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"An Effective Integration of various Influencing Criteria to Analyse the Best Supplier by Using Analytic Hierarchy Process in Supply Chain"

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Abstract. This paper is aimed to present a decision making approach by using analytic hierarchy process to deal with the dynamic nature of suppliers in supplier selection problems. In broad sense suppliers are responsible for the success and failure of any organization, so the selection process of supplier should be efficient enough. Identify the efficient supplier in supply chain become a key strategic consideration. The main motive of supplier selection process is to minimize purchase risk, maximize overall value to the buyer, and develop long-term relationships between purchasers and suppliers in today's competitive industrial environment. Supplier selection process essentially depends on some important factor such as cost, quality, serviceability, capacity and compliance (CC) and supplier portfolio (SP). All these factors are selected on the basis of their influence on the overall performance of the firm and customer satisfaction. So there is a basic need to develop an approach which integrates all these important factors with their respected weights. It is a multi-objective problem which is solved with the help of comparative study of supplier selection by using an analytical hierarchy process (AHP) in supply chain management. Case study also conducted to show the impact of the adopted methodology where a more effective ratings are generated to efficiently rank the suppliers which are dynamic in nature.

Keywords.AHP, Supplier Selection (SS), Supply Chain Management

1. Introduction

In today's highly competitive and vibrant environment, optimization of supply chain to meet the increasing customer's demand is an important task for manufacturing organizations, within due time keeping the desired quality level in lowest cost. According to authors Enyinda and Chris I. (2010) [1], selection of efficient suppliers is an important issue for purchasing department. In the current paradigm of lean production, there have been many managerial modifications in vendor-rating systems of manufacturing organization as given by Riccardo and Valeria (2003) [6].

The traditional approaches for supplier selection were based especially on price but with the advent of time, need for more dynamic and wide-ranging approach was felt. Essentially, supplier selection is a decision process. As proposed by Francisco, Lauro and Luiz (2014) [2], the decisions are based on evaluation of suppliers on multiple quantitative as well as qualitative criteria. However, Remica and Ainesh (2015) [5] proposed that uncertainty in cost , quality, demand, lead time and vendor's capacity makes selection of suppliers more challenging, whereas Nilesh R ware, S. P. Singh and D. K. Banwet (2014) [3] concluded that supplier selection is dynamic in nature as business of any organization is a continuous process. When considering a multi-period possibility, number of suppliers could be changed in each period, depending upon the organization's requirement. Due to the fluctuations in alternative suppliers and number of criteria, Analytic Hierarchy Model and Fuzzy Logic were incorporated to efficiently obtain the solution of supplier selection

problem. The decision based on Analytic Hierarchy has been best explained by Thomas L. Saaty (1990) [7] who presented a mathematical model using pairwise comparison ratio matrix. Nydick and Ronald (1992) [4] then used this model for supplier selection considering quality, service, delivery and cost as the prime factors responsible for supplier selection.

However, in today's scenario, for efficient selection of supplier, the purchaser must consider supplier's portfolio one of its criteria in terms of supplier awareness towards certifications and standards and its level of being responsible and friendly towards the environment and their employees. A review by Wan Lung Ng [8] discussed an efficient and comprehensive model for multiple criteria supplier selection problem. Francisco, Lauro and Luiz (2014) [2] used a Hybrid model combining Fuzzy AHP and Fuzzy TOPSIS to select suppliers more effectively. Comparing of the Fuzzy AHP and the Fuzzy TOPSIS methods in regard to seven factors such as (i) commitment to quality, (ii) technical capability, (iii) flexibility, (iv) financial situation, (v) on-time delivery, (vi) reputation, (vii) geographic location that are particularly relevant to the problem of supplier selection.

In this paper, numbers of criteria for supplier selection process are grouped into some specific factors viz. Quality, Serviceability, Cost, Capacity & Compliance and Supplier's Portfolio. All these factors have their own importance and this is presented with the help of their weights which improves the overall selection process. All these factors are represented as Indices and integration of analytic hierarchy process with these factors makes an efficient model to suggest the best supplier for the firm in a very less time.

2. ADOPTED METHODOLOGY

The process of supplier selection comprises of criteria formulation and qualification of potential suppliers. This will lead to the ultimate selection of one or two main suppliers. Here, an analytic hierarchical process (AHP) is used which includes different criteria for best supplier selection and relative importance of each supplier on the basis of different criteria. This analytic hierarchical model is shown in the Figure 1. Number of criteria can be varied according to the researcher's preference and liking and number of suppliers can be varied depending upon the product requirement.

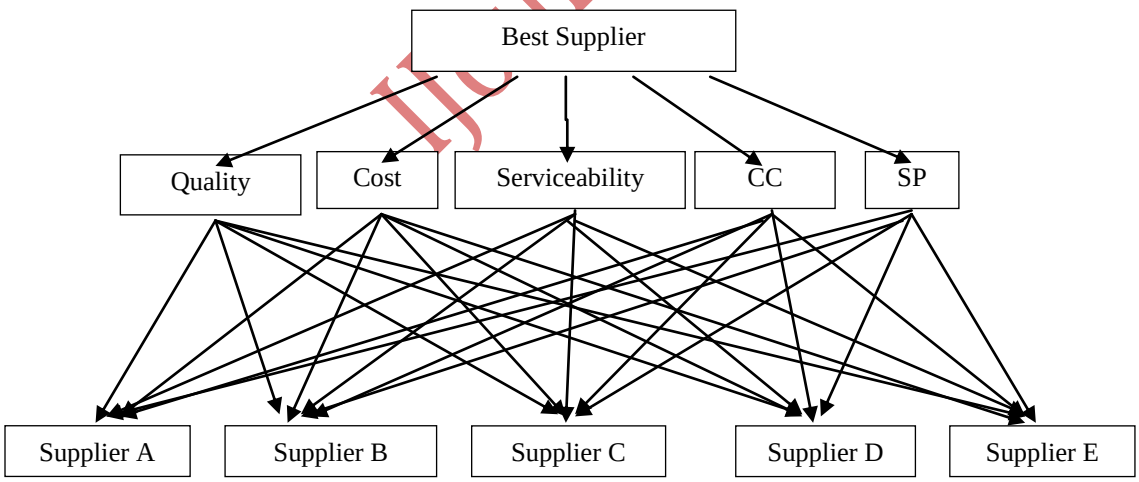

Figure 1.AHP Model for Supplier Selection

2.1 Assumptions

For applying the AHP to the industrial firm following assumptions to be made:

a) Pairwise comparisons can be made between each of the criteria with the variation in the importance of the criteria capable of being evaluated on a Saaty's ratio scale.
b) Relative importance of each supplier with respect to different criteria is assumed on the basis of supplier's performance.
c) Priority vector is assumed to satisfy relative importance of all variables

2.2 Integration of Criteria

There are various parameters which highly influence performance of the firm so basically there is an integration in which all parameters are covered and represented as an index of the particular supplier are as follows:

2.2.1. Quality Index

It is one of the most important criteria because all firms work on best quality principal. Weight of this criterion is calculated with the help of AHP and this presents what numbers of rejections are found in a constant number of sample.

$$Qualityindex = \frac{10 - r_i}{10} \quad (1)$$

Here,

r_i = number of rejected products

The number of units in one sample is considered to be constant as 100 and the maximum rejection allowed for any supplier is 10.

2.2.2. Cost index

As it is well known that cost is the basic parameter which is used to select the best supplier and cost index involves analysis of transportation cost of all available suppliers for the constant quantity (N) and per product cost.

$$Cost\ index = \frac{(N \times U_s) + T_s}{\sum_{s=1}^{S}[(N \times U_s) + T_s]} \quad (2)$$

Here,

N=number of required product

U_s= unit cost by s^{th} supplier {s=1, 2, 3……}

T_s= transportation cost of s^{th} supplier {s=1, 2, 3……}

2.2.3. ServiceabilityIndex

Serviceability is an index which shows the commitment and effectiveness of the supplier. Commitment is in the form of days to deliver the product while effectiveness is in the form of service of defected items and time taken for service. These two things are merged to give ranking for serviceability of the supplier.

Table 1. Delivery ranking.

S. No.	Time to delivery	Rating (R_1)
1	As per Schedule	5
2	10-15 days delay	4
3	15-20 days delay	3
4	20-30 days delay	2
5	More than 30 days delay	1

The rating are used to provide a serviceability index to all alternative suppliers,

$$SI = \frac{R_{1_s} + R_{2_s}}{\sum_{s=1}^{S}[R_{1_s} + R_{2_s}]} \quad (3)$$

2.2.4. Capacity & Compliance (CC) Index:

The evaluation of CC Index includes various parameters such as Manufacturing Capacity of the firm, Annual Turnover, Flexibility etc. Higher the manufacturing capacity and turnover of the firm, higher will be its CC Index. Best supplier in all these parameters can be given a rating of 1 while the worst supplier can have a rating as low as 0.

2.2.5. Supplier Portfolio:

A firm with more advanced and number of certificates of quality and standards followed in manufacturing will be given a higher ranking. Best supplier will be given a rating as high as 1 and the worst will be given as 0.

2.3 Construct Relative Importance Matrix and normalized Priority Vector for 'n' criteria

Constructing the relative importance matrix for 'n' criteria (attributes), the numbers of comparisons are to be made between attributes and the number of required comparisons is evaluated as follows,

$$\text{Number of comparisons required} = \frac{n^2-n}{2} \quad (4)$$

Where,

n = number of criteria / variables

Assuming that $w_1, w_2, , \ldots . w_n$ is the set of criteria and $a_{ij} = (w_i/w_j)$ represents the relative ratio of w_i and w_j,

$$A=[a_{ij}]=w_i/w_j=\begin{bmatrix} w_1/w_1 & w_1/w_2 & \ldots & \ldots & w_1/w_n \\ w_2/w_1 & w_2/w_2 & \ldots & \ldots & w_2/w_n \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ w_n/w_1 & w_n/w_2 & \ldots & \ldots & w_n/w_n \end{bmatrix} \quad (5)$$

Equation (5) is also be written as

$$A=\begin{bmatrix} 1 & a_{12} & \cdots & \cdots & a_{1n} \\ 1/a_{12} & 1 & \cdots & \cdots & a_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ 1/a_{1n} & 1/a_{2n} & \cdots & \cdots & 1 \end{bmatrix} \quad (6)$$

If w_i is equally important as w_j, then a_{ij}=1

If w_i is more important than w_j, then a_{ij} >1

If w_i is less important than w_j, then a_{ij} <1

Here $a_{ij} = 1/a_{ji}$ (i, j = 1, 2, 3…n)

2.4 Normalized priority vector for 'n' criteria

All the elements of each row of the matrix (6) are multiplied together and take the n^{th} root of the product, after calculating the n^{th} root of each row divide it with summation of n^{th} root column to get an element of a vector termed as "priority vector".

$$R = \begin{bmatrix} a_1{}' \\ a_2{}' \\ \vdots \\ a_n{}' \end{bmatrix} \quad (7)$$

Where;

$a_1{}', a_2{}', \ldots a_n{}'$ = Elements of Priority Vector

2.5 Consistency Test

The next stage is to calculate λ_{max} so as to lead to the Consistency Index (i.e. CI) and the Consistency Ratio (i.e. CR).

$$\lambda = \begin{bmatrix} v_1/a_1{}' \\ v_2/a_2{}' \\ \vdots \\ \vdots \\ v_n/a_n{}' \end{bmatrix} \quad (8)$$

$$\lambda_{max} = \left[\sum_{m=1}^{n} v_m/a_m{}'\right]/n \quad (9)$$

$$CI = (\lambda_{max} - n)/(n-1) \quad (10)$$

$$CR = CI/RI \quad (11)$$

Where,

CI= Consistency index

CR= Consistency ratio

RI represents random consistency index, the value of RI is taken from saaty random judgement table 2. Saaty (1990) argue that a CR<0.10 indicates weight of the criteria is consistence.

Table 2.Random Judgement indices.

N	2	3	4	5	6	7	8	9	10
RI	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

2.6 Construct a relative importance matrix and priority vector for all suppliers with respect to each criterion

Assuming that $c_1, c_2, c_3, \ldots . c_n$ is the set of suppliers and $\theta_{ij} = (c_i / c_j)$ represents the relative ratio of c_i andc_j. There will be 'M' matrices for 'n' criteria, if the number of suppliers is assumed to be "s", and then the order of each matrix will be $s \times s$.

$$M_n = \begin{bmatrix} 1 & \theta_{12} & \cdots & \theta_{1s} \\ 1/\theta_{12} & 1 & \cdots & \theta_{2s} \\ \vdots & \vdots & \vdots & \vdots \\ 1/\theta_{1s} & 1/\theta_{s2} & \cdots & 1 \end{bmatrix} \quad (12)$$

2.7 Normalized priority vector for all suppliers with respect to each criterion

$$M_n{}' = \begin{bmatrix} \theta_A{}' \\ \theta_B{}' \\ \vdots \\ \theta_s{}' \end{bmatrix} \quad (13)$$

$\theta_s{}'$is the priority vector for s[th] supplier based on n[th] criterion

2.8 Evaluation of the final rating for each supplier

The final ranking of each supplier is calculated by summing up the multiplications of normalized priority vector for each supplier with normalized priority vector of each criterion.

$$P_S = \theta_s{}' \times \alpha_1{}' + \theta_s{}' \times \alpha_2{}' + \theta_s{}' \times \alpha_3{}' + \cdots\cdots\cdots \theta_s{}' \times \alpha_n{}' \quad (14)$$

Table 3. Final Rating of Supplier.

	Criteria 1	Criteria 2	Criteria 3	…	Criteria 'n'	Rating
	$(a_1{}')$	$(a_2{}')$	$(a_3{}')$	...	$(a_n{}')$	
Supplier A	$\theta_A{}'$	$\theta_A{}'$	$\theta_A{}'$	...	$\theta_A{}'$	P_A
⋮	⋮	⋮	⋮	⋮	⋮	⋮
Supplier S	$\theta_s{}'$	$\theta_s{}'$	$\theta_s{}'$	...	$\theta_s{}'$	P_S

2.9 Select the best supplier

The best supplier is selected based on the final rating allotted to each supplier. The higher the ranking, the better the supplier is.

3. Case study

This case study is conducted to collect the required data for validation of the described methodology, as well as observe the firms approach. Out of the large number of part required for completing the assembly of Eicher Tractor's is selected for study purpose. There four suppliers were found for this part, termed as A (i.e. Inspros engineers Pvt Ltd.), B (i.e. Quality Engg. Insultion Pvt Ltd.) , C (i.e. Mascasts Bombay Pvt Ltd.) & D (i.e. Electrical control and systems). There different index ratings are as follows:

Table 4. Values for Quality Index.

Quality	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E
$\boldsymbol{n}_i$	50	50	50	50	50
$\boldsymbol{r}_i$	0	0	3	3	2
Q	1	1	0.94	0.94	0.96

Table 5. Values for Cost Index.

Cost	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E
U_s	15000	15000	14500	14500	13500
T_s	25,0000	40,0000	20,0000	32,0000	32,0000
C	0.2056	0.2073	0.1995	0.2001	0.1864

Table 6. Values for Serviceability Index.

Serviceability	Supplier A	Supplier B	Supplier C	Supplier D	Supplier E
R_1	4	5	5	5	3
R_2	4	4	3	1	3
S	0.2051	0.2307	0.2051	0.2051	0.1538

4. Analysis using Microsoft Excel

4.1. Relative Importance Matrix and normalized Priority Vector for all criteria

With the help of observed rating the relative importance matrix is constructed using Microsoft excel and consistency is also checked as given in the table 7.

Table 7. Excel sheet of priority vector of all criteria.

	Pairwise Comparison for the five criteria											
	Q	C	S	CC	SP	N^{th}	R	A×R	λ	λm	CI	CR
Q	1	1	2	5	6	2.268	0.351	1.771	5.047	5.11547	0.0289	0.0258
C	1	1	2	4	5	2.091	0.324	1.638	5.063			
S	0.50	0.50	1	3	4	1.246	0.193	0.976	5.062			
CC	0.20	0.25	0.33	1	3	0.549	0.085	0.443	5.217			
SP	0.17	0.20	0.25	0.33	1	0.048	0.048	0.247	5.189			
					Total	6.462	1.00		25.577			

4.2. The relative importance matrix and normalized priority vector for all suppliers with respect to different criteria

Different supplier's data is used to construct these matrixes and all index ratings provide an efficient comparison between all alternative suppliers.

4.2.1. Priority vector with respect to quality

Ratings of quality index are used to construct this relative importance matrix as given in the table (4).

Table 8. Excel sheet of Suppliers priority vector with respect to quality.

	Pairwise Comparison with respect to Quality											
Supplier	A	B	C	D	E	N^{th}	R	A×R	λ	λm	CI	CR
A	1	1	1.25	1.5	1.5	1.230	0.238	1.196	5.017	5.01338	0.0033	0.030
B	1	1	1.5	1.75	2	1.393	0.270	1.354	5.017			
C	0.8	0.667	1	1.5	1.5	1.037	0.201	1.008	5.014			
D	0.667	0.57	0.67	1	1	0.760	0.147	0.738	5.009			
E	0.67	0.5	0.67	1	1	0.740	0.143	0.719	5.010			
				Totall		5.161	1.00		25.067			

4.2.2. Priority vector with respect to cost

Collected data related to all costs made a base for making such a large number of comparisons.

Table 9. Supplier's priority vector with respect to cost.

Pairwise Comparison with respect to Cost												
Supplier	A	B	C	D	E	N^{th}	R	A×R	λ	λm	CI	CR
A	1	0.985	0.894	0.955	0.955	0.957	0.191	0.956	5.000	5	0.000	0.000
B	1	1	0.908	0.97	0.97	0.972	0.194	0.971	5.000			
C	1.118	1.101	1	1.07	1.07	1.071	0.214	1.070	5.000			
D	1.04712	1.03	0.93458	1	1	1.002	0.200	1.001	5.000			
E	1.05	1.03093	0.93	1	1	1.002	0.200	1.001	5.000			
				Total		5.004	1.00		25.00			

4.2.3. Priority vector with respect to serviceability

Service reports play an important role in rating the supplier for their overall serviceability as accurate as possible.

Table 10.Supplier's priority vector with respect to serviceability.

Pairwise Comparison with respect to Serviceability												
Supplier	A	B	C	D	E	N^{th}	R	A×R	λ	λm	CI	CR
A	1	1.1	0.5	1.2	1.3	0.970	0.188	0.944	5.031	5.021	0.005	0.004
B	0.9	1	0.55	0.9	0.95	0.844	0.163	0.817	5.005			
C	2	1.818	1	1.5	2	1.613	0.312	1.570	5.033			
D	0.83	1.11	0.67	1	1	0.908	0.176	0.883	5.026			
E	0.77	1.052	0.50	1	1	0.835	0.161	0.809	5.012			
				Total		5.169	1.000		25.107			

4.2.4. Priority vector with respect to Capacity and Compliance

Table 11.Excel sheet of supplier's priority vector with respect to CC.

Pairwise Comparison with respect to Compliance												
Supplier	A	B	C	D	E	N^{th}	R	A×R	λ	λm	CI	CR
A	1	0.95	1.1	1.2	1.25	1.094	0.216	1.081	5.013	5.00668	0.0017	0.0015
B	1.1	1	1.3	1.5	1.75	1.291	0.255	1.275	5.009			
C	0.909	0.769	1	1.1	1.3	1.00	0.197	0.986	5.000			
D	0.83	0.67	0.909	1	1.2	0.905	0.178	0.892	5.002			
E	0.80	0.5714	0.77	0.833	1	0.782	0.154	0.773	5.009			
				Total		4.455	1.00		25.033			

4.2.5. Priority vector with respect to supplier portfolio

Table 12.Excel sheet of supplier's priority vector with respect to supplier portfolio.

Pairwise Comparison with respect to Supplier Portfolio												
Supplier	A	B	C	D	E	N^{th}	R	A×R	λ	λm	CI	CR
A	1	0.75	1.2	1.4	1.75	1.171	0.213	1.080	5.067	5.063	0.016	0.014
B	1.3	1	2	4	3	2.00	0.364	1.845	5.069			
C	0.833	0.5	1	2	1.5	1.046	0.190	0.958	5.034			
D	0.714	0.25	0.5	1	1.3	0.650	0.118	0.605	5.116			
E	0.57	0.33	0.67	0.769	1	0.628	0.114	0.575	5.034			
				Total		5.495	1.00		25.320			

4.3. Final Ranking for each Supplier

By using criteria priority vector as well as suppliers' priority vectors with respect to each influencing criteria, final rankings of different suppliers are obtained using eq. (14).

Table 13. Excel sheet of Supplier's ranking.

Priority Matrix for Ranking of Suppliers						
	Quality	Cost	Serviceability	CC	SP	Ranking
	0.351	**0.324**	**0.193**	**0.085**	**0.048**	
Supplier A	0.238	0.191	0.188	0.216	0.213	**21.0 %**
Supplier B	0.270	0.194	0.163	0.255	0.364	**22.8 %**
Supplier C	0.201	0.214	0.312	0.197	0.190	**22.6 %**
Supplier D	0.147	0.200	0.176	0.178	0.118	**17.10 %**
Supplier E	0.143	0.200	0.161	0.154	0.114	**16.40%**

5. Results

With respect to overall rating scores of alternative suppliers, supplier A (21.02%) is most preferred, followed by supplier B (22.82%), supplier C (22.59%), supplier D (17.11%), supplier E (16.4) Essentially, supplier B is judged to be overall best.

- This approach gives a clear perspective of all suppliers' performances with respect to most influencing criteria and consistency ratioisvalidating it.
- Selecting the best supplier using the effective method will improve overall performance of the firm up to a great extent. The rating differences between firm's approach and this approach are as follows:

Table 15. Rating Comparison.

Supplier	Rating according to the Eicher Tractor's approach	Rating according to the adopted methodology
A	20%	21.02%
B	20%	22.82%
C	20%	22.59%
D	20%	17.11%
E	20%	16.46

6. Conclusion and Future Scope

AHP is a widely used decision-making tool which is further modified with the help of efficient involvement of all influencing factors. Both factors, qualitative as well as quantitative are considered here. This methodology not only covers some of the parameters of the production firm, it involves critical integration of all affecting variables with their effective weights which make this method more emphatic as well as well suited to the practical condition of the organization.

It is the initial phase of this integration, which requires more calculation; it can be reduced with the help of advanced software involvement and inclusion of programming, which will provide different index values with more efficiency. There can be an implementation of different mathematical approaches to obtain the priority vector and new factors introduction can further modify this method with respect to time.

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