A Systems Engineering Methodology for Wide Area Network Selection using an Analytical Hierarchy Process

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Abstract

In this paper, we apply a systems engineering methodology to select the most appropriate wide area network (WAN) media suite, according to organizational technical requirements, using an Analytic Hierarchy Process (AHP). AHP is a mathematical decision modeling tool that utilizes decomposition, determination, and synthesis to solve complex engineering decision problems. AHP can deal with the universal modeling of process engineering decision-making, which is difficult to describe quantitatively, by integrating quantitative and qualitative analysis. We formulate and apply AHP to a hypothetical case study in order to examine its feasibility for the WAN media selection problem. The results indicate that our model can improve the decision-making process by evaluating and comparing all alternative WANs. This shows that AHP can support and assist an organization in choosing the most effective solution according to its demands. AHP is an effective resource-saver from many perspectives—it gives high performance, economic, and high quality solutions.

Keywords: Analytical Hierarchy Process, Wide Area Network, AHP Consistency, WAN alternatives.

1. Introduction

A Wide Area Network (WAN) provides users with the facility to connect to a network through a specific medium. With WANs, multiple devices can be connected using wireless network distribution methods, thus providing single or multiple access points for connection. Government and businesses frequently utilize WANs to communicate and transfer data from one location to another. Without any geographical barriers, a WAN can be used to perform daily functions more efficiently and effectively (Groth and Skandier, 2004). Several connection topologies are available, such as Leased Lines, Circuit switching, Packet switching, and Cell relay (McQuerry, 2003).

Many multi-criterion decision making techniques are available; among them, the most popular is the Analytic Hierarchy Process (AHP) proposed by Saaty (1980). AHP is used to select the best of multiple options for a wide range of planning, decision making, and comparison choices.

In this paper, we consider a theoretical medium-size company located in Riyadh, Saudi Arabia, that wishes to build its own network. The company has five branches across the country. There are over 60 employees located in the company's headquarters, and about 45 employees in each branch. The company has decided to start building a network, but has found that there are many solutions. Each choice has advantages and disadvantages, but the chosen one should be that which best fits the company's requirements. These requirements and their priorities were discussed in detail, and alternative specifications have also been proposed. The range of options confused the company stakeholders, who did not know which choice was best. In this paper, AHP is applied to calculate each choice preference percentage in order to select the best overall solution.

2. Related Work

There has been considerable research into both WANs and AHP. For WANs, the multiple options available each have some advantages and disadvantages. It is important that companies and organizations choose that which is right for them on the basis of their needs. We now discuss some related work that supports our research.

Very interesting and valuable work on AHP has been done by Subramanian and Ramanathan (2012). They evaluated, reviewed, and analyzed 291 different journal papers related to AHP. It was found that many AHP applications considered qualitative and quantitative problems, and they were largely used for managerial, complex, and real-time problems. AHP was mostly applied to supply chain and process design problems. The authors also developed a framework for the identification of research gaps in the decision-making arena.

Traditionally, project risk management frameworks have focused on managing business risks rather than considering operational risk, although this is also important in business. To cover this gap, Dey (2010) developed a framework for their integration. After reviewing different risk management frameworks, he found some flaws and then developed a conceptual risk management framework using AHP and a risk map. Test results for this framework over an oil pipeline construction project showed it was very effective for managing project risk. A combined approach of AHP and risk mapping provides an easy method of managing all risks during a project. This model can be used for risk management on complex projects.

Another interesting study on the measurement of project complexity using AHP was conducted by Vidal et al. (2011). By highlighting their limitations, they studied existing complexity measures and identified different aspects of project complexity. For the evaluation of project complexity, they used AHP to develop a multi-criteria approach that could be used in a multi-project environment alongside a defined project complexity index. A case study of the entertainment industry was used to implement and verify their multi-criteria approach, which obtained satisfactory results.

In computer systems, multiple weaknesses and holes are being discovered on a daily basis. It is important for system administrators to understand which bugs need to be given priority and fixed on an urgent basis. For this purpose, Liu et al. (2012) defined a methodology to ascertain the severity of weaknesses using qualitative and quantitative techniques. They analyzed hundreds of weaknesses in the Vulnerability Rating and Scoring System (VRSS), Common Vulnerability Scoring System (CVSS), and X-Force evaluation system. Their findings showed that vulnerabilities are often close to each other and are not easily separable. To solve these problems, they categorized and defined priority levels for weaknesses in the system using AHP on the basis of VRSS. Their results demonstrated that the level of different weakness types was improved by applying quantitative characterization and the Common Vulnerabilities and Exposures (CVE) technique.

In complex environments with alternative projects and assorted measurements to allow different criteria, the use of Multi-criteria Analysis (MCA) is widespread. Bottero et al. (2011) presented applications of different MCA methods related to wastewater treatment (WWT) technology. AHP and the Analytic Network Process (ANP) were considered the most reliable decision-making tools, as they provide basic elements of the decision process and, between them, find the best alternative. With the help of some specific software packages, AHP and ANP techniques were applied to different models; results showed that phytoremediation was the most suitable technology for small WWT industries.

The selection of an optimal network in terms of Quality of Service (QoS), performance, consumption of energy, and network access is a crucial process. Chamodrakas and Martakos (2012) presented a method to provide the optimal network selection to balance both performance and energy consumption. To attain a given QoS for different applications, and adopt different energy consumption metrics within applications, they used different utility functions. A Fuzzy Set Representation TOPSIS method was applied to overcome the inconsistency of the utility functions, and the abnormality problem was solved by calculating the network rating as the aggregation of multiple criteria. The results of simulations demonstrated the suitability and effectiveness of their proposed method.

Virtual Private Networks (VPNs) provide secure and reliable data transfer through a public network. Every customer can use a secure channel after presenting their password or a compatible certificate. Rossberg and Schaefer (2011) summarized and highlighted different VPN scenarios and issues, generating different functional objectives by different VPN deployment scenarios. For instance, as network topologies become more complex, they tend to restrict the QoS mechanism, and different security considerations make it difficult for users to judge whether a VPN is secure or not. For manually configured VPNs, weaker security approaches are available in terms of functional and non-functional aspects. Auto-configured VPNs could provide more reliable and secure transmission compared to manual configuration, as there is always the possibility of human error, but more work is needed to prove this point.

For Internet Service Providers (ISPs), resource management is a most important matter that requires the automatic and efficient management of resources. Robert et al. (2012) proposed an Autonomic Service Architecture to provide a solution for such matters. This model works on VPNs that are being controlled by selfish and/or cynical operators. Two major limitations are faced under this model. First, the utilization of unused resources on low-traffic VPNs by crowded VPNs. This must consider any unexpected changes in the QoS of the less-crowded VPN whilst improving the QoS of the crowded VPN. Second, less-crowded VPN operators can refuse to lend free resources to crowded VPNs. To overcome these issues, the model of Robert et al. (2012) is based on four strategies that are derived from a tit-for-tat strategy for the evaluation of cooperative and non-cooperative operators. However, it was noticed that these strategies are not effective for non-cooperative operators. To punish selfish operators for not sharing unused resources, they proposed a sacrificing strategy that required records to be kept for each operator. A reputational-based strategy was also proposed to reduce the need to keep records. The merging and integration of both strategies can force non-cooperative operators to share unused VPN resources with others if necessary.

Hanafizadeh and Mirzazadeh (2011) conducted some interesting work in the telecommunications field on Asymmetric Digital Subscriber Lines (ADSLs). They studied the Iranian telecommunications market, and visualized the ADSL service of the most reputable company using a Self-Organizing Maps (SOMs) algorithm. Market-context variables were identified from a survey, and they obtained a dataset for training the network via questionnaires and customer data. After the system was trained using their SOM network, a U-matrix and variable maps were produced that imparted the relationship between all market variables and segments. The study was based on customer needs and ADSL services. Every customer can choose a different package provided by the telecommunications company on the basis of their needs. Packages are distinguished according to bandwidth, transmission limitations, and billing methods. Using the Fuzzy Delphi method, the authors identified important factors affecting the market context.

Kim et al. (2008) presented a case study on the success of ADSL in Korea. They probed the cooperation between innovative companies and decision-making patterns with the help of a conceptual framework consisting of the different actors in the ADSL system, the process of decision making, and uncertainly levels. They identified success factors, such as the competition between cable modem and ADSL, service fees, government policy for industry, and the increasing domestic equipment industry. It was determined that the focus of decision-making by most participants should shift from investigation to finding, assessing, and accomplishing as the level of untreatable in telecommunication services.

Different network access characteristics are being provided through wireless, Ethernet, modem, ADSL, and dialup services. Wei et al. (2008) proposed a scheme for the classification of access networks. This was divided into three categories: Ethernet, wireless LAN, and low-bandwidth connections (cable, ADSL, or dialup). Identification of the precise network type is always a problem, especially when using ADSL or cable, and wireless connected laptops can report WLAN instead of the exact type. The identification of the correct network type without network assistance requires an end-to-end approach. For this purpose, Wei et al. (2008) used packet pairs and the basic connection characteristics in their algorithm. They showed that the identification of the network type could improve the performance of applications and protocols.

3. Proposed Methodology: Analytic Hierarchy Process (AHP)

AHP works by dividing a large or complex problem into smaller problems, either on one or multiple levels. First of all, we construct a structural hierarchy with the goal at the top. We then determine the criteria and sub-criteria of the problem, and consider each criterion or sub-criterion as a certain perspective or view of the problem, i.e., cost. The bottom of the hierarchy should include alternatives. In essence, “AHP can help describe the general decision operation by decomposing a complex problem into a multi-level hierarchical structure of objectives, criteria, sub-criteria, and alternatives” (Sharma et al., 2008). AHP can be used in complex engineering problems that have a large number of attributes. Saaty (1980) developed AHP from a mathematical basis in the 1970s, since when it has become a very interesting field as it converts each criterion into a quantitative number. Thus, AHP has been extensively studied and refined since its inception. Figure 1 shows each step in AHP. A problem is placed into a hierarchical structure, with the goal in level 1, criteria or factors in level 2, sub-criteria in level 3, and the overall goal in level 4 (Sharma et al., 2008). The priority of each factor is determined by a pair-wise comparison matrix.

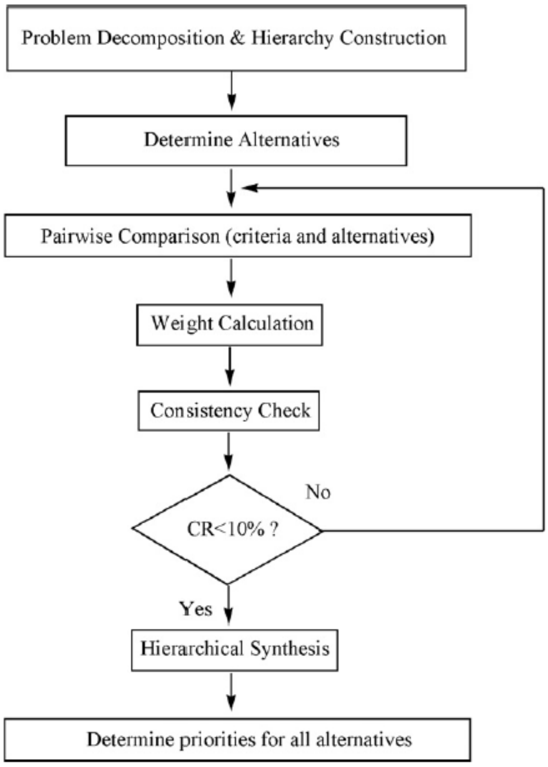

Figure 1. Schematic representation of AHP methodology (Sharma et al., 2008).

After simplifying the problem by dividing it into multiple problems (or factors), all possible solutions (or alternatives) are determined. A pair-wise comparison is applied to establish priorities. An $n \times n$ matrix is constructed, where n is the number of factors, and then the priority of one factor over another is determined according to Table 1 (Bhushan and Rai, 2004):

Table 1. Intensity of importance.

Intensity of importance	**Definition**
1	Equal importance of both elements
3	Weak importance one element over another
5	Essential or strong importance one element over another
7	Demonstrated importance one element over another
9	Absolute importance one element over another
2, 4, 6, 8	Intermediate valued between two adjacent judgments

After assigning a numerical importance to each criterion a_{ij} in the matrix A, we are ready to find the numerical weights (W_1, W_2,…, W_n) of the alternative solutions. In order to find the weights, consider the following equation (Sharma et al., 2008; Douligeris and Pereir, 1994):

$$\begin{bmatrix} a_{11} & a_{12} & \dots & a_{1n} \\ a_{21} & a_{22} & \dots & a_{2n} \\ \vdots & \vdots & \dots & \vdots \\ \vdots & \vdots & \dots & \vdots \\ a_{n1} & a_{n2} & \dots & a_{nn} \end{bmatrix} \cong \begin{bmatrix} W_1/W_1 & W_1/W_2 & \dots & W_1/W_n \\ W_1/W_1 & W_1/W_2 & \dots & W_1/W_n \\ \vdots & \vdots & \dots & \vdots \\ \vdots & \vdots & \dots & \vdots \\ W_n/W_1 & W_n/W_2 & \dots & W_n/W_n \end{bmatrix}$$

In order to obtain the consistency matrix *A*, we raise the priority matrix to the power 2. Then, we apply the following equation to find the eigenvector *X*:

$$A - (\lambda_{max} I)X = 0$$

where I is the identity matrix of size $n \times n$ and λ_{max}, is the principal eigenvalue of *A*. Before we approve this matrix, we should check its consistency using the eigenvector method. Saaty (1980) defined the consistency index (*CI*) as:

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

where λ_{max} is the maximum eigenvalue and *n* is the number of factors in the judgment matrix. For each $n \times n$ matrix, random matrices are generated and their mean *CI* value, called the random index (*RI*), is calculated (Bhushan and Rai, 2004). *RI* represents the average consistency index over numerous random entries of same-order reciprocal matrices. Table 2 shows some values of *RI* (Saaty, 1980):

Table 2. Selected values of the *RI*.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Saaty also defined the consistency ratio (*CR*) according to *CI* and *RI* as:

$$CR = \frac{CI}{RI}$$

Checking the value of *CR* provides the inconsistency in the level of estimation. The inconsistency is acceptable only if *CR* is less than or equal to 10%. Otherwise, we need to revise our subjective judgments to decrease the inconsistency (Saaty, 1980).

4. Applying the AHP Methodology

AHP is mainly used in engineering systems for the purpose of decision-making, such as resource allocation, performance evaluation, conflict solutions, and some other disciplines. The input of AHP depends on the selection and judgment of decision makers, whose cognition of such problems is fully reflected in the decision-making process.

AHP can be applied in six steps (Sharma et al., 2008; Douligeris and Pereir, 1994):

4.1 Define the goal of applying AHP

The goal of applying AHP is to find the best WAN solution for the company, guaranteeing low cost against high efficiency and good quality.

4.2 Define the evaluative criteria used to select the WAN

There are many factors that could affect our decision, including those that the company has identified as well as external factors such as alternative systems and the company's situation.

- **Speed**:

Usually, this factor is primarily considered in terms of ISPs. We can divide this factor into two sub-factors:

- Latency: the time a packet needs to travel from host to host. Low-latency networks are needed for interactive applications, such as online games or videoconferences (Tanenbaum, 2008).
- Bandwidth: the volume of data that can be sent or received per second (also called the data rate). This depends on the communication resource. The standard unit of bandwidth is bits per second (bps, also its multiples: Kbps, Mbps, …).

- **Reliability**:

The reliability of a system can be defined as its resistance to failure and, if it should fail, its ability to fail well (i.e., without catastrophic consequences) and its recovery time. Reliability can also be defined as a component's (or system's) ability to do a specific task under certain conditions for a time period. This is an important factor (Tanenbaum, 2008).

- **Scalability**:

Scalability is the ability of a system to be enlarged or deal with a sudden increase in workload. This feature may be needed in some processes or systems, and will determine how the company is able to add other branches to its network in future (Bagad and Dhotre, 2009).

- **Security**:

Security is the degree of protection against unauthorized access, interception, interruption, loss, and unwanted events. Users, companies, and organizations have different perspectives and levels of importance according to their activities and privacy requirements (Kartalopoulos, 2009).

- **Cost**:

Companies essentially seek to make a profit, so the cost of implementation represents one of the most important factors. This can be divided into two sub-criteria:

- Installation cost: the amount the company pays in the establishment phase.
- Running costs: the amount the company pays periodically (i.e., monthly, annually) to a service provider for the service itself or its maintenance.

4.3 Define, assess, and choose the alternatives

Solutions can be provided in many ways. Experts could suggest different solutions immediately, or a brainstorming technique could be applied to obtain multiple solutions from which to choose. Generally, there are many choices or solutions available for the given problem:

- **Leased Line:**

A Leased Line is a dedicated circuit or connection provided by a service contract between a company that can provide this service and a customer. According to this contract, the service provider should deliver a symmetric connection between multiple locations (two or more). It is known as a 'leased' line because the customer pays a monthly amount to the provider for this service. Unlike a Public Switched Telephone Network (PSTN), Leased Lines do not have a telephone number and connect the served locations constantly (Bagad and Dhotre, 2009).

- **Virtual Private Network (VPN):**

A VPN is a computer network that connects branches, offices, or home users and accesses their internal network remotely and securely. VPNs use the regular internet infrastructure. It is called virtual because it is just an illusion, like a virtual circuit. VPNs provide more security than public lines and lower costs than Leased Lines. Security of information is ensured by encapsulation and encryption methods (Kartalopoulos, 2009).

- **Public Lines:**

This entails the use of public internet lines, like any home user, to connect branches together by paying periodic subscription fees to an ISP. This could be a dial-up connection, ADSL connection, or internet cable connection.

- **Wireless WAN via Satellites:**

Wireless WANs could be a sufficient solution for connecting branches, especially in the case of infrastructure absence, as they cover wide outdoor areas and provide public internet accessibility. Such networks operate on the 2.4 GHz band. The components of a wireless system are base station, wireless relays, and access points (Tanenbaum, 2008).

4.4 Establish each factor of the pair-wise comparison matrix

Using pair-wise comparison, the relative importance of one criterion over another can be expressed according to Table 3:

Table 3. Weight of different criteria.

	Speed	Scalability	Reliability	Security	Cost	Weight
Speed	1	5	1/2	3	2	0.2606
Scalability	1/5	1	1/6	1/3	1/5	0.0462
Reliability	2	6	1	5	3	0.4360
Security	1/3	3	1/5	1	1	0.1277
Cost	1/2	5	1/3	1	1	0.1295
Sum	4.033	20	2.2	11.333	7.2	1

Computation of the weight of criteria:

Speed: the company has no persistent heavy data transfer and no need for videoconferencing, but slow speeds will hamper its work. Therefore, speed is highly important.

Scalability: the company does not intend to open new branches in other cities. Further, as scalability is possible in all network types, it is of low importance.

Reliability: reliability is the most important factor in this network, because its failure would cause many problems to the company and its clients, damaging the reputation of the organization. The company cannot tolerate network failure; therefore, reliability is highly important.

Security: the company has no top secret information, but at the same time, unauthorized access should be prevented. Thus, security is of medium importance.

Cost: although such companies are profit-driven in many ways, they also value customer satisfaction in order to be a good contractor. In other words, some investment is necessary to enhance the company’s reputation and improve customer relations. Therefore, cost also has medium importance.

4.5 Perform the consistency test

Recall from section 2.1 that, if the value of *CR* is less than or equal to 10%, the inconsistency is acceptable. We now apply Saaty’s method to our matrix to check its consistency.

$$\lambda_{max} = [4.033 \quad 20 \quad 2.2 \quad 11.333 \quad 7.2] \times [.2606 \quad .0462 \quad .436 \quad .1722 \quad .1395]^T$$

$\therefore \lambda_{max} = 5.187$

➔ $CI = \frac{\lambda_{max} - n}{n-1} = \frac{5.187-5}{5-1} = 0.04675$

➔ $CR = \frac{CI}{RI}, and\ RI = 1.12 \rightarrow CR = 0.041 =$ 4.1% < 10%

Hence, our subjective evaluation is consistent, because the value of *CR* is less than 10%. This gives us the approval to continue our decision making process.

4.6 Computation of the weight of sub-criteria

- An evaluation of the speed sub-criteria is given in Table 4:

Table 4. Speed sub-criteria.

	Latency	Bandwidth	Weight
Latency	1	1/3	0.25
Bandwidth	3	1	0.75

Latency: the company would use Voice over IP in some communications but has no need for videoconferencing, so its importance is low against bandwidth.

Bandwidth: this has a much higher priority over latency.

- An evaluation of the cost sub-criteria is given in Table 5:

Table 5. Cost sub-criteria.

	Installation	Running	Weight
Installation	1	1/4	0.2
Running	4	1	0.8

Installation Costs: it is assumed that the company will keep this network for 10 years; this means the effect of installation costs will decrease against running costs.

Running Costs: paid periodically, includes service fees and maintenance costs.

Table 6 summarizes all priorities of criteria and sub-criteria:

Table 6. Criteria priorities.

Criteria priority	Weight	Sub-criteria priority	Weight
Speed *C1*	0.2606	Latency *C6*	0.25
		Bandwidth *C7*	0.75
Scalability *C2*	0.0462		
Reliability *C3*	0.4360		
Security *C4*	0.1722		
Cost *C5*	0.1395	Installation costs *C8*	0.2
		Running costs *C9*	0.8

5. Evaluating Alternatives

Each alternative for the company's WAN is offered by a different provider. Thus, before applying the AHP model to the criteria to find the best alternative, the different specifications must be compared. Table 7 shows the specifications offered by several companies: Saudi Telecom Company (STC) (Saudi Telecom Company, online), ExpressVPN (ExpressVPN, online), and Sateline (Sateline, online).

Table 7. Alternative specifications.

	Leased Line	VPN	PSTN	Satellite
Company	STC	ExpressVPN	STC	Sateline
Speed	2 Mbps	unlimited	2 Mbps	3 Mbps
Installation Cost	12000 RS	300 RS	300 RS	800 RS
Running cost	3000 RS	250 RS	200 RS	240 RS

5.1 Speed

Latency: A Leased Line is a private circuit, so it is the best alternative in terms of latency performance (Table 8). VPN uses a public line, so its latency performance is theoretically equal to that of PSTN, but as VPN uses a private channel it will be security authenticated, and thus its latency is worse than a public line. Satellite is the worst alternative, with 360 ms latency.

Table 8. Evaluation of the alternative latencies.

	Leased Line	VPN	PSTN	Satellite	Weight
Leased Line	1	5	3	7	0.587
VPN	1/5	1	0.5	2	0.122
PSTN	1/3	2	1	3	0.217
satellite	1/7	1/2	1/3	1	0.072
Sum	6	6	6	2	1

Bandwidth: Again, as a Leased Line is a private circuit, it is the best alternative in terms of bandwidth (Table 9), as there are no other users with whom the capacity is shared. VPN uses a public line, so it has the same bandwidth as PSTN. Satellite has better bandwidth than a public line, reaching speeds of up to 1Gbps.

Table 9. Evaluation of alternative bandwidths.

	Leased Line	VPN	PSTN	Satellite	Weight
Leased Line	1	3	3	2	0.455
VPN	1/3	1	1	1/2	0.14
PSTN	1/3	1	1	1/2	0.14
satellite	1/2	2	2	1	0.262
Sum	2.166	7	7	4	1

We now apply the overall weight for latency (25%) and bandwidth (75%) to obtain the total speed weightings for each alternative, as shown in Table 10:

Table 10. Weighted alternative speed evaluation.

	(Weight)25%	(Weight)75%	Total
Leased Line	0.587	0.455	0.488
VPN	0.122	0.14	0.136
PSTN	0.217	0.14	0.159
satellite	0.072	0.262	0.214
Sum	1	1	1

5.2 Reliability

As a Leased Line uses a private circuit, it is the most reliable alternative (Table 11). VPN uses a public line, so has the same reliability as PSTN, and Satellite has the least reliability because the wireless signal is somewhat dependent on the weather.

Table 11. Evaluation of alternative reliabilities.

	Leased Line	VPN	PSTN	Satellite	Weight
Leased Line	1	3	3	4	0.515
VPN	1/3	1	1	2	0.189
PSTN	1/3	1	1	2	0.189
satellite	1/4	1/2	1/2	1	0.105
Sum	2.166	5.5	5.5	9	1

5.3 Scalability

Leased Line, VPN, and public line are equivalent in terms of scalability (Table 12), because all of these exist within the communication infrastructure of the provider company. Satellite is more suitable for scalability, because it can reach unmanned areas without the need for additional infrastructure.

Table 12. Evaluation of alternative scalabilities.

	Leased Line	VPN	PSTN	Satellite	Weight
Leased Line	1	1	1	1/3	0.166
VPN	1	1	1	1/3	0.166
PSTN	1	1	1	1/3	0.166
satellite	3	3	3	1	0.5
Sum	6	6	6	2	1

5.4 Security

A Leased Line is a private circuit, which gives high security (Table 13). VPNs use security techniques, so are more secure than public lines and satellite. Satellite is better than a public line.

Table 13. Evaluation of alternative security levels.

	Leased Line	VPN	PSTN	Satellite	Weight
Leased Line	1	3	9	5	0.585
VPN	1/3	1	5	3	0.265
PSTN	1/9	1/5	1	1/2	0.055
satellite	1/5	1/3	2	1	0.102
Sum	1.644	4.53	17	9.5	1

5.5 Cost

- **Installation costs**: A Leased Line is the most expensive (Table 14), because it requires the hire of a private circuit from the provider. VPN is more expensive than a public line, because it entails the cost of a VPN account over the established public line. A Satellite network requires the purchase of equipment for communication.

Table 14. Evaluation of alternative installation costs.

	Leased Line	VPN	PSTN	Satellite	Weight
Leased Line	1	1/9	1/9	1/7	0.0363
VPN	9	1	1	3	0.397
PSTN	9	1	1	3	0.397
satellite	7	1/3	1/3	1	0.168
Sum	26	2.441	2.441	7.142	1

Running costs: The Leased Line is still the most expensive (Table 15). A public line is the cheapest, and Satellite and VPN have approximately equal running costs.

Table 15. Evaluation of alternative running costs.

	Leased Line	VPN	PSTN	Satellite	Weight
Leased Line	1	1/4	1/5	1/4	0.0695707
VPN	4	1	1/2	1	0.245562
PSTN	5	2	1	2	0.439305
satellite	4	1	1/2	1	0.245562
Sum	14	4.25	2.2	4.25	1

We now apply the overall weight for installation costs (20%) and running costs (80%) to obtain the total cost weighting for each alternative, as shown in Table 16:

Table 16. Weighted alternative cost evaluation.

	(Installation Costs) 20%	(Running Costs) 80%	Total
Leased Line	0.0363	0.069	0.062
VPN	0.397	0.245	0.275
PSTN	0.397	0.439	0.430
satellite	0.168	0.245	0.229
Sum	1	1	1

6. Final Result after Evaluating all Alternatives

We now combine all alternative weights into one matrix and multiply it by the factors vector to get the final grade for each alternative. The full weight matrix will be taken from Table 17:

Table 17. Final AHP calculation.

	Speed	Reliability	Scalability	Security	Cost
Leased Line	0.488	0.515	0.166	0.585	0.062
VPN	0.136	0.189	0.166	0.265	0.275
PSTN	0.159	0.189	0.166	0.055	0.430
satellite	0.214	0.105	0.500	0.102	0.229

The matrix formed from the previous table is multiplied by the factors vector, which is given in Table 18:

Table 18. Calculated criteria weights.

Factor	**Weight**
Speed	0.26
Reliability	0.4360
Scalability	0.04
Security	0.1277
Cost	0.129

The resultant vector gives the final rating for each alternative, as shown in Table 19:

Table 19. Final rating for each alternative.

Alternative	Weight
Leased Line	0.4407
VPN	0.1937
PSTN	0.1928
Satellite	0.1730

This table shows every alternative and its rating value according to the previously specified criteria and their respective priority values. As a result, the alternative with the highest rating is most suitable for the company. It can be seen that the Leased Line is ranked first, VPN is second, and PSTN is third in the company assessment methodology. Indeed, the Leased Line solution is by far the most preferred solution.

7. Conclusion

This paper demonstrated the decomposition of a problem into criteria and sub-criteria, allowing the application of the AHP methodology to ensure flexibility of data usage in the WAN selection decision-making process. Moreover, we illustrated the assignment of priorities and their comparison using a pair-wise matrix in order to determine the weight of each factor in the WAN selection process.

AHP is robust and captures both subjective and objective aspects of a decision. AHP also incorporates a technique for checking the consistency of the evaluation, meaning that it is accurate and efficient with respect to each of the needs in the hierarchy (Drake, 1998).

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