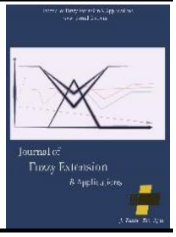
E-ISSN: 2717-3453 | P-ISSN: 2783-1442

Journal of Fuzzy Extension and Applications

www.journal-fea.com

J. Fuzzy. Ext. Appl. Vol. x, No. x (xx) x–x.



Using a combined Fuzzy-AHP and TOPSIS Decision Model for Selecting the Best Firewall Alternative

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Citation:

Using a combined Fuzzy-AHP and TOPSIS Decision Model for Selecting the Best Firewall Alternative. *Journal of fuzzy extension and application* , *Volume* (Issue), PP.

Received: Reviewed: Revised: 21 Accept:

Abstract

Covid-19 pandemic forced all the world to make significant changes in their daily routines. As a result, internet and digital technologies started to be used more ac-tively by individuals and businesses. Due to this digitalization, everyone is more open to digital threats. In order to provide the security of the network, firewalls should be used. Firewalls act as a barrier between the internal and the external networks. Thus, it is more important than ever to choose the right firewall for each network. In this study, an integrated fuzzy-AHP (Analytic Hierarchy Pro-cess) and TOPSIS model is introduced to find out the most suitable firewall. A survey is designed and used to generate the data of this study. This study distin-guishes from other studies by proposing a solution which ranks the firewall al-ternatives using a combination of fuzzy-AHP and TOPSIS models. As a result, among the five different firewall alternatives, the second one is found out to be the best. A solution proposal ranking the firewall alternatives is new in the litera-ture. This approach is used in many different multi-criteria decision making (MCDM) problems before but not in firewall selection. Hence, this study can be considered quite innovative in terms of the problem it handles and the model used. It offers a new solution related to a decision making problem that has start-ed to gain more importance with the current digitalization process due to Covid-19 pandemic.

Keywords: fuzzy-ahp, topsis, firewall, multi-criteria decision making.

1 | Introduction

Internet was a disruptive technology that changed the world drastically. The opera-tion of businesses, communication of individuals and many other routines evolved as a result of the development of internet. Especially, the Covid-19 pandemic increased the usage of internet radically. It required businesses operate online, students take classes online and individuals work remotely connecting to the corporate networks. Since all the world is continuing their daily lives online, cyber security attacks in-creased and as a result, everyone is more vulnerable to digital threats compared to pre Covid-19 period. Therefore, it is very important to provide the security of the network whether it is a corporate or an individual one. Specifically, corporate net-works should be protected from undesired access

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http://dx.doi.org/10.22105/jfea.2021.313606.1167

because a study found out that 70% of cyber-attacks targeted network cloud services and resources in 2019 [1]. A "Firewall" should be used to secure a network. It is a defense device combined of software and hardware products that protect any network from outsider's unauthor-ized access [2]. Firewalls define, control and limit the access to the available network so they basically act as a gateway between the internal and the external network [2, 3].

The most important feature of a firewall is to keep the resources secure within the network behind the firewall. Also, a firewall should have the following; spoofing pro-tection, network address encryption, user authentication, data encryption, bandwidth management and digital signature [2]. In large corporations, more than one network administrator is responsible from the operation of the network [4]. However, it is dif-ficult to preserve a consistent strategy when there are many people responsible from the same tasks. Therefore, the human error factor is too much to ignore in the config-uration of networks and the firewalls. According to a study, sixty percent of security breaches in 2019 were caused by network administrators' mistakes [1]. Thus, extra care should be given while setting up the firewall and ensuring the network security. Network administrators mainly consider the following while choosing their firewall needs; cost, performance, technical support, scalability, ease of use and configura-tion, remote and basic access control, preventing denial-of-service attacks and track-ing logs of Internet usage [2, 3, 5]. However, the major factor for many corporations in the selection of firewall is the cost vs performance balance [5].

The rapid development of technology provided many opportunities to everyone. While this seems great, it actually creates the paradox of choice [6] because decision makers had to evaluate all the alternatives before making a decision in order the choose the best option for their needs [7]. Hence, decision makers prefer to get assis-tance from the software systems called Decision Support Systems (DSS). These sys-tems receive certain data as input, evaluate the data, perform necessary calculations and deliver the best alternative as an output. DSS can use many different models in its calculations. Among most well-known model in Multi-Criteria Decision Making (MCDM) is AHP. It deals with complex issues that include both qualitative and quan-titative considerations. It was developed by Saaty in 1970s [8] and uses a pair-wise comparison method to find the corresponding weights of each criteria which are part of the decision making model. Also, AHP systematizes the most important elements of an issue into a hierarchy, similar to a family tree. [9].

Fuzzy set theory is applied to model the ambiguity and vagueness in decision making problems surfacing due to the subjectivity of human judgement [10]. Lin-guistic terms are used to indicate the preferences of the decision maker. The first scholars who study the decision-making problem with fuzzy sets were Zadeh and Bellman [11]. Fuzzy-AHP started to be used based on fuzzy set theory to eliminate the uncertainties of the AHP technique. The first studies using fuzzy-AHP method was performed by Van laarhoven and Pedrycz [12]. Later on, other academics also used and developed this model in different decision making problems [13-18]. For pair-wise comparisons, Chang introduced triangular fuzzy numbers (TFN) [13]. TFNs based on geometric means are used in this paper to evaluate the preferences of deci-sion makers because it is easier to realize and measure using TFNs.

TOPSIS stands for Technique for Order Preference by Similarity to Ideal Solution. This method was first used by Hwang and Yoon [19]. It is a multi-criteria method for deciding on the best alternative from a limited number of possibilities. The main prin-ciple is that the chosen alternative should be the closest to the positive ideal solution (PIS) but should be the furthest away from the negative ideal solution (NIS) [20, 21, 22]. Due to its comparatively simple mathematical approach, TOPSIS is a highly preferred technique [23]. It has, however, been chastised for its inadequacy in dealing with ambiguous problems [24]. Nonetheless, fuzzy logic-based solutions, such as the fuzzy AHP, can overcome the issues that arise during the subjective evaluation pro-cess. Fuzzy AHP is also commonly employed in real-world scenarios to tackle deci-sion-making issues. As a result, this study devised an integrated process that com-bines the fuzzy AHP and TOPSIS methods. The criteria weights were determined by fuzzy AHP in the first phase of the proposed approach, and the alternatives were ordered using TOPSIS in the second phase.

The aim of this study is to initially outline the main decision criteria for selecting a firewall and then rank the alternative product offers that can meet the firewall needs of an institution. Considering the previous studies mentioned above, it is seen that the integrated fuzzy-AHP and TOPSIS approach is applied in several different decision making issues in many different fields, but not in this one. A solution proposal rank-ing the firewall alternatives is new in the literature. For this reason, this study distin-guishes from others by providing network administrators a new perspective for select-ing the best firewall alternative for their institutions.

The rest of this study is organized as follows. Section 2 contains the methods which is about the fundamentals of AHP, fuzzy set theory, TOPSIS and the proposed integrated approach. Section 3 describes the data collection process. Section 4 repre-sents the findings and the results. Finally, section 5 states the conclusion and men-tions future research opportunities.

2 | Methods

This paper deals with a MCDM problem and it will use the combination of fuzzy-AHP and TOPSIS approaches to explain this problem and will choose the best fire-wall alternative among several different options. Fuzzy- AHP is the merge of two different methods; fuzzy set theory and AHP. This method will be integrated with TOPSIS in order to rank the firewall alternatives.

2.1 | Analytical Hierarchy Process (AHP)

AHP is a well-known MCDM technique to rank the decision alternatives. In AHP, you develop a hierarchy starting from upper level criteria and go one level down with each sub-criteria and at the bottom level, you sort the alternatives. All of the criteria and sub-criteria along with alternatives are then compared pairwise using a scale from 1 to 9 that transforms the choices of humans among existing alternatives as equally, weakly, moderately, strongly and very strongly. In the pairwise comparison matrix, a value of 9 states that one factor is extremely more important than the oth-er, a value of 1/9 states that one factor is extremely less important, and a value of 1 states that both factors are equally important [25]. Despite its success and logical simplicity, this approach is frequently criticized for its incapability to effectively manage the ambiguity related with decision makers' perspective to exact numbers [14, 17, 26]. Fuzzy set theory is introduced to remove this restriction, and started to be used with AHP method.

2.2 | Fuzzy AHP

The fuzzy-AHP method is an advanced technique using the fuzzy set theory de-signed to handle the ambiguities and uncertainties in decision making problems. A membership function, that allocates each object a degree of membership between 0 and 1, characterizes a fuzzy set. The terms 'large, medium, and small' are applied to capture a scope of numerical values in this set [17]. Chang presented triangular fuzzy numbers (TFN) for expressing the smallest and largest possible number of each scale in a pairwise comparison [13]. This study is based on Chang's approach of TFNs. It uses crisp values 1,3,5,7,9 as the geometric means of each linguistic term and calcu-late the TFNs for each one accordingly. In line with this calculation, "equally" is rep-resented as (1,1,1), "weakly" is represented as (2,3,4), "moderately" is represented as (4,5,6), "strongly" is represented as (6,7,8) and "very strongly" is represented as (9,9,9).

2.3 | TOPSIS

TOPSIS is a simple and easy-to-implement MCDM strategy that is implemented when the user prefers a simpler weighting approach. This method ranks the alterna-tives and identifies the best alternative which is close to the PIS and far from the NIS. PIS denotes a solution that maximizes benefit criteria while minimizing cost criteria, whereas NIS denotes a solution that maximizes cost criteria while minimizing benefit criteria [27]. The TOPSIS technique considers both PIS and NIS distances, with the best option being the one that is geometrically closest to PIS and farthest from NIS [28]. Alternatives are graded based on how closely they resemble the ideal solution, avoiding the situation when one option is comparable to both PIS and NIS.

2.4 | Proposed Approach

In this study, a two-step approach is used integrating fuzzy-AHP and TOPSIS methods. The linguistic preferences of experts are mapped with triangular fuzzy numbers using the fuzzy-AHP approach to decide the preferences and relevance of one criterion over another. The fuzzy-AHP method uses a decision hierarchy and pairwise comparisons between criteria. The alternatives are then ranked using TOPSIS based on their overall performance. There are many studies in the literature that combines these two techniques together in order to solve complex MCDM prob-lems [29- 33]. The proposed approach is as follows:

- The linguistic preferences of experts are transformed into TFNs in order to compare the alternatives.

- Using the fuzzy-AHP approach, pairwise comparisons of criteria and alterna-tives are calculated in order to find out the weight vectors of criteria and deci-sion alternatives.

- TOPSIS method is used to normalize the decision matrix, calculate PIS and NIS and finally, rank all of the alternatives.

3 | Data Collection

The data collection phase is divided into two parts. In the first part, data were col-lected from five experts to determine the criteria used in the decision model and the importance (weighting coefficients) of those criteria. In the second part, bids were collected from suppliers in order to identify the alternative services to be used in the model.

During the first stage of data collection, face-to-face interviews were conducted with various experts working in public and private sectors to assess the criteria to be used in the decision-making model. The survey asked for the weight coefficients of the criteria in three main groups and the weight coefficients of the sub-criteria for each group. The characteristics of the five experts participated in this research were as follows; one expert was working as a faculty member at the university, two were engineers and the other two were managers. The expert with the least professional experience was an engineer with 5 years of experience and the most experienced was an IT manager with 28 years of experience. The average professional experience of experts was 16 years.

At the second stage, suppliers providing corporate firewall services were contacted. Pricing and service details were requested for a firewall to be used in a cyber-security laboratory to be constructed at the university. Bids were received from service pro-viders as proforma invoices. Collected bids can be seen in Table 1. Afterwards, a hierarchical structure showing criteria and sub-criteria was constructed for selecting the best firewall alternative problem. This structure is shown in Figure 1.

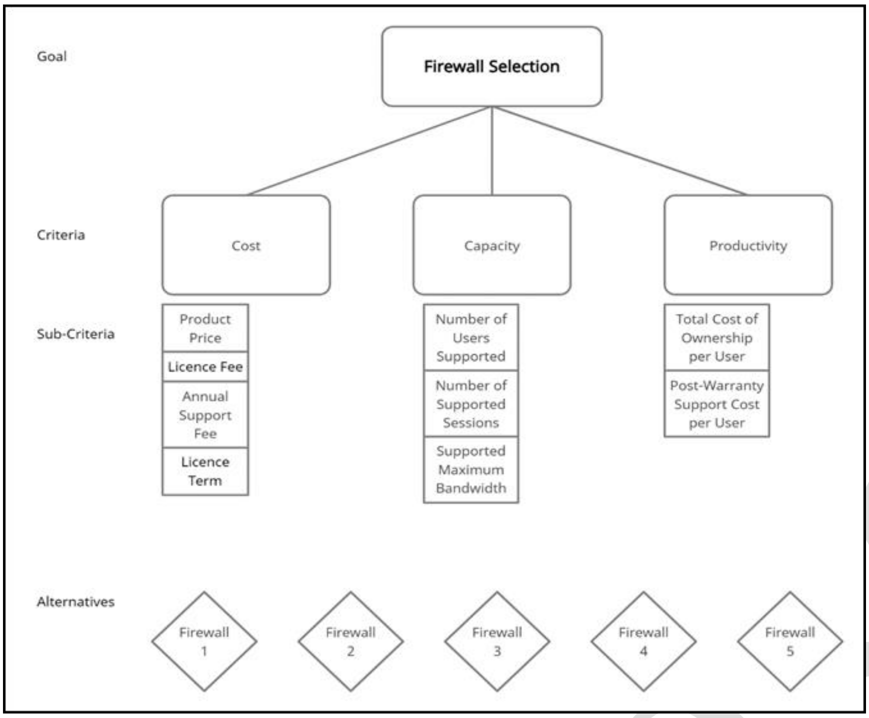

Fig. 1. Hierarchy for Firewall Service Provider.

Table 1. Collected Firewall Alternatives from Service Providers

ALT.	COST				CAPACITY			PRODUCTIVITY	
	Price (usd)	Licence fee (usd)	After warranty support fee (usd)	Licence term (year)	Number of users	Number of sessions	Band width (mbps)	Total cost per user (usd)	Total support cost per user (usd)
A1	5045	1400	1400	1	1500	3000000	8000	4,29	0,93
A2	7600	1900	1900	1	2500	6000000	6000	3,8	0,76
A3	7722	5019	5019	1	500	8000000	36864	25,48	10,03
A4	7722	15058,5	15058,5	3	500	8000000	36864	15,18	10,03
A5	24750	16087,5	16087,5	1	2500	8000000	81920	16,33	6,43

4 | Results

4.1 | Fuzzy AHP Results

In order to determine the best firewall service provider among the alternatives, ini-tially, the fuzzy comparison matrix of the main criteria was developed by a pairwise comparison relevant to the overall goal; given on Table 2.

Following the comparison of main criteria, the comparison matrices of sub-criteria regarding each main criterion were constructed. Table 3 shows the fuzzy comparison matrix of the sub-criteria and the weights of each sub-criterion in regard to main crite-rion C1 as an example. A total of 3 matrices were constructed for all sub-criteria with regard to their main criterion.

Table 2. The Fuzzy comparison matrix of main criteria in regard to the overall objective.

O	C1	C2	C3	Weight
C1	1.0, 1.0, 1.0	1.0, 1.0, 1.0	1.0, 1.0, 1.0	0.318
C2	1.0, 1.0, 1.0	1.0, 1.0, 1.0	0.25, 0.33, 0.50	0.226
C3	1.0, 1.0, 1.0	2.0, 3.0, 4.0	1.0, 1.0, 1.0	0.457

*C1: Cost, C2: Capacity, C3: Productivity

Also, the fuzzy comparison matrices of the firewall alternatives and the weight of each alternative in relation to the corresponding sub-criteria were also constructed. Table 4 shows the alternatives' fuzzy comparison matrix regarding sub-criterion C11. A total of 9 matrices were constructed for all alternatives in regard to their sub-criteria.

Table 3. The fuzzy comparison matrix of the sub-criteria in regard to main criterion C1.*

C1	C11	C12	C13	C14	Weight
C11	1.0, 1.0, 1.0	0.17, 0.20, 0.25	6.0, 7.0, 8.0	6.0, 7.0, 8.0	0.274
C12	4.0, 5.0, 6.0	1.0, 1.0, 1.0	6.0, 7.0, 8.0	6.0, 7.0, 8.0	0.609
C13	0.125, 0.143, 0.167	0.125, 0.143, 0.167	1.0, 1.0, 1.0	1.0, 1.0, 1.0	0.058
C14	0.125, 0.143, 0.167	0.125, 0.143, 0.167	1.0, 1.0, 1.0	1.0, 1.0, 1.0	0.058

* Only one of total of 3 tables is given here. C1: Cost
**C11: Product Price, C12: License Fee, C13: Annual Support Fee, C14: License Term

Table 4. The fuzzy comparison matrix of the alternatives in regard to sub-criterion C11.*

C11	A1	A2	A3	A4	A5	Weight
A1	1.0, 1.0, 1.0	2.0, 3.0, 4.0	2.0, 3.0, 4.0	2.0, 3.0, 4.0	0.167, 0.20, 0.25	0.189
A2	0.25, 0.33, 0.50	1.0, 1.0, 1.0	1.0, 1.0, 1.0	1.0, 1.0, 1.0	0.125, 0.143, 0.167	0.079
A3	0.25, 0.33, 0.50	1.0, 1.0, 1.0	1.0, 1.0, 1.0	1.0, 1.0, 1.0	0.125, 0.143, 0.167	0.073
A4	0.25, 0.33, 0.50	1.0, 1.0, 1.0	1.0, 1.0, 1.0	1.0, 1.0, 1.0	0.125, 0.143, 0.167	0.073
A5	4.0, 5.0, 6.0	6.0, 7.0, 8.0	6.0, 7.0, 8.0	6.0, 7.0, 8.0	1.0, 1.0, 1.0	0.591

* Only one of total of 9 tables is given here. **C11: Product Price

The weights of alternatives regarding each main criterion were determined by add-ing the weights per alternative multiplied by the weights of the relative sub-criteria. The data of main criterion C1 is given on Table 5 as an example.

Table 5. The combination matrix of weights: Sub-criteria of main criterion C1

	C11	C12	C13	C14	Sum
A1	0.051833	0.169739	0.016268	0.0053	0.24314
A2	0.020109	0.158584	0.015199	0.0053	0.199192
A3	0.020109	0.124394	0.011922	0.0053	0.161725
A4	0.020109	0.078152	0.00749	0.03717	0.142921
A5	0.16208	0.078152	0.00749	0.0053	0.253022

* Only one of total of 3 tables is given here.
**C11: Product Price, C12: License Fee, C13: Annual Support Fee, C14: License Term

4.2 | TOPSIS Results

In order to rank the alternative locations, the TOPSIS approach is used. TOPSIS uses the fuzzy AHP-calculated priority weights of alternative firewall services with respect to criteria, as shown in Table 6 below. Table 7 displays the weighted normalized decision matrix.

Table 6. The priority weights of alternative services with respect to criteria.

	C1	C2	C3
A1	0.243140203	0.068287289	0.413816441
A2	0.199192236	0.105126926	0.413816441
A3	0.161725021	0.179397788	0.034640886
A4	0.14292085	0.179397788	0.065099432
A5	0.253021692	0.46779021	0.072626801

Table 7. The weighted normalized decision matrix

	C1	C2	C3
A1	0.168769924	0.028166048	0.318115089
A2	0.1382645	0.043361071	0.318115089
A3	0.112257533	0.073995127	0.026629654
A4	0.09920507	0.073995127	0.050044197
A5	0.175628922	0.192946615	0.055830748

The ranking of alternative services is calculated below using the TOPSIS algorithm. Table 8 provides the results of the examination and the final ranking of firewall service choices.

Table 8. TOPSIS decision matrix showing the best alternative

	S_i^*	S_i^-	C_i
A1	0.164923258	0.299671534	0.645016988
A2	0.1541815	0.294483084	0.656354645
A3	0.321137274	0.047651561	0.129210965
A4	0.303071055	0.05146402	0.145159177
A5	0.262284342	0.183972673	0.412257212

The final score showed that firewall service provider alternative A2 is the most convenient provider followed by alternative A1. Hence the integrated Fuzzy-AHP and TOPSIS models revealed that the problem of corporate firewall service provider selection can be addressed in a systemic and effective manner.

5 | Conclusion

In this study, a multi-criteria decision support model was used for the process of determining a proper firewall service provider, which is a problem that IT experts and managers have difficulty in making decisions.

This study was conducted to determine the most suitable service among the alternatives that can satisfy the firewall requirements of an institution and have technical-ly similar features. In order to tackle this, the data received from experts working as managers, academics and engineers were used. Cost, capacity, productivity criteria and their respective sub-criteria were evaluated by experts. The alternative service providers used in this study were generated by using the actual data in the price offer received from the sales distributors in order to reflect the real market conditions. Using the suggested criteria and the data obtained, alternatives were listed using the combination of fuzzy-AHP and TOPSIS approaches and the calculation steps in the rankings were presented.

The fuzzy-AHP model considered in this study has been shown to be simple, less time-consuming and requiring less computing power [13]. Fuzzy-AHP does not re-quire complex mathematical operations, making it simple to deal with multi-attribute decision-making issues like choosing a firewall service provider and TOPSIS is an easy to use method to rank the alternatives and identify the best one which is close to the PIS and far from the NIS. Therefore, in this study the combination of these two approaches are preferred in order to reach the best solution.

Considering the previous studies mentioned in the introduction, a solution proposal ranking the firewall service provider alternatives is new in the literature. Hence when this study is considered to be a decision-making problem which has not been previ-ously discussed in the literature, it differentiates from others by providing network administrators a new perspective for selecting the best firewall alternative for their institutions. In future studies, the alternatives of this study can be extended and more firewall alternatives can be added or different methods can also be conducted and all of these methods can be compared amongst each other to address the issue of choos-ing a proper firewall alternative. In addition, the method utilized here may be applied to other decision-making problems in different fields and other industries may also use this method.

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