supplier's performance, the principal component analysis (PCA) is used here. Note that PCA is a statistical method for multivariate data analysis that can be used to reduce the amount of data. It transforms original and related measurement variables into a set of orthogonal (uncorrelated) linear functions. The first principal component variable displays the largest variation among the principal component variables and combines all of original variables in a linear fashion. Similarly, the second, third, and the remaining principal component variables have properties that are similar to that of the first principal component variable. That is, the second principal component represents the next largest variation, and so forth. In most practical problems, the analysis of only a portion of the component variables is enough to depict most of the variation information of the multivariate data. Moreover, these principal component variables define a lower dimensional subspace in the simple problem. Normally, the information of the multivariate data in this lower dimensional subspace is sufficient to determine the performance. The detailed PCA process is presented in the following. Readers can refer to Johnson & Wichern (1998) for more information.

Assume that X is a $m \times n$ sample data matrix, where m denotes the number of variables that are observed from a supplier and n represents the number of suppliers being measured. \bar{X} is the sample mean of the observations, which is a m -vector value, and S , a non-singular $m \times m$ symmetric matrix, is the correlation matrix between observations. The spectral decomposition can be used to obtain $D = U^T S U$, where D is a diagonal matrix. The diagonal elements of D , $\lambda_1, \lambda_2, \dots, \lambda_m$,

Applying Six-Sigma to Supplier Development 1225

are the eigenvalues of S , and the columns of U , u_1, u_2, \dots, u_m , are the eigenvectors of S . Consequently, the i th principal component (PC_i) is

$$PC_i = u^T x, \quad i = 1, 2, \dots, m \quad (1)$$

where the x s are $m \times 1$ vectors of the observations of the original variables. The ratio of each eigenvalue to the summation of the eigenvalues is the proportion of variability associated with each principal component variable. That is,

$$w_i = \lambda_i \left/ \sum_{i=1}^m \lambda_i \right., \quad \forall i = 1, 2, \dots, m \quad (2)$$

However, only k principal components can contribute most of the system's variability, e.g. 80% to 90%. By using this subset, the multivariate quality characteristic problem can be reduced in dimension. Jackson (1980) proposes a test for identifying the significant components. It is

$$\chi^2 = -(n-1) \sum_{j=k+1}^m \ln \lambda_j + (n-1)(m-k) \ln \frac{\sum_{j=k+1}^m \ln \lambda_j}{m-k} \quad (3)$$

where χ^2 has $r = (1/2)(m-k)(m-k+1) - 1$ degrees of freedom. The hypothesis $H_0: \lambda_{k+1} = \dots = \lambda_m$ is applied against the alternatives when at least one has a different eigenvalue.

Analysis of the loading and principal components requires that the principal components and their variables closely correspond to each other, i.e. the angle between vectors, represented as R^m , must be small. The correlation between the i th variable and the j th principal component is given by

$$\rho_{ij} = u_{ij} \left(\frac{\lambda_j}{S_{ii}} \right)^{1/2} \quad (4)$$

where u_{ij} denotes the loading for the i th observation in the j th principal component variable, λ_j represents the eigenvalue associated with that principal component, and S_{ii} is the variance of the i th variable.

Now, we define the following single performance score by the first k principle components:

$$\text{Performance Score} = \sum_{i=1}^k w_i PC_i \quad (5)$$

The following is an example that illustrates the procedure. For illustration, we collected process-improvement measurement data from 25 suppliers of a PC manufacturer in Taiwan. The data set includes two major input variables (quality management practice = x_1 and employee training = x_2) and three major output variables (product quality = y_1 , price = y_2 , and delivery = y_3). These five variables are measured with a score from 0 to 100 in which the higher score is the higher performance. For example, on Supplier-3, the five original variables are $x_1 = 73$,

Table 1. The normalized composite scores for the input and output variables of 25 suppliers

Supplier	x_1	x_2	y_1	y_2	y_3
S-1	0.8067	0.7089	0.9045	0.5123	0.3167
S-2	0.8223	0.7297	0.9148	0.6818	0.3557
S-3	0.8992	0.8322	0.9661	1.3226	0.5479
S-4	1.1059	1.1078	1.1039	1.3291	1.0647
S-5	1.2487	1.2983	1.1991	1.2791	1.4217
S-6	1.0061	0.9748	1.0374	1.3000	0.8152
S-7	1.2522	1.3030	1.2015	1.1571	1.4306
S-8	0.8312	0.7416	0.9208	0.8870	0.3779
S-9	1.2250	1.2666	1.1833	0.6265	1.3625
S-10	0.9031	0.8374	0.9687	1.2462	0.5577
S-11	1.2364	1.2818	1.1909	1.0252	1.3909
S-12	1.3952	1.4936	1.2968	1.0307	1.7880
S-13	1.1584	1.1779	1.1389	0.6408	1.1961
S-14	1.1024	1.1032	1.1016	1.5009	1.0559
S-15	1.0111	0.9815	1.0407	1.3722	0.8278
S-16	1.0385	1.0180	1.0590	0.7561	0.8963
S-17	0.8690	0.7920	0.9460	1.0938	0.4725
S-18	0.8189	0.7252	0.9126	1.1863	0.3472
S-19	1.2070	1.2427	1.1714	1.5937	1.3176
S-20	0.9438	0.8917	0.9958	0.8896	0.6594
S-21	1.0865	1.0820	1.0910	0.9074	1.0162
S-22	0.9304	0.8739	0.9869	0.8533	0.6260
S-23	1.0895	1.0860	1.0930	1.0200	1.0237
S-24	0.9185	0.8580	0.9790	0.8442	0.5962
S-25	0.8768	0.8024	0.9512	0.8570	0.4920

$x_2 = 99$, $y_1 = 60$, $y_2 = 50$, $y_3 = 35$. However, to maintain confidentiality, the data are normalized. Table 1 shows the normalized composite scores for the input and output variables of the 25 suppliers. The performance of an individual process improvement effort can be measured by the ratio of the level of output produced by the process effort and the level of process effort, e.g. y_1/x_1 , y_2/x_1 , and y_3/x_1 . Likewise, the performance of a supplier can be measured by all the ratios of output and input measurement data relevant to the process improvement programs of a supplier. The PCA ranking procedure is based on the ratios of individual inputs and outputs, and one more variable takes into account the overall performance of each supplier as follows:

$$d_1 = \frac{y_1}{x_1}, d_2 = \frac{y_1}{x_2}, d_3 = \frac{y_2}{x_1}, d_4 = \frac{y_2}{x_2}, d_5 = \frac{y_3}{x_1}, d_6 = \frac{y_3}{x_2}, d_7 = \sum_{i=1}^6 d_i$$

Table 2 gives the eigenvalue and eigenvector analysis of the correlation matrix of the above seven variables. We have two principal components, PC1 and PC2, which account for 99.94%, (62.98% and 36.96% respectively) of the total sample variance. Thus, the performance score of each supplier can be obtained by:

$$\text{Performance Score} = 0.6298 \times \text{PC1} + 0.3696 \times \text{PC2}$$

Applying Six-Sigma to Supplier Development 1227**Table 2.** The eigenvalue and eigenvector analysis of the correlation matrix of data set d_1-d_7

Eigenvalue	4.4085	2.5875	0.0025	0.0014	1.00E-07	2.00E-08	0.00E+00
Proportion	62.98%	36.96%	0.04%	0.02%	0.00%	0.00%	0.00%
Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7
d_1	0.4602	-0.1592	-0.4537	0.1914	0.7179	-0.0673	0.0210
d_2	0.4584	-0.1680	0.4422	-0.2460	0.0804	0.7065	-0.0083
d_3	0.2409	0.5360	-0.3304	-0.6272	-0.0906	-0.0257	0.3785
d_4	0.3105	0.4711	0.2832	0.6427	-0.1018	-0.0264	0.4212
d_5	-0.4602	0.1592	0.4539	-0.1903	0.6514	-0.0845	0.2985
d_6	-0.4584	0.1681	-0.4441	0.2447	0.0468	0.6968	0.1301
d_7	0.0408	0.6194	0.0777	0.0189	0.1821	0.0493	-0.7568

Table 3 lists the performance scores for all 25 suppliers. The performance evaluation of suppliers can be used to make critical managerial decisions on how to optimize the supplier network, how to allocate resources effectively for supplier development programs, and how to initiate benchmarking and re-engineering programs, etc. Here, the performance score from the PCA method provides

Table 3. Performance score for the 25 suppliers by PCA

Supplier	Performance Score	Rank
S-18	3.0669	1
S-3	2.9944	2
S-10	2.8738	3
S-17	2.7558	4
S-15	2.7460	5
S-14	2.6875	6
S-6	2.6689	7
S-19	2.5788	8
S-8	2.5522	9
S-4	2.4893	10
S-25	2.3850	11
S-20	2.2795	12
S-24	2.2713	13
S-22	2.2584	14
S-2	2.2519	15
S-5	2.2025	16
S-23	2.1722	17
S-7	2.0802	18
S-21	2.0495	19
S-1	2.0151	20
S-11	1.9723	21
S-16	1.9444	22
S-12	1.8102	23
S-13	1.6695	24
S-9	1.5929	25

1228 F.-K. Wang et al.

useful information for the ranking of all suppliers. Those suppliers with the leading scores should be classified as the first tier group for long-term relationships. Those with lower performance scores should be encouraged to upgrade their capabilities. Finally, those suppliers that do not eventually achieve the improvement on their performance score must be eliminated from the supplier base.

Conclusions

When a company attempts to improve the performance of its SCM, it is crucial for it to understand the quality of the supply chain network. Hence, the five steps of the Six-Sigma model are designed to facilitate continuous improvement and process control. Six-Sigma is a systematic, data-driven approach to analysing the root causes of business problems, and is a method for using such measures to analyse, improve, and control the overall quality of the supply chain network. The successful implementation of Six-Sigma depends on committed and effective leadership. Also, it is very important to combine the right projects, the right people and the right tools.

When applying Six-Sigma to supplier development, the continuous improvement itself is a dynamic process of the supply chain network. When multiple dimensions are simultaneously considered in evaluating the overall competence of a supplier, the performance score of each supplier can be obtained by the PCA method. Suppliers with high performance scores are likely to sustain a high level of capabilities, and are better candidates for inclusion in an optimized supplier base. Thus, improvement in the quality of all supply chain processes reduces costs and improves the level of customer service.

Six-Sigma emerges as a new strategy to enhance the performance of SCM. It is believed that the integration of Six-Sigma into SCM will become a standard practice for any e-business application that seeks an advantage in this highly competitive era of globalization.

References

- Avery, S. (2001) Linking supply chains saves Raytheon \$400 million, *Purchasing*, August, pp. 27, 30, 32–34.
- Beamon, B. M. & Ware, T. M. (1998) A process quality model for the analysis, improvement and control of supply chain systems, *International Journal of Physical Distribution & Logistics Management*, 28, pp. 704–715.
- Blakeslee, J. A. (1999) Implementing the six sigma solution, *Quality Progress*, July, pp. 77–85.
- Breyfogle, F. W. (1999) *Implementing Six Sigma: Smarter Solutions Using Statistical Methods* (New York: Wiley).
- Choi, T. Y. & Rungtusanatham, M. (1999) Comparison of quality management practices: across the supply chain and industries, *The Journal of Supply Chain Management*, 35, pp. 20–27.
- Forker, L. B., Mendez, D. & Hershauer, J. C. (1997) Total quality management in the supply chain: what is its impact on performance, *International Journal of Production Research*, 35, pp. 1681–1701.
- Grieco, J. P. L. (1989) Why supplier certification and will it work? *Production and Inventory Management Review and APICS News*, 9(5), pp. 38–42.
- Hahn, C. K., Watts, C. A. & Kim, K. Y. (1990) The supplier development program: a conceptual model, *International Journal of Purchasing & Materials Management*, Spring, pp. 2–7.
- Hahn, G. J., Doganaksoy, N. & Hoerl, R. W. (2000) The evolution of six sigma, *Quality Engineering*, 12, pp. 317–326.

Applying Six-Sigma to Supplier Development 1229

- Harry, M. & Schroeder, R. (2000) *Six Sigma: The Breakthrough Strategy Revolutionizing the World's Top Corporations* (New York: Doubleday).
- Hoerl, R. W. (1998) Six sigma and the future of the quality profession, *Quality Progress*, June, pp. 35–42.
- Hoerl, R. W. (2001) Six sigma black belts: what do they need to know? *Journal of Quality Technology*, 33, pp. 391–406.
- Houshmand, A. A. & Rakotobe-Joel, T. (2000-2001) Integrating the supply chain management and continuous quality improvement approaches by use of the integrated supply chain structural analysis method, *Quality Engineering*, 13, pp. 91–106.
- Jackson, J. E. (1980) Principal components and factor analysis: part I—principal components, *Journal of Quality Technology*, 12, pp. 201–213.
- Johnson, R. A. & Wichern, D. W. (1998) *Applied Multivariate Statistical Analysis* (Singapore: Prentice-Hall).
- Matthews, J., Pellew, L., Phua, F. & Rowlinson, S. (2000) Quality relationships: partnering in the construction supply chain, *International Journal of Quality & Reliability Management*, 17, pp. 493–510.
- Romano, P. & Vinelli, A. (2001) Quality management in a supply chain perspective: strategic and operative choices in a textile-apparel network, *International Journal of Operations and Production Management*, 21, pp. 446–460.
- Simchi-Levi, D., Kaminsky, P. & Simchi-Levi, E. (2000) *Designing and Managing the Supply Chain—Concepts, Strategies and Case Studies* (Singapore: McGraw Hill).
- Sohn, S. Y. & Choi, I. S. (2001) Fuzzy QFD for supply chain management with reliability consideration, *Reliability Engineering and System Safety*, 72, pp. 327–334.
- Wong, A. & Fung, P. (1999) Total quality management in the construction industry in Hong Kong: a supply chain management perspective, *Total Quality Management*, 10, pp. 199–208.
- Wyper, B. & Harrison, A. (2000) Deployment of six sigma methodology in human resource function: a case study, *Total Quality Management*, 11, pp. 720–727.