Estimating the Survivability Impact of Multi-Fiber Wavelength-Division Multiplexing Networks

FAHAD AHMED AL-ZAHRANI
Department of Computer Engineering, Umm Al-Qura University, Mecca 24381, Saudi Arabia
e-mail: fayzahrani@uqu.edu.sa

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ABSTRACT The efficacy of an optical network is determined by the network’s ability to hold out and pull through from failures and disruptions. Achieving the desired impact of survivability is a key imperative for optical network industries. Several practitioners and researchers are working towards realizing the target of maximum survivability of optical network systems. In this league, our research initiative intends to evaluate the impact of survivability of multi-fiber wavelength-division multiplexing networks. To evaluate the impact of survivability factor in optical network through the most accurate means, we used the hybrid multi criteria decision making methodology, the Fuzzy Analytical Hierarchy Process (FAHP) and Fuzzy Technique for Order of Preference by Similarity to Ideal Solution (FTOPSIS). For estimating the impact of survivability in the present endeavour, the authors have taken two layers (two factors at level 1, and 10 factors at level 2) of the survivability factors for calculating the weights and five alternatives for evaluating the survivability impact. The hybrid technique of FAHP and FTOPSIS was developed for our analysis. FAHP evaluated the weights of the factors with respect to their alternatives, whereas the FTOPSIS was employed to calculate the overall impact of survivability. According to the numerical analysis of the selected factors affecting the parameters of the survivability in Wavelength Division Multiplexing (WDM), restoration technique was the most prioritized alternative, and hence needs more focus while engineering the WDM network.

INDEX TERMS Optical network systems survivability of WDM, decision making, fuzzy AHP, fuzzy TOPSIS.

I. INTRODUCTION
The network survivability in Optical Fiber Network Communication (OFNC) ensures the uninterrupted services by the network operator [1]. Natural disasters like earthquake, tsunami, flood, etc., may cause disruption in OFNC. Network failures can result in the loss of data during any kind of disruption, creating problems for both the sender and receiver [2]. Thus, for achieving the target of seamless and uninterrupted services, consistent inventiveness of restoration and protection techniques become an imminent prerequisite. Network or data loss during the data transmission or communication between two or more parties can be restored by the factor known as survivability. The network uses carrier WDM defined as bidirectional multi signal optical communication by the laser light. To secure the optical network from the natural or manmade disasters, we need to secure the communication by the factor of survivability in WDM network. Survivability depends on various factors because frequency of optical network failure is significant as the intervening time between failures is about 367 year per km [1], [2]. According to NSFNet, there is one fiber cut in 5 days in a 26000 km large optical fiber network, [3]–[6]. Further, the possibility of two instantaneous failures in optical network is even higher; approximately 0.0027 with respect to the time of 24 hours per year [7]–[10]. The survivability of WDM means the ability of the network to secure and protect the information during the processing through OFNC.

There are different types of failure in optical network, i.e., port failure, node failure, fiber cut, duct failure and channel failure [3], [4]. In OFNC, the channel is a physical pipe among node in which the optical fibers are stocked into cables [5]. The duct failure occurs when earthquake or any other catastrophic incidents happen and optical network is uprooted. The light path might fail and the fiber may be disrupted, leading to traffic loss. Node failures occur due to fire or flooding. The disruptions or failures due to node failure are significant in OFNC. Channel failure in OFNC is caused by the receiver’s and transmitter’s equipments that are used for channel formation. Network survivability is a

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major challenge for real time transmission. Probability failures are high in WDM network [6]. Moreover, maximizing connection availability in WDM after failure also causes the network disruption. Therefore, the other failures of OFNC are port failures which occur in the router. The survivability of the optical fiber networks are based on these types of failures [7]. These reasons for the failure have been taken into consideration for the intended research work on gauging the impact of survivability in WDM.

Justifying the needs of factors of survivability and its’ impact are important for establishing the durability and the commercial viability of the optical fiber network [8]. The quantitative evaluations of the survivability factor will also ensure the protection and restoration technique of optical network in spite of the occurrence of failures in infrastructure of optical fiber network. There is a tradeoff between survivability and the cost of the optical network [5]–[8], and 100% survivability can be achieved by enthusiastic path protection. More specifically, in the present study, we have determined the survivability impact of alternatives with the help of different factors by using an integrated methodology of FAHP and FTOPSIS.

The main objectives of this research study are:
- To evaluate the impact of the factors.
- Conduct a security assessment of WDM optical network protection and restoration technique.

The two premises stated above will help the developers to make WDM network more survivable [9]. Survivability helps the data security over the transmission network. In the current quantitative analysis, we have specifically selected the techniques of protection and restoration as the first layer of factors. Further, five-five factors for protection and restoration have been taken at level 2 for the estimation process through fuzzy based multi criteria decision analysis process.

Researchers have used various methods to assess survivability factors to accomplish this purpose, and extensive research has also been done to evaluate decision-making techniques. However, very few studies focus on evaluating ranks of survivability factors with applicability to real-world problems in order to boost longevity. Survivability is the essential concern of consumers. Thus, improving survivability services would also increase the acceptance rate of the end product among the users. In addition, companies have their own procedures and methods of evaluation; the assessment of survivability factors is a decision-making problem because of this [10], [11]. Therefore, this study’s evaluation procedure would be very useful for the analysts, particularly in identifying the goals of the factors and to take effective action while maintaining survivability. For information security providers, efficient evaluation of survivability factors is valuable, and it also enhances the overall quality of the product. For more conclusive results, our study uses a combination of three methods to test survivability, which is best achieved through FAHP-FTOPSIS approach [12]–[16]. Every complexity of a situation is taken into account by Fuzzy-logic. Fuzzy-logic assumes greater significance in addressing real-life issues whereby we are unable to determine if the solution to a given problem is completely true or totally false [17]. Different experts have different understanding of factors depending on their awareness and experience levels. This leads to inaccuracies and ambiguities in taking a specific and well-informed decision [18]–[20]. In such a context, Fuzzy-logic gives precise solutions, bringing in more clarity in the midst of several ambiguities that arise in the process of decision making. The FAHP is used to define the factors weights, while the FTOPSIS technique is used to evaluate the potential alternatives according to their performance scores.

Hence, the hybrid methodology of FAHP and FTOPSIS has been used in this study for assessing the weights and the rank of the factors, respectively. FAHP prioritizes the factors and alternatives of survivability in WDM network [21]–[23]. FTOPSIS ranks the factors and their alternatives. The developers have a set of factors from which they need to select the particular factors that determine survivability in WDM [24]–[26]. This process calls for judicious decision making as the developers have to select the factors of the highest preference for different criteria. To address this context, we have opted for the hybrid approach of FAHP and FTOPSIS for conducting the survivability assessment in WDM network.

The rest of the research work is structured as follows: In section 2, the literature perused for profiling this research has been explained. Section 3 describes different factors, alternatives and survivability in WDM. Section 4 explains the methodologies of FAHP and FTOPSIS. The numerical analysis obtained by enlisting the methodologies has been explained in section 5. Section 6 presents a comparison of different methodologies. Section 7 tabulates the sensitivity analysis done in our study to draw more convincing results and presents a comparison of the results of different methodologies; while section 8 details the inferences and discusses the results. Section 9 concludes the study, underscoring the significance of the factor of survivability in WDM.

II. PREVIOUS WORK

Several research studies have been done on WDM in OFNC that address the restoration and protection schemes of survivability [1]–[15]. These studies employ different methodologies which are based on various factors that affect the OFNC. Survivability has also been the focus of researchers in the context of different network implementation techniques. The security of the data being transmitted through the network system is more important. Hence, efficient and effective optical communication should ensure fast as well as reliable data transmission over the OFNC. Our research has specifically underlined the imperativeness of the factors which affect the survivability in optical fiber communication. Then by using FAHP, we evaluated the factors and their respective weights. Thereafter, based on the weights obtained, the respective factors were again evaluated for the ranking through FTOPSIS. While profiling our research, the relevant literature sources...
that we referred to in particular on the survivability of optical fiber network have been detailed below:

- **Habib, M. F., et al. (2013)** - The study evaluated the cost effective approach of spare capacity in WDM network [1]. The quantity of unused capacity component made the network continue even during failure. The method has three steps: First, to select the working route, the security route and achieve its approximation for maintaining computational feasibility. Second, by using the genetic algorithm the authors obtained traffic routes distribution and client working and its working protection route. In conclusion, the wavelengths are allocated to the working light paths and common protection light paths. The use of this method helped to achieve shorter restoration latency. The authors also compared their approach with the single path protection to achieve shorter restoration latency. The authors also compared their approach with the single path protection scheme to establish the effectiveness of the suggested technique.

- **Ahmad J., et al. (2013)** - The study propounded that the network is classified as a multi-layer system. The breakdown at inferior layer may cause numerous failures in higher layer of the network [4]. This work considered the different layers of securities in the network. Based on the measures of connectivity in layer network, new metric is formed in this study. The new metric is named *Min Cross Layer Cut* as an aim for survivable light path direction-finding problem, and is used to develop the algorithm to produce the routing in optical network. We have also selected the *network layer security* in WDM of optical fiber communication as a factor of survivability in our study.

- **A. Alashaikh et al. (2019)** - The study cited that the issues of network are based on cost, availability and service differentiation [6]. In a physical layer of network security, the authors mentioned the embedded approach in high availability of link and nodes called spine. This so called spine enabled the protection, routing and mapping. The embedded network model fulfills the network issues optimally. Drawing from this study, our research also selected the *factor of availability* for evaluation in WDM.

- **Jara, N., (2019)** - The study iterated that survivability is the main factor of data restoration and protection during the network failure. The paper focuses on mesh connection of network topology [8]. Here the different availability requirements and protection of current state are based on different time contexts. This structure provides diverse levels of service protection, performance and flexible optimization.

- **M. Alenezi et al. (2019)** - The study used the FAHP method in software security factors for the determination of the weight of the usable security factor in software security [9]. The paper presents the functional security factors of the software and the methodology of the FAHP determines the individual weight of the factors. Our research study has also adopted FAHP methodology for evaluating and analyzing the impact of survivability in WDM.

- **A. Agrawal et al. (2019)** - The study undertook the decision making method of FAHP for the evaluation of usable security in software. Security is an integral part of software [10]. The improvement of security and usability in software is of paramount importance. To ensure the accurate assessment of both, the authors selected FAHP and applied it for the determination of the weight of the factors used in the software for improving the security for the developer.

- **R. Kumar et al. (2020)** - The study emphasized that the usability and security of the software is a tradeoff between the two [11]. The developers selected the factors between usability and security as per the requirement of the software. The FTOPSIS method is used for the mathematical evaluation of the rank of the affecting factors. The research focused on the usability and threat of the software, and the evaluations done in the study seek to enhance the security of the software and the web application. We have also adopted the FTOPSIS method for assessing the impact of survivability in WDM in the present research endeavor.

The aforementioned studies cite the importance of the research based on the methodology of combined FAHP and FTOPSIS.

### III. WDM Survivability in OFNC

The loss of data during the optical fiber communication results in loss of money, time and security. The factors affecting the survivability due to damage of optical fiber is also one of the major reasons for the loss of data. This research study is based on the factors which affect the survivability of WDM and its alternatives. Our objective is to find out the quantitative impact of survivability on its dependent factors by the related factors of protection and restoration. In this context, the present section discusses about the factors and its dependent alternatives. Alternatives that directly affect survivability are: *Availability [A1], Service Reliability [A2], Restoration Time [A3], Service Restorability [A4], and Dynamic Restoration [A5]* [12]–[15]. The alternates are the entities on which the factor of survivability depends. We have selected factors by multi criteria decision approach as per the need and importance of dependent factors used in OFNC. The dependent factors are classified in two main parts: *Protection [C1] and Restoration [C2]* [16]–[18]. Each main part is further classified into five dependent factors.

**Factors of Survivability in WDM** - Survivability has two layers of factors known as protection and restoration in primary level. Furthermore, protection and restoration have five factors in each layer:

**A. Protection [C1]** - The protection is a necessary task for the survivability in WDM. In normal working condition of optical network, communication between the nodes occurs over the optical fiber network. When the failure
happens, the communication of network is disrupted for which a backup path is selected [12]. The conditions in which communication between the nodes are working without failure is called the protection. The protection is first layer of factors in our research study. Protection has five different dependent factors in second layer of factors of survivability in WDM network.

1. Failure Frequency [C11] - It is defined as the rate of failure of optical network in the given time period [13]. In WDM network, all physical connections are two unidirectional fibers in the opposite direction. Each fiber consists of certain number of wavelength known as the wavelength channel. The failures are link failures and node failures. A single link failure is used to investigate the survivability of optical fiber network. We considered it as factors for our research study.

2. Failure Repair Rate [C12], the alternatives A1 to A5 is exaggerated by the failure recovery rate for numerous failures [14]. The failure repair rate is failed estimation if the path is multi fiber. For A1, the failure repair rate is high. The reduction of service disruption causes the negligible failure repair rate. The alternative A1 is more important than the F5. Failure rate of every path is exponentially circulated with a signify value.

3. Dedicated Path Protection [C13] - In dedicated path protection, each path has a disjoint backup path and wavelength that are reserved and dedicated for optical fiber communication. Link joint path and wavelength are reserved for data transmission. When the fault occurs, the data path is used for the data transmission. It enhances the survivability in WDM network. Here, we considered the [C13] as the second layer factor of the survivability in WDM network.

4. Shared Path Protection [C14] - At the time of communication in a path a link, disjoint backup path and wavelength are reserved for the optical data transmission. The reserved path may be shared with the other path of transmission for the time of failure. This procedure of protection makes the network cost effective compare to the [C13].

5. Path Protection [C15] - The transmitter and receiver part of communication are connected with node. In each connection, nodes needs a backup in failure condition, the link found a backup and restoration for different wavelength channel [15].

B. Restoration [C2] - Protection and restoration are imperative in the WDM networks. The protection methods including protection, speed and mesh like high efficiency of spare capacity. Factors associated with protection take less time as compared to restoration. Restoration uses better resource utilization than protection scheme. In a failure, the optical network restoration leads to dynamic search to restore path. During the network failure condition, the restoration technique recovers the affected traffic of the data [12]. The method of protection also affects the survivability of WDM network. If the complexity of protection increases, it can reduce different alternative of the WDM network.

1. Disruption Holding Time [C21], WDM network have huge capability and dynamic circuit which provides the holding time with elevated frequency [13]. The survivability means the capacity to recover from the failure. The holding time connection means providing vibrant traffic environment and examining the availability of connection. Without the availability consideration in shared path, the holding time is exploited and makes the connection insecure. Collective and enthusiastic path protection guarantees availability. We reduced the auxiliary capacity by the holding time.

2. Number of Disruption [C22], the spare capacity of the survivable WDM networks has static traffic demand. In dynamic traffic, the survivable WDM network numeral linear encoding optimizes the problem. This framework causes the examiner disruption [12]. In a network, new set of demands provide optimum network capability while avoiding examiner disruption in the working network. The optimization method avoids the disruption. The disruptions affect the alternative A1 to A5 in many ways. Thus, disruption must be considered as an alternative in the study of survivability.

3. Link Restoration [C23] - when the failure occurs in optical fiber communication, the network needs to be restored. If the link fails, the upstream failed nodes send a setup message to downstream failed node to establish a disjoint path parallel to the failed link. This process of restoration is called the link restoration [14].

4. Partial Path Restoration [C24] - when failure occurs, the upstream nodes send message to the egress node while the downstream failed node sends teardown message to the egress node. As a result, the partial path is formed to complete the communication between the nodes. This restoration procedure is useful for the optical fiber network in cost effective manner [15].

5. Path Restoration [C25], when a fiber network failure condition occurs, the upstream of failed nodes send a message to the ingress node, while downstream node sends a message to the egress node. As a result, the label switch path is replaced by the new label switch path and forms the intact optical fiber network [16].

Alternatives of survivability in WDM, quantitative analysis of survivability in WDM, we have selected the five alternatives:

A. Service Availability [A1], is necessary condition for present and future application over the internet. The service providers manage secure choice varying between complete security to no security. The [17] focus on service isolation model is based on light path security. The service providers categorize traffic in network as: full protection, no protection and best endeavor. The availability measured in service disruption is also a key alternative of survivability in WDM.
B. Service Reliability [A2], the two alternatives of survivability in WDM networks are reliability and availability. Both have dependent properties; reliability of WDM network is the probability over an interval of time [18]. Reliability has a range from 0 to 1, 0 means non-operational and 1 means perfectly operational. The alternatives reliability and availability are directly proportional to the cost. Making the alternative more reliable and available, incurs additional cost.

C. Restoration Time [A3], it means the time in which the data or optical fiber link is restored and made operational [18]. Link restoration is unidirectional; each connection of link has different wavelength. Restoration path for each connection is performed in parallel with two phase restoration process [19]. The reinstallation effectiveness is the ratio of the number of connections restored after link’s failure to complete the number of connections that traversed across the link.

D. Service Restorability [A4], the survivability in network design achieves fast service restorability [17]. The most widely used network topology is mesh structured. The network failures usually occur due to the optical fiber cut. Fiber cable carries a large amount of data. Fiber cut can lead to huge data loss which affects the revenue. It is indispensable for making optical network survivable and to accomplish rapid restorability against network failures. Therefore, restorability is an important alternative for estimating survivability.

E. Dynamic Restoration [A5], is the protection scheme of WDM network in the failure condition [19]. The restoration process does not preserve special channel in advance but estimates the spare capacity of the network to get replacement of optical channel when the fault occurs. The spare capacity is required more rationally. The routing wavelength assignments calculate the spare capacity. The shortest paths are able to gain the most favorable restoration routes for the traffic obstruction. The dynamic restoration is an alternative of survivability in WDM network.

The different factors/alternatives, as explained above, and their impact on survivability are evaluated by the hybrid methodology FAHP and FTOPSIS. The developers have many choices regarding the design of optical fiber network to select the factors and design the required network. We have considered five alternatives and the two dependent factors in the first layer of factors in our study. For evaluating the optimum survivability, the ten alternatives in the second layer are further classified into five alternatives as shown in figure 1.

Figure 1 shows the alternatives’ and factors’ relation in survivability; we considered A1 to A5 as the alternatives that affect survivability in WDM OFNC. The factors have two layers; layer 1 has two attributes- C1 and C2. The layer 2 has C11 to C15 and C21 to C25 which are the dependent alternatives.

IV. METHODOLOGY
We used the multi-criteria decision making modus operandi for the evaluation of factors in survivability of WDM optical fiber network. The hybrid methodology of FAHP gives the weight of the factors. The FTOPSIS gives the absolute ranking of the factors with respect to the present attributes [20]–[24]. The fuzzy approach of the following methodology has been used in WDM:

The engineers selected the alternatives according to their needs and affixed the initial values according to the quantitative impact of the survivability in WDM OFNC from the proper result, i.e., weights and ranks of the research study. Thereafter, FAHP and FTOPSIS approach were used to determine the impact of survivability in WDM OFNC [25]–[30].
The survivability of WDM network needs to be improved, more so in the wake of natural or manmade calamities which affect the optical fiber network and cause failure. The decision making issues are regularly used for reaching the users’ satisfaction and the security of data. Many strategies and estimation procedure exist in literature that further the understanding of the issues that cause failures in WDM. However, for gauging the impact of survivability in WDM network, FAHP is the most suitable multi-criteria decision selective approach. The fuzzy approach included in AHP gives the most comprehensive scale of decision making. However, FAHP also has some difficulties [31]–[33]. Thus, we included the FTOPSIS and the decision making approach; a hybrid of FAHP and FTOPSIS. This is a unique method, one of its kinds, that assists in efficient assessment of the impact of factors and its alternatives.

FAHP: FAHP is the procedure to determine the critical/hard selection of the problems specifically in survivability of WDM in OFCNR. The FAHP procedure evaluates each individual entity given by the examiner through the average. This categorized approach is known as a hierarchy. The value of fuzzy lies in between 1 and 0 and it represents a specific view. Figure 2 shows the shape of a fuzzy tree. After the structure of fuzzy numbers, we selected the initial value. The next step is to make the Triangular Fuzzy Number (TFN) from the hierarchal structure. The impact of factor and its alternative with one criterion vis-à-vis different alternative criteria is represented through pair-wise comparison of individual factors, which plays a vital role in categorization. Thereafter, in the ensuing step, FAHP transforms the linguistic values into numeric values by using the TFN. In this study, the TFN values are in between the numerical values 1 and 0 [34], [35]. TFN values are used for their simplicity and are valuable due to their alignment with the fuzzy data [36]. FAHP is used to determine the weight of the factors and incorporates the following steps:

**Step 1:** Create the membership function from the TFN expressed in equation 1 and 2.

\[
\mu_a(x) = a \rightarrow [0, 1] \\
\mu_a(x) = \begin{cases} 
\frac{a-B}{B-A}, & A \leq B \leq C \\
\frac{C-B}{C-a}, & B \leq a \leq C \\
0, & a > C \text{ Otherwise}
\end{cases}
\]  

(1)

Let \(l\) = lower limit, \(m\) = middle limit and \(u\) = upper limit in a membership function. The TFN values are shown in figure 2 and its quantitative value in table 1.

Table 1 represents the linguistic weight in the numeric form for our quantitative analysis to determine the impact of survivability.

**Step 2:** Form the matrix and transform the TFN value.

The TFN value is designated as \((l_{ij}, m_{ij}, u_{ij})\) \(l_{ij}\) = lower value, \(m_{ij}\) = middle value and \(u_{ij}\) = upper value, additionally, TFN \(\Phi_{ij}\) is recognized as:

\[
\Phi_{ij} = (l_{ij}, m_{ij}, u_{ij})
\]  

(2)

![FIGURE 2. TFN.](image)

**TABLE 1. TFN scale.**

| Saaty Scale Definition | Fuzzy Triangle Scale |
|------------------------|----------------------|
| 1                      | Fairly Significant \((1,1,1)\) |
| 3                      | inadequately \((2,3,4)\) |
| 5                      | Significant \((5,5,5)\) |
| 7                      | literarily Significant \((6,6,6)\) |
| 9                      | stoutly Significant \((7,7,7)\) |
| 8                      | enormously Significant \((9,9,9)\) |

\[
l_{ij} \leq m_{ij} \leq u_{ij}
\]  

(3)

\[
l_{ij} = \min (J_{ij})
\]  

(4)

\[
m_{ij} = (J_{ij1}, J_{ij2}, J_{ij3})^\frac{1}{3}
\]  

(5)

\[
u_{ij} = \max (J_{ij})
\]  

(6)

The equations 4, 5 and 6 are in the form of \(J_{ij}\), which indicates the comparative values of the two factors specified by the developer \(d\), where \(i\) and \(j\) were selected by the developer. \(\Phi_{ij}\) evaluations are based on the Geometric Mean (GM) by comparison. The GM is used to determine the exact or significant value between the two factors.

Let us consider two factors- \(P\) and \(Q\), \(P = (l_1, m_1, u_1)\) and \(Q = (l_2, m_2, u_2)\). The mathematical operation of the factor is shown below and is represented by equation 7, 8 and 9:

\[
P + Q = (l_1 + l_2, m_1 + m_2, u_1 + u_2)
\]  

(7)

\[
P \times Q = (l_1 l_2, m_1 m_2, u_1 u_2)
\]  

(8)

\[
P^{-1} = \left(\frac{1}{u_1}, \frac{1}{m_1}, \frac{1}{l_1}\right)
\]  

(9)

**Step 3:** Draw the fuzzy pair-wise comparison matrix.

Fuzzy pair-wise comparison matrix is formed with help of equation 10.

\[
\tilde{A} = \begin{bmatrix}
\tilde{k}_{11} & \tilde{k}_{12} & \cdots & \tilde{k}_{1d} \\
\tilde{k}_{21} & \tilde{k}_{22} & \cdots & \tilde{k}_{2d} \\
\vdots & \vdots & \ddots & \vdots \\
\tilde{k}_{n1} & \tilde{k}_{n2} & \cdots & \tilde{k}_{nd}
\end{bmatrix}
\]  

(10)

where \(\tilde{k}_{ij}\) shows the \(d\) decision maker or developer is on both the criteria \(i^{th}\) over \(j^{th}\) in equation 10. In case of more than one developer, the average of differing preferences is selected by the equation 11.

\[
\tilde{k}_{ij} = \sum_{d=1}^{d} \tilde{k}_{ijd}
\]  

(11)
Step 4: Calculate the average preference and form the hierarchy of factors.

With the help of equation 12, we revisited the pair-wise comparison matrix for entirely factors in tree structure on the basis of average preferences.

\[ \tilde{A} = \begin{bmatrix} \tilde{k}_{11} & \cdots & \tilde{k}_{1n} \\ \vdots & \ddots & \vdots \\ \tilde{k}_{n1} & \cdots & \tilde{k}_{nn} \end{bmatrix} \]  

(12)

Step 5: Calculate GM and fuzzy weight of every factor.

Equation 13 shows GM technique; equation 14 helps to determine the fuzzy weight of each factor.

\[ \tilde{p}_i = \left( \prod_{j=1}^{n} \tilde{k}_{ij} \right)^{\frac{1}{n}}, \quad i = 1, 2, 3, \ldots, n \]  

(13)

\[ \tilde{w}_i = \tilde{p}_i \otimes (\tilde{p}_1 \oplus \tilde{p}_2 \oplus \tilde{p}_3 \ldots \oplus \tilde{p}_n)^{-1} \]  

(14)

Step 6: Evaluate the normalized weight.

We calculated the standard and normalized weight criterion with the help of the equation 15 and 16.

\[ M_i = \frac{\tilde{w}_1 \oplus \tilde{w}_2 \oplus \cdots \oplus \tilde{w}_n}{n} \]  

(15)

\[ N_{r_1} = \frac{M_i}{M_1 \oplus M_2 \oplus \cdots \oplus M_n} \]  

(16)

Step 7: Evaluate the Best Non-fuzzy recital.

The centre of area method is used to determine the Best Non-fuzzy Performance (BNP); the significance of the fuzzy weight of every measurement is obtained by the equation 17.

\[ \text{BNPwD1} = \frac{\left[ (u_{w1} - l_{w1}) + (m_{w1} - l_{w1}) \right]}{3} + l_{w1} \]  

(17)

FTOPSIS: The m alternative in geometrical arrangement with m point and n dimensional area, TOPSIS methodology is used in multi-criteria decision selection for ranking. The TOPSIS methodologies are primarily based on the idea of the undeviating and furthermore distance from the positive ideal solution, negative ideal solution for optimum and minimum ideal solution, respectively [36]–[39]. The TOPSIS approach is very useful for allocating the desired position of the alternative and the factor with reference to the criteria. To achieve the uniformity with fuzzy environment, TOPSIS assigns fuzzy numbers according to the preference and represents the significance of criteria. The selected methodology of FAHP and FTOPSIS is suitable for group decision making issues in fuzzy environment. Fuzzy AHP-TOPSIS methodology is as follows:

Step 1: To determine the weights of the estimation factors

The FAHP method gives the weights of the factors with reference to the alternatives.

Step 2: Create fuzzy decision matrix.

The fuzzy decision matrix is created with the help of equation 18 and table 2.

\[ \tilde{K} = \begin{bmatrix} C_1 & \cdots & C_n \\ A_1 & \tilde{x}_{11} & \cdots & \tilde{x}_{1n} \\ \vdots & \ddots & \vdots & \vdots \\ A_m & \tilde{x}_{m1} & \cdots & \tilde{x}_{mn} \end{bmatrix} \]  

(18)

Step 3: Normalize the fuzzy decision matrix.

This is done with the help of equation 19; the normalized fuzzy decision matrix is denoted by \( \tilde{P} \).

\[ \tilde{P} = \left[ \tilde{p}_{ij} \right]_{m \times n} \]  

(19)

The greatest desired level \( u^+_j \) and \( j = 1, 2, \ldots n \) is equal to 1, else the worst is 0. The normalized \( \tilde{p}_{ij} \) continues to be TFNs. For TFNs, the normalization procedure can be achieved in the similar way.

Step 4: Create quantified fuzzy normalized decision matrix.

The weighted fuzzy normalized decision matrix (\( \tilde{Q} \)) is measured from equation 21.

\[ \tilde{Q} = \left[ \tilde{q}_{ij} \right]_{m \times n} \quad i = 1, 2, \ldots, m; \quad j = 1, 2, 3 \ldots n \]  

(21)

where, \( \tilde{q}_{ij} = \tilde{p}_{ij} \otimes \tilde{w}_{ij} \)

The weighted normalized fuzzy decision matrix indicates that the components \( \tilde{q}_{ij} \) are normalized positive TFN. Their range belongs to close interval [0, 1].

Step 5: Evaluate and define FPIS, FNIS.

The Fuzzy Positive-Ideal Solution (FPIS) A+ (aspiration levels), and Fuzzy Negative-Ideal Solution (FNIS) A− (the worst levels) are shown in equation 22 and 23.

\[ A^+ = \left( \tilde{q}_{1j}, \ldots, \tilde{q}_{mj}, \ldots, \tilde{q}_{nj} \right) \]  

(22)

\[ A^- = \left( \tilde{q}_{1j}, \ldots, \tilde{q}_{mj}, \ldots, \tilde{q}_{nj} \right) \]  

(23)

Here \( \tilde{q}_{1j} = (1, 1, 1) \otimes \tilde{w}_{ij} = (L_{w_j}, M_{w_j}, H_{w_j}) \) and \( \tilde{q}_{ij} = (0, 0, 0) \), \( j = 1, 2, 3 \ldots n \).

The detachment of every alternative from FPIS and FNIS is \( \tilde{d}_i^+ \) and \( \tilde{d}_i^- \) of every alternative from A+ and A- can be assessed through the area recompense method as presented in equations 24 and 25.

\[ \tilde{d}_i^+ = \sum_{j=1}^{n} d \left( \tilde{q}_{ij}, \tilde{q}_{ij} \right), \quad i = 1, 2, \ldots, m; \quad j = 1, 2, 3 \ldots n \]  

(24)

\[ \tilde{d}_i^- = \sum_{j=1}^{n} d \left( \tilde{q}_{ij}, \tilde{q}_{ij} \right), \quad i = 1, 2, \ldots, m; \quad j = 1, 2, 3 \ldots n \]  

(25)
TABLE 3. TFN values of factors at level 1.

| (C1)                                | (C2)                                |
|-------------------------------------|-------------------------------------|
| (C1) 1.000000, 1.000000, 1.000000   | 0.305125, 0.389124, 0.561521         |
| (C2) 1.782539, 2.57547, 3.278526   | 1.000000, 1.000000, 1.000000         |

TABLE 4. Fuzzy pair-wise comparison matrix [C1].

| (C11) | (C12) | (C13) | (C14) | (C15) |
|-------|-------|-------|-------|-------|
| 1.000000, 1.000000, | 0.691225, 1.086524, 1.226124, | 0.276524, 1.124114, 1.516254, | 0.495524, 0.933254, 1.215472, | 0.637352, 0.309587, 0.253354, |
| 1.000000, | 1.158475, 1.000000, | 0.357522, 0.695254, 1.000000, | 0.518587, 0.268025, 0.352054, | 0.197652, 0.253354, 0.301854, |
| 0.909124, | 1.128125, 1.000000, | 1.346112, 0.955244, 1.000000, | 1.254751, 0.518587, 1.329548, | 0.435745, 0.197652, 0.253354, |
| 1.494225, | 1.000000, 1.000000, | 1.000000, 0.695254, 1.000000, | 1.552959, 0.518587, 1.329548, | 0.803965, 0.301854, 0.435745, |
| 2.801558, | 3.623524, 0.742251, | 1.254144, 1.000000, 1.000000, | 1.552959, 0.518587, 1.329548, | 0.301854, 0.435745, 0.803965, |
| 4.425552, | 1.438521, 1.000000, | 1.000000, 1.000000, 1.000000, | 1.329548, 0.518587, 1.329548, | 0.435745, 0.803965, 0.301854, |
| 0.517669, | 0.659851, 1.923514, | 2.842141, 0.644251, 1.000000, | 1.000000, 1.000000, 1.000000, | 0.301854, 0.435745, 0.803965, |
| 1.000000, | 3.732215, 1.11245, | 1.11245, 1.000000, 1.000000, | 1.000000, 1.000000, 1.000000, | 0.301854, 0.435745, 0.803965, |
| 1.000000, | 1.569854, 3.952564, | 5.076258, 1.245965, 3.322354, | 2.298893, 1.325415, 1.569542, | 1.000000, 1.000000, 1.000000, |
| 2.040236, | 6.024951, | 3.322354, | 2.045214, | 1.000000, |

Step 6: Evaluate the Closeness Coefficient.

The Closeness Coefficients ($C_{Ci}$) is defined as the relative gaps–degree and it has been calculated by the equation 26. The $C_{Ci}$ build up the alternatives to accomplish the aspiration levels in each factor. The $C_{Ci}$ is cleared to estimate the fuzzy gaps level on the origin of the fuzzy closeness coefficients to recover the alternatives [14], [35], [36]. The $\tilde{d}^+_i$ and $\tilde{d}^-_i$ of each alternative has been intended; the similarities to the ideal solution are estimated.

$$C_{Ci} = \frac{\tilde{k}^-_i}{\tilde{k}^+_i + \tilde{k}^-_i} = 1 - \frac{\tilde{k}^+_i}{\tilde{k}^+_i + \tilde{k}^-_i}, \quad i = 1, 2, \ldots, m \quad (26)$$

Here, $\tilde{k}^-_i$ – defined as fuzzy satisfaction degree in the $i$th alternative, $\tilde{k}^+_i$ – Defined as fuzzy gap degree in the $i$th alternative. On the basis of methodology FTOPSIS, the rank of alternatives is achieved. The next procedure is to assess the survivability of WDM with the help of its causative factors and its alternatives.

V. NUMERICAL ANALYSIS

Quantitative analysis of factors of survivability in WDM OFNC is a difficult task. Estimation and realization of impact is a critical step in making the optical fiber network survivable and to prevent the optical fiber from disintegration due to a fault mentioned in section 3. The successful evaluation of factors and alternatives gives accurate and effective result for optical network industry. We have adopted the hybrid methodology of FAHP and FTOPSIS to achieve the result. Table 1 and equation 1 to 9 have been used for the evaluation of factors.

Linguistic values were transformed into numerical values by TFN. The TFN values were calculated with the help of equation 10 and have been presented in table 4 (for [C1]) and table 5 (for [C2]).

Table 4 represents the values obtained by equation 10 for the calculation, fuzzy pair-wise comparison matrix for the factors of first layer [C1] and its five dependent attributes [C11] to [C15]. The linguistic values are converted into numerical values by TFN values, as shown in table 1.

Table 5 represents the evaluated value by equation 10, fuzzy pair-wise comparison matrix for the factors of first layer [C2] and its five dependent attributes [C21] to [C25]. The numerical values are measured by the TFN values shown in table 1.

From the equation 1 to 17, we calculated the total weight and rank of the factors, as shown in table 6, by FAHP approach. Table 6 represents the layers of factors which are mentioned above in section 3. The primary layers are classified into two types, and the second layer is classified into five dependent alternatives C11 to C15 and C21 to C25 respectively. The weights of the factors are determined by the equation 15 and normalized weights are evaluated by the equation 16. The best non fuzzy performance values are evaluated by referring to equation 17. Then the final rank is formed by the evaluated values.

The pair-wise comparison matrix from the equation 18 is constructed in table 7. The linguistic values of the alternatives with respect to the alternative are mentioned below; it evaluates the linguistic values that were taken from the TFN.

The normalized fuzzy decision matrix is constructed by the equation 19 and 20. The normalized value of alternative is evaluated by referring to equation 17. Then the final rank is formed by the evaluated values.

The weighted normalized decision matrix is evaluated by the equation 21; the calculated value is presented in the table 10. The closeness coefficients of the factors are estimated by the equations 24 and 25 for estimating the value.
TABLE 5. Fuzzy pair-wise comparison matrix ([C2]).

|   | (C21)  | (C22)  | (C23)  | (C24)  | (C25)  |
|---|--------|--------|--------|--------|--------|
| (C21) | 1.000000, 0.000000 | 0.658554, 1.688254 | 1.165254, 1.149254 | 1.439659, 0.268652 | 0.352854, 0.258225 | 0.338699, 0.505575 |
| (C22) | 0.592121, 1.519624 | 1.000000, 0.000000 | 1.000000, 2.159987 | 1.583635, 1.658965 | 1.516325, 0.690665 | 1.005926, 1.511767 |
| (C23) | 0.589852, 0.879522 | 0.694254, 0.465223 | 0.631223, 1.000000 | 1.000000, 1.996545 | 1.000000, 0.896367 | 0.522354, 0.807496 |
| (C24) | 1.939987, 3.731963 | 2.843654, 0.517225 | 0.659321, 0.644123 | 0.757525, 1.000000 | 1.000000, 0.896367 | 1.148696, 1.390366 |
| (C25) | 1.978365, 3.875945 | 2.953385, 0.661511 | 0.994224, 1.238533 | 1.915732, 0.719233 | 0.870622, 1.000000 | 1.000000, 1.000000 |

TABLE 6. Overall weights through the hierarchy.

| First Characteristic | Level | Local Weights of First Level | Second Characteristic | Level | Local Weights of Second Level | Overall Weights | BNP | Final Ranks |
|---------------------|-------|-------------------------------|-----------------------|-------|-------------------------------|----------------|-----|------------|
| C1                  | 0.316589, 0.386658 | 0.329578 | C11                  | 0.208095 | 0.066124, 0.074701, 0.111999 | 0.0842779 | 6   |            |
|                     | 0.226658 | 0.286968 |                     | 0.029987 | 0.000712, 0.000862, 0.001819 | 0.0378881 | 10  |            |
|                     | 0.033158 | 0.041469 |                     | 0.153867 | 0.021712, 0.027625, 0.041323 | 0.0692546 | 8   |            |
|                     | 0.179897 | 0.241996 |                     | 0.489769 | 0.004025, 0.005352, 0.009485 | 0.0776958 | 7   |            |
|                     | 0.514383 | 0.538194 |                     | 0.002358 | 0.266475, 0.290214, 0.347465 | 0.0923458 | 4   |            |
| C2                  | 0.619875, 0.686587 | 0.673368 | C21                  | 0.069589 | 0.013535, 0.014726, 0.015255 | 0.0529804 | 9   |            |
|                     | 0.084695 | 0.107568 |                     | 0.204254 | 0.126599, 0.153258, 0.159795 | 0.2759987 | 1   |            |
|                     | 0.227125 | 0.282547 |                     | 0.027225 | 0.016711, 0.019375, 0.022301 | 0.0899988 | 5   |            |
|                     | 0.033004 | 0.041054 |                     | 0.153785 | 0.095035, 0.120584, 0.166014 | 0.1224985 | 2   |            |
|                     | 0.179958 | 0.241965 |                     | 0.049725 | 0.302371, 0.346346, 0.365328 | 0.0970699 | 3   |            |
|                     | 0.514336 | 0.538189 |                     | 0.649175 | 0.686587, 0.720285, 0.764882 | 1.000000, 1.000000 |

of \(d_1^+\) and \(d_1^-\). The degree of closeness (\(CC_1^+\)) is obtained from equation 26. For evaluating the impact of the factors on survivability in WDM OFNC, five alternatives of the factors are selected for determination of survivability of WDM; all are very sensitive for evaluation.

VI. SENSITIVITY ANALYSIS

The sensitivity analysis is employed to verify the result of survivability of WDM in OFCN. The sensitivity analysis is presented in table 11. The sensitivity analysis calculated by the weight of variables was obtained by the FAHP method. The sensitivity analysis, verified by multiple experiments of each factor with the different experiments, shows different results, as depicted in table 11. The bar graph of the sensitivity analysis is shown in figure 3. The satisfaction degree (\(CC_1^-\)) is calculated by the weight of each factor (F1 to F5 taken as a constant), and by FAHP and FTOPSIS methodology, we calculated the (\(CC_1^-\)).

VII. COMPARISON THROUGH VARIOUS AHP-TOPSIS APPROACHES

For a more emphatic analysis and to verify the reliability and efficiency of the technique, researchers enlist different methods [27]. In this paper, we have used FAHP...
and FTOPSIS methodology to evaluate the efficiency and closeness or accuracy of the result obtained [28]. We compared the result with five different methodologies which are mentioned in table 12 and the graph is shown in figure 4. In classical AHP-TOPSIS, data anthology and estimation of the data is identical as in Fuzzy AHP-TOPSIS but no fuzzification is used. The results elicited through the usual AHP-TOPSIS method are highly interrelated (Pearson correlation coefficient is 0.999176) with the outcome achieved by the quantitative analysis of F-AHP-TOPSIS method and Delphi AHP TOPSIS, Fuzzy Delphi AHP TOPSIS are highly related [29]–[33]. The reliability and efficiency of FAHP, TOPSIS is improved and it is a better procedure than the other approaches.


disruption in restoration technique got the first rank in our evaluation.

The methodology FAHP and FTOPSIS have coordination criteria, the criteria make the implementation of decision complex in design aspect of WDM network. The different

and FTOPSIS methodology to evaluate the efficiency and closeness or accuracy of the result obtained [28]. We compared the result with five different methodologies which are mentioned in table 12 and the graph is shown in figure 4. In classical AHP-TOPSIS, data anthology and estimation of the data is identical as in Fuzzy AHP-TOPSIS but no fuzzification is used. The results elicited through the usual AHP-TOPSIS method are highly interrelated (Pearson correlation coefficient is 0.999176) with the outcome achieved by the quantitative analysis of F-AHP-TOPSIS method and Delphi AHP TOPSIS, Fuzzy Delphi AHP TOPSIS are highly related [29]–[33]. The reliability and efficiency of FAHP, TOPSIS is improved and it is a better procedure than the other approaches.


disruption in restoration technique got the first rank in our evaluation.

The methodology FAHP and FTOPSIS have coordination criteria, the criteria make the implementation of decision complex in design aspect of WDM network. The different alternatives on survivability of WDM in optical fiber network [40], [41]. The present research study’s results establish the efficacy of the proposed methodology in verifying the impact of survivability on WDM. Recovery and protection are the basic requirements for survivability. Furthermore, the protection of optical fiber is the need of time so as to secure the network from the destruction caused by disasters like storm, earthquake, etc. This research paper selected five significant alternatives, two primary and ten secondary dependent factors, which depend on alternatives of survivability in WDM of optical fiber networks. Results show that each factor of optical fiber network has a significant effect on the optical fiber network. The factor - number of disruption in restoration technique got the first rank in our evaluation.

The methodology FAHP and FTOPSIS have coordination criteria, the criteria make the implementation of decision complex in design aspect of WDM network. The different
developers have different criteria for the same system according to their need.

The hierarchy diagram of various alternatives and factors in figure 1 describes the factors and alternatives connectivity in WDM network. These factors are interconnected with each other. To evaluate the impact of survivability in WDM optical fiber network, we evaluated the factors and their dependent alternatives through the hybrid approach of FAHP and FTOPSIS. Thereafter, we validated the methodology of combined FAHP and FTOPSIS to provide the ranking of the result from the hierarchy in figure 3. The key findings of survivability in WDM are:

- Result of the factors affecting the survivability of WDM in optical fiber network provides a systematic and accurate priority list.
- This priority list will be an accurate reference for the developers working in the domain of protection and restoration, and enhancing survivability in WDM.
- The most prioritized alternative is dynamic restoration in evaluated result of the survivability in WDM optical fiber network.
- The most prioritized factor is the number of disruption in the selected alternatives. It is very useful for the researcher and developers to take a restoration path for the data in WDM.
- The study has found five alternatives that affect the survivability in WDM. By adopting this assessment, the weights of the survivability alternatives can be elicited.

Methodology has the limitation of alternatives and dependent factors in WDM network. The number of factors and alternatives increases the complexity of evaluation. Increasing the factors and alternatives in further two or three
levels will make the evaluation more appropriate. The other methodologies of multi criteria decision making are also useful in different aspects and application as per the requirement of developers. In comparison section we have mentioned the result of decision making and compared it with our result which is more appropriate and exact in calculation.

Survivability is the lifeline of efficient optical networks. This research study aims to make the future development of optical fiber more secure and restorable. The comprehensive research of survivability must cover the technically upgraded factors as well as the restoration process in a single manuscript. The present study integrates the two contexts and is very useful for the protection and restoration of survivability in WDM of optical fiber network.

**IX. CONCLUSION**

The survival of wavelength divisions multiplexing (WDM) in the optical fiber communication market can be affected by fault. Even a single fault could cause both monetary inversion and system failures, thus posing a huge obstacle for professionals and installation experts. Therefore, it is important to work on survival mitigation approaches. This study examined the factors as well as their alternatives that are important for the desired level of survivability in WDM network. According to our evaluation, the *dynamic restoration* and *failure repair rate* associated with it attain the topmost priority in WDM. Furthermore, this study employed the Fuzzy based Hybrid Technique of AHP and TOPSIS for ranking the weights of the factors and alternatives obtained through the empirical analysis. The conclusive results tabulated by

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**TABLE 12. Comparison table of methodologies.**

| Approaches/Alternatives | A1     | A2     | A3     | A4     | A5     |
|--------------------------|--------|--------|--------|--------|--------|
| Fuzzy-AHP-TOPSIS         | 0.934589 | 0.868754 | 0.825487 | 0.979854 | 0.902457 |
| Classical-AHP-TOPSIS     | 0.938568 | 0.853526 | 0.807977 | 0.963585 | 0.978795 |
| Fuzzy-AHP-SAM            | 0.928958 | 0.852457 | 0.806299 | 0.965345 | 0.978136 |
| Delphi-AHP-TOPSIS        | 0.933112 | 0.852775 | 0.807748 | 0.963435 | 0.978775 |
| Fuzzy-Delphi-AHP-TOPSIS  | 0.932154 | 0.855111 | 0.809519 | 0.964565 | 0.979226 |

**FIGURE 3.** Bar graph of sensitivity analysis.

**FIGURE 4.** Comparison of Different Methodologies.
our research seek to be an emphatic reference for the experts working in the domain of optical communication network.

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FAHAD AHMED AL-ZAHRANI received the B.Sc. degree in electrical and computer engineering from Umm Al-Qura University, Mecca, Saudi Arabia, in 1996, the M.S. degree in computer engineering from the Florida Institute of Technology, in 2000, and the Ph.D. degree in computer engineering from Colorado State University, in 2005. From to, he was the IT Dean of Umm Al-Qura University. He is currently an Associate Professor with the Department of Computer Engineering, Umm Al-Qura University. He has taught several computer network courses and supervised related research projects. He has had several other responsibilities thereafter. His research interests include high-speed network protocols, sensor networks, optical networks, performance evaluation, the IoT, and blockchain architecture and performance analysis. He is also a member of the International Society for Optical Engineering and the Optical Society of America.