Quantitative Analysis of Requirement Elicitation Techniques through FANP: Security Perspective

Virendra Singh, Dhirendra Pandey, Mohd Waris Khan, Kavita Sahu

Abstract: The last few decades have shown an incredible rise in the production of different types of software according to the user’s needs. Requirement Elicitation techniques for security requirements are one of the most crucial stages of software development life cycle. Based on the Analytical Network Process (ANP) process, this paper analyzes the weighting of elicitation techniques for security requirements in the production of software applications. In other words, the elicitation strategies of security requirements play an important role in the development of secure software. It also analyzes the relationship between security requirement elicitation techniques and their objectives through the use of ANP method and also demonstrates the application of fuzzy ANP method to achieve higher accuracy. When developing a secure software framework, the results provide a better platform. With these facts in mind, the proposed study will also clarify the priority weights of security requirement elicitation techniques that can be used to analyze trade-offs between competing security requirement elicitation techniques and provide a new way for developers when constructing the secure software.

Keywords: Questionnaire, brainstorming, data analysis, group discussion, interview, observation, prototyping, requirement workshop, multi-criteria decision-making (MCDM), Analytic Network Process (ANP).

I. INTRODUCTION

At the time of design in SDLC, the production and development of a security device for testing software systems is a very comprehensive and expensive activity for any organization. A secure software development process is a tenacious activity that requires evaluating all the security properties as security requirement elicitation is an inseparable part of this process [1]. Security check profile modus operandi involves eight techniques including questionnaire, brainstorming, data analysis, group discussion, interview, observation, prototyping, requirement workshop as shown in figure 1. Such characteristics are a keystone in determining and collecting accurate and secure information. In all respects, secure elicitation has become an important need for any organization.

Hence, its protection demonstrates its significance and weighting correspondingly, covering all the issues that may increase or decrease the computer organization’s quality. Therefore, finding new strategies and taking necessary action at the time of security requirement elicitation becomes the necessities of developers.

Security requirement elicitation is an ever-growing area that involves the development of new technologies and techniques that can be used to build secure software. The intruders are always ready to attack both device and user applications, which may or may not easily lacerate computer security [2]. Such intruders ’ main goal is to manipulate the vulnerabilities and gain all the sensitive information or data they can monitor the running system from.

Fig. 1 Requirement Elicitation Techniques

Therefore, the secure requirement elicitation provides a platform through which its actions can be managed smoothly to avoid any possible disturbance. The enactment of security requirement elicitation plays an important role in enhancing the protection of any technology [3,4]. Security check profile with a structured approach throughout the entire SDLC cycle, especially during the design phase, provides a good understanding of software quality and protects against known security risks that can occur at any time [5]. Increasing numbers of security issues or accidents are also a growing concern for business owners and IT industries. Many companies that do not concentrate on security requirement elicitation during the software development process can contain dangerous bugs that can present huge risks to the company.

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The paper was divided into six sections, beginning with multi-criteria decision-making needs and its importance. Section 2, outlines the authors’ history of ANP and related work. Section 3 describes the methodology used in Analytic Network Process. Comprehensive assessment through Fuzzy ANP are explained in section 4. The results and discussion will be illustrated in the section 5. Finally, section 6 presents the conclusion of the research work.

II. NEEDS AND IMPORTANCE

The fundamental purpose of this paper is to define priorities based on weighing and ranking of the elicitation techniques for security requirements by using multi-criteria decision-making processes that illustrate the use of analytical network processes, making the software development process more and more safe and efficient. Since no attempts have been made to prioritize and rank the attributes of requirement elicitation techniques that may affect software security success and its trade-offs, the fuzzy ANP techniques can be used to prioritize the attributes of all security requirement elicitation in profiling terms. Fuzzy ANP provides a more accurate result compared to ANP methodology as it helps to eliminate the problem of confusion and ambiguity in decision-making. This will increase the life span of technology and early detection of vulnerabilities that will directly benefit users / organization by improving security software performance and durability. Analysis of prioritization of security requirement elicitation techniques through the use of FANP, a type of multi-criteria decision analysis [6]. Multi-Criteria Decision Analysis (MCDA) is useful in carrying out various assessments of conflicting elements such as the Multi-Attribute Utility Theory and the Analytic Network Process [6, 7]. Objectives, alternate weights and ranks are three different parts of the MCDA system used in ANP software.

Analytical Hierarchical Process (AHP) is considered to be sufficient in evaluating a group decision, but Saaty found that ANP is more useful in providing their weighting with succinct decisions [8, 9]. However, it was observed that more reliable relationship has been established in the case of fuzzy ANP, which provides full priority analysis by decision-makers [10]. Fuzzy ANP therefore operates with judgmental feedback from a community of decision-makers to build a network of elicitation techniques according to their value or priority. The researchers provide a modified version of AHP, known as ANP, to deal with the complexities and uncertainty of human judgment. The ANP technique is more sophisticated and developed than the AHP technique, while the fuzzy ANP technique is an improvement over the standard ANP approach by which better results can be obtained. This research provides a platform for analyzing security requirement elicitation techniques through the use of quantitative network system and fuzzy ANP methods. We have collected data from various experts from different academic and industry fields in this article. The goal is to determine the safety criteria for elicitation strategies in terms of their weight and levels, according to these various inputs experts. Security requirement elicitation techniques were chosen on behalf of MCDM process to reduce and meet these research characteristics for software's long life and security in the future.

Since ANP is an enhanced AHP interpretation. Saaty suggested using AHP to solve the issue of autonomy on alternatives or criteria, and using ANP to solve the issue of dependency on alternatives or criteria [9, 11]. Figure 1 outlines the actual difference between AHP and ANP as shown below:

Fig. 2. Difference between AHP and ANP Structure
Many decision-making problems cannot be hierarchically organized since they require communication and interdependence of higher-level elements on lower-level elements which form a network-type structure rather than hierarchy. Nonetheless, ANP is crucial in establishing a network system in ANP, criteria at the lower level may provide input on the higher-level criteria, and interdependence between the same level criteria is permitted. Another discrepancy in the calculation method between AHP and ANP is the introduction of a new definition "supermatrix" in ANP [9].

There are several recent applications and research works available in the literature that give better results to the ANP system including Boran et al. used ANP for personnel selection issues [12]. In 2018, the author proposed a network structure of multitudes of security requirement elicitation techniques, through which a complete relationship and interdependencies among these attributes are realized by using FANP [6]; Yazgan applied Fuzzy ANP to pick the shipping rules [13]; Kuo used ANP, Fuzzy DEMATEL and TOPSIS in the international distribution center locating problem [14]; Ayag and Ozdemir applied Fuzzy ANP approach to idea selection [15] and Dagdeviren et al. applied Fuzzy ANP model to define Faulty Behavior Risk (FBR) in the workplace [16].

III. METHODOLOGY

The methodology used in ANP is shown below and all the steps of the ANP method are described as follows:

**Network Structure Formation in Analytic Network Process:** At initial stage construction of network structure with criteria, sub-criteria and alternatives are established. The clusters of all items taken for prioritization and ranking are calculated after these steps. Because ANP is purely based on the system of networking, all the relationship between these clusters is established within things in each cluster. As a consequence, there are few different relationships that have some impact. Nonetheless, those items that have shown direct effect can be regarded as a normal dependency in a generic hierarchy whereas the items that have indirect effect on dependency are not direct and must flow through some other criterion or alternative [8, 9]. Factors showing self-interaction are also a more dynamic effect and the last one is a reciprocal effect showing interdependencies between parameters.

**Formation of Pairwise Comparison Matrices by Analytic Network Process:** This process is achieved by the elements within the clusters. The main objective is to create pairs correlation with control hierarchy on behalf of the criterion or sub-criterion. The effect is obtained on each cluster that is determined by this criterion [6]. As a result, essential weights of all items are calculated and relationships are formed between items by which decision makers compare two items in order to eventually decide the contribution of all factors. Eigenvector are utilized for obtaining the local priority vector which can be achieved through this equation:

\[ PX = \lambda_{\text{max}} X \]  

--- (I)
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Where \( P \) = Pairwise Comparison Matrix, \( X \) = Eigen Vector and \( \lambda_{mb} \) = Eigen Value; \( X \) can be calculated by using Normalization Algorithm.

The comparisons between attributes or techniques of security requirement elicitation are calculated by the following equations:

\[
P = [p_{ij}]_{n \times n}, \quad i = 1, \ldots, n; \quad j = 1, \ldots, n\]  

Significance distribution of factors as percentage is as follows:

\[
Q_i = [q_{ij}]_{n \times 1}, \quad i = 1, \ldots, n\]  

\[
q_{ij} = p_{ij} / \sum_{k=1}^{n} p_{ik}\]  

\[
R = [q_{ij}]_{n \times n}, \quad i = 1, \ldots, n; \quad j = 1, \ldots, n\]  

\[
X_i = \sum_{j=1}^{n} R_{ij} / n\]  

\[
X = [X_i]_{n \times 1}\]  

Formation of Super matrix and Limit Super Matrix: Local priority vectors are allocated to the appropriate super matrix columns in order to achieve global priority in an interdependent structure. The final structure of the obtained supermatrix is identical to step 9 of the Markov chain. Long-term impacts of things are calculated by increasing the super matrix power [5, 6]. Super matrix is therefore a small matrix and each element of it pretends to be the relationship between two objects in the structure as a whole. The power of the matrix is increased to \( 2l+1 \), where \( l \) is an arbitrary large number, to make the primacy of weights. The new matrix established is therefore known as the Super Limited Matrix [9]. In addition, to find the consistency of each element for comparison are using the following expression:

\[
S = [p_{ij}]_{n \times n} \times [X_i]_{n \times 1} = [s_{ij}]_{n \times n}\]  

Table-1: Linguistic Scale

| Equal | (1,1,1) | (1,1,1) |
|---|---|---|
| Evenly Important | \( C_{11} = (1,3,5) \) | (1/3,1,1) |
| Softly important | \( C_{12} = (1,5,7) \) | (1/5,1/3,1) |
| Important in essence | \( C_{13} = (1,7,9) \) | (1/7,1/5,1/3) |
| Strongly important | \( C_{14} = (1,9,11) \) | (1/9,1/7,1/5) |
| Totally important | \( C_{15} = (1,11,13) \) | (1/11,1/9,1/7) |
| Middle values between two adjacent | \( C_{2}, C_{3}, C_{4}, C_{5} \) |

IV. ASSESSMENT THROUGH FUZZY ANP

Specifically, traditional analytical hierarchy processes and analytical network process techniques do not necessarily support or provide a clear picture for assessing in ambiguous, dynamic and imprecise circumstances. So, by using fuzzy ANP in such situations where decision-makers/stakeholders are unsure about the weight level is necessary to solve the uncertainty issue, making FANP an effective decision-making tool in multi-criteria problems. Fuzzy ANP methodology has been shown to be very effective in solving decision-making problems when there are interdependencies within the networks between different elements. The triangular fuzzy membership function is useful to construct a matrix of comparison between the different elements in pairs.

The method discussed in the proposed priority of security requirement elicitation techniques include:
Questionnaire (T1); Data Analysis (T2); Interview (T3); Observation (T4); Requirement Workshop (T5); Prototyping (T6); Group Discussion (T7), Brainstorming (T8). Evaluation of Security requirement elicitation techniques are typically a qualitative measure. As a result, it becomes a challenging task to quantitatively determine the characteristics of security requirement elicitation. Weights and ranks of security requirement elicitation techniques play an important role in highly secure software development. A multi-criteria decision-making (MCDM) framework was used for the development of secure requirements to prioritize security requirement elicitation techniques [5-6]. Figure 2 reflects all the possible relationships and interdependence among the security requirement elicitation network diagram.

![Fig. 4. Network Structure Formation in ANP Method](image)

The aim of this study is to use a hybrid model of MCDM methods for attributes of security requirement elicitation. Table-2 shows the name of the cluster and its symbols. To define the requirements for security requirement elicitation techniques, we use literature review together with a group of experts who have systematized the criteria in eight clusters as shown in table 3. In Table-4 and Table-5, respectively, alpha-cut method for defuzzification of local security requirement elicitation techniques priorities and creation of super matrix from all local priority vectors is shown. In addition, as shown in table-6, weighted matrix is obtained from super matrix. Followed by the weighted supermatrix limit is shown in table-7. Ultimately, we obtained global priorities of security elicitation techniques in Table-8.

| S. N. | Cluster Name       | Cluster Representation |
|------|--------------------|------------------------|
| 1    | Questionnaire      | T1                     |
| 2    | Data Analysis      | T2                     |
| 3    | Interview          | T3                     |
| 4    | Observation        | T4                     |
| 5    | Requirement Workshop | T5                   |
| 6    | Prototyping        | T6                     |
| 7    | Group Discussion   | T7                     |
| 8    | Brainstorming      | T8                     |
Table 3. Pair wise comparison matrix

| Questionnaire (T1) | Data Analysis (T2) | Interview (T3) | Observation (T4) | Requirement Workshop (T5) | Prototyping (T6) | Group Discussion (T7) | Brainstorming (T8) |
|--------------------|--------------------|---------------|------------------|--------------------------|-----------------|-----------------------|-------------------|
| 1.0000, 0.6600, 0.0000 | 0.7000, 0.0950, 0.3500 | 1.5250, 2.3540, 2.9010 | 1.6920, 2.4140, 3.1470 | 1.5490, 2.3540, 2.9010 | 0.5520, 0.6390, 0.9050 | 1.0850, 2.2000, 2.8500 | 0.4510, 0.8500, 1.0000 |
| - | 1.0000, 0.0000, 0.0000 | 0.4450, 0.8500, 2.1500 | 1.4590, 1.8590, 2.2150 | 0.4510, 0.8500, 1.0000 | 1.5530, 2.2000, 2.8500 | 1.0850, 2.2000, 2.8500 | 0.4510, 0.8500, 1.0000 |
| - | - | 1.0000, 1.0000, 1.0000 | 1.0850, 1.5000, 1.5420 | 1.0850, 1.5000, 1.5420 | 0.5520, 0.6390, 0.9050 | 1.0850, 2.2000, 2.8500 | 0.4510, 0.8500, 1.0000 |
| - | - | - | 1.0000, 1.0000, 1.0000 | 1.0850, 1.5000, 1.5420 | 0.5520, 0.6390, 0.9050 | 1.0850, 2.2000, 2.8500 | 0.4510, 0.8500, 1.0000 |
| - | - | - | - | 1.0000, 1.0000, 1.0000 | 0.3980, 0.5850, 0.6620 | 0.3980, 0.5850, 0.6620 | 0.4510, 0.8500, 1.0000 |
| - | - | - | - | - | 1.0000, 1.0000, 1.0000 | 1.0000, 1.0000, 1.0000 | 1.0000, 1.0000, 1.0000 |

Table 4. Defuzzification by using Alpha-Cut Method

| Questionnaire (T1) | Data Analysis (T2) | Interview (T3) | Observation (T4) | Requirement Workshop (T5) | Prototyping (T6) | Group Discussion (T7) | Brainstorming (T8) | Weights |
|--------------------|--------------------|---------------|------------------|--------------------------|-----------------|-----------------------|-------------------|---------|
| 1.0000 | 1.1700 | 0.9900 | 2.5630 | 2.6670 | 2.3440 | 0.9750 | 2.5450 | 0.1688 |
| 0.5850 | 1.0000 | 1.6300 | 1.2750 | 1.8530 | 1.7940 | 2.5450 | 2.1200 | 0.1470 |
| 1.1210 | 0.5710 | 1.0000 | 0.9890 | 2.6060 | 0.6910 | 2.1200 | 1.8850 | 0.1770 |
| 0.38600 | 0.8250 | 1.850 | 1.0000 | 2.1770 | 0.7710 | 1.8850 | 1.7670 | 0.1343 |
| 0.3480 | 0.5400 | 0.3840 | 0.4590 | 1.0000 | 1.8210 | 1.7670 | 2.5450 | 0.1022 |
| 0.4750 | 0.5570 | 1.4850 | 1.2580 | 0.5458 | 1.0000 | 1.4360 | 2.1200 | 0.0901 |
| 1.0710 | 0.4140 | 0.4720 | 0.5290 | 0.5660 | 0.6850 | 1.0000 | 1.8850 | 0.1006 |
| 0.5570 | 1.4850 | 1.2580 | 0.5458 | 0.5570 | 1.4850 | 1.2580 | 1.0000 | 0.0800 |

CI 0.00237
Table 5. Supermatrix

|                | Questionnaire (T1) | Data Analysis (T2) | Interview (T3) | Observation (T4) | Requirement Workshop (T5) | Prototyping (T6) | Group Discussion (T7) | Brainstorming (T8) |
|----------------|--------------------|--------------------|----------------|------------------|--------------------------|-----------------|-----------------------|-------------------|
| Questionnaire (T1) | 1.0000             | 0.2520             | 0.1510         | 0.2250           | 0.2450                   | 0.3450          | 0.2480                | 2.3440            |
| Data Analysis (T2)  | 0.2920             | 1.0000             | 0.3470         | 0.2170           | 0.2470                   | 0.2450          | 0.2230                | 1.7940            |
| Interview (T3)      | 0.2570             | 0.2511             | 1.0000         | 0.2170           | 0.1547                   | 0.2214          | 0.2230                | 0.6910            |
| Observation (T4)    | 0.2300             | 0.2277             | 0.2140         | 1.0000           | 0.1314                   | 0.0645          | 0.1180                | 0.7710            |
| Requirement Workshop (T5) | 0.1551           | 0.1514             | 0.0847         | 0.1660           | 1.0000                   | 0.0450          | 0.0250                | 1.8210            |
| Prototyping (T6)    | 0.0688             | 0.0947             | 0.0230         | 0.0890           | 0.0750                   | 1.0000          | 0.1240                | 1.0000            |
| Group Discussion (T7) | 0.1100            | 0.2500             | 0.2230         | 0.1000           | 0.1400                   | 0.1111          | 1.0000                | 0.6580            |
| Brainstorming (T8)  | 0.1100             | 0.2500             | 0.2230         | 0.1000           | 0.1400                   | 0.1111          | 1.1121                | 1.0000            |

Table 6. Weighted Supermatrix

|                | Questionnaire (T1) | Data Analysis (T2) | Interview (T3) | Observation (T4) | Requirement Workshop (T5) | Prototyping (T6) | Group Discussion (T7) | Brainstorming (T8) |
|----------------|--------------------|--------------------|----------------|------------------|--------------------------|-----------------|-----------------------|-------------------|
| Questionnaire (T1) | 0.5120             | 0.1350             | 0.0540         | 0.1450           | 0.1150                   | 0.1450          | 0.1170                | 0.1270            |
| Data Analysis (T2)  | 0.1460             | 0.5000             | 0.1530         | 0.1270           | 0.1478                   | 0.1270          | 0.1850                | 0.1780            |
| Interview (T3)      | 0.1240             | 0.1250             | 0.5000         | 0.1160           | 0.0788                   | 0.1780          | 0.1250                | 0.0780            |
| Observation (T4)    | 0.1250             | 0.1140             | 0.1160         | 0.5015           | 0.0640                   | 0.0780          | 0.0544                | 0.0780            |
| Requirement Workshop (T5) | 0.0750           | 0.0800             | 0.0440         | 0.0831           | 0.0490                   | 0.0780          | 0.0145                | 0.5780            |
| Prototyping (T6)    | 0.0340             | 0.0500             | 0.0120         | 0.0442           | 0.0370                   | 0.5780          | 0.0978                | 0.1270            |
| Group Discussion (T7) | 0.1100            | 0.2500             | 0.2230         | 0.1000           | 0.1400                   | 0.1111          | 0.5000                | 0.1780            |
| Brainstorming (T8)  | 0.1100             | 0.2500             | 0.2230         | 0.1000           | 0.1400                   | 0.1111          | 0.1101                | 0.5000            |

Table 7. Limit Supermatrix

|                | Questionnaire (T1) | Data Analysis (T2) | Interview (T3) | Observation (T4) | Requirement Workshop (T5) | Prototyping (T6) | Group Discussion (T7) | Brainstorming (T8) |
|----------------|--------------------|--------------------|----------------|------------------|--------------------------|-----------------|-----------------------|-------------------|
| Questionnaire (T1) | 0.1799             | 0.1780             | 0.1789         | 0.1780           | 0.1789                   | 0.1782          | 0.1785                | 0.1783            |
| Data Analysis (T2)  | 0.1571             | 0.1571             | 0.1571         | 0.1571           | 0.1571                   | 0.1571          | 0.1571                | 0.1570            |
| Interview (T3)      | 0.1682             | 0.1682             | 0.1682         | 0.1682           | 0.1682                   | 0.1682          | 0.1682                | 0.1682            |
| Observation (T4)    | 0.1251             | 0.1251             | 0.1248         | 0.1250           | 0.1249                   | 0.1251          | 0.1251                | 0.1251            |
| Requirement Workshop (T5) | 0.0922           | 0.0922             | 0.0920         | 0.0920           | 0.0918                   | 0.0920          | 0.0922                | 0.0920            |
| Prototyping (T6)    | 0.1031             | 0.1031             | 0.1031         | 0.1031           | 0.1031                   | 0.1031          | 0.1030                | 0.1031            |
| Group Discussion (T7) | 0.1126            | 0.1126             | 0.1126         | 0.1126           | 0.1126                   | 0.1126          | 0.1126                | 0.1126            |
| Brainstorming (T8)  | 0.0628             | 0.0628             | 0.0628         | 0.0628           | 0.0628                   | 0.0628          | 0.0624                | 0.0627            |
Table 8. Global Priorities of Elicitation Techniques

| Elicitation Techniques | Global Priorities | Ranks |
|------------------------|------------------|-------|
| Questionnaire (T1)     | 0.1789           | 1     |
| Data Analysis (T2)     | 0.1571           | 3     |
| Interview (T3)         | 0.1682           | 2     |
| Observation (T4)       | 0.1251           | 4     |
| Requirement Workshop (T5) | 0.0922       | 7     |
| Prototyping (T6)       | 0.1031           | 6     |
| Group Discussion (T7)  | 0.1126           | 5     |
| Brainstorming (T8)     | 0.0628           | 8     |

In this paper, the author applied fuzzy analytic network process and made an attempt to examine the priority of requirement elicitation techniques by using the data received from various industrialist, researchers and experts in order to realize the activities of the real world. The original data used for the estimation was kept the same in order to check the relationship between the various methods on an equal basis. The results of these methods should be clearly showing the consistency of the findings based on the data fed. In Table-2 to Table-8, the data thus obtained by applying the Fuzzy ANP are given.

V. RESULTS AND DISCUSSIONS

A systematic literature review was performed in this paper to define and corroborate the prioritization of different security requirement elicitation techniques by weight. The author suggested a network structure of multitudes of security requirement elicitation techniques through which a detailed relationship and interdependencies between these techniques are realized. In addition, a questionnaire is used to gather the opinion of various experts on the eight techniques of security requirement elicitation. The experts come from both academia and the software industry in order to realize the activities of the real world. The weights of each security requirement elicitation techniques were determined by using fuzzy ANP techniques. From the above result, it is found that among all other techniques of security requirement elicitation, questionnaire is the most desirable and required element. Therefore, the classification of secure requirement elicitation techniques according to their respective objectives should be pursued in order to obtain the best possible results, as shown above.

VI. CONCLUSION

In this era security requirement elicitation is a booming area for research. Factors contributing in requirement elicitation techniques played a vital role in success of secure software development process. This paper described about security requirement elicitation techniques with respect to software development life cycle. We use FANP to make decisions and are taking into consideration several factors that influence such choices. We evaluate the weights affected by the clusters on the techniques of security requirement elicitation in figure 5. Hence, according to the research conducted based on Fuzzy ANP, questionnaire and interview are found to be the most prioritized techniques among all.
This priority wise listing of techniques is helpful in deciding the most significant techniques among the multitude of techniques in requirement elicitation process. Further, this prioritization will also help in providing a guideline to developers for successful implementation of security requirement elicitation in software development process.

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