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FORECASTING AND PREDICTION BY MEANS OF THE ANALYTIC HIERARCHY PROCESS (AHP) IN THE FIELD OF SUPPLY CHAINS

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Abstract

Supply chain management is a critical aspect of modern businesses, with companies striving to optimize their operations for efficiency and profitability. Accurate forecasting and prediction play a pivotal role in achieving these objectives. The study investigates the use of the Analytic Hierarchy Process (AHP) as a robust decision-making tool in supply chain forecasting and prediction. The core of this study involves the development of an AHP-based forecasting and prediction framework tailored to the supply chain domain. AHP is a systematic approach that enables decision-makers to evaluate various forecasting models using a hierarchy of criteria, sub-criteria, and alternatives. The framework also enables the incorporation of expert opinions, historical data, and real-time information, ensuring a comprehensive and adaptable approach to forecasting. Case studies and empirical evidence are presented to demonstrate the effectiveness of the AHP-based framework in improving supply chain forecasting accuracy and decision-making. These examples showcase how AHP can assist in demand forecasting, inventory management, supplier selection, and other critical supply chain activities.

Key words: *Analytic Hierarchy Process (AHP), decision-making, supply chain, case study.*

INTRODUCTION

Dr. Thomas L. Saaty developed the Analytic Hierarchy Process (AHP) in the late 1970s, a versatile decision-making method that helps individuals and organizations make complex decisions by structuring problems into a hierarchical framework, comparing alternatives, and quantifying subjective judgments. It has found applications in a wide range of fields, including business, engineering, healthcare, environmental management, and more.

With the application of multiple criteria, a decision will be made to decide on the production of a place that will serve to be competitive to all. The selection of a location for a specific product, with certain features, should increase the income. Therefore, from the many methods of multi-criteria decision-making, we will keep the AHP method.

AHP recognizes that decision-making often involves multiple criteria or factors that need to be considered simultaneously. These criteria can be both quantitative and qualitative, and they may have varying degrees of importance or priority.

AHP can readily handle quantitative criteria. These are the criteria that are measured using numerical values, such as cost, length, weight, or any other metric. Decision-makers can assign precise numerical values to these criteria, which makes it relatively straightforward to compare and evaluate alternatives based on these criteria. AHP can use these numerical values to calculate the relative importance weights for the criteria.

AHP is also well-suited for dealing with qualitative criteria. Qualitative criteria are often more abstract or subjective, and they may not be easily quantifiable. Examples of qualitative criteria include factors like reputation, customer satisfaction, or environmental impact. In AHP, decision-makers can use a scale (often a 1 to 9 scale in Table 1) to express the relative importance or preference for these criteria. The scale values are then used in pairwise comparisons to derive the criteria weights.

AHP offers a systematic method for evaluating and prioritizing criteria and alternatives, enabling decision-makers to make informed and consistent choices.

MULTI-CRITERIA DECISION-MAKING (MCDM) METHODS

AHP is highly beneficial in handling intricate decisions involving multiple stakeholders, conflicting objectives, and both quantitative and qualitative factors. It provides a structured and transparent framework for decision-making, promoting consistency and reducing the potential for bias.

Other multi-criteria decision-making (MCDM) methods can be used to solve specific problems instead of the Analytic Hierarchy Process (AHP). The choice of the most appropriate MCDM method depends on the nature of the problem, the available data, and the preferences of the decision-makers. Here are some other MCDM methods that can be used:

1. Multi-Attribute Utility Theory (MAUT): MAUT is a method that combines decision-maker preferences and numerical values to assess alternatives. It allows decision-makers to assign utilities and weights to various criteria and then calculate the overall utility of each alternative.
2. TOPSIS (Technique for Order of Preference by Similarity to Ideal Solution): TOPSIS is a method that identifies the alternative that is closest to the ideal solution while being farthest from the worst solution. It uses a geometric mean or weighted sum approach to evaluate alternatives.
3. ELECTRE (Elimination and Choice Expressing Reality): ELECTRE is a family of MCDM methods that involve ranking alternatives based on their concordance and discordance with predefined criteria. It is useful when dealing with qualitative and imprecise data.
4. PROMETHEE (Preference Ranking Organization Method for Enrichment Evaluations): PROMETHEE is a method that ranks and selects alternatives by comparing them with each other based on preference functions. It considers criteria that represent positive and negative preferences.
5. Simple Additive Weighting (SAW): SAW is a straightforward method that calculates a weighted sum of criteria for each alternative. The alternative with the highest sum is chosen as the best.
6. Weighted Sum Model: Similar to SAW, this method involves assigning weights to criteria and calculating the weighted sum for each alternative. It is a basic but widely used approach in MCDM.
7. Goal Programming: Goal Programming is used when there are multiple conflicting objectives. It tries to find a solution that minimizes the deviations from these objectives.
8. Analytic Network Process (ANP): ANP is an extension of AHP that allows for more complex and interdependent relationships between criteria and alternatives.

The choice of the MCDM method should be based on the specific characteristics of the problem, the availability of data, the preferences of the decision-makers, and the nature of the decision criteria. AHP is just one tool in the broader toolbox of MCDM, and different methods may be better suited to address certain types of problems.

RESEARCH METHODOLOGY

Mathematical-model optimization methods are utilized in mining planning and design, involving the definition and development of a mathematical model. The set of modelling methods can be categorized based on the application position.

The decision-making process is often complex due to competing and conflicting goals among available criteria or alternatives, often involving weighted alternatives that meet the desired goals. The challenge lies in selecting the most suitable options to achieve the set of overall objectives. The term "analytical hierarchical process" (AHP) refers to the examined problem with the choice and is based on the idea of balance used to identify the overall relative significance of a group of traits, actions, or criteria. The modeling process involves organizing complex decision-making problems into a hierarchy of levels, assigning weights using double-piece matrices, and using an expert decision support system to calculate the normalized weight. The qualities at the base of the hierarchy are estimated using these weights, with the four steps being recognized as follows:

- Problem structuring,
- Data collection,

- Relative weight assessment, and
- Determining the solution to the problem.

The problem structuring stage involves breaking down complex decision-making problems into hierarchies, where each level represents a smaller number of managed attributes. These hierarchies are then broken down into elements that correspond to the next level, allowing for effective problem-solving and identifying significant attributes to achieve the overall goal. This method provides exceptional flexibility in decision-making processes and allows for the realization of independence, as attributes can disintegrate at different hierarchical levels.

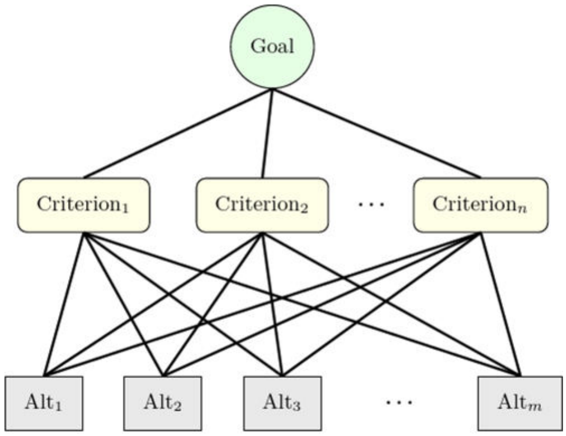

Fig. 1 Structuring the problem
source: https://github.com/manuelalferez/ahp

The second stage of the AHP involves data collection and measurement, assigning relative estimates of attribute pairs to hierarchical levels. A nine-point scale for weight distribution is used, which has proven highly reliable in solving real-world problems, as shown in Table 1.

Table 1. Nine-point scale according to Saaty

AHP (AIJ)	**Num. Rating**	**Reciprocal**
Extreme Importance	9	0.1111
Very strong to extremely	8	0.1428
Very strong Importance	7	0.2
Strongly to very strong	6	0.3333
Strong Importance	5	1
Moderately to Strong	4	3
Moderate Importance	3	5
Moderately	2	7
Importance	1	9

The evaluation of relative weights takes place at the method's third stage (AHP).

The AHP method involves locating a composite normalized vector by multiplying weight vectors by all subsequent levels. This vector is then used to determine the relative priorities of all subjects at the lowest hierarchical level, enabling the achievement of the overall problem's goals. The method has been successfully used to solve real-world problems such as choosing an operating system for a local computer network, studying product/market/distribution, and predicting product prices.

RESEARCH STUDY USING THE METHOD OF ANALYTICAL HIERARCHICAL PROCESS

Analytical hierarchy process is utilized globally in a wide range of decision-making scenarios in domains including the government sector, commerce, industry, health, shipbuilding, and education. It has a specific applicability in group decision-making, or group choices.

This paper proposes a modern scientific methodology, AHP, for selecting the most favorable producers and suppliers of leather material for a company, utilizing multi-criteria decision-making methods as a modern approach. [2]

1. Analyze the issue.
2. Identify alternatives.
3. Selection of criteria and definition of their weights.
4. To transform the qualities of the attributes.
5. Making a multi-criteria model.
6. Determining the optimal solution.

A production plan is crucial for efficient and cost-effective production, requiring knowledge of procurement, operation, and material resources. It involves selecting materials based on bidder offers, considering transport and material prices as factors. The process ensures accurate selection of materials, ensuring efficient and cost-effective production. Orders are made from specific locations and distances, ensuring optimal results. The problem requires analyzing technical-economic parameters and creating a model for selecting an appropriate material manufacturer and supplier using a multi-criteria decision-making method. Four hypothetical models of material manufacturers and suppliers are provided for an industrial process involving chemical preparations with basic characteristics. [3], [4]

To demonstrate the AHP method through an example in a real environment, four alternative locations will be taken where a particular product can be manufactured. These producers should use an industrial process that will have to meet certain criteria, namely:

Criterion 1 - Price of material,
Criterion 2 - Material performance,
Criterion 3 - Delivery time,
Criterion 4 – Location,
Criterion 5 - Material quality.

The AHP method is utilized for multi-criteria decision-making in this hypothetical problem-solving scenario, where input criteria are evaluated quantitatively and qualitatively to create a decision matrix, as described in previous chapters.

SOLVING A MULTI-CRITERIA MODEL IN SELECTING THE BEST MANUFACTURER ACCORDING TO THE REQUIREMENTS OF A COMPANY

The calculation methodology uses the AHP method for multi-criteria decision-making described in the previous chapters. The data used in this problem-solving example are fictitious.

Table 2. Evaluation matrix / comparison of criteria

	c1	**c2**	**c3**	**c4**	**c5**
c1	1	2	1	4	1
c2	½	1	2	3	2
c3	1	½	1	3	2
c4	¼	⅓	⅓	1	1
c5	1	½	½	1	1

Table 3. Normalized matrix / weight values

	c1	c2	c3	c4	c5	AMOUNT	WEIGHT	CA
c1	0.2667	0.4615	0.2069	0.3333	0.1429	1.4113	0.28226	1.05847
c2	0.1333	0.2308	0.4138	0.25	0.2857	1.3136	0.26272	1.13846
c3	0.2667	0.1154	0.2069	0.25	0.2857	1.1247	0.22494	1.08717
c4	0.0667	0.0769	0.069	0.0833	0.1429	0.4388	0.08776	1.05299
c5	0.2667	0.1154	0.1034	0.0833	0.1429	0.7117	0.14234	0.99637

A decision matrix is initially created using quantitative and qualitative evaluations of the criteria that were used as input data for the model; after processing, the subsequent matrix is produced. An assessment matrix, or matrix of comparison pairings, is created based on the established hierarchical structure and the decision maker's assigned preferences.

After finding the largest eigenvalue, the next step is to find the consistency index CI. We do that through the following formula:

$$CI = \frac{\lambda_{max} - n}{n - 1} = \frac{5.321 - 5}{5 - 1} = 0.08025$$

The next and also the last step is finding the ratio of consistency CR.

$$CR = \frac{CI}{RI} = 0.074433097 < 10\%$$

since it is less than 10% or 0.10, it follows that the level of inconsistency is acceptable.

The AHP algorithm method transforms qualitative attributes into numerical values and ranks them for each alternative in a matrix form. This method decomposes the problem into sub-problems, making them easier to understand and subjectively evaluate. Subjective assessments are converted into numerical values and ranked for each alternative using Saaty's numerical values. The following is a presentation of the findings and numerical values from the AHP analysis for all four cities. Numerical values for the above values will be displayed separately:

Table 3. Evaluation matrix of comparison pairs in relation to the criterion price of the material

Price of the material	#1	#2	#3	#4	#1	#2	#3	#4	WEIGHT
Pristina	1	2	0.2	9	0.1513	0.4444	0.0625	0.6923	0.338
Athens	0.5	1	1	2	0.0756	0.2222	0.3125	0.1538	0.191
Nis	5	1	1	1	0.7563	0.2222	0.3125	0.0769	0.342
Skopje	0.1111	0.5	1	1	0.0168	0.1111	0.3125	0.0769	0.129
	6.6111	4.5	3.2	13					

Calculating the consistency index C.I = 0.069288, and finding the ratio of consistency CR

$$CR = 0.07698669 < 10\%$$

From the price of the material criterion, the best ranked city is Nis.

Table 4. Evaluation matrix of comparison pairs in relation to the criterion material performance

Material performance	#1	#2	#3	#4	#1	#2	#3	#4	WEIGHT
Pristina	1	0.25	1	1	0.1429	0.0476	0.2857	0.2308	0.177
Athens	4	1	1	0.3333	0.5714	0.1905	0.2857	0.0769	0.281
Nis	1	1	1	2	0.1429	0.1905	0.2857	0.4615	0.270
Skopje	1	3.0003	0.5	1	0.1429	0.5715	0.1429	0.2308	0.272
	7	5.2503	3.5	4.3333					

Calculating the consistency index C.I = 0.0840097, Lambda max = 4.837225 and finding the ratio of consistency CR

$$CR = 0.093344156 < 10\%$$

From the material performance criterion, the best ranked city is Athens.

Table 5. Evaluation matrix of comparison pairs in relation to the criterion delivery time

Delivery time	#1	#2	#3	#4	#1	#2	#3	#4	WEIGHT
Pristina	1	0.1111	0.5	0.25	0.0625	0.0105	0.1915	0.0588	0.081
Athens	9	1	0.1111	2	0.5625	0.0942	0.0426	0.4706	0.292
Nis	2	9.0001	1	1	0.125	0.8482	0.383	0.2353	0.398
Skopje	4	0.5	1	1	0.25	0.0471	0.383	0.2353	0.229
	16	10.611	2.6111	4.25					

Calculating the consistency index C.I = 0.6330768, Lambda max = 6.408036 and finding the ratio of consistency CR

$$CR = 0.70341 < 10\%$$

From the delivery time criterion, the best ranked city is Nis.

Table 6. Evaluation matrix of comparison pairs in relation to the criterion location

Location	#1	#2	#3	#4	#1	#2	#3	#4	WEIGHT
Pristina	1	1	2	1	0.2857	0.25	0.2222	0.3125	0.268
Athens	1	1	1	1	0.2857	0.25	0.1111	0.3125	0.240
Nis	0.5	1	1	0.2	0.1429	0.25	0.1111	0.0625	0.142
Skopje	1	1	5	1	0.2857	0.25	0.5556	0.3125	0.351
	3.5	4	9	3.2					

Calculating the consistency index C.I = 0.068739, Lambda max = 4.29352 and finding the ratio of consistency CR

$$CR = 0.07637617 < 10\%$$

From the location criterion, the best ranked city is Skopje.

Table 7. Evaluation matrix of comparison pairs in relation to the criterion material quality

Material quality	#1	#2	#3	#4	#1	#2	#3	#4	WEIGHT
Pristina	1	1	2	1	0.2857	0.2	0.4444	0.25	0.295
Athens	1	1	0.5	1	0.2857	0.2	0.1111	0.25	0.212
Nis	0.5	2	1	1	0.1429	0.4	0.2222	0.25	0.254
Skopje	1	1	1	1	0.2857	0.2	0.2222	0.25	0.239
	3.5	5	4.5	4					

Calculating the consistency index C.I = 0.0636905, Lambda max = 4.19107 and finding the ratio of consistency CR

$$CR = 0.070767196 < 10\%$$

From the material quality criterion, the best ranked city is Pristina.

Table 8. Summary results of AHP

Summary	Price of material Weighting Score	Material performance Weighting Score	Delivery time Weighting Score	Location Weighting Score	Material quality Weighting Score	Final Score
Pristina	0.338	0.177	0.081	0.268	**0.295**	0.225
Athens	0.191	**0.281**	0.292	0.240	0.212	0.245
Nis	**0.342**	0.270	**0.398**	0.142	0.254	**0.306**
Skopje	0.129	0.272	0.229	**0.351**	0.239	0.224

The example given above shows the decision-making process that will have an optimal source for the procurement of materials for the needs of a company that wants to determine a certain product with certain criteria. Further analysis using the AHP method shows that the best producer for safety is Nis. From the result it can be determined that it is farthest as a location, but it has better delivery time, quality, and cost of material to produce in that city.

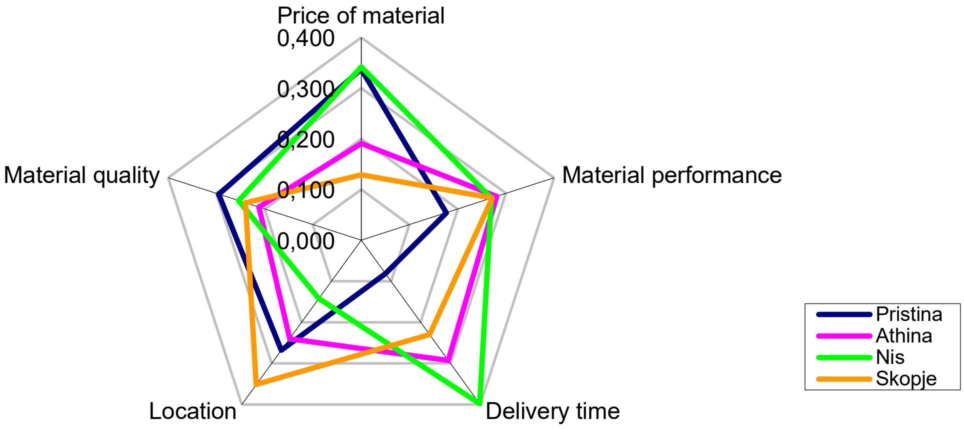

Figure 1. Graphical representation of the AHP result

CONCLUSION

There are many companies that get advantages from implementing the AHP technique in their daily operations, but there are also many more businesses that are still unaware of the potential of the AHP. We hope that this article, together with the analyses and findings that are attached, will help people realize why such an approach should be used throughout the selection process.

AHP is a powerful technique for enhancing forecasting and prediction in supply chains. It enables decision-makers to consider multiple criteria, balance trade-offs, and make more informed choices. However, successful implementation requires a commitment to data quality and ongoing refinement of the decision model. When used effectively, AHP can contribute to improved supply chain performance, cost reduction, and increased customer satisfaction.

This study sheds light on the potential of the Analytic Hierarchy Process as a valuable tool for supply chain professionals and decision-makers. The research underscores the importance of adapting advanced decision-making techniques to the evolving challenges of supply chain management, ultimately paving the way for more efficient and responsive supply chain operations in an increasingly dynamic global marketplace.

The outcomes of this research suggest that integrating the Analytic Hierarchy Process into supply chain forecasting and prediction can lead to more informed, accurate, and resilient supply chain strategies. By considering the various dimensions of decision-making and accommodating changing business environments, this approach contributes to enhanced supply chain performance and competitiveness.

There are many companies that can use the methods of decision making and analysis. One of them is the AHP method, which can help in deciding which the strategic ones are. An example is given of a company deciding that it will redirect production, which will have to make a decision to keep certain details that are important to it. From the results, it can be concluded that Nis is the solution, which is also shown in the picture above that all the criteria show that the expected request is correct. Figure 1 shows that there is the greatest deviation in price and quality in almost all cities, but this is a good indicator if we take it into account.

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ПРОГНОЗИРАЊЕ И ПРЕДВИДУВАЊЕ СО ПОМОШ НА АНАЛИТИЧКИОТ ПРОЦЕС НА ХИЕРАРХИЈАТА (AHP) ВО ОБЛАСТА НА СИНЏИРИ НА СНАБДУВАЊЕ

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Апстракт

Управувањето со синџирот на снабдување е критичен аспект на модерните бизниси, при што компаниите се стремат да ги оптимизираат своите операции за ефикасност и профитабилност. Точното прогнозирање и предвидување играат клучна улога во постигнувањето на овие цели. Студијата ја истражува употребата на аналитичкиот процес на хиерархија (AHP) како робусна алатка за донесување одлуки во прогнозирањето и предвидувањето на синџирот на снабдување. Целта на оваа студија вклучува развој на рамка за прогнозирање и предвидување базирана на AHP, прилагодена на доменот на синџирот на снабдување. AHP е систематски пристап кој им овозможува на носителите на одлуки да оценат различни модели на предвидување користејќи хиерархија на критериуми, под-критериуми и алтернативи. Рамката овозможува и инкорпорирање на експертски мислења, историски податоци и информации во реално време, обезбедувајќи сеопфатен и приспособлив пристап кон предвидувањето. Прикажани се студии на случај и емпириски докази за да се покаже ефективноста на рамката заснована на AHP во подобрувањето на точноста на прогнозирањето на синџирот на снабдување и донесувањето одлуки. Овие примери покажуваат како AHP може да помогне во предвидувањето на побарувачката, управувањето со залихите, изборот на добавувачи и други критични активности на синџирот на снабдување.

Клучни зборови: *Аналитички хиерархиски процес (AHP), одлучување, синџир на снабдување, студија на случај.*