A Project entitled

Sensitivity Analysis on Supplier Selection and Supply Chain Logistics Optimization Using AHP and Linear Programming.

by

Satvik Dosapati

Submitted as partial fulfillment of the requirements for the ISE 251

Graduation Writing Assessment Requirement

Instructor: Dr. Behin Elahi

Date: 14th December 2023

An Abstract of

Sensitivity Analysis on Supplier Selection and Supply Chain Logistics Optimization Using AHP and Linear Programming.

by

Satvik Dosapati

Abstract:

In a fast-moving, dynamic world, we need to move things quickly and must be able to make very quick decisions. In the supply chain industry, we have a lot of factors that will be involved in getting a product from one place to another. It all boils down to the fact that we need to keep track of the storage limits in the warehouse. If the limits are low, then we need to restock from the suppliers. Choosing a supplier is a major issue, as they need to be reliable, quick, and cost-effective. There are multiple ways to select a supplier. Here, our focus is on performing a sensitivity analysis on supplier selection and supply chain logistics optimization by employing the Analytic Hierarchy Process (AHP) and linear programming techniques. We would be using real-time data, which is taken from our selected research papers.

Focusing on the methodology and our approach in performing the analysis, we would be conducting sensitivity analysis by taking an SME's (subject matter expert) opinion on the parameters we consider. The data is then taken into a reciprocal matrix which is later normalized. By doing this, we will be able to get a new perspective on the ranking of the supplier as the conditions change over a period of time and demand. This analysis enhances our understanding of the reliability and robustness of AHP in real-world scenarios.

We will also work on the sensitivity analysis of linear programming, exploring the impact of variable factors like demand and warehouse capacity on the distribution network. This step aims to show the adaptability and responsiveness of the linear programming model to dynamic logistical conditions.

We would like to get the optimal values from the analysis that would show the supplier ranking based on different factors and parameters, which would make the selection easier based on our main metric of selection. The outcome of the analysis would be to give the stakeholders insights for making easier decisions and to show an overall way to enhance and optimize the supply chain process.

Keywords: Supply Chain, AHP, logistics, optimization, linear programming, sensitivity analysis, warehouse, distribution network.

Table of Contents:

1. Introduction:

Competent supplier selection and supply chain logistics optimization are essential components for organizational success in the modern business environment. Utilizing Linear Programming and the Analytical Hierarchy Process (AHP) as analytical tools, this study analyzes the key aspects of these methods. The study intends to provide insightful data that may enhance organizations decision-making processes, thereby improving their sustainability and competitiveness.

The study's importance lies in the critical role that logistics and suppliers play in the overall functioning of businesses. Organizations need to wisely choose suppliers and improve logistics in an era where supply chains are ever more complex and interconnected in order to stay adaptable and responsive to market demands. The findings of this analysis are expected to provide practical solutions for businesses aiming to improve their supplier selection processes and enhance the efficiency of their supply chain logistics.

Our main motive will be to make a supplier selection process by performing a sensitivity analysis on the supply chain data set we have from our main reference research paper. We will be considering quality as the top priority and check if it has any changing effects on the supplier selection process.

In simpler terms we would like to discuss and validate the data set obtained from the main reference research paper and provide optimization to the decision-making methodologies.The next parts build an in-depth foundation for our research aims and problem description by diving deeper into the literature in order to categorize findings and limitations.

1.1 Multi Criteria Decision Making:

Multi-Criteria Decision Making (MCDM) is a methodology that addresses the challenges of decision-making in situations where multiple criteria need to be taken into account. It is used in various domains, including management, engineering, economics, environmental science, and more. The complexity arises when the decision-makers have a lot of options and have to select using a specific criteria. must navigate through a multitude of alternatives, each characterized by its unique set of attributes and associated criteria.

MCDM methodologies provide a structured and rigorous framework for decision-makers to navigate this complexity. These techniques help in organizing, analyzing, and prioritizing information to facilitate the selection of the most suitable alternative. A crucial aspect of MCDM is acknowledging the potential conflicts and trade-offs between different criteria. In many real-world scenarios, achieving the best outcome in one criterion may come at the expense of another, requiring decision-makers to carefully balance these competing interests.

There are a lot of MCDM techniques, some of the widely used ones include Analytic Hierarchy Process (AHP), Analytic Network Process (ANP), TOPSIS (Technique for Order of Preference

by Similarity to Ideal Solution), and ELECTRE (Elimination and Choice Expressing Reality). These methods offer different approaches to handling decision problems, accommodating various decision-maker preferences, and capturing the nuances of the decision context.

In essence, Multi-Criteria Decision Making is a comprehensive and systematic approach that empowers decision-makers to navigate the intricacies of complex decision problems, ensuring that the chosen solution aligns with their objectives, incorporates trade-offs, and optimally balances the diverse criteria at play.

1.2 Analytic Hierarchy Process and How it works

When it comes to decision-making processes, the Analytical Hierarchy Process (AHP) is a powerful and responsive method that is frequently used in a variety of industries to assist in navigating challenging decisions and ranking criteria for decisions. Dr. Thomas L. Saaty created Analytic Hierarchy Process (AHP), a methodical framework for assessing and prioritizing options in a hierarchical fashion.

Fundamentally, AHP involves restructuring a complicated decision problem into a hierarchical structure with several criteria and possible solutions. Pairwise comparisons and judgments are assigned by decision-makers in order to determine the relative importance of criteria and the performance of alternatives. AHP then uses mathematical algorithms to combine these evaluations, developing a thorough ranking that helps well-informed decision-making.

1.1.1 AHP Applications

1.1.1.a Supplier Selection and Procurement:

AHP helps organizations in evaluating and selecting suppliers based on various criteria, including cost, service speed, reliability, and quality. For example: In the automotive industry, AHP can be applied to assess potential suppliers, considering factors like production capacity, quality standards, and cost competitiveness.

1.1.1.b Strategic Planning:

AHP is extensively utilized in strategic planning to prioritize organizational goals, allocate resources efficiently, and determine strategic initiatives. For example: A company deciding on strategic initiatives for market expansion might employ AHP to assess criteria such as market potential, resource availability, and regulatory factors.

1.1.1.c Project Portfolio Management:

AHP aids in prioritizing and selecting projects within a portfolio by considering factors such as return on investment, resource requirements, and alignment with organizational objectives.For example : A construction company employing AHP might prioritize projects based on criteria like profitability, timeline, and environmental impact.

1.1.1.d New Product Development:

AHP supports decision-making in new product development by assessing criteria such as market demand, technical feasibility, and financial viability.For example: A technology firm deciding on the development of a new software product could use AHP to evaluate criteria like user requirements, development costs, and market trends.

1.1.1.e Resource Allocation:

AHP helps organizations in allocating resources effectively by evaluating the relative importance of competing demands. For example: A healthcare organization could use AHP to prioritize resource allocation among various departments, considering factors like patient needs, staff availability, and equipment requirements.

1.2 Linear Programming and How it works

One of the most potent mathematical techniques in optimization is called linear programming, or LP. It gives organizations a methodical way to make decisions when they have limited resources. With respect to a set of linear constraints, LP aims to maximize or minimize an objective function. It was developed for handling complicated allocation problems. This optimization technique has been widely adopted across a range of industries, helping businesses make well-informed and effective decisions in order to accomplish their objectives.

The fundamental process of Linear Programming is the expression of an objective function mathematically, along with a set of linear constraints that symbolize the restrictions or conditions placed on the variables of choice. Given the constraints, the goal is to determine the ideal values for these decision variables that, depending on the situation, maximize or minimize the objective function. Linear programming also has similar applications as AHP.

2. Literature Review:

In order to understand and learn the complex concepts of supplier selection and supply chain logistics optimization, a review of the literature is crucial. The importance of supplier interactions in determining organizational performance has been highlighted by prior studies. Reliability, affordability, and flexibility of the supplier are examples of factors that become crucial selection criteria.

The table above gives us a summary of the key findings and limitations observed from the four different research papers.

The literature review includes 17 research papers by examining the findings and limitations of previous works in supply chain management and logistics optimization.

Additionally, research shows that Analytic Hierarchy Process (AHP) is a strong tool for supplier selection decision-making, providing an organized method for comparing and evaluating

multiple factors. Meanwhile, by taking into account variables like transportation costs, inventory levels, and production schedules, linear programming has proven successful in optimizing supply chain logistics.

Although there is a lot of research on each of these methods separately, there is a clear lack of information in the literature on how AHP and linear programming work together to improve supply chain logistics and supplier selection. Through the integration of these analytical tools, this study aims to bridge this gap by providing a comprehensive approach to decision-making that takes both supplier selection and logistical efficiency into account.

Theme of the research paper	**Key Findings**	**Limitations observed**
Supplier Selection in Yarn company	It focuses on optimizing the distribution network from the yarn company to the warehouse and customers.	Collected data is from only one person's perspective and it does not provide a diverse opinion.
	The main motive in doing this analysis is to ease the selection of the supplier for the yarn company.	
Supplier Selection using AHP	AHP proves effective in ranking supplier selection criteria.	Reliance on individual opinions in data collection.
	Linear Programming aids in optimizing distribution networks.	Assumptions may impact model accuracy.
Logistics Warehouse Fire Risk	AHP and fuzzy comprehensive assessment contribute to a reasonable and effective risk assessment model.	Data limitations, not covering all dynamic situations.
	Identification of significant risk factors and their weights.	Neglecting factors like inflammable materials.
Airport Choice by Freight Forwarder	AHP structures criteria for airport choice, considering costs, connection quality, and fleet availability.	Assumptions about aircraft capacity and cargo mass.
	Freight forwarders prioritize geographical location, total costs, and ground team capabilities.	

Freight Forwarder Selection	AHP methodology simplifies multi-criteria decision-making, identifying specialized service as crucial.	Basic assumptions in the AHP process.
	Proven experience and knowledge of regulations deemed essential for freight forwarder selection.	

Table 1 - Literature Review Categorization

2.1 Literature Review on Supply Chain Optimization and Distribution Network Application with AHP in a Yarn Company

The main objective of the research paper was to address challenges in the supply chain management of a yarn company. It focuses on optimizing the distribution network from the yarn company to the warehouse and customers. The main motive in doing this analysis is to ease the selection of the supplier for the yarn company.

The applied methodology for this paper was by performing the analysis of AHP and Linear programming. AHP allows in developing a ranking based on a set of parameters. Linear programming helps us in developing a model for a distribution network.

The main assumptions made in the study are that the supply chain management and optimization can significantly reduce costs and improve efficiency. There are no limitations mentioned here in the paper, but I believe that the data collected for the AHP analysis is based on only one person's opinion and the reliance on the accuracy of data and assumptions in Linear Programming models which can be challenged.

After doing an intensive research and detailed deep dived study the authors found that using AHP for supplier selection and Linear Programming for optimizing distribution networks can lead to significant improvements in the supply chain management of a yarn company.

For the future research the authors can focus on expanding the model to include average inventory turns and the cost of waiting. We can also work on including sensitivity analysis of the linear programming model.

2.2 Literature Review on Assessment on logistics warehouse fire risk based on analytic hierarchy process

The main objective of this paper is to assess the risk of fire in a logistics warehouse. They aim to achieve safe and efficient logistics operations. The major focus is on identifying and analyzing the contributing factors for fire risk in a warehouse.

The applied methodology in this research paper is the following: The author focused on AHP and fuzzy comprehensive assessment. A hierarchical model is designed with a target layer of logistics warehouse fire risk, criterion layers (warehouse building, goods, management, environment), and associated index layers with secondary indicators. The weights for each index are determined through subject matter experts (SMEs) consultation, and the fuzzy comprehensive assessment is applied to evaluate and analyze the logistics warehouse fire risk.

The following assumptions were made to continue with the research in this domain of study:
1. The AHP method is assumed to accurately capture and represent expert judgments for determining the weights of assessment factors. 2. The research assumes that the parameters selected are a correct measurement of the assessing risk of fire in a warehouse.

Here are the following limitations that are observed in the study: The data is collected by SMEs and it does not have all the dynamic situations that a logistics warehouse has to face in its day to day operations. There is a factor of causing the fire (inflammable materials) that has not been taken into consideration while working on the analysis.

The application of the assessment model to a logistics warehouse showed that the methodology is reasonable, effective, and feasible. The study provides a structured and quantifiable approach to evaluating fire risk, highlighting the significant risk factors and their respective weights in contributing to overall fire risk.

While the paper does not explicitly suggest areas for future research, the potential directions could include refining the assessment model with more comprehensive data, applying the model to a wider range of logistics warehouse scenarios, and integrating technological advancements in fire risk assessment.

2.3 Literature Review on An AHP approach to airport choice by freight forwarder.

The main objective of the paper is to explore how freight forwarders choose airports and create supply chains in the air cargo market. Starting from the shipper until the customer. The research aims to propose different options to shippers and understand the factors affecting the choice of airports by freight forwarders. This choice would contribute to the development of the business models in terms of efficiency, reliability, and cost.

The study employs the Analytic Hierarchy Process (AHP) to structure and rate criteria that influence airport choice. AHP is used for multi-criteria decision-making, providing a systematic approach to selecting the most suitable airport based on factors like total transport costs, connection quality, and fleet availability. The methodology includes real data from Serbian, Croatian, and Slovenian markets to illustrate the approach.

The study assumes that aircraft capacity is sufficient and that the chargeable mass for cargo is the actual mass (kg). This is an important value as the cost of the goods in handling by the ground team and aircraft cargo will depend on the total mass of the products.

The major findings from the study are that freight forwarders consider factors like the geographical location, total costs, quality of connections, and ground team capabilities for handling cargo when choosing an airport. The paper also identifies the need for airports and airlines to develop more flexibility and efficient operations to accommodate changing cargo trends and attract more demand.

The further scope of the research paper can include by conducting a thorough survey of freight forwarder airport choices to develop a model based on the real time data. It also says that we can assess the preference of cargo routings for freight forwarders to either use a road transportation method(trucking) or by sending the goods in air via a cargo.

2.4 Literature Review on Multi-Criteria Decision System for the Selection of A Freight Forwarder Using AHP.

The primary objective of this research is to develop a process for evaluating and selecting a freight forwarder using the Analytical Hierarchy Process (AHP) methodology. This process involves a multi-criteria evaluation of freight forwarders, assessing them based on quality of service, specialized service network, competitive price, information and technology, and sustainability.

This paper also focuses on AHP methodology for making decisions and having an overall effective process flow. This method simplifies the process of decision making by using the judgment of a subject matter expert and giving values to the pairwise comparisons using ratios and reciprocal matrices.

Only basic assumptions regarding the AHP process were made in this study.

The study revealed that specialized service is the most important decision, with a weight of 54.3%, followed by quality of service, competitive price, information and technology, and sustainability. Within these criteria, proven experience and knowing the regulations were identified as the most important sub-criteria, with weights of 36.2% and 18.1%, respectively. Freight forwarder B was determined to be the best option based on these criteria.

According to the research paper further focus of study can be given in applying this methodology to various industries in different geographical locations to validate and if possible refine the way of approach. It also suggests that we can combine other decision making tools with the AHP methodology for a better result with higher confidence in the data.

2.5 Literature Review on Warehouse operator selection by combining AHP and DEA methodologies.

The primary motive of the study is to develop a systematic approach for selecting warehouse operators by integrating the Analytic Hierarchy Process (AHP) and the Data Envelopment Analysis (DEA). This approach aims to assist companies in deciding which warehouse

operators should be included in their distribution network, focusing on maximizing service/cost-effectiveness and taking into account both qualitative and quantitative criteria.

The methodology combines AHP and DEA. AHP is used to evaluate the service capabilities of alternative warehouse operators based on multiple criteria, including both qualitative and quantitative factors. DEA is then employed to incorporate the cost factor and determine the most cost-effective warehouse operators based on the preferences derived from the AHP analysis. This dual approach allows for a comprehensive evaluation of warehouse operators from both service and cost perspectives.

This study mainly assumes that all the warehouse activities are outsourced to third-party operators. It also assumes that the main analysis is conducted to define potential warehouse locations and gather more information on the operations of alternative warehouse operators.

There are no specific limitations mentioned in the paper but I believe that the quality of data collected matters in AHP will be an issue as it includes the opinion of one Subject matter expert.

The paper's main contribution lies in the combination of AHP and DEA methodologies to address the warehouse operator selection problem. This approach shifts the focus from a traditional cost-oriented perspective to a more balanced view that considers customer preferences, service quality, and cost-effectiveness, thereby offering a more holistic decision-making framework.

The further research can be done by applying the concepts in different industries and various geographical locations.

3. Problem Statement and Objectives of the Study:

The current state of supplier selection processes and supply chain logistics in many organizations lacks a systematic and integrated approach, resulting in suboptimal decisions, increased costs, delays, and diminished overall performance. This study addresses the need for a comprehensive framework that simultaneously evaluates supplier selection criteria and optimizes supply chain logistics.

The study has three main objectives. First, it aims to assess the criteria influencing effective supplier selection using Analytic Hierarchy Process (AHP). This involves identifying and prioritizing key factors such as cost, quality, reliability, and flexibility. Second, the study seeks to optimize supply chain logistics through Linear Programming techniques, considering variables like transportation costs, product production cost, inventory levels, and production schedules. The goal is to develop a model that enhances overall supply chain efficiency and uses the best path network such that the product travels the most optimal way from the factories to the distribution center and finally ends up at the customers. Finally, the study intends to provide a comprehensive decision-making framework by integrating results from AHP and Linear Programming. This unified framework aims to guide organizations in making informed decisions

related to supplier selection and supply chain logistics optimization, thereby improving overall operational performance.

The targeted deliverables encompass refined decision-making frameworks, models, and methodologies contributing to the optimization and efficiency of supply chain management processes. Through these objectives, the research aims to address critical gaps in existing literature and provide practical solutions for industries grappling with complex supply chain dynamics.

4. Methodology, Study Area, and Applied/Collected Data:

We used a few concepts of lean methodology in this project. The major theme of the team was to make sure that we save time in the process of making decisions. We wanted to simplify and apply the PDCA (Plan Do Check Act) methodology. We used AHP as a tool to implement this technique. Our study area covered the business of maintaining a Yarn company and choosing a supplier for their regular produce. The major impact of the selection was based on four criteria namely Cost, Quality, service speed and reliability of the supplier.

Our main focus was on the benefit criteria of the above mentioned attributes. We followed the four steps that are involved in making a priority ranking of all the attributes for all the four suppliers. Using Linear programming we were able to understand the distribution networks and arrive at results to find the optimal path network for the logistics and supply chain of the yarn company.

5. Data analysis, Results and discussion:

In this section we will discuss the data and will also give a detailed explanation on how we proceeded with the data analysis, which led us to the results and our decision of which supplier has to be selected.

5.1 Step 1: Pairwise comparison matrix for the criteria:

For the first step we construct a pairwise comparison matrix for the first criteria. We considered all the four criterias and constructed a 4x4 reciprocal matrix to find the sum of each of the columns. For example the first 4x4 reciprocal matrix we constructed was for the quality criteria. Table 2 depicts the picture of the construction of a pairwise comparison matrix.

Quality Criteria				
Supplier no	S1	S2	S3	S4
S1	1	1/5	3	1

S2	5	1	5	3
S3	1/3	1/5	1	1/3
S4	1	1/3	3	1
Column Sum	7.3333	1.7333	12.0000	5.3333

Table 2 - Pairwise comparison matrix for Quality Criteria.

After constructing the matrix we need to normalize the values in each cell and construct a normalized matrix. The process of doing this is by dividing the value in each individual cell by the column sum for that particular column. Post performing this operation on each cell of the matrix we will be able to normalize the entire matrix. Table 3 shows the normalized version of the matrix with the new values. In the normalized matrix we calculate the average of each row of the matrix for every supplier from S1 to S4. After calculating the row averages we will add them up to find the column sum. If the whole matrix is normalized we will end up with a sum as 1 for the column. As shown the column sum for our analysis is also 1 which directly says that we are proceeding in the correct direction by validating our analysis so far.

Quality Criteria					
Supplier no	S1	S2	S3	S4	Row Averages
S1	0.1364	0.1154	0.2500	0.1875	0.17231
S2	0.6818	0.5769	0.4167	0.5625	0.55948
S3	0.0455	0.1154	0.0833	0.0625	0.07667
S4	0.1364	0.1923	0.2500	0.1875	0.19154
Column Sum					1.00000

Table 3 - Normalized Matrix for Quality Criteria.

The above mentioned steps have to be repeated for all the remaining criteria as well so that we will be able to construct a matrix that has a relation between the four criterias and the four suppliers. The first step in constructing the matrix is by collecting all the row averages of the normalized matrix of all the 4 criterias. This is done to establish a direct connection between the suppliers and criterias. Table 4 shows the values and correlation between the attributes.

Criteria				
Supplier no	Cost	Quality	Service Speed	Reliability
S1	0.26335	0.17231	0.09670	0.12187

S2	0.12187	0.55948	0.25165	0.55789
S3	0.05689	0.07667	0.55495	0.26335
S4	0.55789	0.19154	0.09670	0.05689

Table 4 - Matrix showing the relation between suppliers and criteria

5.2 Step 2: Computation of priority vector (weight of criteria)

For this step we would be comparing the criterias in the row and column of the matrix. We rank the importance of each criteria by comparing them to the other criterias. We then normalize the matrix using the same method as step 1 normalization. After getting the normalized values and taking an average of the rows we will arrive at the priority vector. For this part of the analysis our results are 0.1454 for cost criteria, 0.6102 for the quality criteria, 0.1939 for the service speed criteria and 0.0505 for reliability criteria. The sum of all the average values is equal to one. We can validate the analysis by using the same technique by finding the row average which should be 1.

5.3 Step 3: Check for consistency and validity

This step is basically used for only two main reasons. The first one is to find the consistency index of the dataset and the other one is to validate our analysis. We utilized the excel function =MMULT to perform multiplication of multiple arrays. The first step is done by performing a matrix multiplication for the priority vector matrix with the priority vector to arrive at a product. Step 3 is clearly shown in Table 5 below.

Check for consistency and validity					Preference Vector		Product
1	1/6	1/2	5	X	0.1454	=	0.5964
6	1	4	8		0.6102		2.6619
2	1/4	1	4		0.1939		0.8391
1/5	1/8	1/4	1		0.0505		0.2043

Table 5 - Checking consistency and validity of analysis

After arriving at the product, we then proceed to the next part of the analysis which is dividing the product value with the preference vector. Each value in the cell is divided by the product value of the respective row. We then sum up the values of the arrived products and divide it by 4 as we have four criteria and four suppliers. The value we arrive at the end after performing the analysis indicates Lambda Max. In our analysis for λmax The value is 4.2099.

Since we now have all the required values we can find the consistency index of the dataset by using the formula $CI = (\lambda max - n)/(n - 1)$
Here, n refers to the number of criteria.

Below is the reference table (Table 6) which is universally accepted and was given by Dr. Thomas L. Saaty when AHP methodology was proposed to the world for the first time.

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	1.51

Table 6 - Reference table

The last part in this step is to validate our analysis with the standard RI. So, we arrive at a product CI/RI which is 0.0777 (0.0700/0.90). All the values of CI/RI which are less than 0.10 are said to be as consistent and hence validating our analysis.

5.4 Step 4: Ranking the suppliers and final results.

This is the final step in AHP wherein we find the final ranking of the suppliers for all the different criterias. We multiply the row averages table (Table 4) with the preference vector values we arrived at. We use the same function in excel (MMULT) to multiply the arrays and arrive at a final score for each of the suppliers. Our analysis for this part of the step led to the following values and supplier scores. The below table (Table 7) shows the final scores we arrived at.

Supplier	Score	Rank
Supplier 2	0.4361	1
Supplier 4	0.2196	2
Supplier 3	0.1760	3
Supplier 1	0.1683	4

Table 7 - Final score and ranking of the suppliers

5.5 Sensitivity analysis results for all the criterias.

After computing the ranking for the quality criteria we then performed the sensitivity analysis for the remaining 3 criterias by changing the values for each alternative option we had. We discussed the topic with a Subject Matter Expert (SME) and decided to tweak a few values of each criteria based on the KPI's (Key Performance Indicators) of that particular attribute when compared with the other alternative. We repeated all the steps of AHP to perform the analysis and ended with the final ranking values which were not very different from the rank we initially obtained. Nevertheless, we could validate only two sets of values from our sensitivity analysis (Quality and Reliability). The values obtained for cost and service speed criteria could not be validated and hence we did not proceed with the results. In the same way we could not validate our analysis for the results obtained from Linear programming as well.

6. Conclusions and Further Scope of the project:

The Yarn Company used the lean principles to solve their problems of choosing a supplier and determined the optimal logistical network for their distribution. This network has considered the factors of cost, speed and shipment of the product which was produced in different distribution centers. The Final ranking of the raw materials suppliers are Supplier 2 > supplier 4 > Supplier 3 > Supplier 1.

The future scope of the project can include adding more parameters and additional constraints to widen the range of sensitivity analysis of our AHP model. Also, we can complete the sensitivity analysis of the distribution network model to see how resilient the model is to changes. We can also see the effects of selecting a preferred supplier have on the optimized distribution network. We can add additional value to the analysis by including factors such as real time customer demand for the products, location density of the population having more demand and also the distance between each location to see how it has the effects on the distribution network and optimal path network to be selected by the stakeholders.

7. References following APA standard:

SLno	Citation for reference column using APA format
1	Ertuğrul, İ., & Özbay, B. (2013). Supply chain optimization and distribution network application with AHP in a yarn company. Textile and Apparel, 23(2), 87-93.
2	Ren, S. (2012). Assessment on logistics warehouse fire risk based on analytic hierarchy process. Procedia Engineering, 45, 59-63.

3	Dožić, S., Babić, D., Kalić, M., & Živojinović, S. (2023). An AHP approach to airport choice by freight forwarder. Sustainable Futures, 5, 100106.
4	Mohsen, B. M. (2023). Multi-Criteria Decision System for the Selection of A Freight Forwarder Using AHP. Procedia Computer Science, 220, 135-144.
5	Korpela, J., Lehmusvaara, A., & Nisonen, J. (2007). Warehouse operator selection by combining AHP and DEA methodologies. International journal of production economics, 108(1-2), 135-142.
6	Tahriri, Farzad; Osman, M. Rasid; Ali, Aidy; Yusuff, Rosnah; Esfandiary, Alireza (2008) : AHP approach for supplier evaluation and selection in a steel manufacturing company, Journal of Industrial Engineering and Management (JIEM), ISSN 2013-0953, OmniaScience, Barcelona, Vol. 1, Iss. 2, pp. 54-76, https://doi.org/10.3926/jiem.v1n2.p54-76
7	*Sulistio, H., Waty, M., Setiawan, M. I., Kurniasih, N., & Ahmar, A. S. (2018). Sensitivity analysis with AHP method: Selection of foundation design on Bridge Sei Muara Bulan Anak 2. Journal of Physics: Conference Series, 1028, 012069. https://doi.org/10.1088/1742-6596/1028/1/012069*
8	*F. Bingqing and C. Liting, "Study on Warehouse Site Selection based on AHP," 2020 5th International Conference on Information Science, Computer Technology and Transportation (ISCTT), Shenyang, China, 2020, pp. 276-280, doi: 10.1109/ISCTT51595.2020.00055*
9	Agarwal, Prince & Sahai, Manjari & Mishra, Vaibhav & Bag, Monark & Singh, Vrijendra. (2014). Supplier Selection in Dynamic Environment using Analytic Hierarchy Process. International Journal of Information Engineering and Electronic Business. 6. 20-26. 10.5815/ijieeb.2014.04.03.
10	Integrated GIS-AHP Optimization for Bioethanol from Oil Palm Biomass Supply Chain Network Design: Nurul Hanim Razaka,*, Haslenda Hashimb, Nor Alafiza Yunusb, Jiří Jaromír Klemešc, Guest Editors: Jeng Shiun Lim, Nor Alafiza Yunus, Jiří Jaromír Klemeš
11	A Comprehensive Performance Evaluation of Chinese Energy Supply Chain under “Double-Carbon” Goals Based on AHP and Three-Stage DEA Xiaoqing Huang 1,2,*, Xiaoyong Lu 3, Yuqi Sun 2,*, Jingui Yao 4 and Wenxing Zhu 2
12	Optimization of Logistics System with Fuzzy FMEA-AHP Methodology Guangying Jin *, Qingpu Meng and Wei Feng
13	A Hybrid Supply Chain Risk Management Approach for Lean Green Performance Based on AHP, RCA and TRIZ: A Case Study; Fatima Ezzahra Essaber 1,*, Rachid Benmoussa 1 , Roland De Guio 2 and Sébastien Dubois 2
14	Erdogan, M., & Ayyildiz, E. (2022). Investigation of the pharmaceutical warehouse locations under COVID-19—A case study for Duzce, Turkey. *Engineering Applications of Artificial Intelligence*, *116*, 105389.
15	Rabia, M. A. B., & Bellabdaoui, A. (2023). Collaborative intuitionistic fuzzy-AHP to evaluate simulation-based analytics for freight transport. *Expert Systems with Applications*, *225*, 120116.
16	Singh, R. K., Chaudhary, N., & Saxena, N. (2018). Selection of warehouse location for a global supply chain: A case study. *IIMB management review*, *30*(4), 343-356.
17	Marzouk, M., & Sabbah, M. (2021). AHP-TOPSIS social sustainability approach for selecting suppliers in the construction supply chain. *Cleaner environmental systems*, *2*, 100034.