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Supplier Selection Criteria and Methods in Supply Chain

(A Statistical Approach)

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***Abstract*—In today's competitive environment, vendor selection is considered as a strategic issue in the effective management of a supply chain. Keeping in view the strategic importance of the supplier's role in the functioning of supply chains the researchers have developed number of criteria, methods and models for supplier selection. This study involves a comprehensive review of different methods of supplier selection available in the literature and suggests a new approach based on statistical analysis on different characteristics of the supplier. The suggested approach includes the use of Multivariate analysis of variance and Duncan's multiple range test to assess the variations of the suppliers with respect to their different quality characteristics and use of desirability function to measure the performance status of different suppliers considering all the critical characteristics. The calculated desirability value measured in a 0-1 scale provides a single performance index for each supplier. The methodology was implemented in an Indian industry. It has an immense scope of application in supplier selection problem to improve the performance of supply chain management system.**

***Keywords*—vendor selection criteria, multivariate ANOVA, desirability function**

I. Introduction

Supply chain management (SCM) is a network of businesses and in this network there are several critical decision making problems. One of them is selection of supplier. In today's competitive environment it is impossible to successfully produce high quality, low cost products without considering a satisfactory set of suppliers. In most industries, the cost of raw materials and component parts represents the largest percentage of the total product cost. Therefore, selecting the right suppliers is the key to procurement process. For many years, the traditional approach to supplier selection has been to select suppliers solely on the basis of price. Selecting the right supplier and making a long-term mutually beneficial relationship with them can have significant effects on financial and operational success. The growing role and dependence on suppliers within the company's business chain increases the need for objective assessment of supplier performance. Hence the research need is identified to develop selection criteria and methodology for supplier. This paper aims to present a statistical approach for the same. The subsequent sections include literature survey, proposed methodology applied in an Indian industry, analysis and results, conclusion and significance of the study.

II. Literature Survey

There exists a rich content of literature on supplier selection methodology and criteria. Weber, C. A. et al. [1] reviewed, annotated, and classified 74 related articles which have appeared since 1966. Specific attention was given to the criteria and analytical methods used in the vendor selection process. In response to the increased interest in Just-In-Time (JIT) manufacturing strategies, and analysis of JIT's impact on vendor selection was also discussed by the authors. Since 1966, many criteria have been employed to evaluate and select supplier. Dickson [2] identified 23 different criteria for supplier selection. Evans [3] proposed that price, quality and delivery are key criteria for supplier evaluation in the industrial market. Shipley [4] suggested that supplier selection involve three criteria, namely, quality, price and delivery lead time. Ellram [5] suggested that in the supplier selection process, firms must to consider whether product quality, offering price, delivery time, and total service quality meet organizational demand.

Tung and Torng [6] presented a fuzzy decision-making approach to deal with the supplier selection problem in supply chain system. Lewis [7] suggested that of all the responsibilities that related to purchasing, none was more important than the selection of a proper source. Zeng, A. Z. [8] developed an integrated optimization framework for joint decisions of sourcing and lot sizing for sustaining time-based competitiveness. Sharland et al. [9] empirically examined the impact of cycle time on supplier selection and on the effectiveness of long-term relationships with suppliers, as reflected in the commitment and trust developed. Lin et al. [10] identified the factors affecting the supply chain quality management. Svensson [11] investigated the models of supplier segmentation and supplier selection criteria. Empirical illustrations of supplier segmentation based on the perspectives of a VM (vehicle manufacturer) and its suppliers are presented. Lee et al. [12] proposes a methodology which identifies the managerial criteria using information derived from the supplier selection processes and makes use of them in the supplier management process. Monczka et al. [13] suggested seven step methodology for supplier selection and evaluation process. Li and Fun [14] proposed a supplier performance measure using the concept of dimensional analysis to obtain an index called the VPI (Vendor Performance Index). Weber and Desai [15] demonstrated the use of data envelopment analysis for measuring vendor performance and efficiency. Weber and Ellram [16] explore the use of a multi-objective programming approach as a method for supplier selection in a just-in-time (JIT) setting. Maggie and Tummala [17] formulated an AHP (analytical hierarchy process) based model and applied it to a real case study to examine its feasibility in selecting a vendor for a telecommunications system. Hill and Nydick [18] have shown how AHP can be used to structure the supplier selection process. Elanchezhian, C. [19] used a versatile technique namely multi criteria decision making (MCDM) technique which involves the analytical network process (ANP) and technique for order performance by similarity to ideal solution (TOPSIS) method to select the best vendor. Min, H. [20] proposes multiple attribute utility theory (MAUT) which can help purchasing professionals to formulate viable sourcing strategies in the changing world marketplace particularly for international supplier selection. Sanayei, A. et al. [21] proposed an integrated approach of multi-attribute utility theory and linear programming (LP) for rating and choosing the best suppliers. Shyur and Shih [22] proposed a hybrid model for supporting the vendor selection process. Mukherjee K. [23] provided a systematic review of supplier selection and evaluation process from 2005 to 2012 to answer three main questions: (i) Which method is more appropriate for supplier selection? (ii) Which evaluating criteria were most cited? (iii) Is present trend of research is adequate enough to support proactive buying?

III. Proposed Methodology for Supplier Selection- A Case Study

Over the years, a number of techniques have been proposed to solve the supplier selection problem. The long list of approaches includes linear programming (LP), mathematical programming models, multiple-objective programming, statistical and probabilistic methods, data envelopment analysis (DEA), cost-based methods (CBM), case-based reasoning (CBR), neural networks (NN), AHP, analytic network process (ANP), fuzzy set theory, and techniques for order preference by similarity to ideal solution (TOPSIS). In this paper we will show a statistical approach to assess suppliers' performance and evaluate their performance status by an index. With the basis of the index best supplier was selected.

A. Problem

The present study was carried out in Ferro-Alloy industry situated in South-Eastern India. The raw material of manufacture of ferro-alloys are chrome ore, coke and fluxes. These material mixed in a required proportion constituent a charge. Each charge is fed into a furnace in which chemical processing takes place resulting in liquid ferro-alloys. The liquid alloys is then cast into the form of small ingots. The main raw material for producing ferro-alloys was chrome ore. Various suppliers were supplying chrome ore. Different characteristics of chrome ore were tested at the receiving stage on the basis of which the lots were accepted. Lower yield and poor quality of the finished product became a matter of great concern for the management. A past study revealed that apart from other reasons, poor quality of chrome ore was one of the most important factors leading to various problems during production thereby lowering the yield and degrading the quality of charged chrome produced. Hence a study was initiated to assess the variation in quality of chrome ore supplied by various supplier and developing a vendor rating system to identify the best supplier.

B. Data Collection

There are different quality characteristics (chemical analysis viz., Cr_2O_3, Cr/Fe Ratio, MgO, Al_2O_3, SiO_2, CaO, S, P) of different lots supplied by different suppliers. 6 major suppliers were selected for the study. Three critical characteristics were identified discussing with technical personnel. For the sake of maintenance of confidentiality name of the suppliers and data on characteristics are coded. In the subsequent section of the paper we will refer the name of the suppliers as S1, S2, S3, S4, S5, S6 and the quality characteristics under study as Q1, Q2, Q3.

The present practice of inspection of chrome ore is to take a random sample from the consignment and record the different chemical characteristics for these samples. The inspection department maintains data on the various quality characteristics supplier-wise and consignment-wise. From the past inspection records, seven consignments were selected at random for each of the six suppliers. From each consignment, data on Q1, Q2 and Q3 were collected for five randomly selected samples. This gave rise to a total of 6x7x5 = 210 observation on each of the three characteristics under consideration.

C. Approach

In order to detect whether the suppliers significantly differ with respect to the chrome ore quality and whether the quality varies significantly in different consignments of a supplier, the data were analysed using the statistical technique of Multivariate Analysis of Variance (MANOVA).

A two-stage nested model was used for analysing the data through MANOVA:

$$y_{ijk} = \mu + \alpha_i + \beta_{j(i)} + e_{ijk} \quad (1)$$

Where; y_{ijk} represents the Q1, Q2 and Q3 for kth item in jth consignment of ith supplier. μ is the overall mean effect?

α_i is the effect due to supplier i.

$\beta_{j(I)}$ is the effect due to consignment with-in supplier i.

$e_{ijk} \sim MN(\underset{\sim}{0}, \Sigma)$ is the random error, assumed to be distributed as multivariate normal with mean $\underset{\sim}{0}$ and variance - covariance matrix Σ

Thus; the consignments are nested within suppliers while the items in a consignment are nested within consignments.

The supplier effect was tested against the effect of consignment within supplier which, in turn, was tested against the error term representing the items within consignments (within cell error).

Results of multivariate analysis of variance on Q1, Q2 and Q3 are summarised in the next section (vide- Table- III)

Since the effects due to supplier and consignment within supplier were found to be highly significant through MANOVA (vide table-III), it was decided to test significance of these effects separately for each of the three quality characteristics under consideration. This was achieved using the technique of Univariate Analysis of Variance (ANOVA). Results of univariate analysis of variance for the three quality characteristics Q1, Q2 and Q3 are displayed in table-IV.

The result of MANOVA and ANOVA were obtained using statistical package.

After having found that the suppliers differ significantly in regard to quality of Chrome ore supplied, the suppliers were then classified into homogeneous groups with respect to a particular characteristic such that the suppliers in a group do not differ among themselves with regard to the quality characteristic under consideration. This was done by testing the individual averages pairwise using Duncan's Multiple Range Test. The results of the analysis are furnished in Table-V.

Next, it was decided to grade the suppliers with respect to the quality of Chrome ore supplied by them using a single value to represent each supplier. Since three quality characteristics (Q1, Q2, Q3) were considered which were to be balanced against each other, the problem was to systematically combine the individual quality characteristics, each obtained from different scales of measurement into a single quantitative index representing the overall quality. The desirability function suggested by Harrington J [24] provided a solution to this problem in which the combination was achieved by transforming the measured quality characteristic (x) into a desirability value (d) between 0 to 1 using the following transformation for one sided specifications (i.e., only LSL or only USL given):

$$d = e^{-e^{-(a+bx)}} \qquad (2)$$

The constants and b for each characteristic were found out by assigning two values of d (between 0 and 1) the corresponding values of x. The two values of d were taken as 0.37 (at LSL or at USL) and 0.63 (corresponding to the best available quality). The values of x corresponding to desirability values of d = 0.37 and d = 0.63 were found after discussion with the management and are shown in table-VI.

After having found out the desirability functions for the characteristics Q1, Q2 and Q3, the original values of the quality characteristics were transformed into the d-scale. Next, for each supplier, characteristic-wise desirability was found by using desirability function for that characteristic. Finally, the overall desirability value for each supplier was computed as the geometric mean of its desirability values for Q1, Q2 and Q3. The results are shown in table-VII. Based on the desirability value the best supplier was selected.

D. Results and Analysis

Following table shows the specification of three quality characteristics under study.

TABLE I. SPECIFICATIONS FOR CHROME ORE

Sl.No.	Characteristic	Unit	Requirement
1.	Q1	%	2.8 Min
2.	Q2	%	3.2 Min
3.	Q3	%	20 Max

All the quality characteristics are having one sided specification.

The collected data were summarised to find out supplier-wise average for the characteristics Q1, Q2 and Q3. The results are displayed in table II.

TABLE II. SUMMARY OF DATA ON CHROME ORE QUALITY

Supplier	Characteristic		
	Q1	*Q2*	*Q3*
S1	2.86	3.36	15.21
S2	2.74	3.30	17.21
S3	2.87	3.42	16.65
S4	2.78	3.32	17.04
S5	2.87	3.41	16.57
S6	2.89	3.41	15.67

In order to detect whether the suppliers significantly differ with respect to chrome ore quality and whether the chrome ore quality varies significantly in different consignments of a supplier, the data were analysed using the statistical technique of Multivariate Analysis of Variance (MANOVA).

A two-stage nested model was used for analysing the data through MANOVA:

Results of multivariate analysis of variance on Q1, Q2 and Q3 are summarised in table III.

TABLE III. MANOVA ON Q1, Q2 AND Q3

Effect (Source of Variation	Test name	Computed value of test statistic	Approx.F-Value	Significance of F	Remark
Due to Supplier	Pillais	0.845	2.823	0.001	Effect due to supplier is highly significant
	Hotellings	1.993	4.340	0.000	
	Wilks	0.290	3.558	0.000	
Due to Consignment within supplier	Pillais	1.343	3.783	0.000	Effect due to consignment within supplier is highly significant
	Hotellings	2.653	4.046	0.000	
	Wilks	0.159	3.912	0.000	

Results of univariate analysis of variance for the three quality characteristics Q1, Q2, and Q3 are displayed in table I

V.

TABLE IV. ANOVA ON Q1, Q2 AND Q3

Characteristics	Source of Variation	DF	SS	MS	F	Significance	Remarks
Q1	Supplier	5	0.63657	0.12731	11.06	0.000	Significant
	Consignment within Supplier	36	0.41430	0.01151	3.11	0.000	Significant
	Item within Consignment within Supplier	168	0.62104	0.00370			
	Total	209	1.67191				
Q2	Supplier	5	0.46976	0.09395	7.78	0.000	Significant
	Consignment within Supplier	36	0.43470	0.01207	4.25	0.000	Significant
	Item within Consignment within Supplier	168	0.47676	0.00284			
	Total	209	1.38122				
Q3	Supplier	5	156.01238	31.20248	3.30	0.015	Significant
	Consignment within Supplier	36	340.11086	9.44752	5.92	0.000	Significant
	Item within Consignment within Supplier	168	267.93200	1.59483			
	Total	209	764.05524				

The underlying assumptions of the ANOVA model, namely normality and homoscedasticity were then verified for all the characteristics. Normality of residuals was verified using normal probability plots and histograms of cell means. The normal probability plots did not indicate any great departure from normality. The assumption of homoscedasticity of cell variances was tested using Cochran's C-test and plots of cell variances and s.d.'s against cell means.

In each case, the tests did not indicate any serious violation of the assumptions. After having found that the suppliers differ significantly in regard to quality of Chrome ore supplied, the suppliers were then classified into homogeneous groups with respect to a particular characteristic using Duncan's Multiple Range Test. The results of the analysis are furnished in table V.

TABLE V. GROUPING OF SUPPLIERS BASED ON CHROME ORE QUALITY

Characteristic	Suppliers	Average
Q1	S6, S3, S5, S1	2.87
	S2, S4	2.76
Q2	S3, S6, S5	3.41
	S1, S4	3.34
	S2	3.30
Q3	S1, S6	15.44
	S5, S3, S4,S2	17.02

Next, desirability function constants were estimated from the specifications of the quality characteristics. The estimated constants are furnished in Table-VI.

TABLE VI. DESIRABILITY FUNCTIONS FOR QUALITY CHARACTERISTICS

Characteristic	Values of the variable for		Desirability function constants	
	d = 0.37	***d = 0.63***	***a***	***b***
Q1	2.8	3.0	-10.7231	3.8317
Q2	3.2	3.4	-12.2558	3.8317
Q3	20	15	3.0712	-0.1533

After having found out the desirability functions for the characteristics Q1, Q2 and Q3, the original values of the quality characteristics were transformed into the d-scale. Next, for each supplier, characteristic-wise desirability was found by taking the geometric mean of the individual desirability values for that characteristic. Finally, the overall desirability value of a supplier was computed as the geometric mean of its desirability values for Q1, Q2 and Q3. The results are shown in table VII.

TABLE VII. SUPPLIER WISE DESIRABILITY VALUES

Supplier	Characteristic			Overall
	Q1	***Q2***	***Q3***	
S1	0.45	0.58	0.62	0.54
S2	0.29	0.51	0.52	0.43
S3	0.47	0.65	0.55	0.55
S4	0.34	0.53	0.53	0.46
S5	0.47	0.64	0.56	0.55
S6	0.49	0.64	0.60	0.57

Based on the overall desirability values of six suppliers S6 was chosen as the best supplier.

IV. CONCLUSIONS

The following conclusions were drawn from the analysis of the data.

- Effect due to supplier is highly significant considering 3 quality characteristics simultaneously
- Effect due to consignment within supplier is highly significant considering 3 quality characteristics simultaneously
- Effect due to supplier is highly significant considering each quality characteristic separately
- Effect due to consignment within supplier is highly significant considering each quality characteristics separately.
- Grouping of suppliers has been done for each quality characteristic.
- Based on the overall desirability values of six suppliers S6 was chosen as the best supplier.

V. SIGNIFICANCE OF THE STUDY

This study presents a structured methodology for supplier selection and evaluation based on statistical analysis considering all quality characteristics of all suppliers. This methodology can be applied for vendor selection and vendor rating for any industry irrespective of its nature of products and its characteristics. The use of desirability function converges all characteristics of the supplier into a single point in a 0-1 scale and desirability value of each supplier indicates its performance index in a 0-1 scale. Hence it has a vast scope of application. After selecting a suitable supplier its performance can be monitored using its desirability value. The future scope of research may involve developing a suitable monitoring scheme for the desirability value of the selected supplier.

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