# APPLICATION OF AHP METHOD IN DESIGNING OPTIMAL DISTRIBUTION NETWORK

**Ismaila Abubakar**
Department of Marketing, Purchasing & Supply
Adamawa State Polytechnic, Yola,
Nigeria.

**Abstract**
*Various performance dimensions and product characteristics need to be considered when designing effective and efficient distribution network for manufacturing organisations. Recently, researchers have begun to realise that the decision and integration effort in distribution network design should be driven by a comprehensive set of performance metrics and also product characteristics. In this paper, I recount product features to optimizing distribution network design and adopt cost and service factor performance metrics as the decision criteria. Multi-criteria decision-making methodology – Analytical Hierarchy Process (AHP) is then developed to take into account both qualitative and quantitative factors in the best distribution network design selection. By using AHP methodology I could optimize the selection of delivery network design followed by relevant choices for decision making in a manufacturing company in Nigeria.*

***Key words:*** *Network design, Analytical Hierarchy Approach, Optimal distribution, Multi-criteria decision*

## Introduction

Most manufacturing enterprises are organized into networks of manufacturing and distribution sites that acquire raw material, transform them into finished goods, and distribute the finish goods to customers. A supply chain which consists of all parties involved, directly or indirectly, in fulfilling a customer request is traditionally characterized by the flow of materials and information both within and between business entities. Network design decisions are among the most important supply chain decisions as their implications are significant and long lasting. Distribution refers movement and storage of a product from the supplier point to a customer point in the supply chain. Distribution is pivot to the overall profitability of a firm because it directly impacts both the supply chain cost and the customer fulfilment.

Effective distribution can be used to achieve a lot of supply chain objectives - from low cost to high responsiveness. As a result, companies in the same industry often select very different distribution networks (Rao, Stenger, & Wu, 1994). A network designer needs to consider product characteristics as well as network requirements when deciding on the appropriate delivery network. There are various network designs each with their own strengths and weaknesses. Hence choosing the best delivery network design or a combination of designs is a major challenge for the decision maker. Research in the design category involves contributions from different disciplines. According to (Ballou, Lee, & Billington, 1992), "design of the supply chain determines its structure, i.e., it focuses on the location of decision spots and the objectives of the design". A distribution design should be able to integrate the various elements of supply chain and should strive for the optimization of the chain rather than the entities or group of entities.

Information sharing and its control play a vital role in integration of the different elements of the chain and require highly coordinated efforts of both engineers and managers (Fisher & Raman, 1996). Design needs to focus primarily on the objectives and not just the development of tools used in decision making. This paper primarily deals with the design/selection of an appropriate distribution network to achieve optimal performance, which is measured using a set of criterion.

**Background**

**Performance criterion and product Features for network design options**

When considering distribution between any other pair of stages, such as supplier to manufacturer, many options pop up. Chopra and Meindl (2001) said there are two key decisions when designing a distribution network:

(a) Will product be conveyed to the client area or got from a predetermined site?

(b) Will product flow through an intermediary (or intermediate location)?

Based on the choices for the two decisions, six distinct distribution network designs can be suggested as follows:

1. Manufacturer storage with direct shipping.
2. Manufacturer storage with direct shipping and in-transit merge.
3. Distributor storage with package carrier delivery.
4. Distributor storage with last mile delivery.
5. Manufacturer/distributor storage with customer pickup.
6. Retail storage with customer pickup.

Product features as well as network requirements should be considered when deciding on the appropriate delivery network. These networks have different strengths and weaknesses. The blend used depends on product features and needs of the customers. To survive and remain competitive, companies needs to consider the performance measure when designing effective distribution network. At the highest level, performance of a distribution network should be evaluated keeping the companies' objective in mind which can be appraised along two dimensions:

(a) Customer needs that are met.

(b) Cost of meeting customer needs.

Thus, a firm must evaluate the impact of customer service and cost as it compares different distribution network options.

Most often managers make qualitative analysis such as balanced score card to design the distribution network. Through their experience and intuition they select a combination of these network designs. A multi-criteria decision-making tool known as analytical hierarchy process (AHP) (Saaty, 1980) is hereby proposed in order to determine the most appropriate combination(s).

**Analytic hierarchy process (AHP)**

The Analytic Hierarchy Process (AHP) is a structured technique for helping management deal with complex decisions. Rather than prescribing a "correct" decision, the AHP helps in determining one. Based on mathematics and human psychology, AHP was developed by Thomas Saaty in the 1970s and has been extensively studied and refined since then. The method provides a comprehensive and rational framework for structuring a problem, for representing and quantifying its elements, for relating those elements to overall goals, and for evaluating alternative solutions. It is used throughout the world in a wide variety of decision situations, in fields such as government, business, industry, healthcare, and education.

Several firms supply computer software to assist in applying the process. Users of the AHP first decompose their decision problem into a hierarchy of more easily comprehended sub-problems, each of which can be analyzed independently. The elements of the hierarchy can relate to any aspect of the decision problem—tangible or intangible, carefully measured or roughly estimated, well- or poorly-understood—anything at all that applies to the decision at hand.

Once the hierarchy is built, the decision makers systematically evaluate its various elements, comparing them to one another in pairs. In making the comparisons, the decision makers can use concrete data about the elements, or they can use their judgments about the elements' relative meaning and importance. It is the essence of the AHP that human judgments, and not just the underlying information, can be used in performing the evaluations.

The AHP converts these evaluations to numerical values that can be processed and compared over the entire range of the problem. A numerical weight or priority is derived for each element of the hierarchy, allowing diverse and often incommensurable elements to be compared to one another in a rational and consistent way. This capability distinguishes the AHP from other decision making techniques.

In the final step of the process, numerical priorities are derived for each of the decision alternatives. Since these numbers represent the alternatives' relative ability to achieve the decision goal, they allow a straightforward consideration of the various courses of action.

**Basic AHP approach settings**

The foundation of AHP is a set of axioms that carefully delimits the scope of the problem environment (Saaty, 1980). It is based on the well-defined mathematical structure of consistent matrices and their associated right-eigenvector's (non zero vector) ability to generate true or approximate weights (Saaty, 1980). The AHP methodology compares criteria, or alternatives with respect to a criterion, in a natural, pairwise mode. AHP uses a fundamental scale of absolute numbers that has been proven in practice and validated by physical and decision problem experiments. The fundamental scale has been shown to be a scale that captures individual preferences with respect to quantitative and qualitative attributes just as well or better than other scales (Saaty, 1980). It converts individual preferences into ratio scale weights that can be combined into a linear additive weight w(a) for each alternative a. The resultant w(a) can be used to compare and rank the alternatives and, hence, assist the decision maker in making a choice. Given that the three basic steps are reasonable descriptors of how an individual comes naturally to resolving a multicriteria decision problem, then the AHP can be considered to be both a descriptive and prescriptive model of decision making.

**AHP axioms**

Every theory is based on axioms, basic and implicitly included facts that make the theory applicable. AHP is based on three relatively simple axioms.

The first axiom, the reciprocal axiom, requires that, if PC(EA,EB) is a paired comparison of elements A and B with respect to their parent, element C, representing how many times more the element A possesses a property than does element B, then PC(EB,EA) = 1/PC(EA,EB). The second, or homogeneity axiom, states that the elements being compared should not differ by too much, else there will tend to be larger errors in judgment. When constructing a hierarchy of objectives, one should attempt to arrange elements in clusters so that they do not differ by more than an order of magnitude in any cluster. (The AHP verbal scale ranges from 1 to 9). Presented in table 3.

The third axiom states that judgments about, or the priorities of, the elements in a hierarchy do not depend on lower level elements. This axiom is required for the principle of hierarchic composition to apply.

**Method application and results**

More and more researchers are realizing that AHP is an important generic method and are applying it to various manufacturing areas (Chan and Jiang, 2000). In addition to the wide application of AHP in many areas including manufacturing, marketing information system etc, recent research and industrial activities of applying AHP on other selection problems are also quite active (Lai, Trueblood and Wong). AHP has thus been successfully applied to a diverse array of problems. The process proposed in this study is for selecting the optimal distribution network design in terms of performance metrics and product characteristics. The importance of decisions in the role of distribution within a supply chain helps us to identify factors that are vital when designing a distribution network. Distribution refers to the steps taken to move and store a product from a supplier stage to a customer stage in a supply chain. Distribution is key driver of the overall profitability of a firm because it affects both supply chain cost and customer experience. Therefore, suitable distribution network can be used to achieve a variety of supply chain objectives ranging from low cost to high responsiveness. Case study of Bajabure Industrial Complex was use for this work. Bajabure Industrial Complex is a manufacturer of matrasses and polythene products in Nigeria with two distribution centres, one located in north eastern part where the factory is located and the other in north western part. Bajabure Industrial Complex distributes directly to these two large distribution centres while obligating small distributors to buy from these two large distributors. Products move directly to these two distribution chains, but move through an additional stage when going to smaller markets. Bajabure Industrial Complex decision makers want to re-engineer the distribution network and want to select the best distribution network from a set of network design options. Furthermore, they need justification for the selections. Usually firms can make many different choices when designing their distribution network. A poor distribution network can hurt the level of service that customer receives while increasing the cost. An inappropriate network can have significant negative effect on the profitability of the firm and can even lead to failure. The appropriate choice of distribution network results in customer needs satisfied at the lowest possible cost. The decision makers of Bajabure Industrial Complex pointed out a couple of distribution network designs such as 'manufacture storage with in-transit merge', 'manufacture storage with pickup', and 'retail storage with customer pickup'. The characteristics of these distribution networks are supplied in Table 1. The decision makers want to prioritize performance metrics based on cost and service factor for evaluation of the optimal network design. For cost factor we consider inventory, transportation and facilities and handling. Therefore, at this evaluation criterion focus should be on reducing cost while keeping the service factor constant. Next for customer demand, to satisfy customers, response time and product variety becomes priority. Based on the two priorities – cost factor and service factor, Bajabure Industrial Complex wants to design the best distribution network among the provided options. A ranking of these designs can help the decision maker to choose easily the best design or a combination of designs instead of picking a wrong design (often obtained from subjective analysis) that may lead to inefficiency and loss. A schematic representation of the methodology is given in Fig. 1. At first we consider the evaluation in terms of performance metrics followed by product characteristics. The process proposed for selecting the optimal network comprises the following steps:

***Step 1: Define the evaluative criteria used to select the optimal distribution network:***

Administrators and managers from Bajabure Industrial Complex mark were interviewed in which two evaluation criteria and five evaluation sub-criteria were incorporated. Each criteria was defined in terms of performance (table 2) fig.2 schematically illustrates the developed AHP model for performance metrics hierarchy.

***Step 2: Establish each factor of the pair-wise comparison matrix:***

In this step, the elements of a particular level are compared pair-wise, with respect to a specific element in the immediate upper level. A judgment matrix is formed and used for computing the priorities of the corresponding element. First, a criterion is compared pair-wise with respect to the goal. The judgment Matrix, denoted as a will be formed using the comparison Let $A_{1,} A_{2, \ldots} A_n$ be the set of stimuli. The quantified judgments on pairs of stimuli A A are presented by A=[$a_{ij}$] I, j= 1, 2….,n. The comparison of any two criteria $C_i$ and $C_j$ with respect to the goal is made using the question of the type of the two criteria $C_i$ and $C_j$ which is more important and how much. Saaty [11] suggests the use of a nine-point scale to transform the verbal judgment into numerical quantities representing the values of $a_{ij}$. Table 3 lists the definition of nine-point scale. Larger number assigned to the pair-wise comparisons means larger differences between criteria levels. The entries $a_{ij}$ are governed by the following rules: $a_{ji} > 0$, $a_{ji} = 1/aij$, $a_{ij,} = 1$ for all í. This scale can be applied with ease to criteria that can be defined numerically as well as to those cannot be defined numerically. Relative importance scale is presented .The decision maker is supposed to specify their judgment of the relative importance of each contribution of criteria towards achieving the overall goal.

***Table 2: performance type for defining critical and sub-criteria type***

| | **Code name** | **Performance definition** |
|---|---|---|
| **Criteria** | | |
| Cost factor | $C_f$ | Cost of meeting customer needs |
| Service factor | $C_s$ | Customer needs that are met |
| **Sub criteria** | | |
| Inventory | $C_i$ | To decrease cost |
| Transportation | $C_t$ | To decrease cost |
| Facilities and handling | $C_{fh}$ | To decrease cost |
| Response time | $C_r$ | Customer satisfaction |
| product variety | $C_p$ | Customer satisfaction |

***Table 3: Pair-wise comparison scale* (11)**

| **Intensity of importance** | **Definition** |
|---|---|
| 1 | Equal importance of both elements |
| 3 | Weak importance one element over another |
| 5 | Essential or strong importance one element over another |
| 7 | Demonstrated importance one element over another |
| 9 | Absolute importance one element over another |
| 2,4,6, 8 | Intermediate valued between two adjacent judgments |

***Step 3:*** calculate the eigenvalue and eigenvector

Having recorded the numerical judgments $a_{ij}$ in the matrix $A$. the problem is to recover the numerical weights ($W_{1,}\ W_{2,} \ldots, W_n$) of the alternatives from this matrix. In order to do so, consider the following equation

$$\begin{matrix} a_{11} & a_{12} & \ldots & ai_n \\ a_{21} & a_{22} & \ldots & a_{2n} \\ . & . & . & \\ . & . & . & \\ a_{ni} & a_{n2} & a_{nn} & \end{matrix} \qquad \begin{matrix} W1/W1 & W1/W2 & \cdots & W1/Wn \\ W1/W1 & W1/W2 & \cdots & W1/Wn \\ . & . & & . \\ . & . & & . \\ Wn/W & Wn/W2 & \cdots & Wn/Wn \end{matrix}$$

Moreover, let us multiply both matrices in Eq. (3) On the right with the Weights vector $W=(W_1$ $W_{2....}w_n)$, where $W$ is a column vector. The result of the Multiplication of the matrix of pair-wise ratios with W is $_nW$, hence it follows:

$AW = {}_nW.$

This is a system of homogenous linear equations. It has a non-trivial solution if and only if determinant of $A - {}_nI$ vanishes, that is, $n$ is an eigenvalue of A.$I$ is an $n$ x $n$ identity matrix. Saaty's method computes $W$ as the principal right eigenvector of the matrix A; that is $AW = \lambda_{max}W$,

Where $\lambda_{max=}$is the principle eigenvalue of the matrix $A$. if matrix $A$ is a Positive reciprocal one then $\lambda_{max} \geq n$ [12]. If $A$ is a consistency matrix, eigenvector $X$ can be calculated by $A - (\lambda_{max})\ X = 0.$

Here, using comparison matrix, the eigenvectors were calculated by Eqs. (5) and (6).

Table 4: summarizes the result of the eigenvectors for criteria, sub-criteria, and distribution network design. Besides, the result for each level relative weight of the element are Shown in table 4.

***Step 4: Perform the consistency test***

The eigenvector method yields a natural measure of consistency. Saaty, (1997) defined the consistency index(CI) as:

***Table 4:***

***Weights of criteria, sub-criteria, and choice***

| **Criteria** | **Weights** | **Sub-criteria** | **Weights** | **Manufacture storage within transit merge** | **Manufacture storage within transit merge** | **Retail storage with customer pickup** |
|---|---|---|---|---|---|---|
| $C_f$ | 0.667 | $C_i$ | 0.151 | 0.280 | 0.584 | 0.135 |
| | | $C_i$ | 0.796 | 0.415 | 0.779 | 0.180 |
| | | $C_{fh}$ | 0.051 | 0.766 | 0.158 | 0.758 |
| $C_3$ | 0.333 | $C_r$ | 0.900 | 0.091 | 0.909 | 0.818 |
| | | $C_p$ | 0.100 | 0.585 | 0.280 | 0.134 |

***Table 5:*** **Comparison matrix of relative weight among alternatives (metrics)**

| **Ranking** | **Category** | **Relative weight** |
|---|---|---|
| 1. | Manufacture storage with customer pickup | 1.000 |
| 2. | Retail storage with customer pickup | 0.702 |
| 3. | Manufacture storage with in-transit merge | 0.240 |

$CI= \lambda_{max} - n/(n\text{-}1),$

Where $\lambda_{max}$ is the maximum eigenvalue and $n$ is the number of factors in the judgment matrix. Accordingly, Saaty (1997) defined the consistency ratio (CR) as:

CR = CI/RI

For each size of matrix $n,$ random matrices were generated and their mean CI value, called the random index (RI). Where RI represents the average consistency index over numerous random entries of same order reciprocal matrices. The consistency ratio CR is a measure of how a given matrix compares to a purely random matrix in terms of their consistency indices. A value of the consistency ratio CR $\leq 0.1$ is considered acceptable. Larger values of CR require the decision-maker to revise his judgment. Results of the consistency test and the CR of the comparison matrix from the available inter-view and previous data are all $\leq 0.1$, indicating 'consistency'.

***Step 5: Calculate the overall level hierarchy weight to select the distribution network design:***

The composite priorities of the alternatives are then determined by aggregating the weight throughout the hierarchy. The composite priorities of the alternatives are shown in Tables 5 and fig. 3. According to Table 5, “manufacture storage with customer pickup” is optimal design network selection for the Bajabure Industrial Complex distribution centre in terms of performance metrics.

***Evaluation of distribution network design in terms of product characteristics:***

Following the same preceding procedure, in this phase we propose to obtain the best distribution network design with respect to product characteristics. In this case we do not have the sub-category as was the case in the previous example. The four criteria we selected are – “high demand product’, ‘medium-demand product’, ‘many product sources’, and ‘high product variety’, fig. 4 diagrammatically illustrates the developed AHAP model for product characteristics.

The priorities for criteria and alternatives are shown in Table 6. Besides, the results for criteria and alternatives relative weight of the elements are shown in Table 6.

Retail storage with customer pickup

Manufacture storage with customer pickup

Manufacture storage with in-transit merge

0 0.2 0.4 0.6 0.8 1.0 1.2

**Score**

***Fig. 3 Score graph for delivery network selection in terms of metrics***

To select the Optional Distribution network

Level Goal

High product variety (Pv) high demand product (Ph)

Many product source (Ps)

Medium demand product (Pm)

High demand product (Ph)

Level II

Criteria

**High demand product (Ph)**

**High demand product (Ph)**

**High demand product (Ph)**

Level III
Alternative

*Fig. 4: proposed AHP model for product characteristics hierarchy*

*Table 6: weights of criteria alternatives*

| Criteria | Weights | Manufacture Storage with in-transit merge | Manufacture storage with pickup | Retail storage with customer pickup |
|---|---|---|---|---|
| $P_h$ | 0.162 | 0.091 | 0.091 | 0.818 |
| $P_v$ | 0.489 | 0.223 | 0.321 | 0.454 |
| $P_3$ | 0.190 | 0.123 | 0.203 | 0.454 |
| $P_m$ | 0.157 | 0.148 | 0.160 | 0.690 |

*Table 7: Comparison matrix of relative weight among alternative*

| Ranking | Category | Relative weight |
|---|---|---|
| 1 | Retail storage with customer pickup | 1.000 |
| 2 | Manufacture storage with customer pickup | 0.398 |
| 3 | Manufacture storage with in-transit merge | 0.298 |

The composite priorities of the alternatives are shown in Table 7: and fig. 5. "Retail storage with customer pickup" is optimal design network selection for the Bajabure Industrial Complexdistribution centre in terms of product demand.

Bajabure Industrial Complex wants to select the best distribution design based on product characteristics that can provide high availability levels of relatively common but varied demand products. They provided the same distribution network design options with the previous case.

Manufacture storage with in-transit merge
Manufacture storage with customer pickup
Retailer storage with customer pickup

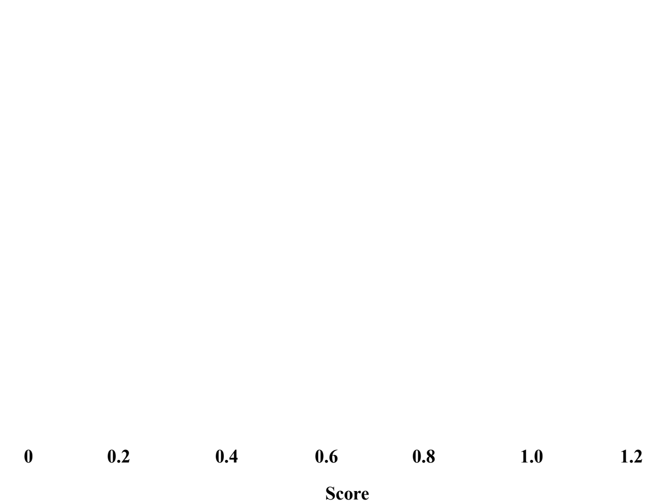


*Fig. 5: score for delivery network selection in terms of product*

***Table 8:*** *Selection of decision –making results*

| **Results** | **Distribution network designs AHP rating (weight)** | **Final decision** |
|---|---|---|
| ***Performance metrics*** | | |
| MS in-transit merge | 0.240 | Choose MS storage customer pickup |
| MS storage customer pickup | 1.000 | |

| | | |
|---|---|---|
| RS customer pickup | 0.702 | |
| ***Product characteristics*** | | |
| MS in-transit merge<br>MS storage customer pickup<br>RS customer pickup | 0.298<br>0.398<br>1.000 | Choose RS storage customer pickup |

Choose Manufacture storage and RS: retail storages

Analysis performed using the proposed methodology for the two cases and results obtained, Bajabure Industrial Complex can now select the distribution network designs from its given options.

Referencing the analyses from Table 8, Bajabure Industrial Complex can opt to use a combination of two distribution network designs (manufacture storage pickup in terms of performance and retain storage customer pickup in terms of product characteristics) to achieve its objectives. According to the given options by the decision makers of Home pl Bajabure Industrial Complex, we provided network that is tailored to match the characteristics of product and performance along with the needs of the customers can either pick them up or have them shipped depending on the urgency. Slower moving items can be stocked at the two large distribution centres and shipped to customer within a day or two. We also see that the performance characteristics of a network with manufacture storage with pickup can lower delivery costs and provide a faster response time than other networks.

Thus the hybrid network recommended for Bajabure Industrial Complex match the characteristics of product and the needs of customer.

**CONCLUSION:**

The case study presented above illustrated how multiple criteria (eg. Level-1 performance metrics) can be included in the AHP approached to permit a more flexible and inclusive use of data in a decision on distribution network design selection. It has also been demonstrated how the AHP weighting can be compared against factors in the distribution network design selection process. The AHP methodology can select the best set of multiple distribution networks to satisfy profitability and customer satisfaction.

As the preceding examples illustrate, firms can make many different choices when designing their distribution network. A poor distribution network can hurt the level of service that customers receive while increasing the cost. An inappropriate network can have significant negative effect on the profitability of the firm. The appropriate choice of distribution network results in customer needs being satisfied at the lowest possible cost.

This study illustrated the use of a multi-criteria technique, namely AHP. AHP can combine quantitative and qualitative factors to handle different groups of actors, and to combine the options of many experts. Selecting a distribution network is extremely complex, and often relies on the subjective assessment of decision makers. Particularly, administrators in some companies lack objective decision-making procedures and clearly defined evaluation criteria. The proposed AHP-based algorithm significantly contributes to optimizing distribution network selection process. Specially, the proposed algorithm can assist decision makers in solving similar multi-criteria problems by offering an objectives and systematic method of selecting the network design in terms of cost and service factors. Finally, the proposed procedure enables managers to adjust a combination of network design to eliminate risk and to enhance service quality and profitability. This study could identify the characteristics and criterion that affect the final result of distribution design process; therefore, this study could effectively select the best distribution network, results in customer needs being satisfied at the lowest possible cost.

## References


Ballou, R.H.(1992) Business Logistics Management, Prentice Hall, Englewood Cliefs, NJ, Third Edition

Chan, F.T.S. Jiang, B. (2000), Development of intelligent decision support tools to aid the design of flexible manufacturing systems, Int. J. Prod. Econ. 65.

Chopra, S; Meindl, P. (2001) Supply Chain Management: Strategy, Planning, Operation, Prentice Hall, NJ.

Fisher, M.L. Raman, A. (1996), Reducing the cost of demand uncertainty through accurate response to early sales, Oper. Res. 44.

Lee, H.L & Billington, C. (1992), Supply Chain Management. Pitfalls and Opportunities.

Rao, K., A. Stenger and H. J. Wu. (1994). Training future logistics managers: logistics strategies within the corporate planning framework." Journal of Business Logistics, vol. 15, no. 2, 249.

Saaty, T. L.(1980) The Analytic Hierarchy Process, McGraw-Hill, NY, 1980.

Saaty, T. L.(1990) Decision Making for Leaders, RWS Publications, PA, 1990.