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Analytic Hierarchy Process Modelling for Supplier Selection in a Manufacturing Supply Chain

Ovundah King Wofuru-Nyenke*
Department of Mechanical Engineering
Faculty of Engineering
Rivers State University
Port Harcourt, Nigeria.

Abstract: Manufacturing supply chains are important for national economic development as they create jobs, enable trade and deliver products. Decision-making is a crucial aspect of manufacturing supply chain optimization. In the course of optimizing supply chains, supply chain managers and engineers have to make several decisions such as supplier selection, materials selection, production scheduling, routing, inventory management, pricing strategies as well as evaluation of various product designs, to name a few. In this paper, the Analytic Hierarchy Process (AHP) method was utilized in selecting the best supplier among three (3) alternatives. The decision-making model was built in the SuperDecisions software, with the goal being Supplier Selection, the four (4) criteria being Price, Responsiveness, Communication and Stability. While the three (3) alternatives are Supplier 1, Supplier 2 and Supplier 3. Pairwise comparisons were conducted and the result of ranking the alternatives indicated that Supplier 1 is the best supplier of raw materials to the manufacturing supply chain. The sensitivity analyses indicated that the results are robust, with the inconsistency value being 0.06948 which is less than 0.1. This study provides a procedure for implementing the AHP method of decision-making for supplier selection in a manufacturing supply chain.

Keywords: *Analytic hierarchy process, manufacturing supply chain, multi-criteria decision making, supplier selection, economic development.*

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I. INTRODUCTION

Governments around the world are consistently making efforts to satisfy economic objectives such as increased employment and quality of life, stability of prices of products and services as well as sustainable growth of their economy. These efforts include trade and tax policies that encourage increased manufacturing and production, regulation of financial institutions as well as monetary and fiscal policies [1]. Several countries across the world are restructuring their economy to encourage increased productivity and improved quality of life [2]; [3]; [4]; [5]. In Nigeria, manufacturing supply chains are crucial for sustaining these types of efforts, achieving these economic objectives and hence improving the economy of a country where agriculture and farming for subsistence is more predominant among the masses [6]; [7].

Products of metalworking processes are very common in everyday life [8]; [9]; [10]. Hence, metalworks manufacturing supply chains are very common. Suppliers constitute an important echelon in any manufacturing supply chain network. They are responsible for providing the initial raw materials which are refined, during production, into finished commodities [11]; [12]. Therefore, the problem of choosing the best supplier among alternatives is a complex problem encountered by supply chain managers and engineers worldwide [13]; [14]; [15]. According to the ancient Greek philosopher Aristotle, excellence is

*Correspondence concerning this article should be addressed to Ovundah King Wofuru-Nyenke, Department of Mechanical Engineering, Faculty of Engineering, Rivers State University, Port Harcourt, Nigeria. E-mail: ovundah.wofuru-nyenke@ust.edu.ng
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never an accident. It is always the result of high intention, sincere effort, and intelligent execution; it represents the wise choice of many alternatives – choice, not chance, determines your destiny.

Analytic Hierarchy Process (AHP) is a multi-criteria decision-making method for selecting the best alternative from a group of several alternatives [16]; [17]. AHP has been known to be flexible enough to be integrated with other improvement techniques such as Linear Programming, Fuzzy Logic, Quality Function Deployment, etc. enabling the analyst to benefit from the combined methods and achieve the overall goal [18]; [19]; [20]. The method has been used in several supply chain optimization applications [21]; [22]; [23]. It has proven to be a viable tool for supply chain management and optimization. Moreover, AHP can involve absolute measurements where alternatives are compared with standard levels or relative measurement where alternatives are pairwise compared [24]. The decision-making method helps analysts in finding the best alternative that achieves the goal, based on their understanding of the problem. Therefore, the tool involves a mathematical synthesis of a number of judgements about the decision problem at hand [25]. The method involves structuring a decision-making problem as a hierarchy. This hierarchy is arranged as an upside-down tree where the main goal is placed on top. While objectives that meet the main goal are placed at the second level. These objectives can be further decomposed into third-level objectives, and each set at each level meets the objective of the level to which they are subordinate. At the lowest level, the alternatives are listed and then pairwise compared [26].

The importance of selecting the best supplier cannot be overemphasized. It is impossible for a company to reach its competitive advantage of providing products or services at low cost without the appropriate suppliers [13]. This means that the competitiveness of a supply chain is largely influenced by the performance of its suppliers [27]. Nowadays, industries have become more competitive than ever. This has led to the need for supply chains to make the right decisions in order to survive and acquire reasonable profit. Therefore, the appropriate supplier may lead to better performance of the company and more profits [28]; [29]. On the other hand, selecting the wrong supplier can affect supply chain performance, leading to an ineffective supply chain, that hardly meets the demand of consumers.

The aim of this study is to develop an AHP multi-criteria decision-making model for supplier selection in a manufacturing supply chain. The study aims to propose a viable decision-making model that can be used to solve the supplier selection problem. The objectives of the study include development of a decision hierarchy and AHP model, priority calculation and pairwise comparisons, as well as consistency checks. The following section describes the various methods used in accomplishing the aim and objectives.

II. METHODOLOGY

This study evaluates three (3) suppliers of mild steel sheets to a manufacturer that produces metal products, in order to find the best supplier considering several criteria. The AHP model was built using the SuperDecisions software. The model consists of clusters of elements arranged in levels. The first cluster is the goal cluster containing the goal element, the second is a criteria cluster containing the criteria elements, and finally, the alternatives cluster containing the alternative elements. Figure 1 shows the decision hierarchy and the various clusters and their elements.

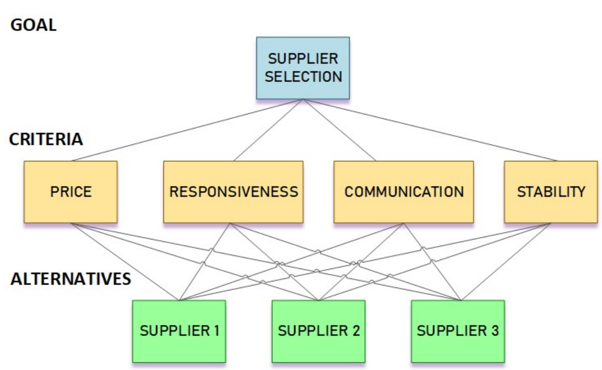

Fig. 1. Decision Hierarchy

From Figure 1, the goal is selection of the best supplier for the metalworks manufacturing supply chain. The suppliers were evaluated based on four (4) general criteria namely: Price, Responsiveness, Communication and Stability. The price criterion entails that the mild steel sheets are affordable and provide the best value for money in terms of quality. The responsiveness criterion requires that the supplier can provide quick delivery service, thereby helping the supply chain speedily respond to varying customer demands, as well as sudden emergencies. The communication criterion necessitates that the supplier attends routine meetings, provides feedback, as well as communicates openly and regularly, giving warning in situations when supplies are unavailable. The stability criterion entails that the supplier is financially capable of delivering the mild steel sheets regularly, and at the time of need.

A. *Priority Calculation*

Priorities are scores for ranking the importance of alternatives in the decision. AHP uses pairwise comparisons by expressing a preference between only two alternatives, instead of simultaneous comparison among all the alternatives. In SuperDecisions the pairwise comparisons are evaluated on a fundamental 1 – 9 scale, as shown in Table 1.

TABLE 1
THE 1 – 9 FUNDAMENTAL SCALE

Degree of Importance	Definition
1	Equal Importance
2	Weak
3	Moderate Importance
4	Moderate plus
5	Strong Importance
6	Strong plus
7	Very Strong or demonstrated Importance
8	Very, very strong
9	Extreme importance

Source: Saaty [30]

The number of necessary comparisons for each comparison matrix, N, was obtained from IshizakaandNemery [31] as

$\mathrm{N} = \frac{\mathrm{n}^2-\mathrm{n}}{2}$........(1)

where n is the number of alternatives/criteria. There are several methods for calculating the priorities from a pairwise comparison matrix [32].The Approximate Method was used in this study. According to Ishizakaand-Nemery [31] the method is based on two steps:

i. Summation of the elements of row i:

$r_i = \sum_i a_{ij}$.......(2)

where r_i is the sum of the elements of row i, a_ij is an element of row i and column j.

ii.Normalization of the sums:

$p_i = \frac{r_i}{\sum_i r_i}$..........(3)

where p_i is the normalization of the sums, r_i is the sum of the elements of row i.

B. *Consistency Check*

It is possible for contradictions to occur when several successive pairwise comparisons are presented. A consistency check is usually performed on the comparison matrix to detect possible contradictions in the entries. According to IshizakaandNemery [31], a matrix filled by pairwise comparison a_ij is called consistent if the transitivity and reciprocity rules are respected.

C. *Transitivity Rule*

$a_{ij} = a_{ik} \cdot a_{kj}$........(4)

where a_ij is the comparison of alternative i with alternative j.

D. *Reciprocity Rule*

$a_{ij} = \frac{1}{a_{ji}}$..........(5)

where i, j and k are any alternatives of the matrix. Supposing that preferences p_i are known, a perfectly consistent matrix given by

$$A = \begin{bmatrix} p_1/p_1 & \dots & p_1/p_j & \dots & p_1/p_n \\ \dots & 1 & \dots & \dots & \dots \\ p_i/p_1 & \dots & 1 & \dots & p_i/p_n \\ \dots & \dots & \dots & 1 & \dots \\ p_n/p_1 & \dots & p_n/p_j & \dots & p_n/p_n \end{bmatrix}$$

can be constructed because all the comparisons a_ij obey the equality

$a_{ij} = \frac{p_i}{p_j}$..........(7)

where p_i is the priority of the alternative i. The consistency index (CI) is given by [30]:

$\mathrm{CI} = \frac{\lambda_{\max}-\mathrm{n}}{\mathrm{n}-1}$......(8)

where λ_{max} is the maximal eigenvalue and n is the number of alternatives/criteria.

E. Analytic Hierarchy Process Model

The AHP model created in the SuperDecisions software is presented in Figure 2. From Figure 2, there is one (1) goal, four (4) criteria and three (3) alternatives. The model seeks to determine the best supplier among the alternatives, considering the various criteria.

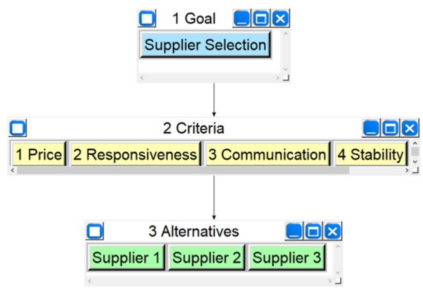

Fig. 2. AHP model

F. Sensitivity Analysis

Sensitivity analysis is usually the last step of the decision process. In this step, input data is slightly modified to observe the impact on the results. Sensitivity analysis allows for the evaluation of different scenarios which may result in change in ranking. If the ranking changes, the results are sensitive. If the ranking does not change, the results are robust. In Super Decisions, sensitivity analysis is performed by plotting the priority of a particular criteria on the x axis and plotting the priorities of the alternatives on the y axis. Next, the priority of the criteria is varied and the impact on the priorities of the alternatives is evaluated.

III. RESULTS AND DISCUSSION

This section presents the results of applying the AHP model to the supplier selection problem. The objective is to select the best supplier considering the various supplier evaluation criteria. The pairwise comparison matrix for the decision model is shown in Table 2.

TABLE 2
CRITERIA PAIRWISE COMPARISON MATRIX

	P	R	C	S
P	1	6	1/4	2
R	1/6	1	1/6	1/3
C	4	6	1	4
S	1/2	3	1/4	1

P stands for Price, R for Responsiveness, C for Communication and S for Stability. Using the 1 – 9 scale in Table 1, Table 2 implies that comparing each criterion with itself, each criterion is of equal importance. However, Price is strong plus more important than Responsiveness, Communication is moderate plus more important than Price, and Price is weakly more important than Stability. The inconsistency of this comparison is shown in Figure 3.

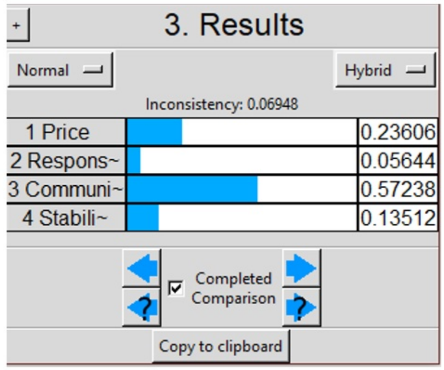

Fig. 3. Inconsistency of pairwise comparisons.

An inconsistency value greater than 0.1 implies that the judgements are inconsistent and need to be corrected. From Figure 3, the inconsistency is 0.06948 which is less than 0.1. Therefore, no correction of judgements is needed. The results of ranking the alternatives were obtained with the Synthesis command in SuperDecisions and are shown in Figure 4.

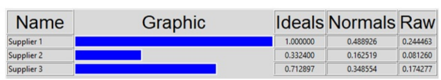

Fig. 4. Results of alternatives comparisons.

From Figure 4, the Normals column presents the results in the form of priorities. The results show that Supplier 1 is the best choice for the manufacturing supply chain. The Ideals column shows the results divided by the largest value so that the best choice has a priority of 1.0. Therefore, Supplier 3 is 71.3% as good as Supplier 1. While Supplier 2 is 33.2% as good as Supplier 1.

Sensitivity analyses were conducted on the results to determine their robustness. The sensitivity plots were generated in the SuperDecisions software, by plotting the priority of the criteria on the x axis and the priorities of the alternatives on the y axis. The results of the sensitivity analyses are shown in Figures 5, 6, 7 and 8.

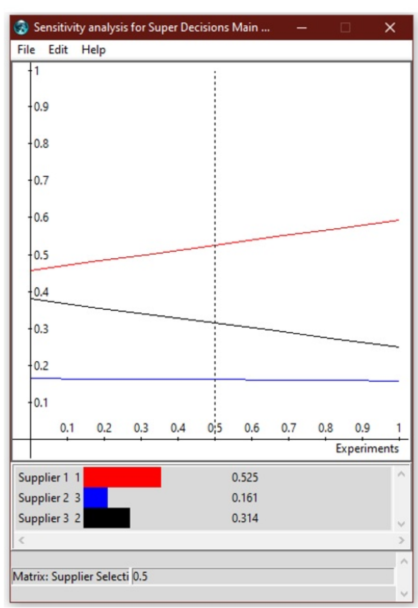

Fig. 5. Sensitivity plot of alternatives priorities versus price priorities

From Figure 5, at the point when Price priority is 0.5, Supplier 1 priority is 0.525, Supplier 2 priority is 0.161 and Supplier 3 priority is 0.314. The figure shows that when the Price priority is less than 0.5 or greater than 0.5, the Supplier 1 remains the best alternative.

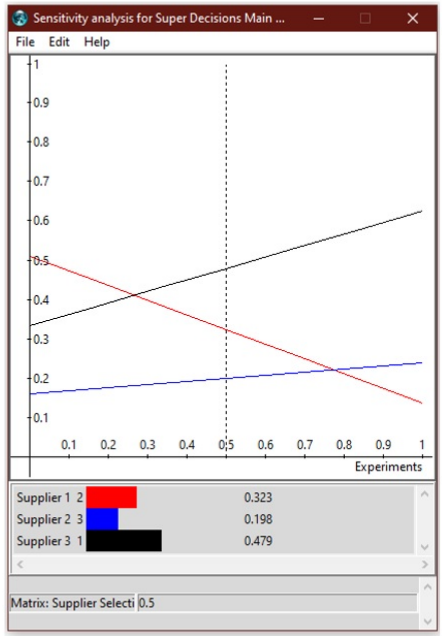

Fig. 6. Sensitivity plot of alternatives priorities versus responsiveness priorities

From Figure 6, at the point when Responsiveness priority is 0.5, Supplier 1 priority is 0.323, Supplier 2 priority is 0.198 and Supplier 3 priority is 0.479. The figure shows that when the Responsiveness priority is greater than 0.5, Supplier 3 remains the best alternative. When the Responsiveness priority is less than 0.5, Supplier 3 is still the best alternative, until about 0.27 when further reduction of the Responsiveness priority leads to the best alternative becoming Supplier 1.

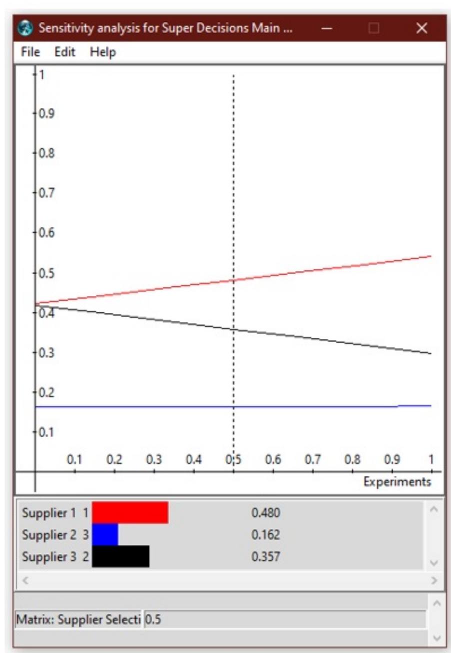

Fig. 7. Sensitivity plot of alternatives priorities versus communication priorities.

From Figure 7, at the point when Communication priority is 0.5, Supplier 1 priority is 0.480, Supplier 2 priority is 0.162 and Supplier 3 priority is 0.357. The figure shows that when the Price priority is less than 0.5 or greater than 0.5, Supplier 1 remains the best alternative.

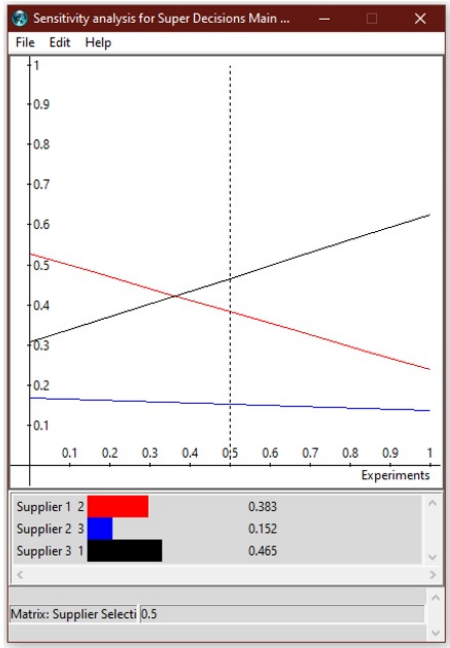

Fig. 8. Sensitivity plot of alternatives priorities versus stability priorities

From Figure 8, at the point when Stability priority is 0.5, Supplier 1 priority is 0.383, Supplier 2 priority is 0.152 and Supplier 3 priority is 0.465. The figure shows that when the Stability priority is greater than 0.5, Supplier 3 remains the best alternative. When the Responsiveness priority is less than 0.5, Supplier 3 is still the best alternative, until about 0.37 when further reduction of the Responsiveness priority leads to the best alternative becoming Supplier 1. From the foregoing, the results can be deemed to be robust, since small changes in the criteria priorities do not lead to large changes in the ranking.

IV. CONCLUSION

Manufacturing supply chain optimisation is an important engineering practice for national economic development. Supply chain managers and engineers are constantly in situations where they need to select the best alternative among several alternatives. Multi-criteria Decision Analysis has proven to be a viable means of achieving this objective. This study contributes to knowledge by utilising the AHP multi-criteria decision-making method for selecting the best supplier among alternatives in a metalworking supply chain. The study portrays the AHP method as a viable tool for selecting suppliers in a manufacturing supply chain. The decision-making problem was modelled in the SuperDecisions software, with the goal being Supplier Selection, the criteria being Price, Responsiveness, Communication and Stability. While the alternatives are Supplier 1, Supplier 2 and Supplier 3. Pairwise comparisons were conducted and the result of ranking the alternatives indicated that Supplier 1 is the best supplier of raw materials to the manufacturing supply chain. The sensitivity analyses indicated that the results are robust, with the inconsistency value being 0.06948. This study provides a procedure for implementing the AHP method of decision-making by supply chain analyst, for supplier selection. Further research can include the utilisation of other multi-criteria decision-making methods for supply chain analysis and optimisation. Also, the decision-making model can be made to include various levels of sub-criteria, in order to model the decision-making problem more accurately.

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