

# A Fuzzy-based Unified Technique for Assessment of Software Security Testing

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## Abstract

In light of the widespread need for and utilisation of software applications in the present scenario, the major challenge for to-day's information technology experts is to ensure efficacious as well as secure software systems. Software systems are vulnerable to attacks and may be used by malicious users or cybercriminals. Such threats have led to the development of various software security techniques for securing software systems. The software's security is highly influenced by the security attributes at the design phase of the development life cycle. In this league, the present study enlists the use Fuzzy Analytic Network Process (FANP) to obtain weights of the security attributes for developing a secure design of the software system. The FANP is used to identify the relationship between the security attributes and to prioritise them. Moreover, the prioritisation of the security attributes with respect to the test plan specification has also been undertaken in the study. This methodology would be helpful in balancing the trade-off between the conflicting security attributes. The study is an attempt to investigate and propose an alternate methodology for planning and testing the software systems.

**Keywords:** Multiple criteria decision making (MCDM); fuzzy analytic network process (FANP); security attributes

## 1. Introduction

Testing software for bugs to make secure software systems is a topic of intense study for both software developers and security experts in the IT industry today. As the use of computers grew more widespread, developers' views evolved, and they opted for speedier but ambiguous approaches, resulting in error-prone written codes. The deterioration of software or the presence of bugs in software has been the cause of increase in the number of fatalities and has resulted in the loss of billions of dollars across the globe [1]. The end users have also had to spend money on antivirus software every year to keep their systems safe. The vast majority of the studies that were carried out in the field of secure software testing concentrated on the issues that arose during the process of technological development, in addition to the spotting of obstacles and opportunities. However, many of these studies didn't prioritise the security attributes in the order of their importance to facilitate a more systematic mechanism for accomplishing the desired level of security in the design phase.

Software developers and researchers need to design security testing frameworks that are both powerful and efficient if they want to have a competitive advantage in the marketplace [2]. This will reduce the total number of critical software failures. The implementation of a flawless and thoroughly designed strategy that incorporates security attributes would reduce the risk of potential security breaches to a great extent. The procedure for carrying out the security testing profile includes the specification of security test plans in addition to security attributes [2,3]. The procedure for the security test plan for software security testing includes the following four parts: Environmental (P1), Strategic (P2), Technical (P3), and Operational (P4), and the security attributes include authentication (A1), authorization (A2), confidentiality (A3), availability (A4), integrity (A5), non-repudiation (A6), and resilience (R7). As a result, FANP is used to establish a connection between the test plan specifications and the security attributes.

This research will assist the developers in economising on the time, effort, and expenses invested in building software systems. Additionally, detailed identification, analysis, and mitigation will help produce high quality software. The primary objective of this study can be succinctly outlined as follows:

- The study deals with the analysis of the key security attributes impacting software operations.
- The study presents a quantification of security attributes which has been done to assess the importance of these attributes in the industrial applications.
- To get a vivid outcome in the context of quantification, numerous security attributes pertaining to the software testing procedure have been addressed by applying the fuzzy analytic network process.
- This research also delivers a comprehensive detailing for readers about security traits, which consequently leads to the groundwork for further security enhancements.

The entire article has been segregated into six specific sections. In Section 2, the needs of the MCDM process as well as its importance are presented. Section 3 provides an overview of the background and prior research conducted in the domain of ANP (Analytic Network Process). The evaluation of different security attributes using the fuzzy ANP methodology is extensively discussed in Section 4. Section 5 delves into the results obtained from the experiment. Finally, Section 6 serves as the conclusion of the research study, summarizing the key findings and implications

## **2. Importance and Need**

The software developers must emphasize upon the design of the product at each step of development. Different aspects of the system's security are the primary determinants of this. Now-a-days, the process of developing secure software has turned into a cooperative effort [4]. During the process of developing secure software, the developers seek a wide variety of options from which to select security attributes. When the experts design secure software based on their knowledge, experience, and the end-user's demands, the resulting solutions offer several benefits. Thus, the developers place a strong emphasis on the MCDM methodology and decision tools in order to arrive at precise decisions that enhances both the user satisfaction and security [5]. As a solution to software security issues, the developers should regularly improve software security constraints. Since software security is the top priority of the developers, they should implement quicker and more effective approaches for testing it.

Hence, it is important for the developers to be aware of the importance of certain security attributes while designing the software. The process of addressing the relative rank of various

attributes and determining their priority is referred to as "prioritization of attributes." When it comes to the design of the test plan, the primary emphasis of this article is on the identification of the priorities that are dependent on the weighting and ranking of the various security attributes. The process of selecting the most efficacious security solution from a set of alternatives can be a complex and challenging task. To achieve this objective, a decision-making process is chosen that incorporates MCDM techniques, specifically utilizing the ANP method. By employing this technique, the security and reliability of the application software are enhanced [6, 7]. This goal is achieved by implementing a decision-making methodology that incorporates MCDM techniques.

### 3. Background

MCDM is one of the most effective procedures for dealing with the uncertainties and ambiguities that may arise due to multiple perspectives [5, 8]. The software can be made more secure and reliable by identifying the priorities of the security attributes based on their weight and ranking. The multi-criteria decision-making process is useful for prioritizing security attributes. The results obtained through this strategy can be used to enhance the security of software. This method is appropriate for the software industry because every organization has its own rules for developing the intended software.

The MCDM approach is well-suited for determining the significance of security attributes and plays a valuable role in the execution of security test cases. The various techniques of MCDM that can be employed to determine the weightage of attributes, their rankings, and their respective relationships among each other are shown in Table 1.

**Table1:** Some existing approaches on various techniques of MCDM

| Author's Name/ Year           | Focus of the relevant work                                                           | Summary of the contribution                                                                                                                                                                                                                                                                                                                                                                                                                                                                                       |
|-------------------------------|--------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| M. Qasim, et al., 2021, [9]   | An overview of software regression testing techniques for test case prioritization.  | The researchers have conducted a comprehensive analysis of the methodology for test case prioritization, which is presented in this study. This review covers research studies from 2010 onwards to the most current ones. The study's major goal is citing the techniques that have been researched in depth vis-à-vis those haven't been, and where there is opportunity for improvement.                                                                                                                       |
| I. Emovon, et al., 2020, [10] | A review of the application of MCDM method in material selection for optimal design. | In this study, the hybrid approach, which combines multiple MCDM methods, emerged as the most frequently employed material selection method across all application categories. Cost was identified as the most commonly utilized decision criterion for selecting the optimal option. The journal "Materials and Design" was found to be of utmost importance in this field, while the year 2013 witnessed the highest number of publications on material selection. Additionally, India stood out as the country |

|                                      |                                                                                                                                         |                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|--------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 2019, Chen et al., [11]              | C-Y Obtaining fuzzy weights for the Fuzzy Analytic Network Process using the fuzzy inverse matrix.                                      | with the highest utilization of MCDM techniques.<br>This study introduces a novel mathematical programming technique that utilizes fuzzy inverse matrix to determine the limiting distribution of the fuzzy supermatrix. Numerical results demonstrate that the proposed technique minimizes the dispersion of fuzzy weights, providing validation for its effectiveness.                                                                                         |
| A. Mohammadzadeh, et al., 2018, [12] | K. This study focuses on the prioritization of Internet of Things (IoT) challenges in Iran using a Fuzzy ANP approach.                  | In this work, the authors perused 206 papers on test case generation and prioritization methodologies. After identifying a large number of research gaps, the authors advised enhancing test case selection by making use of FANP. The findings revealed that "technical" and "privacy and security" issues dominate the IoT. Among the sub-factors, business model, architecture and design, and education and training were identified as the most significant. |
| Afrin, et al. 2017, [13]             | This paper proposes an integrated approach that combines Fuzzy AHP and Fuzzy TOPSIS methods for the selection of software requirements. | The authors explored fuzzy AHP and fuzzy TOPSIS for software requirement selection. This research study discusses functional and non-functional software requirements, which affect several factors. The study highlights the limitations of the current software requirements selection technique and introduces a combined fuzzy AHP and fuzzy TOPSIS approach to address this issue. The authors leverage hybrid MCDM for enhanced results.                    |

Soft computing uses methods that utilize inaccuracy and uncertainty to gain resilience, tractability, and low solution costs. In many different ways, it has succeeded in capturing the attention of society. Satty created ANP, a method that is included in MCDM. Decision making in uncertain and complex scenarios typically involves subjective, vague, and imprecise descriptions of the environment, decision elements, and judgments [14, 15]. Expert decision makers often utilize qualitative assessment criteria, resulting in different interpretations of the same information. Thus, extracting precise data or point estimates from multiple assessments can be a huge problem in result tabulation. In this context, ANP determines goals, alternative weights, and rankings—three MCDM process components utilized in the Analytic Network Process. The ANP method is superior to the AHP approach. More significantly, the fuzzy ANP method, which is an improvisation of the traditional ANP technique, produces greater outcomes [16].

The research findings suggest that utilizing Fuzzy Analytic Network Process (FANP) can result in a more relevant set of attributes for evaluating the significance of security attributes in relation to test plan specifications. This article presents a review of data collected from specialists in academia and industry, whose contributions undergo a

weighing and ranking process using a security test plan specification. This enables the determination of the importance of specific security attributes. By employing Fuzzy ANP, a network of security attributes and test plan specifications is established based on their priority and importance, utilizing judgmental input from decision-makers. The Fuzzy ANP approach facilitates a more accurate relationship and enables decision-makers to conduct comprehensive priority analysis [17].

#### Analytic Network Process (ANP)

The ANP utilizes priority scales derived from individual judgments to analyze various decisions. Unlike the AHP, the ANP does not assume dependencies between upper-level and lower-level elements or between elements within the same level. ANP facilitates interaction and feedback not only within individual clusters but also between clusters. Figure 1 provides a visual representation highlighting the key differences between hierarchies and networks. In a hierarchical model, the linear structure depicts the goal, criteria, sub-criteria, and alternatives. Conversely, a network model comprises cycles that interconnect clusters (outer dependence) and loops that connect a cluster to itself (inner dependence) [15, 18]. The four main stages of the ANP are summarized below.

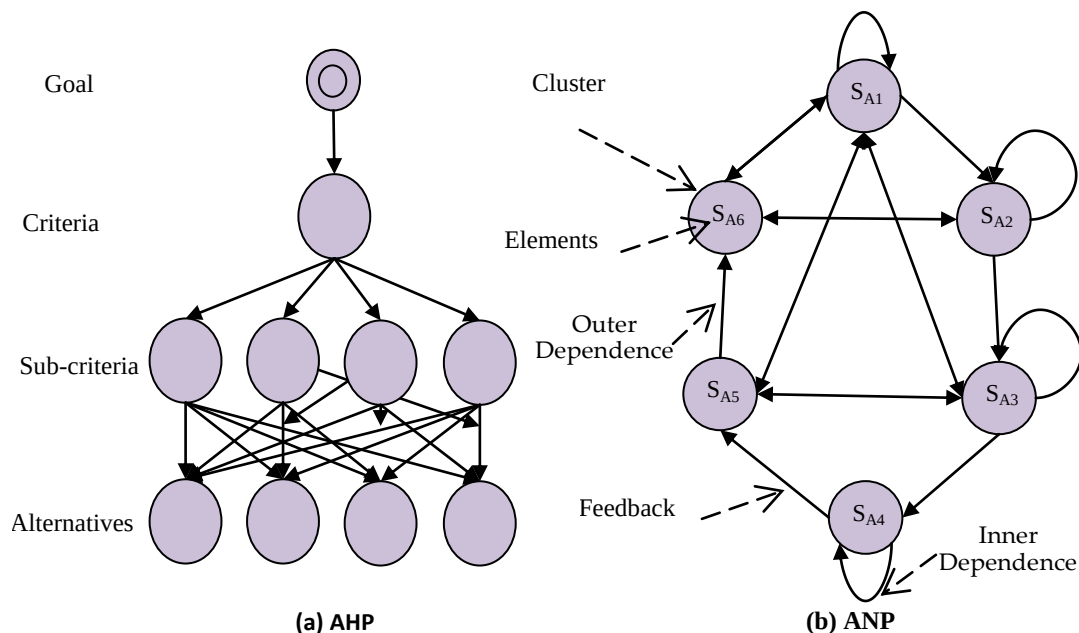


**Figure 1:** Structural difference between AHP & ANP

**Step 1:** Creating the Structure of the Network- The first step in building an ANP model is to do an in-depth investigation of the decision problem and the aspects that are pertinent to it. After the problem has been specified, the components, including the criteria, the sub-criteria, and the possible alternatives, are defined, and then clusters of these elements are built in the appropriate order. After that, a network model is constructed by taking into account the relationships that exist between and among these element clusters. The model should enable influence to be conveyed from one cluster to another and back, either directly or indirectly, from the second cluster.

**Step 2:** Local Priority Assessment and Pairwise Comparison involve quantifying the priority of elements, such as criteria, sub-criteria, and alternatives. Decision-makers compare the superiority of two elements or clusters at a time, known as pairwise comparison. The judgments are obtained by answering how significantly one element or cluster affects another element or cluster in relation to a criterion. Saaty's 1-9 scale is used to quantify the responses, where a score of 1 signifies no noticeable difference, and a score of 9 indicates overwhelming dominance [15]. Reciprocal values are assigned for inverse comparisons, denoted as  $S_{ij} = 1/S_{ji}$ , representing the relative dominance of the  $i^{\text{th}}$  element compared to the  $j^{\text{th}}$  element [7, 14].

Following the pairwise comparisons, a local priority vector is obtained for each comparison matrix. This vector represents the estimated relative dominance of the elements (or clusters) being compared and is derived by solving the following equation:

$$S \cdot w = \lambda_{\text{enb}} \cdot w \quad (1)$$

Where  $S$  is the pairwise comparisons matrix,  $w$  is the priority vector, and  $\lambda_{\text{enb}}$  is the eigenvalue of  $A$  with the highest value.

**Step 3:** Formation of Supermatrix and Limit Super Matrix: A network requires more intricate interactions among its decision-making elements than the opportunities provided by local priorities. Saaty proposes the use of supermatrix technique for not only retrieving the overall priorities of the components but also to capture the transmission of influence along all of the pathways that are established in the network. In this method, each of the local priority vectors is input as part of a column inside a matrix that is referred to as a supermatrix [7, 19]]. This partitioned matrix shows how an element on the left affects an element on the top. As a result, the supermatrix operates as an essential prerequisite. After forming the supermatrix, it is raised to limiting powers to show each element's cumulative effect on all the other elements [19]. It must first be converted to a column stochastic matrix (weighted supermatrix with each column summing to unity before determining the limit.

$$\lim_{n \rightarrow \infty} W^k \quad (2)$$

Where  $k$  is any arbitrary very large number. The reducibility, primitivity, and cyclicity of a stochastic supermatrix are the three characteristics that influence the limiting priorities of the matrix. If the subsequent powers do not converge to a single matrix and yield different limit results,  $W$  is called cyclic. In this particular scenario, the limiting priorities are determined by taking the average of the succeeding matrices during the whole cycle. This calculation is known as the Cesaro sum.

$$\frac{1}{N} \sum_{n=1}^N W_{n-1} \lim_{n \rightarrow \infty} (WN)^k \quad (3)$$

Where  $N$  indicates the length of cycle. The values included in the limit supermatrix are a representation of the overall relative dominance of one element in the network over another.

**Step 4:** Ranking and Selection of Alternatives: The overall priorities of the elements, known as the total ranking, can be obtained by examining the respective rows of the normalized limit supermatrix. The decision elements that received high overall priorities are deserving of greater consideration than the others.

In most cases, the characteristics of security are evaluated qualitatively. Therefore, doing quantitative assessments of the security factors becomes difficult. Hence, the relative importance of the various security attributes, as expressed by their weights and rankings,

plays a vital part in the highly secure design of the software. The suggested mechanism of network structure for several security attributes with test plan specification reveals their comprehensive relationships and interdependencies. ANP's mesh structure allows many-to-many relationships between security testing attributes, which ultimately lead to improved findings. With the use of ANP, we were able to establish the weightage of each of the different security attributes. This also allowed us to rank them. It will be helpful in assigning priorities to the various test cases for software security. In order to analyze this, the authors have presented the problem in the form of a weighted graph and used the ANP's compatibility across matrices that are dependent on one another.

### *Methodology*

The study employs a fuzzy ANP-based methodology as part of the MCDM process to help individuals and groups dealing with complicated compositions collate into precise solutions. The ANP methodology, which provides an overview of all of the processes that are included in the ANP approach, is described below.

- Determine the security attributes relating to the test plan specification that will have an impact on the testing.
- Established a network structure.
- Build fuzzy pair wise comparison matrices and fuzzy aggregated matrices for each of the experts.
- Determine the significance of the vectors and provide defuzzified aggregated pair wise comparison matrices.
- If the consistency ratio is higher than the standard value, then go to the step (f) otherwise, go to step (c).
- After computing the unweighted supermatrix, the weighted supermatrix, and the limit supermatrix, examines the results to determine the relative weight of each attribute.
- To normalize the results, calculate their values and subsequently arrange the characteristics in descending order.

This research uses triangular fuzzy numbers (1–9) to express subjective pairwise comparisons of the selection process (equal to totally important) and highlight the vagueness (Table 2). TFNs are utilized for subjective pair-wise comparisons of the experts' judgments in this study. The authors converted the linguistic values into fuzzy scales using the triangular fuzzy membership function conversion scale. Further, in this study, we used a linguistic scale to weigh security attributes in relation to test plan specifications [18, 19].

**Table 2:** Linguistic scale

| <b>Linguistic Scales</b>           | <b>Fuzzy Scale</b> | <b>Reciprocal Fuzzy Scale</b> |
|------------------------------------|--------------------|-------------------------------|
| Just Equal                         | (1,1,1)            | (1,1,1)                       |
| Evenly Important                   | M1=(1,1,3)         | (1/3,1,1)                     |
| Softly important                   | M3=(1,3,5)         | (1/5,1/3,1)                   |
| Important in essence               | M5=(3,5,7)         | (1/7,1/5,1/3)                 |
| Strongly important                 | M7=(5,7,9)         | (1/9,1/7,1/5)                 |
| Totally important                  | M9=(7,9,9)         | (1/9,1/9,1/7)                 |
| Middle values between two adjacent | M2, M4, M6, M8     |                               |

### Fuzzy ANP (FANP)

The ANP is the most all-encompassing framework available for analyzing corporate decisions. It enables interaction and feedback not just between clusters of components but also inside individual clusters of elements themselves. The feedback element cites the possible complexities that might emerge due to diverse perceptions amongst different stakeholders. Fuzzy ANP is an effective method for multi-criteria decision making, especially in contexts where stakeholders are unclear about weights. Fuzzy ANP is effective in solving decision-making issues when network elements are interdependent [7, 20]. The triangular fuzzy membership function creates a pair-wise comparison matrix between components. Figure 2 provides a linguistic representation of all the possible attributes and alternatives.

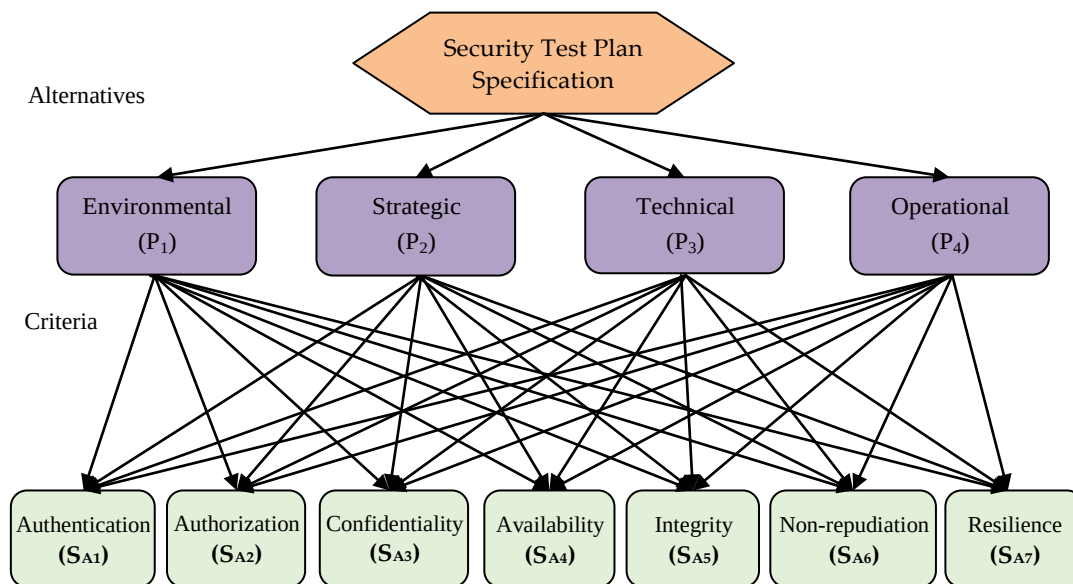


**Figure 2:** Security attribute network structure in relation to test plan specification

## 4. Security Attributes Evaluation in Relation to Test Plan Specification

Security attributes are inherently qualitative in nature, making the task of quantifying them a dynamic endeavor. When designing highly secure software, assigning weights and rankings to security attributes becomes crucial. In this study, a MCDM approach is employed to prioritize these attributes, giving them appropriate significance. Figure 3 depicts a network diagram showcasing the potential relationships and interdependencies among the security attributes.

The significance level of these attributes often varies, posing a challenge in establishing appropriate criteria. To address this issue, several tools, such as the AHP and ANP, are available for handling such known problems. The MCDM approach leverages various soft computing techniques, with ANP being widely embraced by decision-makers and researchers for priority analysis [21, 22].

In this research, the authors enhance decision-making using the fuzzy ANP technique, considering the interdependence between higher-level and lower-level nodes. Fuzzy ANP enables the creation of a network structure to address decision-making challenges by

considering various components and alternatives. To achieve a higher level of accuracy, the authors apply the fuzzy ANP technique in this study.

#### *Evaluation using Fuzzy ANP*

In decision-making processes that involve complex and uncertain circumstances, it is often necessary to address problems where descriptions of the environment and decision elements are inherently subjective, ambiguous, and inaccurate. The aim of this study is to develop an implementation plan for a hybrid model of Multi-Criteria Decision Making (MCDM) strategies specifically tailored to address different aspects of security attributes. To tackle the challenges posed by such problems, this article proposes a fuzzy approach to the traditional Analytic Network Process. Furthermore, the authors introduce the use of comparison ratios as fuzzy numbers, which helps account for the imprecise and subjective nature of human judgments, thereby enhancing the accuracy of the results obtained. The various alternatives and cluster names are shown in Table 3, along with the corresponding symbols.

**Table 3:** A Description of the alternative scenarios and the clustering

| S. No. | Alternatives & Clusters name with their Symbols |                                                                                                                                                                                                 |
|--------|-------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1      | Alternative Name                                | Environmental ( $P_1$ ); Strategic ( $P_2$ ); Technical ( $P_3$ ); Operational ( $P_4$ )                                                                                                        |
| 2      | Cluster Name                                    | Authentication ( $S_{A1}$ ); Authorization ( $S_{A2}$ ); Confidentiality ( $S_{A3}$ ); Availability ( $S_{A4}$ ); Integrity ( $S_{A5}$ ); Non-repudiation ( $S_{A6}$ ); Resilience ( $S_{A7}$ ) |

We carried out a literature study with the assistance of an established group of industry professionals to determine the criteria for the security attributes in accordance with the test plan specification. We found that there was a total of seven significant security attributes, each of which had a high likelihood of occurrence and played an essential role in determining the security test plan specification. The primary effect of this stage was to produce criteria, and it also formed clusters consisting of alternatives, as indicated in table 5. Thereafter, pair-wise comparison matrices were created to resolve the FANP matrix. After this, a hierarchical network structure consisting of pairwise comparison matrices was built in order to evaluate the relative value of various security criteria in connection to test plan formulation while also taking into account the interdependence of the cluster. The next step that needed to be done was to carry out pairwise comparison matrices in order to solve the FANP matrix. After establishing the interdependence of the cluster, a hierarchical network structure of pair-wise comparison matrices was built to assess the relative importance of various security attributes in test plan specification, as illustrated in table 6. The subsequent phase included the formation of unweighted and cluster super-matrices, which are shown in tables 7 and 8, respectively. The unweighted super-matrix contained local priorities that were insulated from pairwise comparisons. The influence priority of an element is set to zero when that element has no impact on any other elements. Thereafter, the component was weighted with the cluster matrix weight corresponding to it. In the later phases, which are described in tables 9 and 10, the weighted super-matrix was converted to a limited matrix to a limited matrix by raising the weighted super matrix to powers by multiplying it by itself. The

alpha-cut for defuzzification of the local priority, which resulted in the weighted super-matrix being transformed into a limited matrix, is discussed.

#### *Creating Pairwise Comparison Matrices with ANP and Obtaining the Priority Vector*

The fuzzy pairwise comparison matrices of the decision elements are established by eliciting judgments in the first phase. Decision makers are required to execute a series of pairwise comparisons of dominance with regard to a common attribute or trait. In this study, the responses to the pairwise comparison questions are scaled according to the flexible fuzzy dominance scale (see table-1). The main objective is to do pairwise comparisons for a control hierarchy criteria or sub-criterion. The impacts on each cluster that are influenced by that criterion are obtained [7, 23]. As a consequence of this, important weights are set for each of the elements, and relationships between the items are formed. This enables the decision-makers to compare two items and, ultimately, determine the contribution of all of the elements.

In the comparison matrix, the values of pairwise comparisons are assigned. Eigenvectors are used to obtain the local priority vector, which is calculated using the following equation:

$$XW = \lambda_{\text{enb}} W \quad (4)$$

X, W, and  $\lambda_{\text{enb}}$  are the pairwise comparison matrix, eigenvector, and eigenvalue, respectively, from eq. (1).

Saaty proposed a normalization algorithm for an approximate solution to w [9].

Using the following equations, the comparison between factors is obtained and the matrix is established:

$$X = [x_{ij}]_{n \times n}; i = \overline{1, n}; j = \overline{1, n} \quad (5)$$

Significance distribution of factors as percentage is as follows:

$$Y_i = [y_{ij}]_{n \times 1}, i = \overline{1, n} \quad (6)$$

$$y_{ij} = x_{ij} / \sum_{i=1}^n x_{ij} \quad (7)$$

$$Z = [z_{ij}]_{n \times n}, i = \overline{1, n}; j = \overline{1, n} \quad (8)$$

$$w_i = \sum_{j=1}^n z_{ij} \quad (9)$$

$$W = [w_i]_{n \times 1} \quad (10)$$

#### *Formation Super Matrix and Limit Super Matrix*

In this phase, each computed fuzzy local priority vector is initially placed into the appropriate column of the fuzzy supermatrix. This is done in order to acquire global priority. The final structure of the produced super matrix is similar to the Markov chain process. The long-term effects of items on each other are determined by increasing the power of the super matrix [24, 25]. As a result, the super matrix is a limited matrix, and each part of it asserts that it represents the relationship between two items of the entire system. To equalize the weights, the matrix's power is increased to  $2l + 1$ , where  $l$  is an arbitrary large number. Thus, the newly formed matrix is known as a limited Super matrix [14]. In addition, to determine the consistency of each item for comparison, the following formula is used:

$$P = [x_{ij}]_{n \times n} \times [w_i]_{n \times 1} = [p_i]_{n \times 1} \quad (11)$$

$$Q_i = p_i / w_i; i = \overline{1, n} \quad (12)$$

$$\lambda = \sum_{i=1}^n Q_i / n \quad (13)$$

$$CI = (\lambda - n) / (n - 1) \quad (14)$$

$$CR = CI / RI \quad (15)$$

In equation (12), CR, CI and RI refer to the consistency ratio, consistency Indicator and random indicator respectively. The pairwise matrix was examined through the consistency index (CI). The consistency index (CI) must be less than 0.10 to be acceptable [7].

The unweighted supermatrix makes use of the priorities that are derived from the different pair wise comparisons. A column of attributes contains all the priorities in respect to all the attributes that have been compared pair wise that have influence on the control criterion “security testing attributes”. Finally, fuzzified aggregated pair wise comparison matrix for attributes is prepared by analyzing the experts’ responses, as shown in table 4.

**Table 4:** Comparison matrix (authorization pairwise) under clusters relations

|          | $S_{A2}$ | $S_{A7}$ | $S_{A6}$ | $S_{A1}$ | $W$   |
|----------|----------|----------|----------|----------|-------|
| $S_{A2}$ | 1.000    | 3.560    | 2.050    | 1.140    | 0.400 |
|          | 1.000    | 5.591    | 3.091    | 1.711    |       |
|          | 1.000    | 7.610    | 4.210    | 2.430    |       |
|          | 0.131    | 1.000    | 0.731    | 0.231    |       |
| $S_{A7}$ | 0.182    | 1.000    | 1.190    | 0.310    | 0.500 |
|          | 0.280    | 1.000    | 2.201    | 0.452    |       |
|          | 0.240    | 0.451    | 1.000    | 0.271    |       |
|          | 0.321    | 0.840    | 1.000    | 0.390    |       |
| $S_{A6}$ | 0.490    | 1.370    | 1.000    | 0.692    | 0.040 |
|          | 0.410    | 2.240    | 1.440    | 1.000    |       |
|          | 0.591    | 3.271    | 2.541    | 1.000    |       |
|          | 0.880    | 4.390    | 3.661    | 1.000    |       |

Table 5 displays the pair wise comparison matrix of security attributes in which column of all the attributes are prioritized according to their weightage that have influence on the control criterion.

**Table 5:** Pairwise comparison matrix for security attributes in relation to test plan specification

|                          | $S_{A3} \rightarrow P_2$ | $S_{A2} \rightarrow P_1$ |       |       | $S_{A2} \rightarrow P_2$ |       | $W$   |
|--------------------------|--------------------------|--------------------------|-------|-------|--------------------------|-------|-------|
| $S_{A2} \rightarrow P_1$ | 1.000                    | 1.000                    | 1.000 | 0.420 | 0.660                    | 1.221 | 0.391 |
| $S_{A2} \rightarrow P_2$ | 0.821                    | 1.530                    | 2.371 | 1.000 | 1.000                    | 1.000 | 0.610 |

The priorities determined by different pair-wise comparisons are obtained by the unweighted supermatrix. A column of attributes contains all the priorities in respect to all the attributes that have been compared pair wise that have influence on the control criterion “security testing attributes”. In the end, a fuzzified aggregated pair wise comparison matrix

for attributes is generated by conducting an analysis of the opinions of experts using the geometric average method. Table 6 provides an illustration of the prepared matrix.

**Table 6:** Unweighted supermatrix for security attributes in relation to test plan specification

|                 |                    | S <sub>A1</sub> | S <sub>A2</sub> |                 | S <sub>A3</sub> |                 | S <sub>A4</sub> |                 |                 | S <sub>A5</sub> |                 | S <sub>A6</sub> |                 |                 |                 | S <sub>A7</sub> |                 |                 |                 |
|-----------------|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
|                 |                    | S <sub>A1</sub> | S <sub>A2</sub> | S <sub>A2</sub> | S <sub>A3</sub> | S <sub>A3</sub> | S <sub>A3</sub> | S <sub>A4</sub> | S <sub>A4</sub> | S <sub>A4</sub> | S <sub>A5</sub> | S <sub>A5</sub> | S <sub>A6</sub> | S <sub>A6</sub> | S <sub>A6</sub> | S <sub>A6</sub> | S <sub>A7</sub> | S <sub>A7</sub> | S <sub>A7</sub> |
|                 |                    | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              |
|                 |                    | P <sub>1</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  | P <sub>4</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  |
| S <sub>A1</sub> | S <sub>A1</sub> -> | 0.0             | 1.0             | 1.0             | 1.0             | 1.0             | 1.0             | 0.0             | 0.0             | 0.0             | 1.0             | 1.0             | 1.0             | 1.0             | 1.00            | 1.0             | 1.0             | 1.0             | 1.0             |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 0               | 00              | 00              | 00              | 00              |
|                 | S <sub>A2</sub> -> | 0.0             | 0.0             | 1.0             | 0.0             | 0.3             | 0.5             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.6             | 0.7             | 0.9             |
| S <sub>A2</sub> | P <sub>1</sub>     | 00              | 00              | 00              | 00              | 80              | 90              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 60              | 90              | 30              |
|                 | S <sub>A2</sub> -> | 0.0             | 1.0             | 0.0             | 0.0             | 0.6             | 0.4             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.3             | 0.2             | 0.0             |
|                 | P <sub>2</sub>     | 00              | 00              | 00              | 00              | 10              | 10              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 40              | 10              | 70              |
| S <sub>A3</sub> | S <sub>A3</sub> -> | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 1.0             | 1.0             | 1.0             | 1.0             | 0.7             | 0.6             | 0.7             |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 90              | 90              | 50              |
|                 | S <sub>A3</sub> -> | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.2             | 0.3             | 0.2             |
| S <sub>A4</sub> | P <sub>2</sub>     | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 10              | 10              | 50              |
|                 | S <sub>A3</sub> -> | 0.0             | 0.0             | 0.0             | 1.0             | 1.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             |
|                 | P <sub>3</sub>     | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              |
| S <sub>A5</sub> | S <sub>A4</sub> -> | 0.0             | 0.0             | 0.0             | 0.4             | 0.0             | 0.0             | 0.0             | 0.9             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.4             | 0.4             | 0.4             |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 80              | 00              | 70              | 00              | 10              | 00              | 80              | 00              | 00              | 00              | 00              | 00              | 00              | 30              | 50              |
|                 | S <sub>A4</sub> -> | 0.0             | 0.0             | 0.0             | 0.4             | 0.0             | 0.7             | 0.6             | 0.0             | 0.0             | 0.4             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.5             | 0.4             | 0.5             |
| S <sub>A6</sub> | P <sub>2</sub>     | 00              | 00              | 00              | 00              | 00              | 20              | 80              | 00              | 00              | 90              | 00              | 00              | 00              | 00              | 00              | 20              | 30              | 30              |
|                 | S <sub>A4</sub> -> | 0.0             | 0.0             | 0.0             | 0.1             | 1.0             | 0.2             | 0.3             | 0.1             | 0.0             | 0.4             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.1             | 0.0             |
|                 | P <sub>3</sub>     | 00              | 00              | 00              | 20              | 00              | 20              | 20              | 00              | 00              | 30              | 00              | 00              | 00              | 00              | 00              | 90              | 40              | 20              |
| S <sub>A7</sub> | S <sub>A5</sub> -> | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.6             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.7             | 0.5             | 0.3             |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 00              | 00              | 70              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 90              | 20              | 60              |
|                 | S <sub>A5</sub> -> | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.3             | 0.0             | 0.0             | 0.0             | 1.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.2             | 0.4             | 0.6             |
| S <sub>A7</sub> | P <sub>2</sub>     | 00              | 00              | 00              | 00              | 00              | 30              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 10              | 80              | 40              |
|                 | S <sub>A6</sub> -> | 0.0             | 1.0             | 1.0             | 0.2             | 0.5             | 0.3             | 0.0             | 0.0             | 0.0             | 1.0             | 1.0             | 0.0             | 0.0             | 1.0             | 1.0             | 0.3             | 0.6             | 0.5             |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 00              | 90              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 60              | 00              | 20              |
| S <sub>A7</sub> | S <sub>A6</sub> -> | 0.0             | 0.0             | 0.0             | 0.2             | 0.3             | 0.1             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.1             | 0.0             | 0.1             |
|                 | P <sub>2</sub>     | 00              | 00              | 00              | 90              | 20              | 60              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 30              | 00              | 30              |
|                 | S <sub>A6</sub> -> | 0.0             | 0.0             | 0.0             | 0.2             | 0.1             | 0.2             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.2             | 0.1             | 0.1             |
| S <sub>A7</sub> | P <sub>3</sub>     | 00              | 00              | 00              | 60              | 00              | 60              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 40              | 90              |
|                 | S <sub>A6</sub> -> | 0.0             | 0.0             | 0.0             | 0.2             | 0.0             | 0.2             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.3             | 0.2             | 0.1             |
|                 | P <sub>4</sub>     | 00              | 00              | 00              | 50              | 00              | 80              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 50              | 60              |
| S <sub>A7</sub> | S <sub>A7</sub> -> | 0.0             | 0.4             | 0.8             | 0.0             | 0.8             | 0.3             | 0.0             | 0.0             | 0.0             | 0.8             | 0.5             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 00              | 00              | 70              | 00              | 00              | 00              | 00              | 30              | 00              | 00              | 00              | 00              | 00              | 00              | 00              |
|                 | S <sub>A7</sub> -> | 0.0             | 0.5             | 0.0             | 0.0             | 0.1             | 0.3             | 0.0             | 0.0             | 0.0             | 0.1             | 0.1             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             |
| S <sub>A7</sub> | P <sub>2</sub>     | 00              | 00              | 50              | 00              | 30              | 50              | 00              | 00              | 00              | 10              | 80              | 00              | 00              | 00              | 00              | 00              | 00              | 00              |
|                 | S <sub>A7</sub> -> | 0.0             | 0.1             | 0.1             | 0.0             | 0.0             | 0.2             | 0.0             | 0.0             | 0.0             | 0.0             | 0.2             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             |
|                 | P <sub>3</sub>     | 00              | 00              | 50              | 00              | 60              | 80              | 00              | 00              | 00              | 80              | 90              | 00              | 00              | 00              | 00              | 00              | 00              | 00              |

Table 7 provides a comprehensive overview of the process involved in analyzing the cluster matrix. This involves preparing the cluster matrix and calculating the importance vectors of criteria. Additionally, a consistency test is conducted to ensure reliable results. The importance weights of each security attribute are then depicted in the corresponding column of the cluster matrix. These weights are estimated based on the unweighted supermatrix provided earlier in the analysis. This step allows for a clear representation of the significance of each security attribute within the context of the cluster matrix.

**Table 7:** Cluster matrix for security attributes

|                 | S <sub>A1</sub> | S <sub>A2</sub> | S <sub>A3</sub> | S <sub>A4</sub> | S <sub>A5</sub> | S <sub>A6</sub> | S <sub>A7</sub> |
|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| S <sub>A1</sub> | 0.000           | 0.290           | 0.151           | 0.000           | 0.311           | 0.210           | 0.150           |
| S <sub>A2</sub> | 0.000           | 0.400           | 0.071           | 0.000           | 0.000           | 0.000           | 0.110           |
| S <sub>A3</sub> | 0.000           | 0.000           | 0.140           | 0.000           | 0.000           | 0.181           | 0.130           |
| S <sub>A4</sub> | 0.000           | 0.000           | 0.160           | 0.371           | 0.181           | 0.171           | 0.120           |
| S <sub>A5</sub> | 0.000           | 0.000           | 0.070           | 0.000           | 0.020           | 0.000           | 0.111           |
| S <sub>A6</sub> | 0.000           | 0.040           | 0.150           | 0.000           | 0.190           | 0.211           | 0.171           |
| S <sub>A7</sub> | 0.000           | 0.050           | 0.100           | 0.000           | 0.120           | 0.000           | 0.000           |

A supermatrix is a key component in the analysis of security testing attributes. It is represented as a two-dimensional matrix where the primary vectors or attributes of security testing from the paired comparison are placed in the corresponding columns of the supermatrix. To ensure consistency and comparability, the supermatrix is then transformed into a reduced matrix where the sum of each column equals one, resulting in a column stochastic matrix. This transformation allows for a clearer understanding of the relative impacts of each criterion on the other criteria. By creating supermatrices for each criterion, the interdependencies and relative influences between criteria can be effectively demonstrated and compared. This process aids in evaluating the overall significance and relationships between different security testing attributes.

**Table 8:** The weighted supermatrix for security attributes in relation to test plan specification

|                 |                    | S <sub>A1</sub> |                 | S <sub>A2</sub> |                 | S <sub>A3</sub> |                 |                 | S <sub>A4</sub> |                 |                 | S <sub>A5</sub> |                 | S <sub>A6</sub> |                 |                 |                 | S <sub>A7</sub> |                 |  |
|-----------------|--------------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|-----------------|--|
|                 |                    | S <sub>A1</sub> | S <sub>A2</sub> | S <sub>A2</sub> | S <sub>A3</sub> | S <sub>A3</sub> | S <sub>A3</sub> | S <sub>A4</sub> | S <sub>A4</sub> | S <sub>A4</sub> | S <sub>A5</sub> | S <sub>A5</sub> | S <sub>A6</sub> | S <sub>A6</sub> | S <sub>A6</sub> | S <sub>A6</sub> | S <sub>A7</sub> | S <sub>A7</sub> | S <sub>A7</sub> |  |
|                 |                    | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              | ->              |  |
|                 |                    | P <sub>1</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  | P <sub>4</sub>  | P <sub>1</sub>  | P <sub>2</sub>  | P <sub>3</sub>  |  |
| S <sub>A1</sub> | S <sub>A1</sub> -> | 0.0             | 0.2             | 0.2             | 0.2             | 0.1             | 0.1             | 0.0             | 0.0             | 0.0             | 0.3             | 0.3             | 0.2             | 0.3             | 0.2             | 0.2             | 0.1             | 0.1             | 0.1             |  |
|                 | P <sub>1</sub>     | 00              | 90              | 90              | 00              | 60              | 80              | 00              | 00              | 00              | 10              | 80              | 70              | 40              | 60              | 60              | 50              | 50              | 50              |  |
| S <sub>A2</sub> | S <sub>A2</sub> -> | 0.0             | 0.0             | 0.4             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.1             |  |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 30              | 50              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 70              | 90              | 00              |  |
|                 | S <sub>A2</sub> -> | 0.0             | 0.4             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             |  |
|                 | P <sub>2</sub>     | 00              | 00              | 00              | 00              | 50              | 30              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 40              | 20              | 10              |  |
| S <sub>A3</sub> | S <sub>A3</sub> -> | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.2             | 0.2             | 0.2             | 0.2             | 0.1             | 0.0             | 0.1             |  |
|                 | P <sub>1</sub>     | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 20              | 90              | 10              | 10              | 00              | 90              | 00              |  |
|                 | S <sub>A3</sub> -> | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             | 0.0             |  |
|                 | P <sub>2</sub>     | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 00              | 30              | 40              | 30              |  |

|          |                      |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|----------|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| $S_{A3}$ | $S_{A3} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.1 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_3$                | 00  | 00  | 00  | 90  | 50  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  |
|          | $S_{A4} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.3 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $S_{A4}$ | $P_1$                | 00  | 00  | 00  | 00  | 00  | 10  | 00  | 40  | 20  | 00  | 00  | 00  | 00  | 00  | 00  | 50  | 50  |
|          | $S_{A4} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_2$                | 00  | 00  | 00  | 80  | 00  | 30  | 50  | 00  | 00  | 90  | 00  | 00  | 00  | 00  | 00  | 60  | 50  |
| $S_{A5}$ | $S_{A4} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.2 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_3$                | 00  | 00  | 00  | 30  | 70  | 40  | 20  | 40  | 00  | 80  | 00  | 20  | 00  | 00  | 00  | 10  | 20  |
|          | $S_{A5} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $S_{A5}$ | $P_1$                | 00  | 00  | 00  | 00  | 00  | 50  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 90  | 60  |
|          | $S_{A5} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_2$                | 00  | 00  | 00  | 00  | 00  | 30  | 00  | 00  | 00  | 20  | 00  | 00  | 00  | 00  | 00  | 20  | 50  |
| $S_{A6}$ | $S_{A6} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.2 | 0.0 | 0.0 | 0.2 | 0.2 | 0.0 | 0.1 |
|          | $P_1$                | 00  | 40  | 40  | 40  | 00  | 50  | 00  | 00  | 00  | 90  | 40  | 00  | 00  | 50  | 50  | 60  | 00  |
|          | $S_{A6} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $S_{A6}$ | $P_2$                | 00  | 00  | 00  | 60  | 50  | 30  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 20  | 00  |
|          | $S_{A6} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_3$                | 00  | 00  | 00  | 50  | 20  | 50  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 40  | 20  |
| $S_{A7}$ | $S_{A6} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_4$                | 00  | 00  | 00  | 50  | 00  | 50  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 00  | 50  | 40  |
|          | $S_{A7} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.1 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| $S_{A7}$ | $P_1$                | 00  | 20  | 40  | 00  | 80  | 40  | 00  | 00  | 00  | 00  | 80  | 00  | 00  | 00  | 00  | 00  | 00  |
|          | $S_{A7} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_2$                | 00  | 30  | 00  | 00  | 10  | 40  | 00  | 00  | 00  | 10  | 30  | 00  | 00  | 00  | 00  | 00  | 00  |
| $S_{A7}$ | $S_{A7} \rightarrow$ | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|          | $P_3$                | 00  | 10  | 10  | 00  | 10  | 30  | 00  | 00  | 00  | 10  | 40  | 00  | 00  | 00  | 00  | 00  | 00  |

Table 8 illustrates the weighted supermatrix, which is derived by multiplying each element of the attribute at the top of the supermatrix based on their priority order. This multiplication process determines the values for the alternative elements in the weighted supermatrix. Each column in the supermatrix is carefully adjusted so that the sum of all the values in that column equals 1. This normalization ensures that the weighted supermatrix accurately reflects the relative importance and contributions of each attribute within the matrix. By achieving column sums of 1, the weighted supermatrix provides a clear representation of the proportional significance of each attribute in relation to others.

**Table 9:** The limit supermatrix for security attributes in relation to test plan specification

|          |                      | $S_{A1}$      |               | $S_{A2}$      |               | $S_{A3}$      |               | $S_{A4}$      |               | $S_{A5}$      |               | $S_{A6}$      |               | $S_{A7}$      |               |
|----------|----------------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|---------------|
|          |                      | $S_{A1}$      | $S_{A2}$      | $S_{A2}$      | $S_{A3}$      | $S_{A3}$      | $S_{A3}$      | $S_{A4}$      | $S_{A4}$      | $S_{A4}$      | $S_{A5}$      | $S_{A5}$      | $S_{A6}$      | $S_{A6}$      | $S_{A6}$      |
|          |                      | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ | $\rightarrow$ |
|          |                      | $P_1$         | $P_1$         | $P_2$         | $P_1$         | $P_2$         | $P_3$         | $P_1$         | $P_2$         | $P_3$         | $P_1$         | $P_2$         | $P_1$         | $P_2$         | $P_3$         |
| $S_{A1}$ | $S_{A1} \rightarrow$ | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           | 0.1           |
|          | $P_1$                | 50            | 50            | 50            | 50            | 50            | 50            | 50            | 50            | 50            | 50            | 50            | 50            | 50            | 50            |
|          | $S_{A2} \rightarrow$ | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           |
| $S_{A2}$ | $P_1$                | 40            | 40            | 40            | 40            | 40            | 40            | 40            | 40            | 40            | 40            | 40            | 40            | 40            | 40            |
|          | $S_{A2} \rightarrow$ | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           | 0.0           |

|                       |                            |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-----------------------|----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                       | <b>P<sub>2</sub></b>       | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  | 30  |
|                       | <b>S<sub>A3</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>1</sub></b>       | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  | 80  |
| <b>S<sub>A3</sub></b> | <b>S<sub>A3</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>2</sub></b>       | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  |
|                       | <b>S<sub>A3</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>3</sub></b>       | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  |
|                       | <b>S<sub>A4</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>1</sub></b>       | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  |
| <b>S<sub>A4</sub></b> | <b>S<sub>A4</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>2</sub></b>       | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  | 50  |
|                       | <b>S<sub>A4</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>3</sub></b>       | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  | 40  |
|                       | <b>S<sub>A5</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| <b>S<sub>A5</sub></b> | <b>P<sub>1</sub></b>       | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  |
|                       | <b>S<sub>A5</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>2</sub></b>       | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  |
|                       | <b>S<sub>A6</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>1</sub></b>       | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  | 60  |
| <b>S<sub>A6</sub></b> | <b>S<sub>A6</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>2</sub></b>       | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  |
|                       | <b>S<sub>A6</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>3</sub></b>       | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  |
|                       | <b>S<sub>A6</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>4</sub></b>       | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  |
|                       | <b>S<sub>A7</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| <b>S<sub>A7</sub></b> | <b>P<sub>1</sub></b>       | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  |
|                       | <b>S<sub>A7</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>2</sub></b>       | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  | 20  |
|                       | <b>S<sub>A7</sub>-&gt;</b> | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
|                       | <b>P<sub>3</sub></b>       | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  | 10  |

The limit supermatrix, as presented in Table 9, is derived from the weighted supermatrix. In this process, the importance weight of each security attribute is assigned to the corresponding column of the limit supermatrix. These weights are obtained from the analysis conducted on the weighted supermatrix, which reflects the relative significance of each attribute. By incorporating the importance weights into the limit supermatrix, a clear representation of the relative importance and contributions of each security attribute is established. This aids in further understanding and decision-making regarding the prioritization and evaluation of security attributes within the context of the overall analysis.

## 5. Experimental Results and Discussion

This study examined the recent literature to identify and validate the ranking of the most relevant and significant security attributes for deriving a credible and efficient software testing plan. Depending on the weights of the different attributes, the study devises a hierarchical model that ranks the attributes in the order their respective priority. A questionnaire was used to obtain the perspectives of the experts from academia as well as

the software industry in this context. Their responses were recorded to gain a better understanding of the current state of affairs. Based on the aforementioned assumption, the FANP was used to evaluate the weights of the security attributes.

According to the findings that are shown in tables 10 and 11, it has been found out that authorization and integrity are the most important and essential security attributes. To achieve optimum security, the security attributes should be arranged according to their degree of importance for eliciting the most effective results. Figure 3 shows the network structure of security attributes' clusters limit weights, while Figure 4 shows them in relation to test plan specification. The results indicate that the suggested fuzzy supermatrix approach does yield satisfactory results. In comparison to the current methods in the literature with precise supermatrix calculations, it is evident that the suggested method provides additional information and more flexibility to the decision maker, and is more appropriate for representing uncertainties.

**Table 10:** Global priorities of security attributes

| Security Attributes        | Final Weights |
|----------------------------|---------------|
| (Authentication) $S_{A1}$  | 0.150         |
| (Authorization) $S_{A2}$   | 0.070         |
| (Confidentiality) $S_{A3}$ | 0.111         |
| (Availability) $S_{A4}$    | 0.150         |
| (Integrity) $S_{A5}$       | 0.040         |
| (Non-repudiation) $S_{A6}$ | 0.121         |
| (Resilience) $S_{A7}$      | 0.041         |

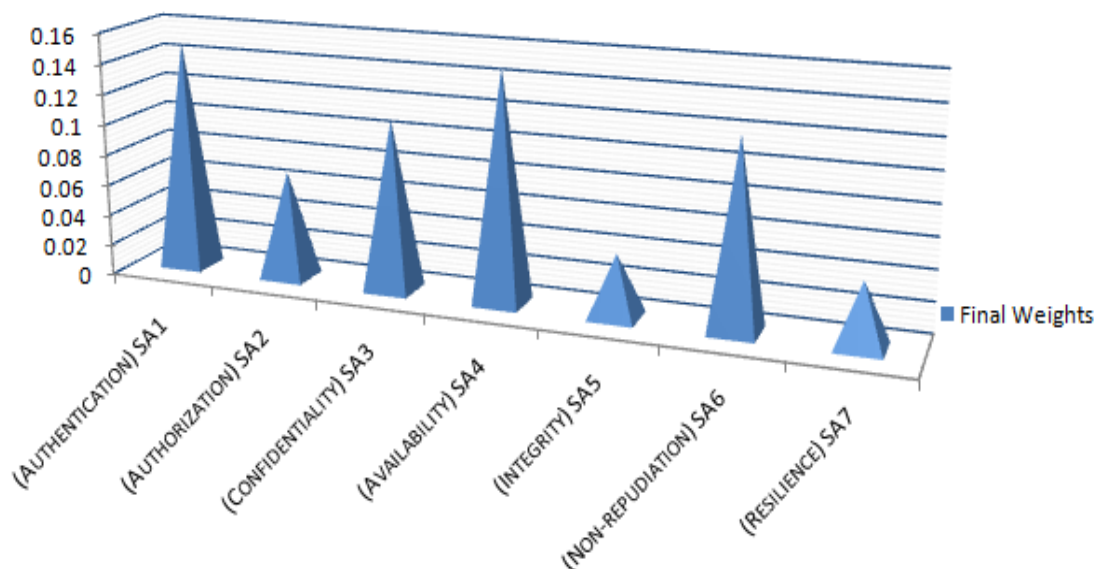


**Figure 3:** Clusters limit weights in the network design of security attributes

**Table 11:** Global priorities for security attributes in relation to test plan specification

| Final Weights            | Fuzzy ANP |
|--------------------------|-----------|
| $S_{A1} \rightarrow P_1$ | 0.140     |
| $S_{A2} \rightarrow P_1$ | 0.030     |
| $S_{A2} \rightarrow P_2$ | 0.030     |
| $S_{A3} \rightarrow P_1$ | 0.070     |
| $S_{A3} \rightarrow P_2$ | 0.010     |
| $S_{A3} \rightarrow P_3$ | 0.010     |
| $S_{A4} \rightarrow P_1$ | 0.050     |
| $S_{A4} \rightarrow P_2$ | 0.050     |
| $S_{A4} \rightarrow P_3$ | 0.040     |
| $S_{A5} \rightarrow P_1$ | 0.020     |
| $S_{A5} \rightarrow P_2$ | 0.010     |
| $S_{A6} \rightarrow P_1$ | 0.050     |
| $S_{A6} \rightarrow P_2$ | 0.010     |
| $S_{A6} \rightarrow P_3$ | 0.020     |
| $S_{A6} \rightarrow P_4$ | 0.020     |
| $S_{A7} \rightarrow P_1$ | 0.010     |
| $S_{A7} \rightarrow P_2$ | 0.010     |
| $S_{A7} \rightarrow P_3$ | 0.001     |

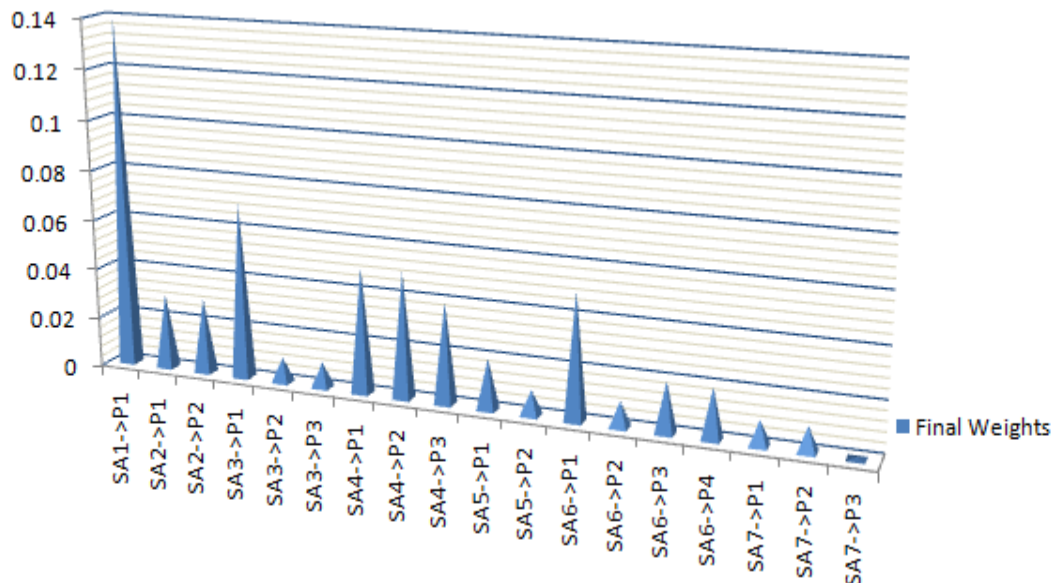


**Figure 4:** Clusters limit security attribute weights in the network design for test plan specification

These methods' results should clearly demonstrate the consistency of the findings based on the data fed. The data obtained by applying the Fuzzy ANP are shown in Tables 3–12. Table-11 summarises the priorities of security testing attributes based on their weightages, which are presented in percentages. The factors with the highest weights are ranked 1 ( $S_{A1}$  and  $S_{A4}$ ), while the factors with the lowest weights are ranked 7 ( $S_{A5}$  and  $S_{A7}$ ). For Validation of the Table 12 shows the results. Further, the comparisons in Table 12 shown the highly correlations (0.9997) between results.

**Table 12:** Validation of the results

| <b>Final Weights</b>     | <b>Fuzzy ANP</b> | <b>Fuzzy AHP</b> |
|--------------------------|------------------|------------------|
| $S_{A1} \rightarrow P_1$ | 0.140            | 0.130            |
| $S_{A2} \rightarrow P_1$ | 0.030            | 0.040            |
| $S_{A2} \rightarrow P_2$ | 0.030            | 0.020            |
| $S_{A3} \rightarrow P_1$ | 0.070            | 0.080            |
| $S_{A3} \rightarrow P_2$ | 0.010            | 0.010            |
| $S_{A3} \rightarrow P_3$ | 0.010            | 0.010            |
| $S_{A4} \rightarrow P_1$ | 0.050            | 0.040            |
| $S_{A4} \rightarrow P_2$ | 0.050            | 0.060            |
| $S_{A4} \rightarrow P_3$ | 0.040            | 0.030            |
| $S_{A5} \rightarrow P_1$ | 0.020            | 0.030            |
| $S_{A5} \rightarrow P_2$ | 0.010            | 0.010            |
| $S_{A6} \rightarrow P_1$ | 0.050            | 0.040            |
| $S_{A6} \rightarrow P_2$ | 0.010            | 0.010            |
| $S_{A6} \rightarrow P_3$ | 0.020            | 0.030            |
| $S_{A6} \rightarrow P_4$ | 0.020            | 0.010            |
| $S_{A7} \rightarrow P_1$ | 0.010            | 0.020            |
| $S_{A7} \rightarrow P_2$ | 0.010            | 0.010            |
| $S_{A7} \rightarrow P_3$ | 0.001            | 0.001            |

## 6. Conclusion

Security testing is the subject of extensive research at present. As the demand for efficient and reliable software systems increases, it is even more essential for the developers to employ techniques that can provide optimum results in security testing while developing the software. In this league, the present study identifies and prioritizes the security attributes in relation to the security test plan specification. In environmental cases, authentication and integrity are the important factors, as found in the FANP-based study. As a result, authentication in the environment is important for the successful implementation of security testing. This priority-based list of security factors would be an important and credible reference for the developers in determining the most important factors among a slew of options. Furthermore, this priority list will also provide the developers with security testing guidance for particular test scenarios. Security attributes that may impact software projects are difficult to detect and may vary from project to project due to the large-scale diversity of software applications in the real world. In such a scenario, the developers may use the devised list of priorities with their test plan specification to decide which security considerations from the list of security attributes drive the test plan for optimum security as per the application. In the future, prospects will involve improving and expanding existing approaches to create even more robust security testing practices in the constantly shifting context of cloud computing.

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