T.C.
İSTANBUL KÜLTÜR UNIVERSITY
INSTITUTE OF GRADUATE STUDIES

# DEVELOPMENT OF AN EXCEL-VBA BASED DECISION SUPPORT SYSTEM FOR NETWORK ENGINEERS

**Masters of Applied Science Thesis**

**Hussain AONI**

**1900006258**

**Department: Industrial Engineering**

**Program: Engineering Management**

**Supervisor: Assist. Prof. Okay ISIK**

**JANUARY 2022**

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**JANUARY 2022**

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I would like to express my gratitude to all those who gave me the possibility to complete this study. I want to thank my family and Dr. Okay Isik for their support.

JANUARY 2022 Hussain AONI

# TABLE OF CONTENTS

# LIST OF TABLES

# LIST OF FIGURES

# LIST OF SYMBOLS

$A$ Comparison matrix for criteria evaluation

$CI$ Consistency index

$CR$ Consistency Ratio

$RI$ Random index

$R_i$ The overall score

$W_i$ Comparison matrix average weight

$\boldsymbol{\lambda_{max}}$ The eigenvector

| | |
|---|---|
| **Üniversite** | **: İstanbul Kültür Üniversitesi** |
| **Enstitü** | **: Lisansüstü Eğitim Enstitüsü** |
| **Anabilim Dalı** | **: Endüstri Mühendisliği** |
| **Programı** | **: Mühendislik Yönetimi** |
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# ÖZET

## AĞ MÜHENDİSLERİ İÇİN EXCEL-VBA TABANLI KARAR DESTEK SİSTEMİ GELİŞTİRİLMESİ

**Hüseyin AONI**

Yönlendirici (router), Internet altyapısında bir ağı diğer ağlara bağlamaktan ve veri paketlerinin hedeflerine ulaşmasında en etkin yolu bulmaktan sorumlu oluğu için, herhangi bir bilgisayar ağının kalbinde yer alan donanımsal bir bileşendir. En iyi yönlendiriciyi seçmek, ağ mühendisleri için kritik bir karardır, çünkü çok sayıda yönlendirici markası, marka modelleri ve her yönlendiriciyi birbirinden ayıran birçok ölçüt vardır. Yönetim becerilerinin eksikliği veya teknik sorunlar nedeniyle, ağ mühendisleri ağları için yanlış yönlendiriciyi seçebilir. Bu çalışmada, uygun yönlendiricinin seçimi için, çok kriterli bir karar verme yöntemi olan Analitik Hiyerarşi Süreci (AHP) yöntemine dayalı bir Karar destek sistemi (KDS) geliştirilmiştir. KDS, Microsoft-Excel'le entegre edilmiş Visual Basic for Applications (VBA) kullanılarak oluşturulmuştur. KDS'miz, Microsoft-Excel çalıştıran herhangi bir bilgisayarda kullanılabilen, kullanıcı dostu bir XLSM dosyasıdır. Önerilen KDS, dört kriter (Maliyet, Güvenilirlik, Verim ve Bağlantı Noktası sayıları) ve dört marka alternatifi (Cisco, Juniper, Huawei ve MikroTik) temelinde test edilmiştir. Geliştirilen KDS, karar vericinin (KV) kriterleri ve kriterlere göre yönlendiricileri kıyaslama sürecine eşlik eder ve sonunda en uygun yönlendiriciyi önerir. Ek olarak, KV'nin karşılaştırma matrisinin tutarsız olması durumunda, KDS KV'nin orijinal tercihlerinde küçük değişiklikler yaparak sıfır tutarsızlık oranını garanti eder. Önerilen yöntemin, literatürde yayınlanmış veri setleriyle test edilerek, tutarsızlığı azaltmaya yönelik olarak geliştirilen diğer yöntemlere göre üstünlükleri ortaya konmuştur.

**Anahtar Kelimeler:** Analitik Hiyerarşi Süreci (AHP), Karar Destek Sistemi (DSS), Visual Basic for Applications (VBA), Tutarlılık, Yönlendirici.

**Bilim Dalı Sayısal Kodu:** IEM 3900

| | |
|---|---|
| **University** | **: İstanbul Kültür University** |
| **Instittute** | **: Institute of Graduate Studies** |
| **Department** | **: Industrial Engineering** |
| **Program** | **: Engineering Management** |
| **Supervisor** | **: Assist. Prof. Okay ISIK** |
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## ABSTRACT

## DEVELOPMENT OF AN EXCEL-VBA BASED DECISION SUPPORT SYSTEM FOR NETWORK ENGINEERS

**Hussain AONI**

A router is a hardware component at the heart of any computer network, as it is responsible for connecting a network to other networks in the Internet infrastructure and finding the most efficient way for data packets to reach their destination. Choosing the best router is a critical decision for network engineers because there are so many router brands, brand models, and many criteria that distinguish each router. Due to lack of managerial skills or technical issues, network engineers may choose the wrong router for their network. In this study, a Decision Support System (DSS) based on the Analytical Hierarchy Process (AHP) method, which is a multi-criteria decision making method, has been developed for the selection of the appropriate router. The DSS is built using Visual Basic for Applications (VBA) integrated with Microsoft-Excel. The proposed DSS is a user-friendly XLSM file that can be used on any computer running Microsoft-Excel. The DSS was tested based on four criteria (Cost, Reliability, Efficiency and Port counts) and four brand alternatives (Cisco, Juniper, Huawei and MikroTik). The developed DSS accompanies the decision maker's (DM) comparison process of criteria and the alternative routers according to each criterion, and finally recommends the most suitable router. In addition, if the comparison matrix of DM is inconsistent, the proposed DSS makes minor changes to the original preferences of DM, ensuring a zero inconsistency rate. The proposed method has been tested with data sets published in the literature, and its advantages over other methods to reduce inconsistency have been demonstrated.

**Keywords:** Analytical hierarchy process (AHP), Decision Support System (DSS), Visual Basic for Applications (VBA), Consistency, Router.

**Science Code:** …IEM 3900

# 1. INTRODUCTION

## 1.1. Background

Computer networks started as a connection between two computers to exchange data in one physical location. Nowadays it became a connection of billions of devices such as phones, tablets, and laptops. We called This huge connection the Internet. People use the Internet to share data, make video calls, gaming and do online teaching. Behind the scenes, there are infrastructures and protocols that make the Internet work. These infrastructures consist of data centers, wireless antennas, and Fiber optics distributed around the globe. Each data center contains Routers, Switches, and servers. The person who is responsible to install and maintain the data centers is called the network engineer.

From the begging, the Router plays an essential role in the Internet and computer networks. A router is a computer network device responsible for connecting computer networks. Also, select the best path for the packet through the Internet and deliver the packet to its final destination. There are many vendors which they provide routers the most popular ones are Cisco, Juniper, Huawei, and Mikrotik.

## 1.2. The Aim of the Research

Based on the previous observation at the Internet service providers (ISP) there is a problem in the process of selecting the best routers for their networks. The decision-makers which are network engineers chose the router according to their experience and observation without a clear decision-making procedure due to the busyness with technical tasks and lack of management skills. Many times this leads to buying the wrong vendor or not a compatible router for the current network. This research aims:

1. Choose the optimum method to solve the previously mentioned problem.

2. Create a user-friendly DSS to help DM to select the best alternative.
3. Suggest a new method to make the DM comparison matrix consistent.

### 1.3. Hyphotesis

1. What kind of platforms will able to run the DSS?
2. Does the DSS will be able to save the time of network engineers?
3. Does the overall scores will be the same after the application of zero consistency method?

### 1.4. Contribution

Today, the lack of tools that support network engineers in making decisions motivated us to create a DSS. Our DSS is made based on the analytical hierarchy process (AHP) it is a multi-criteria decision making method (MCDM). We programmed this DSS by using visual basic for application (VBA) in Microsoft-Excel. It can be used by any DM without the need to have experience with the AHP. The DM only needs to insert the criteria and the alternatives and choose the importance by using scroll bars. In case the final decision was not consistent, we programed our DSS with a new method. This method made the criteria evaluation comparison matrix consistent with CR equal to zero without making a change on the final decision.

The rest of the paper is structured as follows: Section II discusses previous work in decision-making, DSS, and MCDM methods. Section III describes the AHP method and its equations which have been used to solve the problem of router selection. Section IV shows the results of running the VBA and the zero CR consistency method and the best alternative with the highest overall score. Section V described the conclusion and the recommendations for further researches.

# 2. LITERATURE REVIEW

The decision support systems (DSS) came to light in the mid-1960s when minicomputers developed to make the decisions more accurate and effective by using quantitative decision-making methods (Hayrapetyan, 2013). Many studies and researches have been done till today. DSS is working as the middle phase between raw data and the final solution (Cortes et al., 2001). Decision-makers are using DSS in both academia and real-world business. DSS have been arranged into five categories, and these five categories are

- Data,
- Communication,
- Document,
- Knowledge, and
- Model.

They help decision-makers who are working alone or in a group in many fields such as clinical, textile, education, and telecommunication to make the best decision for themselves, departments, and companies. A group decision support system (GDSS) is a decision support system that consists of multiple decision-makers. The GDSS is a group of decision-makers who collaborate to choose the most effective alternative (Lolli et al., 2015). In 1981 the first global conference was made in Atlanta regarding DSS. (Power et al., 2019) discussed the origins and the development of the decision system and they provided a literature reviewed on both DSS and automated decision system.

## 2.1. Multi-Criteria Decision-Making Methods (MCDM)

It is simple to make a personal decision in our day-to-day life when we do not have many choices. But sometimes we have several choices to select among them we can only separate between the choices by looking at the criteria and using multi-criteria decision-making methods. These methods reduce human interaction and human errors but they do not make the decisions instead of a human.

There are many multi-criteria decision making methods such as:

a. Simple Additive Weighting (SAW),
b. Simple Multi-Attribute Rating Technique (SMART),
c. Analytical Hierarchy Process (AHP),
d. Fuzzy Set Theory,
e. Technique for Order Preference by Similarity to the Ideal Solution (TOPSIS), and
f. Elimination at Choice Translating Reality (ELECTRE).

A brief list of references for each of these methods is given in Table 2.1. In the next part, the details of the methods and published research studies will be presented.

**Table 2.1:** Summary of MCDM methods and its application

| Reference | Method | GUI | Field application |
|---|---|---|---|
| Nemes et al., 2019 | P-graph | yes | Computer networks |
| Malathy & Muthuswamy, 2015 | TOPSIS with Knapsack | No | Wireless networks |
| (Lin & Yeh, 2012) | TOPSIS with NSGA-II | No | Computer networks |
| Li & Zhang, 2014 | TOPSIS with 2-tuple linguistic information | No | Computer networks security |
| Cahyapratama & Sarno, 2018 | SAW and AHP | No | Select the best singer |
| Rathee et al., 2020 | SAW and TOPSIS | No | IoT security |
| Irvanizam (2017) | SAW | No | Scholarship recipient |
| Setyani & Saputra, 2016 | SAW | Yes | Determine flood-prone areas |
| Wang (2019) | SAW with relative preference relation | No | Evaluation problems |
| Sadly et al., 2018 | SMART method | No | Satellite vendor selection |
| Lavik et al., 2020 | SMART method | No | Crops protection |
| Haddara (2018) | SMART method | No | ERP selection |
| Mesran et al., 2017 | ELECTRE | No | Lecturer selection |
| Yücel & Görener, 2016 | ELECTRE & AHP | No | Company acquisition |
| Zhang et al., 2018 | ELECTRE | No | Network virtualization |

| Reference | Method | GUI | Field application |
|---|---|---|---|
| Yanie et al., 2018 | ELECTRE | Yes | We-based application |
| Supraja & Kousalya, 2016 | ELECTRE & AHP | No | Computer systems |
| Leal (2020) | AHP | No | Business applications |
| Sari et al., 2017 | AHP | No | HR department |
| Narabin & Boonjing, 2016 | AHP | No | Student selection for dormitory |
| Marinoni (2004) | AHP & VBA | Yes | Land use assessment |
| Hayrapetyan, 2011 | AHP & VBA | Yes | Teacher assessment |

### 2.1.1. Technique for Order Preference Similarity to the Ideal Solution (TOPSIS)

It is one of the multi-attribute decision-making (MADM) methods that use rank alternatives. It was found in 1981 by Yoon and Hwang. (Malathy & Muthuswamy, 2015) used TOPSIS method with dynamic programming to provide the best handover decision for mobile users during roaming. Their study showed their new method TOPSIS with Knapsack is better than TOPSIS because it gives better quality of service (QOS) and fewer handover failures. The decision making was depending on five criteria which are (Cost, RTT, signal strength, reliability, and traffic handling priority).

(Lin & Yeh, 2012) used TOPSIS with non-dominated sorting genetic algorithm II (NSGA-II) in computer networks. Their study depends on two opposite criteria which are reliability and cost. They tried to decrease the cost and increase network reliability, and this problem is called a trade-off. They defined reliability in networking as sending data from one point to another successfully. In their research, they used TOPSIS to allocate the optimal middle solution. Also, they distinguished multi-criteria optimization problems into two categories which are minimization and maximization.

TOPSIS is one of the famous methods used to solve the problem of multi-attribute decision making (MADM). TO choose the best alternative depending on TOPSIS the alternative should have the longest distance to the negative optimal solution and have the nearest distance to the positive optimal solution (Li & Zhang, 2014). They used

TOPSIS for hybrid MADM with 2-tuple linguistic information for decision making to evaluate the security of computer networks.

### 2.1.2. Simple Additive Weighting (SAW)

SAW is one of the MADM methods which find the total score for each alternative, by multiplying the weights of the attributes with the ratings of the alternatives for each attribute. SAW's first step is a decision matrix construction based on the intersection of criteria and alternatives. (Cahyapratama & Sarno, 2018) used SAW method for data ranking of alternatives. They created a DSS by combining AHP and SAW to select the best singer which led to 84.61% accuracy.

(Rathee et al., 2020) created a DSS to make IoT (internet of things) data secured. Their DSS is based on the hierarchy integration of the TOPSIS and the SAW methods. The integration of the TOPSIS with the SAW created more precise decisions. The SAW method was used to find the weighted sum for alternatives. Also, the SAW method has been developed to remove the drawbacks of parameters and inefficient. The result showed that the SAW method reduced the cost of communication and also reduced the complexity of computation.

The SAW is recognized as weighted linear combinations and its calculation can be done by using a programming language. Irvanizam (2017) used multi-attribute DSS based on SAW to choose the student who receives a scholarship. He used Java programming language to make SAW calculations. He created DSS to choose among several alternatives the best value one depending on four criteria after that ranking each alternative optimal score value.

The SAW is a multi-attribute decision-making method that uses the weighted summation concept to rate all alternatives. The SAW method selects the best alternative which has the highest overall score. The SAW method supports a geographic information system and because of that (Setyani & Saputra, 2016) used it to create a DSS to locate flood-prone areas. This DSS was used to warn the government and society before floods happen.

The fuzzy environment is a decision-making environment where the alternatives are not clearly defined. Using MCDM methods such as the SAW to solve decision-making problems under a fuzzy environment is called fuzzy generalization. Wang

(2019) used fuzzy multi-criteria decision-making (FMCDM) based on the SAW method because it is the simplest MCDM. The decision-making problems under a fuzzy environment have been solved rapidly and easily.

### 2.1.3. Simple Multi-Attribute Rating Technique (SMART)

SMART is a simple and accurate multi-criteria decision-making method developed in 1977 by Edwards (Siregar et al., 2017). It is used in situations where there are alternatives and criteria and these criteria should have weight and value. (Siregar et al., 2017) created a DSS based on the SMART method to collect data regarding multi-criteria and multi-attribute. The SMART method needs short a time to make the calculations if there are dynamic alternatives and three criteria. But this time will be increase if a dynamic and constant alternative has been added.

The SMART method showed excellent results when it was deployed for DSS working with many criteria. Risawandi (2016) in his research gave a general review about the working of the SMART method with a high number of criteria. He mentioned that it is the simplest among multi-attribute methods in responding to decision-maker's requirements. By adding specific functionality or combining it with other methods, the SMART method can be further developed according to his conclusion. It works based on providing each criterion with weight values; these values describe the importance of one criterion among others. The SMART method can be used by decision-makers for quantitative and qualitative approaches. Also to simplify the comparison and calculation of alternative values it uses the scale between 0 and 1 for weighting.

Satellite systems require outstanding funds and involve multiple stakeholders for governments. (Sadly et al., 2018) created a DSS based on the SMART method to select the best satellite system vendor among several vendors depending on multi-criteria and multi-stakeholders. . They used this method with a group of decision-makers because it can convert complex problems to simple analysis which leads to affect the stakeholder understanding. In his research three points have been concluded about this method first it can be used to develop a group of decision-making, second create a more systematic decision-making process, finally, DSS with SMART method need less time to select a vendor.

The SMART method has been applied in many multi-attribute fields for example (Lavik et al., 2020) used it in their research to help Norwegian farmers to chose the best strategy to protect crops. The alternatives are four strategies to protect crops and the criteria are (gross margin, labor use, environmental behavior, environmental toxicity, and human health). Another example Haddara (2018) used SMART to select and evaluate enterprise resource planning (ERP) system for a multinational company.

#### 2.1.4. Elimination and Choice Expressing Reality (ELECTRE)

It is one of the multi-criteria decision-making methods founded in 1966 by Roy (Mesran et al., 2017). He used this method to find the best computer lecturer in the university. In his research, the decision-makers chose the best decision based on five criteria and three alternatives. (Supraja & Kousalya, 2016) said that the ELECTRE method is a positioning strategy and it produces fast answers for the problems in many fields. They used this method with AHP to select the best computer system. The selection of computer systems is based on three PCs choices and four criteria.

The ELECTRE method is converting quantitative solutions to more verbal results. Instead of alternatives, this method depends on the pairwise comparison. (Yücel & Görener, 2016) said in contrast to Mesran, the European consultancy company SEMA was the origins of the ELECTRE method in 1965. Also, they said that Bernard Roy developed this method in 1968 during his work on decision making. In their research, they created an MCMD system that uses the AHP method for weighting criteria and the ELECTRE method to rank and choose the best alternatives. They helped investors to evaluate company acquisition opportunities in Turkey based on six criteria and four alternatives.

(Zhang et al., 2018) used the ELECTRE method in the network virtualization (NV) field. They adopted this method because it diminishes the order complexity and raises the computation efficiency without exposing the algorithm performance. Also, they used this method to find the values of node ranking because the calculations are easier than using TOPSIS. They mentioned another reason why they chose this method which is the time complexity of this method. To solve VNE (virtual network embedding) problems, they created a new algorithm called ELECTRE-VNE.

ELECTRE method is applied in situations where the number of criteria is low and the number of alternatives is high. (Yanie et al., 2018) created web-based DSS using MySQL database and PHP programming language. This web-based DSS is using the ELECTRE method which can be applied in many decision-making cases. They created this DSS with a web-based application because there are many papers on DSS but only a few of them applied DSS in applications.

### 2.1.5. Analytical Hierarchy Process (AHP)

It is one of the MCDM methods developed by Saaty in 1977. It is used in many applications in diverse fields such as engineering, politics, and economics because it is a powerful tool for multi-criteria decision-making. This method work by giving each alternative a value to distinguish it from other alternatives and each value is used to select the best alternative depending on a hierarchical structure. To make a decision it is required many comparisons and because of this drawback, many senior executives stop using it to solve important problems. Leal (2020) create a simple AHP method by making it do one comparison followed by one formula to make AHP more attractive for business applications.

(Sari et al., 2017) used software DSS with AHP called program super decision to help the HR department to select the most proper CV for a specific vacancy. Asia Exotica Company used this method to choose the right employee among candidates who apply for the same job depending on multiple criteria. These criteria are Education, Work experience, age, and marital status. In his paper, He weighted the criteria by using a pairwise comparison matrix. He used the software DSS because it is considered accurate, fast, and reduces human mistakes in the process of decision making. In his methodology He depended on two steps first He built the hierarchy that consists of (goal, criteria, and alternatives) as shown in Figure 2.1. The goal is the candidate employee who gets the highest ranking. Second data collection and analysis were done by expert interviewers.

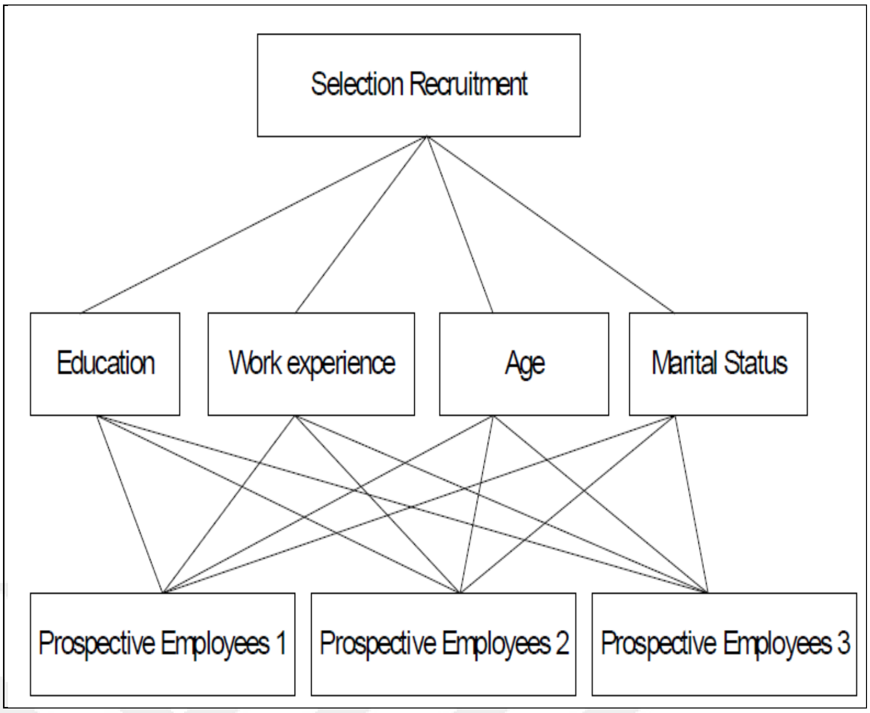


**Figure 2.1:** (Sari et al., 2017) AHP Hierarchy.

(Narabin & Boonjing, 2016) used analytical hierarchy process as DSS to choose the proper student for dormitory among many candidates. They used this method because it eliminates bias in the process of decision-making. They built the hierarchy tree depending on four criteria (Level, distance, parent income, and the number of siblings) and 16 sub-criteria. In their research, they used the sub-criteria. They calculated the consistency ratio (CR) which should be less than 0.1 to check the consistency of the student selection. Also, they used Saaty's scale for pairwise comparison.

### 2.2. AHP Method with Visual Basic for Applications (VBA)

VBA is a relatively simple programming language working with all Microsoft Office products and it has the ability to handle data rapidly. Today, Microsoft Excel is used in almost all the PCs running on Windows operating system. Excel contains several tools that help data analysis, optimization, data manipulation, and etc. Its spreadsheet layout and simple mathematical functions give an advantage over other mathematical software. All these advantages in Excel plus the VBA made teachers and students depend on it. Bernard & Senjayawati, 2019) think that using VBA with Microsoft Excel is more effective for math learning. Marinoni (2004) used the AHP method with VBA to develop ArcGIS (land use assessment system) to help decision-makers choose the right land. In his research, he depends on three criteria and he found criteria weights by using VBA macro with the AHP method. He wrote the program by using visual basic language with Arcobjects (ArcGIS platform).

(Hayrapetyan et al., 2011) created a DSS is consisting of one Excel sheet based on VBA with a user-friendly environment for multi-criteria decision-making. The AHP method has been used which works based on pairwise comparison matrices. This system is created for schools and universities to help the dean to evaluate the value of the teachers to promote them. The DSS is depending on three criteria (teaching, research, and service), the weight for each criterion has been found and after that, the total scores for the teachers have been calculated. This DSS has been called the Evaluator

### 2.3. DSS for Telecommunications

DSS is used in all aspects of Telecommunication such as mobile services, Fiber optics, and computer networks. DSS helps Telecom and network engineers to make the right decisions through a user-friendly platform where the engineer can input data and receive more than one solution. DSS is used to provide the decision-makers with several solutions regarding fiber-optic coverage for the Andalusian area in Spain depending on population and economic criteria (Cortes et al., 2001).

### 2.4. DSS for Computer Networks

(Sergeevich et al., 2018) proposed automated Multi-criteria DSS software for computer networks. To solve the problem of choosing the effective computer network configuration based on different vendors. They used a multi-criteria evolutionary algorithm which is FFGA (Fonseca and Fleming's Genetic Algorithm). Their decision depends on three criteria which are (performance, reliability, and cost) and four different alternatives to choose among them. Their results show that an automated DSS can be used as a tool for computer network design at the primary phase.

(Nemes et al., 2019) developed DSS based on the P-graph method to measure the reliability and robustness of computer network security. They modeled computer network topology by P-graph and run optimization to measure the robustness. A P-graph method is already used to model engineering systems, business processes, and supply chains. Professor Fan and Friedler developed the P-graph method in the 1970s. This method consists of raw materials and operating units. To find the optimal solution there are three algorithms in the P-graph to select among them which are:

a. The maximal structure generation (MSG).
b. The solution structure generation (SSG).
c. The accelerated branch and bound (ABB).

The software developed by (Nemes et al., 2019) relies on the P-graph method and SSG algorithm.

### 2.5. Computer Networks

It is responsible for transferring data from one end-device to another such as computer, laptop, and mobile. Computer networks start as a connection between two computers and it is called peer to peer. Dordal (2020) said that it is developed to be a LAN (Local Area Network) which is several end-devices connected in one building or one company by a device called the Hub. Computer networks continue to grow and end-users in one LAN need to connect to end-user in another LAN. At this time WAN (Wide Area Network) was discovered. WAN is responsible to connect LANs by a device called a Router and media such as wireless links and Fiber optics. Each computer networks consist of several devices such as routers, firewalls, switches, servers, and end-users as shown Figure 2.2.

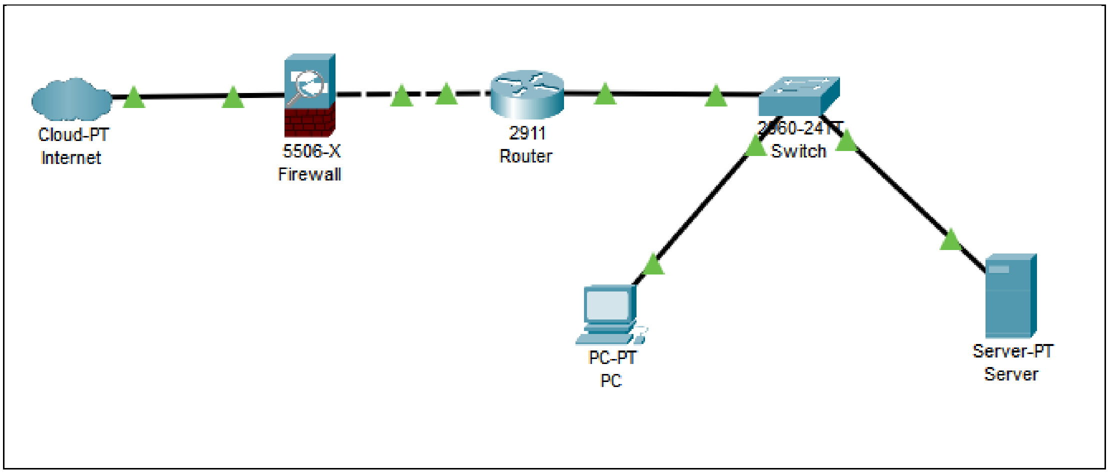


**Figure 2.2:** Computer Networks Devices

### 2.5.1. Routers

They are essentially layer devices interconnecting LANs and WANs to the Internet. Newman (2018) said that the router is responsible for choosing the best path for each packet depending on a dynamically updated routing table. Each router consists of interfaces, power supply, RAM, NVRAM, and Flash. There are several global vendors for routers such as Cisco, Huawei, Juniper, and MikroTik. To choose between these vendors the network engineers need to consider several criteria. In this research, four criteria were considered: cost, reliability, throughput (is the bandwidth that the router can handle), and ports number. Also, there are wirelesses routers which provide us with Wifi but it is not a part of our research.

# 3. METHODOLOGY

Due to its simplicity, we used the analytical hierarchy process (AHP) method as a multi-criteria decision support system to help decision-makers (network engineers) to choose the best alternative. The alternatives in this paper are computer networks vendors. The DSS helped network engineers to choose the best router for their topology among several vendors based on multi-criteria. We created a user-friendly DSS program by using visual basic for application (VBA) in Microsoft Excel. Our program consists of a single XLSM file where the decision-maker can insert preference data smoothly. The flowchart of the proposed DSS can be seen in the Figure 3.1.

The details of the proposed method will be given next:

**Step 1:** Decision-makers need to insert the names of their criteria and alternatives in the text boxes and press the set button. The number of criteria and the number of alternatives will determine the dimensions of the comparison matrices.

Step 2: The comparison matrices for criteria and alternatives need to be constructed. One matrix will be for criteria evaluation and four matrices for the alternatives evaluation based on each criterion. Equation (3.1**)** displays the structure of the comparison matrix (Hayrapetyan, 2011). We choose the importance of each criterion and alternative against each other by scroll bar based on the Saaty scale. The values of Saaty scale are shown in Table 3.1.

$$A=\begin{bmatrix} a_{11} & a_{12} & a_{1j} & a_{1n} \\ a_{21} & \ddots & a_{23} & a_{2n} \\ a_{i1} & a_{i2} & a_{ij} & a_{3n} \\ a_{n1} & a_{n2} & a_{n3} & a_{nn} \end{bmatrix}, \quad \text{where} \quad a_{ii} = 1, \text{ and } \quad a_{ij} = \frac{1}{a_{ji}} \; (i, j = 1,2,\dots,n) \qquad \textbf{(3.1)}$$

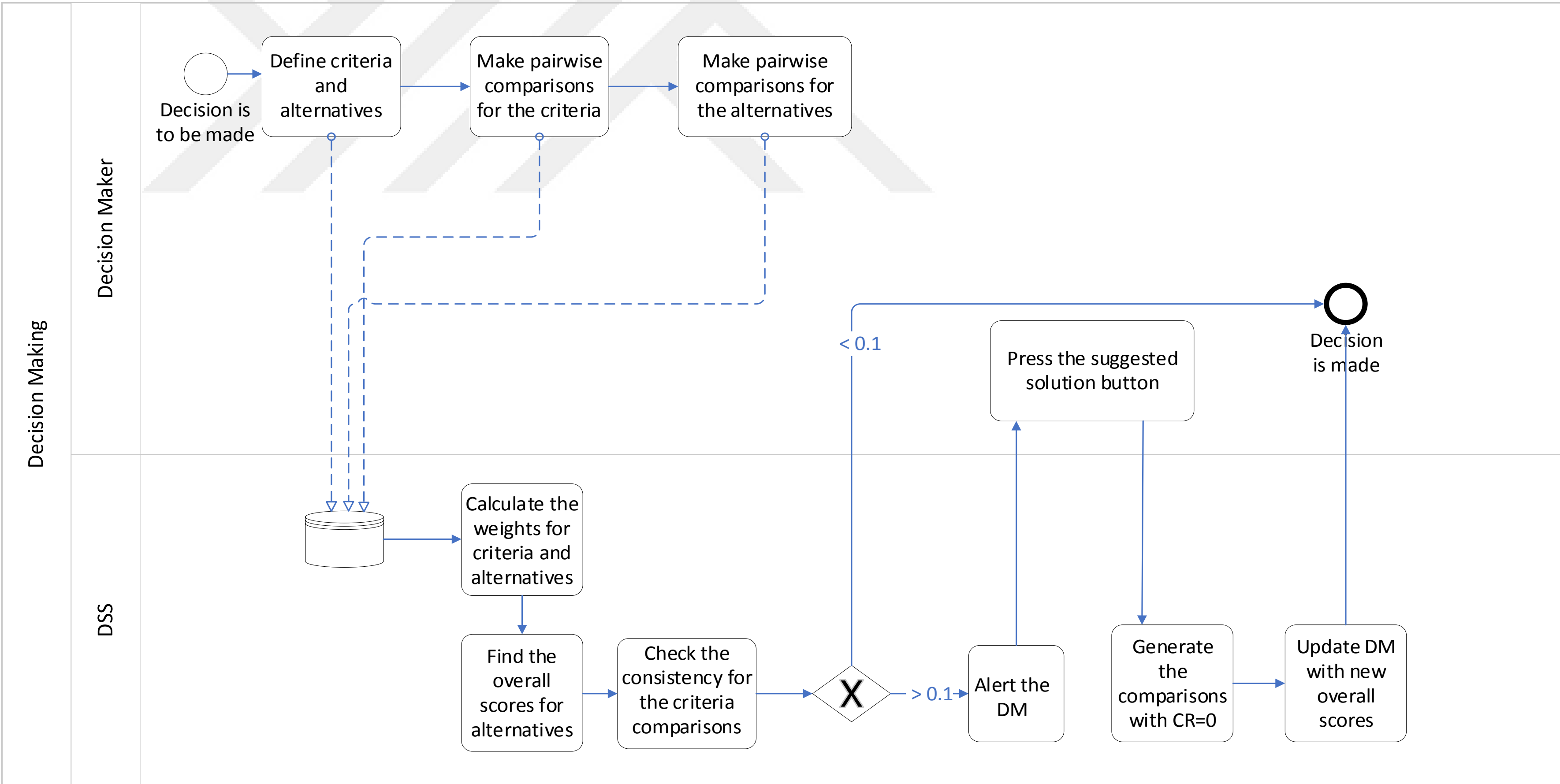


**Figure 3.1:** Methodology Flowchart

**Table 3.1:** Saaty Scale

| Intensity of importance | Description |
|---|---|
| **1** | Equal |
| **3** | Weakly more important |
| **5** | Strongly more important |
| **7** | Very strongly more important |
| **9** | Absolutely more important |

After the decision-maker chooses the importance and presses the set button not only compassion matrices will be constructed but also the weight for each matrix will be calculated by Equation (3.2) (Hayrapetyan, 2011).

$$w_i = \frac{1}{n} \sum_{j=1}^{n} \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}}, \quad \text{where } (i = 1,2, \dots, n) \qquad \textbf{(3.2)}$$

**Step 3:** The overall score for alternatives needs to be calculated through Equation 3.3 (Hayrapetyan, 2011).

$$R_i = \sum_{j=1}^{n} S_{ij} W_i$$

Where $S_{ij}$ is the relative score of alternative (*i*) against alternative (*j*) **3.3)**

To find the calculated overall scores for the alternatives, the user needs to press the find overall score button. Using a bar chart instead of decimal numbers here, may help DM how significant DM's relative preference over alternatives.

**Step 4:** The final step is to check the consistency of the comparison matrix through three equations (Hayrapetyan, 2011):

a) We find eigenvector by the Equation **(3.4)**.

$$\lambda_{max} = \frac{1}{n}\frac{\sum_{j=1}^{n} a_{ij} w_j}{w_i}, \qquad (i, j = 1, 2, \dots, n) \qquad \textbf{(3.4)}$$

b) Consistency index (*CI*) and consistency ratio (*CR*) can be found using the Equations **(3.5)** and **(3.6)**.

$$CI = \frac{\lambda_{\max - n}}{n - 1} \qquad \textbf{(3.5)}$$

$$CR = \frac{CI}{RI} \qquad \textbf{(3.6)}$$

Where *RI* is the random index and Table 3.2 shows *RI* values with respect to number of criteria below. The consistency ratio (*CR*) should be less than 0.1 according to Saaty.

**Table 3.2:** Random index values with respect to number of criteria

| n | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| RI | 0 | 0 | 0.52 | 0.89 | 1.13 | 1.25 | 1.35 | 1.43 | 1.47 | 1.5 |

If the *CR* is more than 0.1, it means that the constructed matrix is not consistent. In this paper, we suggested a method to make the consistency ratio equal to zero without too much interference on the DM's original matrix, and our trials showed that the relative positions of the overall scores showed a slight change from the original one. According to (Xu & Xiong, 2017) we can find the ordering vector for any consistent matrix based on any of its columns or rows. If the original matrix is not consistent the row of the matrix has been used to generate several consistent matrices after that the closest one to the original matrix will be chosen as shown in Equation 3.7.

$$a_{ij} = \frac{w_i}{w_j} \quad i, j \in \Omega \qquad \textbf{3.7)}$$

Let $a_1$ be the weights in the first row of the comparison matrix, then to have a perfect consistent matrix all the other rows need to follow Equation 3.8.

$$a_{ij} = \frac{a_{1j}}{a_{1i}}, \qquad i \neq j \qquad \textbf{3.8)}$$

This method suggests automating the calculation of the last three cells in the matrix. For example the three cells $a_{23}$, $a_{24}$, and $a_{34}$ will calculated by Equation 3.9.

$$\begin{bmatrix} & a_{12} & a_{13} & a_{14} \\ & & a_{23} & a_{24} \\ & & & a_{34} \\ & & & \end{bmatrix} \quad a_{23} = \frac{a_{13}}{a_{12}}, \quad a_{34} = \frac{a_{14}}{a_{13}}, \quad a_{24} = \frac{a_{14}}{a_{12}} \qquad \textbf{3.9)}$$

We put two conditions to restrict the result with the Saaty scale, first if DM's inputs for the first row result as $a_{1j}/a_{1i}>9$, then to remain within the Saaty scale, the numerator will be divided by 9. And if the result of $a_{1j}/a_{1i}<1/9$ the numerator will multiply by 9. These two conditions have been added to keep the values generated from the divided processes in the range of the Saaty scale.

# 4. IMPLEMENTATION AND RESULTS

In our example, a network engineer (decision maker) was assumed to use the AHP method to select the best router vendor for a typical network topology. The network engineer's choice was based on four criteria (cost, reliability, throughput, and ports number). The alternatives will be four vendors (Cisco, Juniper, Huawei, and MikroTik). Once the network engineer opens the Excel file, he launches the VBA form with a single click as shown in Figure 4.1.

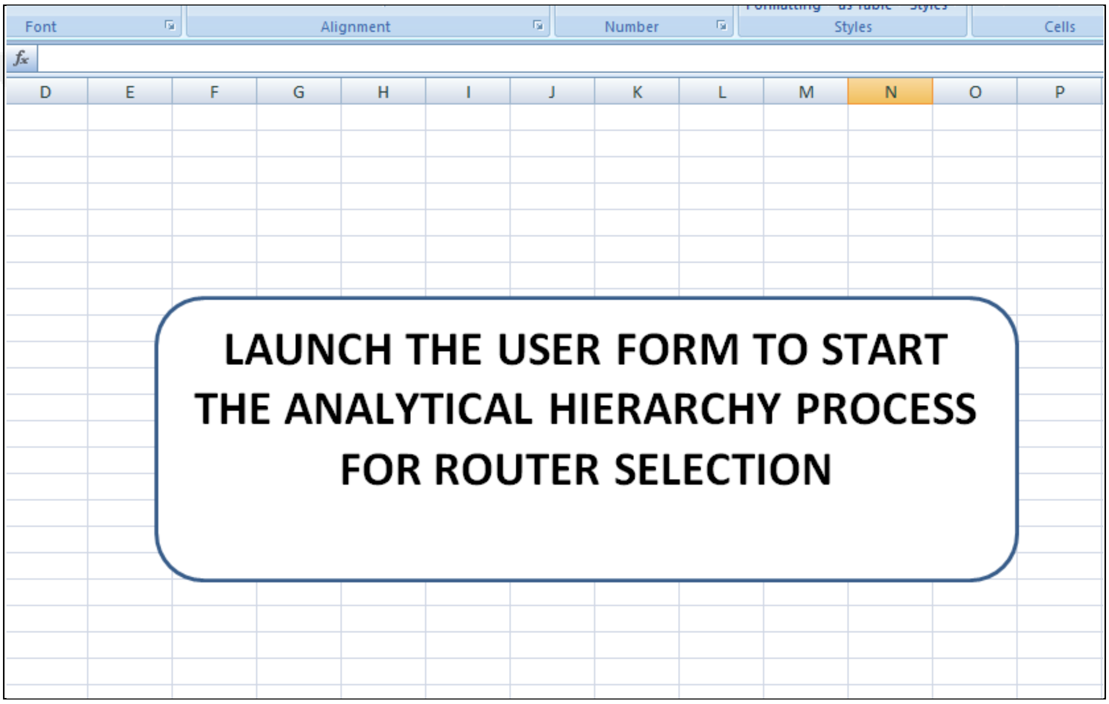


**Figure 4.1:** Launch the User Form

After the user form is launched, the network engineer inserts the criteria and the alternatives as shown in Figure 4.2.

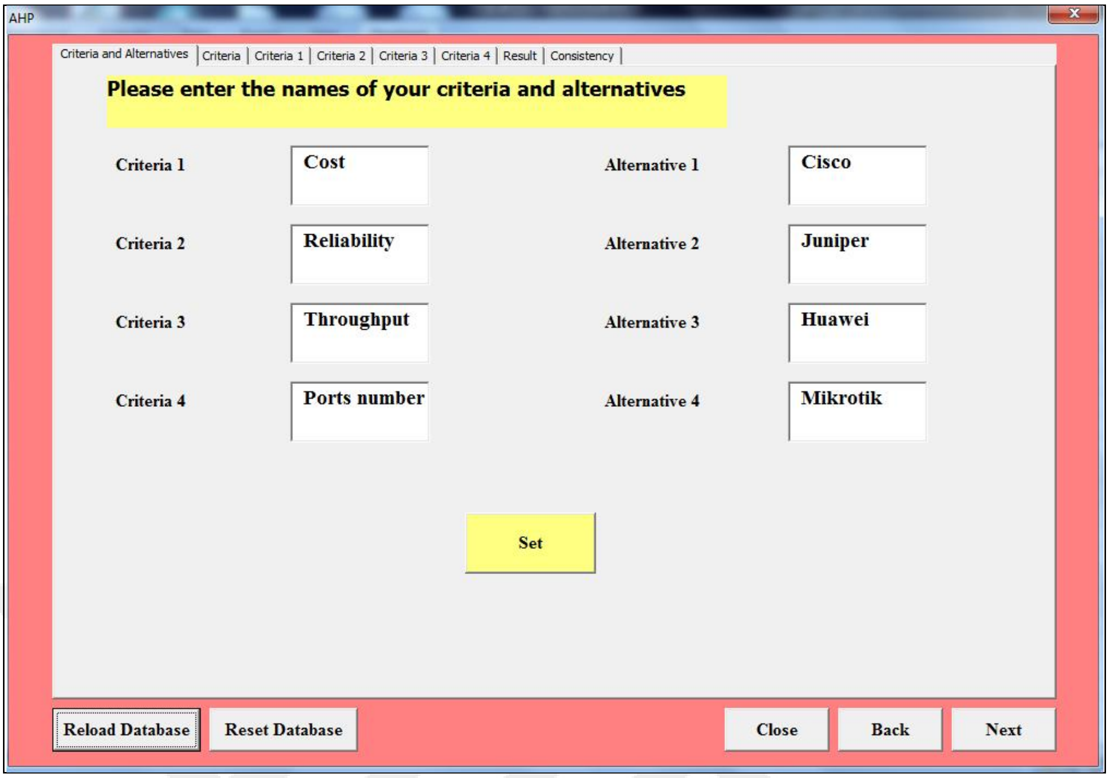


**Figure 4.2:** Setting the criteria and the alternatives

## 4.1. Comparison Matrix

The decision-maker (DM) uses the user forms that we developed in VBA, to make pair-wise comparisons both for the criteria and the router alternatives. DM also compared alternatives to each other based on each criterion by using the scroll bars as shown in Figure 4.3.

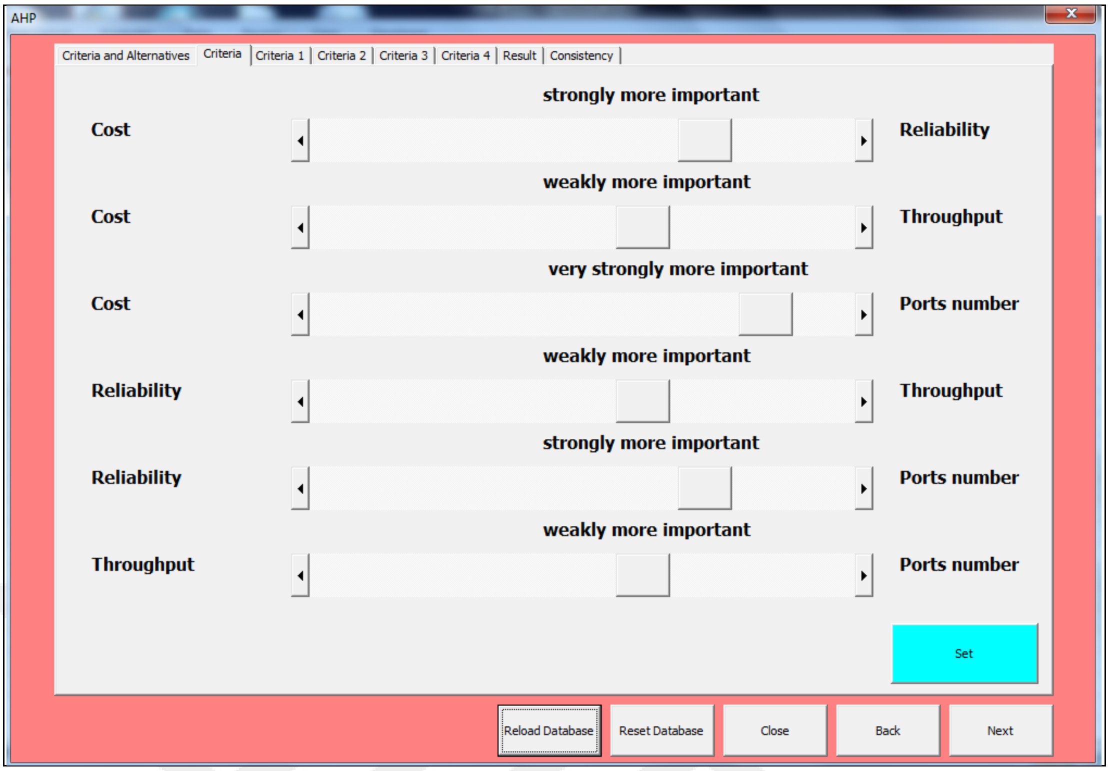


**Figure 4.3:** Criteria Evaluation

The VBA program generated the comparison matrices and saved them at the database sheet in Excel. Five comparison matrices have been generated. The first comparison matrix is criteria evaluation as shown in Table 4.1.

**Table 4.1:** Criteria evaluation comparison matrix

| | Cost | Reliability | Throughput | Ports number |
|---|---|---|---|---|
| Cost | 1 | 5 | 3 | 7 |
| Reliability | 1/5 | 1 | 3 | 5 |
| Throughput | 1/3 | 1/3 | 1 | 3 |

| | | | | |
|---|---|---|---|---|
| Ports number | 1/7 | 1/5 | 1/3 | 1 |

A comparison matrix for alternatives evaluation based on the Cost criterion as shown Table 4.2.

**Table 4.2:** Alternatives comparison based on Cost Criterion

| Cost | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|
| Cisco | 1 | 1/3 | 1/5 | 1/7 |
| Juniper | 3 | 1 | 1/3 | 1/5 |
| Huawei | 5 | 3 | 1 | 1/3 |
| MikroTik | 7 | 5 | 3 | 1 |

A comparison matrix for alternatives evaluation based on the reliability criterion as shown in Table 4.3.

**Table 4.3:** Alternatives comparison based on Reliability Criterion

| Reliability | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|
| Cisco | 1 | 3 | 3 | 5 |
| Juniper | 1/3 | 1 | 3 | 5 |
| Huawei | 1/3 | 1/3 | 1 | 5 |
| MikroTik | 1/5 | 1/5 | 1/5 | 1 |

A comparison matrix for alternatives evaluation based on the throughput criterion as shown in Table 4.4.

**Table 4.4 :** Alternatives comparison based on Throughput Criterion

| Throughput | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|
| Cisco | 1 | 3 | 1/3 | 3 |
| Juniper | 1/3 | 1 | 1/5 | 3 |
| Huawei | 3 | 5 | 1 | 5 |
| MikroTik | 1/3 | 1/3 | 1/5 | 1 |

A comparison matrix for alternatives evaluation based on the ports number criterion as shown in Table 4.5.

**Table 4.5 :** Alternatives comparison based Ports number Criterion

| Ports number | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|
| Cisco | 1 | 1/3 | 1/5 | 1/7 |
| Juniper | 3 | 1 | 1/3 | 1/5 |
| Huawei | 5 | 3 | 1 | 1/3 |
| MikroTik | 7 | 5 | 3 | 1 |

### 4.2. The Average Weight

After the creation of the comparison matrices the comparison matrices have been normalized. The normalization was done by summing each column in the matrix and dividing each cell in the column by the column sum. The row sum of the normalized matrix is the average weight for each criterion. In Table 4.6, the second column shows the average weights for the criteria comparison matrix, and the consecutive rows show the relative scores of alternatives with respect to criteria.

**Table 4.6 :** The Average Weight

| | Weight | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|---|
| Cost | 0.5521 | 0.0569 | 0.1219 | 0.2634 | 0.5579 |
| Reliability | 0.2485 | 0.4817 | 0.2821 | 0.1759 | 0.0604 |
| Throughput | 0.1434 | 0.2445 | 0.1360 | 0.5430 | 0.0765 |
| Ports number | 0.0559 | 0.0569 | 0.1219 | 0.2634 | 0.5579 |

### 4.3. The Overall Score

The overall score for each alternative is found by taking the inner product of criteria weight vector and the score vector of an alternative by using the SUM-PRODUCT function. The alternative with the highest overall score is the best vendor for the DM. In our example, the MikroTik vendor took the highest score with 0.3652 as shown in Table 4.7.

**Table 4.7 :** The overall score

| | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|
| OVERALL SCORE | 0.1894 | 0.1637 | 0.2817 | 0.3652 |

The DM pressed the overall score button to find the best alternative in a graph as shown in Figure 4.4.

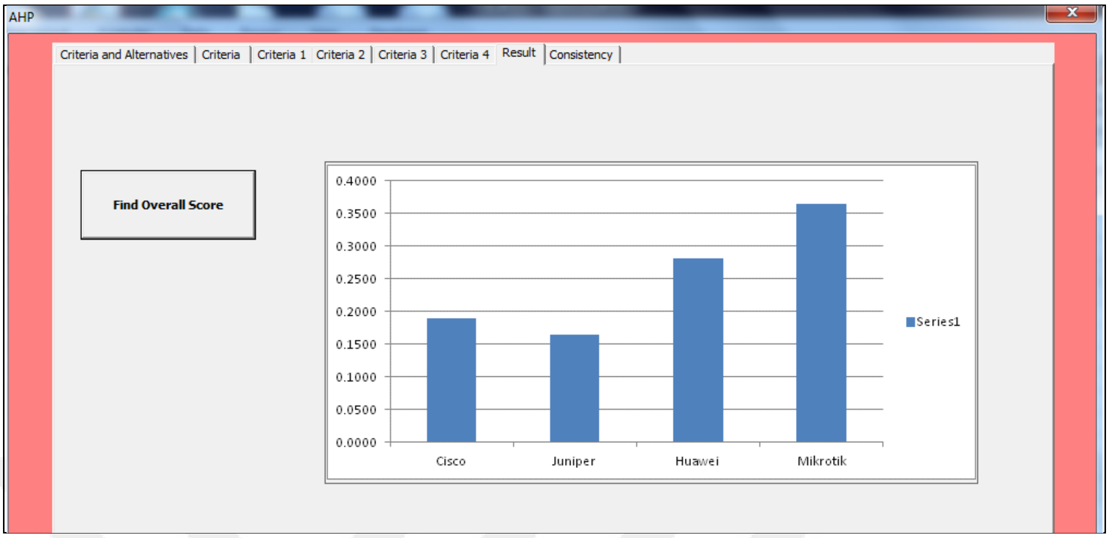


**Figure 4.4:** The graph of overall scores

## 4.4. Consistency Check

The CI and the CR values for the criteria comparison matrix is calculated once the DM presses on the consistency check button. Before that, the RI is calculated when the DM determines the number of criteria. All results are as follows: CI is 0.102, RI is 0.9, and CR is 0.1134. Since CR > 0.1, a message popped up that warned the DM that the criteria evaluation comparison matrix was inconsistent. The consistency check operation is shown in Figure 4.5.

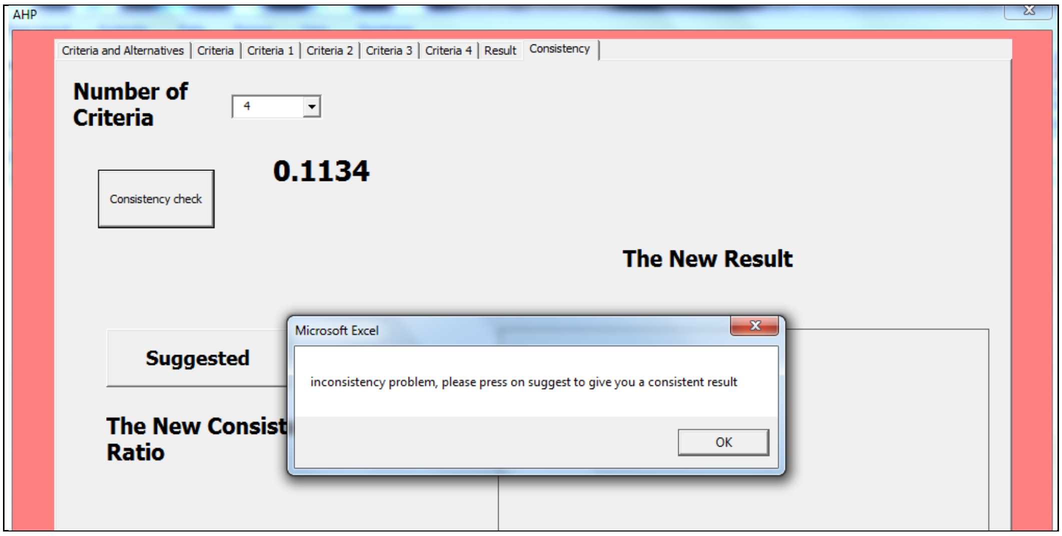


**Figure 4.5:** Consistency check result

In our example, the comparison matrix is inconsistent according to Saaty because the CR is more than 0.1. In this case, a suggested message popped up to the DM offered him a new consistent comparison matrix for criteria evaluation with zero CR. A new average weight founded, and the overall score was calculated again according to the new average weight. A new consistency comparison matrix for criteria evaluation was found as shown in Table 4.8.

**Table 4.8:** The New Comparison Matrix

| S Array | Cost | Reliability | Throughput | Ports number |
|---|---|---|---|---|
| Cost | 1 | 5 | 3 | 7 |
| Reliability | 1/5 | 1 | 3/5 | 7/5 |
| Throughput | 1/3 | 5/3 | 1 | 7/3 |
| Ports number | 1/7 | 5/7 | 3/7 | 1 |

Table 4.9 shows the positive and negative deviations that were made to the original comparison matrix to make it consistent. The deviations have been found according to the number of movements that happened to the original value based on the Saaty scale. For example, if the original value was 3 and became 5 this mean 2 positive movements on the Saaty scale and the deviations is +2. If the original value was 2 and became 1 the deviations is equal to -1.

**Table 4.9:** Comparison Matrix Deviations

| Compared Criteria | Original judgment | Adjusted judgment | +Deviations | -Deviations |
|---|---|---|---|---|
| A-B | 5 | 5 | | |
| A-C | 3 | 3 | | |
| A-D | 7 | 7 | | |
| B-A | 0.2 | 0.2 | | |
| B-C | 3 | 0.6($\sim\mathbf{1/2}$) | | 3 |
| B-C | 5 | 1.4($\sim\mathbf{1}$) | | 4 |
| C-A | 1/3 | 1/3 | | |
| C-B | 1/3 | 1.6667($\sim\mathbf{2}$) | 3 | |
| C-D | 3 | 2.3333($\sim\mathbf{2}$) | | 1 |
| D-A | 1/7 | 1/7 | | |
| D-B | 1/5 | 0.7143($\sim\mathbf{1}$) | | 3 |
| D-C | 1/3 | 0.4286($\sim\mathbf{1/2}$) | | 1 |

The new average weight for the new comparison matrix has been founded as shown in Table 4.10.

**Table 4.10:** A New Average Weight

| | Cost | Reliability | Throughput | Port numbers |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Average Weight | 0.5966 | 0.1193 | 0.1989 | 0.0852 |

Finally, the new overall score has been calculated as shown in Table 4.11.

**Table 4.11:** A New Overall Score

| | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|
| OVERALL SCORE | 0.1449 | 0.1438 | 0.3085 | 0.4028 |

When we compared the new overall score with the first Table 4.7 we found a small change in the results. But still, the MikroTik vendor is the best choice. Table 4.12 shows the change that happened to the overall score after the new method with zero consistency has been applied. Figure 4.6 shows a comparison between the original and the suggested overall score.

**Table 4.12:** A comparison between the original and the new overall scores

| | Cisco | Juniper | Huawei | MikroTik |
|---|---|---|---|---|
| Original Overall Score | 0.1894 | 0.1637 | 0.2817 | 0.3652 |
| New overall score | 0.1449 | 0.1438 | 0.3085 | 0.4028 |


**Figure 4.6:** Comparison of original and suggested overall scores

## 4.5. Inconsistency Example

We compared our zero CR consistency method to the nonlinear programming method developed by (Pereira & Costa, 2015). In this example, the two methods have been applied to one inconsistent comparison matrix consisting of 7 criteria, 21 compared criteria, and the CR is 0.1122. Table 4.13 shows the inconsistent comparison matrix.

**Table 4.13:** Inconsistent Matrix

| | A | B | C | D | E | F | G | Weight |
|---|---|---|---|---|---|---|---|---|
| A | 1 | 1/3 | 1/5 | 1 | 1/4 | 2 | 3 | 0.085 |
| B | 3 | 1 | 1/2 | 2 | 1/3 | 3 | 3 | 0.154 |
| C | 5 | 2 | 1 | 4 | 5 | 6 | 5 | 0.365 |
| D | 1 | 1/2 | 1/4 | 1 | 1/4 | 1 | 2 | 0.074 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| E | 4 | 3 | 1/5 | 4 | 1 | 3 | 1 | 0.199 |
| F | 1/2 | 1/3 | 1/6 | 1 | 1/3 | 1 | 1/3 | 0.048 |
| G | 1/3 | 1/3 | 1/5 | 1/2 | 1 | 3 | 1 | 0.076 |

The nonlinear programming method makes a change to the comparison matrix by a maximum of one or two deviations. When the maximum deviation is equal to one the CR will be accepted which is less than 0.1 but not zero. We compared our method to the nonlinear programming method with a maximum of two deviations because in this case, the CR will be zero just like in our method. Table 4.14 shows the changes that happened to the comparison matrix after applying the nonlinear programming method.

**Table 4.14:** Comparison Matrix with Deviation equal to two (Pereira & Costa, 2015).

| | A | B | C | D | E | F | G | Weight |
|---|---|---|---|---|---|---|---|---|
| A | 1 | 1/2 | 1/6 | 1 | 1/2 | 1 | 1 | 0.071 |
| B | 2 | 1 | 1/3 | 2 | 1 | 2 | 2 | 0.143 |
| C | 6 | 3 | 1 | 6 | 3 | 6 | 6 | 0.429 |
| D | 1 | 1/2 | 1/6 | 1 | 1/2 | 1 | 1 | 0.071 |
| E | 2 | 1 | 1/3 | 2 | 1 | 2 | 2 | 0.143 |
| F | 1 | 1/2 | 1/6 | 1 | 1/2 | 1 | 1 | 0.071 |
| G | 1 | 1/2 | 1/6 | 1 | 1/2 | 1 | 1 | 0.071 |

We used the first row from the original comparison matrix in our zero CR method to find the new consistent matrix. Because they generated values more than 9 (out Saaty scale) the compared criteria (A-F) and (A-G) has been divided by 9. Table 4.15

shows the changes that happened to a comparison matrix and its average weight to make it consistent.

**Table 4.15:** Comparison Matrix with Zero CR Method.

| | A | B | C | D | E | F | G | Weight |
|---|---|---|---|---|---|---|---|---|
| A | 1 | 1/3 | 1/5 | 1 | 1/4 | 2/9 | 3/9 | 0.047 |
| B | 3 | 1 | 0.6 | 3 | 0.75 | 0.67 | 1 | 0.14 |
| C | 5 | 1.67 | 1 | 5 | 1.25 | 1.11 | 1.67 | 0.233 |
| D | 1 | 1/3 | 1/5 | 1 | 1/4 | 0.22 | 1/3 | 0.047 |
| E | 4 | 1.33 | 0.8 | 4 | 1 | 0.89 | 1.33 | 0.186 |
| F | 4.5 | 1.5 | 0.9 | 4.5 | 1.125 | 1 | 1.5 | 0.209 |
| G | 3 | 1 | 0.6 | 3 | 0.75 | 0.67 | 1 | 0.14 |

We had 21 compared criteria in the original matrix, in order to make the comparison matrix consistent, the Zero consistency method needed 14 modifications while the nonlinear programming method needed 17 modifications with the original matrix. Zero consistency method needed to modify less number of compared criteria. The maximum deviation in the nonlinear programming method is 2 on the other hand the maximum deviation in the Zero CR method is 5. Table 4.16 shows the differences between the zero CR method and the nonlinear programming method in terms of modifications and deviations.

**Table 4.16:** A comparison between Zero CR and (Pereira & Costa, 2015) method

| Compared Criteria | Original Judgment | Nonlinear Adjusted | Zero CR Adjusted | Nonlinear Deviations | Zero CR Deviations |
|---|---|---|---|---|---|
| A-B | 1/3 | 1/2 | 1/3 | 1 | 0 |
| A-C | 1/5 | 0.1667 | 1/5 | -1 | 0 |
| A-D | 1 | 1 | 1 | 0 | 0 |
| A-E | 1/4 | 1/2 | 1/4 | 2 | 0 |
| A-F | 2 | 1 | 0.22(~1/5) | -1 | 5 |
| A-G | 3 | 1 | 1/3 | -2 | 4 |

| | | | | | |
|---|---|---|---|---|---|
| B-C | 1/2 | 1/3 | 0.6(~1/2) | -1 | 0 |
| B-D | 2 | 2 | 3 | 0 | 1 |
| B-E | 1/3 | 1 | 0.75(~1) | 2 | 2 |
| B-F | 3 | 2 | 0.67(~1/2) | -1 | 3 |
| B-G | 3 | 2 | 1 | -1 | 2 |
| C-D | 4 | 6 | 5 | 2 | 1 |
| C-E | 5 | 3 | 1.25(~1) | -2 | -4 |
| C-F | 6 | 6 | 1.11(~1) | 0 | -5 |
| C-G | 5 | 6 | 1.67(~2) | 1 | -3 |
| D-E | 1/4 | 1/2 | 1/4 | 2 | 0 |
| D-F | 1 | 1 | 0.22(~1/5) | 0 | -4 |
| D-G | 2 | 1 | 1/3 | -1 | -3 |
| E-F | 3 | 2 | 0.89(~1) | -1 | -2 |
| E-G | 1 | 2 | 1.33(~1) | 1 | 0 |
| F-G | 1/3 | 1 | 1.5(~2) | 2 | 3 |

We took another example from (Pereira & Costa, 2015), this time, inconsistent comparison matrix consisting of 8 criteria, 28 compared criteria, and the CR is 0.161. Table 4.17 shows the inconsistent comparison matrix and the average weight.

**Table 4.17:** Inconsistent comparison matrix (Pereira & Costa, 2015)

| | A | B | C | D | E | F | G | H | Weight |
|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 5 | 3 | 7 | 6 | 6 | 1/3 | 1/4 | 0.173 |
| B | 1/5 | 1 | 1/3 | 5 | 3 | 3 | 1/5 | 1/7 | 0.054 |
| C | 1/3 | 3 | 1 | 6 | 3 | 4 | 6 | 1/5 | 0.188 |
| D | 1/7 | 1/5 | 1/5 | 1 | 1/3 | 1/4 | 1/7 | 1/8 | 0.018 |
| E | 1/6 | 1/3 | 1/3 | 3 | 1 | 1/2 | 1/5 | 1/6 | 0.031 |
| F | 1/6 | 1/3 | 1/4 | 4 | 2 | 1 | 1 | 1/2 | 0.036 |
| G | 3 | 5 | 1/6 | 7 | 5 | 1 | 1 | 1 | 0.167 |
| H | 4 | 7 | 5 | 8 | 6 | 2 | 1 | 1 | 0.333 |

Table 4.18 shows the comparison matrix with average weight after applying the nonlinear programming method with maximum 1 deviation to the inconsistent matrix. The CR for the below comparison matrix is equal to 0.0931.

**Table 4.18:** Comparison Matrix with Deviation equal to one (Pereira & Costa, 2015).

| | A | B | C | D | E | F | G | H | Weight |
|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 4 | 2 | 8 | 7 | 5 | 1/2 | 1/3 | 0.189 |
| B | 1/4 | 1 | 1/3 | 4 | 2 | 2 | 1/4 | 1/6 | 0.063 |
| C | 1/2 | 3 | 1 | 6 | 3 | 3 | 5 | 1/4 | 0.174 |
| D | 1/8 | 1/4 | 1/6 | 1 | 1/2 | 1/3 | 1/6 | 1/9 | 0.021 |
| E | 1/7 | 1/2 | 1/3 | 2 | 1 | 1/2 | 1/5 | 1/7 | 0.034 |
| F | 1/5 | 1/2 | 1/3 | 3 | 2 | 1 | 1/2 | 1/3 | 0.059 |
| G | 2 | 4 | 1/5 | 6 | 5 | 2 | 1 | 1/2 | 0.155 |
| H | 3 | 6 | 4 | 9 | 7 | 3 | 2 | 1 | 0.304 |

We used the first row from the original comparison matrix in our zero CR method to find the new consistent matrix. Because they generated values less than 9 (out Saaty scale) after the dividing process the compared criteria (A-G) and (A-H) have been multiplied by 9. Table 4.19 shows the consistent matrix with zero CR and the average weight after we applied our method.

**Table 4.19:** Consistent matrix with Zero CR method

| | A | B | C | D | E | F | G | H | Weight |
|---|---|---|---|---|---|---|---|---|---|
| A | 1 | 5 | 3 | 7 | 6 | 6 | 3 | 2.25 | 0.359 |
| B | 1/5 | 1 | 0.6 | 1.4 | 1.2 | 1.2 | 0.59 | 0.45 | 0.072 |
| C | 1/3 | 1.67 | 1 | 2.33 | 2 | 2 | 1 | 0.75 | 0.12 |
| D | 0.14 | 0.71 | 0.43 | 1 | 0.86 | 0.86 | 0.43 | 0.32 | 0.051 |
| E | 1.67 | 0.83 | 1/2 | 1.67 | 1 | 1 | 1/2 | 0.37 | 0.06 |
| F | 1.67 | 0.83 | 1/2 | 1.17 | 1 | 1 | 1/2 | 0.37 | 0.06 |
| G | 1/3 | 1.67 | 1 | 2.33 | 2 | 2 | 1 | 0.75 | 0.12 |

| H | 0.44 | 2.22 | 1.33 | 3.11 | 2.66 | 2.66 | 1.33 | 1 | 0.159 |
|---|---|---|---|---|---|---|---|---|---|

The original comparison matrix has 28 pairwise comparisons and to make it consistent the zero CR method 22 modifications were required. The maximum deviations needed by zero CR are 5. Table 4.20 shows the original and the adjusted compared criteria by zero CR method, and the deviations.

**Table 4.20:** The original and the adjusted compared criteria

| Compared Criteria | Original Judgment | Zero CR Adjusted | Zero CR Deviations |
|---|---|---|---|
| A-B | 5 | 5 | 0 |
| A-C | 3 | 3 | 0 |
| A-D | 7 | 7 | 0 |
| A-E | 6 | 6 | 0 |
| A-F | 6 | 6 | 0 |
| A-G | 1/3 | 3 | 4 |
| A-H | 1/4 | 2.25(~2) | 4 |
| B-C | 1/3 | 0.6(~1/2) | 1 |
| B-D | 5 | 1.4(~1) | -4 |
| B-E | 3 | 1.2(~1) | -2 |
| B-F | 3 | 1.2(~1) | -2 |
| B-G | 1/5 | 0.6(~1/2) | 3 |
| B-H | 1/7 | 0.45(~1/2) | 5 |
| C-D | 6 | 2.33(~2) | -4 |
| C-E | 3 | 2 | -1 |
| C-F | 4 | 2 | -2 |
| C-G | 6 | 1 | -5 |
| C-H | 1/5 | 0.75(~1) | 4 |
| D-E | 1/3 | 0.86(~1) | 2 |
| D-F | 1/4 | 0.86(~1) | 3 |
| D-G | 1/7 | 0.43(~1/2) | 5 |
| D-H | 1/8 | 0.32(~1/3) | 5 |
| E-F | 1/2 | 1 | 1 |
| E-G | 1/5 | 1/2 | 3 |
| E-H | 1/6 | 0.38(~1/3) | 3 |
| F-G | 1 | 1/2 | -1 |
| F-H | 1/2 | 0.38(~1/3) | -1 |
| G-H | 1 | 0.75(~1) | 0 |

# 5. CONCLUSION

In this paper, we proposed a DSS based on AHP method to help the DM (Computer Networks Engineers) to select the best router brand alternative. The decision was based on four criteria (Cost, Reliability, Throughput, and Ports number). The alternatives are four Routers brands (Cisco, Juniper, Huawei, and MikroTik). To facilitate the operation of selecting the best Router brand we develped a user-friendly program consisting of one XLSM file by using the VBA in the Microsoft-Excel. The DM inserted all the criteria and alternatives into the program and chose their importance. The VBA program made all the AHP method calculations including the overall scores and the consistency. The consistency check showed that the comparison matrix is inconsistent according to Saaty. To solve the inconsistency issue we added a new part to our VBA program. This part suggested to the DM applying a method on the criteria evaluation comparison matrix. This method has alwayes zero CR, same alternative selection, and less changes to DM orignal matrix as shown in example comapred to (Pereira & Costa, 2015) method..

The answers for the hypothesis questions are following:

1. the DSS can be used on any computer system that runs Microsoft-Excel.
2. the DSS saved DM time by suggesting a zero CR method instead of redoing the judgement to reach a consistent comparaison matrix.
3. the overall scores slightly changed but with the same best alternative

For further researches, we recommend that the zero CR method should be applied to all comparison matrices not only on criteria evaluation comparison matrix. We think this will not change the values of the overall scores after applying the zero CR method. In the future more criteria may addedd to the DSS with more alternatives brands.

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