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Implementation of FDSS (Fuzzy Decision Support System) Sugeno Model in Optimizing Bandwidth Requirement Management of Web-Based Networks

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ABSTRACT

To increase the efficacy of bandwidth allocation at PT. Digdaya Monokrom Group, this study describes the development of a Fuzzy Decision Support System (FDSS) utilizing the Sugeno methodology. The Waterfall development process is employed for the purposes of system planning, construction, and maintenance. The study consists of three primary stages: the creation of fuzzy sets, the development of fuzzy rules, and the process of defuzzification. The study findings demonstrate that the utilization of FDSS has effectively improved the distribution of bandwidth. The distribution has shifted from a uniform one to a more optimized allocation, focusing on the Execution, Content Creator, Administration, and Research Team departments. During a four-week monitoring period, modifications were implemented to distribute bandwidth based on the preferences and needs of various departments, while adhering to the limitations of the current broadband subscription. This has enhanced the efficient exploitation of network resources. The research findings highlight the efficacy of FDSS in prioritizing resource allocations according to specific departmental requirements, consequently improving service quality and maximizing bandwidth subscription capacity. This demonstrates the implementation of strategic management methodologies to optimize the allocation of network resources, resulting in enhanced organizational efficiency and production.

Keywords: Bandwidth Allocation, Fuzzy Decision Support System, Network Resource Management, Sugeno Methodology, Waterfall Development.

INTRODUCTION

The Interconnection Network, sometimes known as the Internet, is a worldwide computer network that links different locations across the globe utilizing the Internet Protocol Suite standard[1]. The internet currently has a fairly large role in human life, and current technological advances support this role, resulting in the use of computers and internet technology in various fields, such as completing school assignments, studying, managing family finances, listening to music, watching videos, and enjoy the game[2]. The inception of the internet was initially recognized in Indonesia throughout the 1990s[3]. The advent of information technology, particularly the internet, has expanded worldwide connectivity, enabling limitless interactions, market opportunities, and the establishment of global commercial networks. The internet, functioning as both infrastructure and network, has significantly enhanced the efficacy and efficiency of company operations. It serves as a vital platform for publication, communication, and access to essential information[4]. The internet is categorized into many types based on its size, including Local Area Network (LAN), Wide Area Network, and Metropolitan Area Network (MAN)[5].

In the dynamic and ever-changing contemporary business environment, organizations must adjust their strategies to fulfill the growing need for internet infrastructure[6]. The proliferation of local area networks (LANs) and the growth of online activities require the implementation of efficient coordination strategies to optimize the requirements for network bandwidth. Ensuring ongoing connectivity and meeting the increasing requirements of an organization is of utmost importance. In the digital era, it is crucial to have efficient bandwidth management to ensure fair distribution of bandwidth among all users[7].

Bandwidth is the measure of the transmission capacity of data packets in computer networks, which determines the amount of information that can be transferred in a specific time period. Internet bandwidth refers to the quantification of data transmission consumption, commonly measured in bits per second (bps)[8],[9]. The speed of data transmission at a certain region is influenced by the available bandwidth capacity[10]. Higher bandwidth facilitates faster communication by enabling the allocation of packet routing types, packet size, burst routing support, and burst convergence plans. These factors collectively determine the amount of bandwidth allocated to the routing class[11]. Frequently, the bandwidth inside an internet group is not utilized efficiently, hence impacting the functionality of the network. As the user base expands, the availability of network bandwidth becomes a crucial consideration[12].

Companies in the internet connectivity industry face numerous obstacles that can interrupt client network services. One difficulty is the substantial surge in network users that surpasses the company's bandwidth capability. This can result in network congestion and a decline in performance[13]. Therefore, to tackle this problem, it is necessary to implement bandwidth management.

Bandwidth management refers to a collection of methods and resources used to decrease congestion in a network. These methods include data compression, prioritizing bandwidth based on specific criteria, blocking certain traffic, shaping traffic, and controlling traffic flow[14]. Bandwidth management is the process of optimizing the allocation and utilization of network resources to facilitate efficient communication and coordination among computer networks within a given context. Bandwidth management refers to the implementation of policies in network management to promote optimal network performance and equitable distribution of resources among users[7], [15]. In addition, proper bandwidth management can address the issue of bandwidth monopoly, ensuring that other computers receive a fair and equitable allotment of bandwidth[16].

To assess the equitable distribution of bandwidth management, a Decision Support System (DSS) will be employed. A DSS is a constituent of a computer-based information system that aids in the decision-making process inside an organization or corporation[17]. Within the realm of decision support systems (DSS) development, there has been a notable progression towards the utilization of a fuzzy-based system called the Fuzzy Decision Support System (FDSS). This system aids in making managerial or intuitive decisions to resolve problems by supplying the required information, which is subsequently assessed to generate an alternative decision[18].

Fuzzy logic, introduced by Lotfi A. Zadeh in 1965, has found applications in diverse industries as a means of representing human thought in a system[19]. The fuzzy notion employs mathematics that is comprehensible, adaptable to imprecise data, capable of representing intricate non-linear functions, and possesses various other advantages[20]–[22].

Sugeno's fuzzy logic has demonstrated its efficacy in a diverse array of applications across other sectors. These applications encompass decision support systems for weather prediction, arranging lecture times, computing service delivery commissions (such as jastip services), and determining production quantities using online data. Sugeno's fuzzy logic has continuously demonstrated its ability to generate accurate forecasts and efficient solutions throughout various studies[23]–[26]. The literature research findings indicate that Sugeno's fuzzy logic is a dependable approach for addressing challenges related to uncertainty and complexity due to its capacity to generate numerical outputs through a linear combination of inputs.

The utilization of Sugeno fuzzy logic can yield practical and ideal outcomes, particularly in the realm of bandwidth control, where issues such as fluctuations in network usage and lighting conditions can pose significant obstacles. The Sugeno fuzzy logic, with its capacity to address communication challenges and offer precise numerical solutions, has significant promise in the development of a Fuzzy Decision Support System (FDSS) for effectively managing bandwidth and promptly responding to network requirements. By employing the Sugeno fuzzy logic approach to construct FDSS, one can greatly enhance the efficiency and excellence of network services.

The utilization of FDSS with Sugeno fuzzy logic in bandwidth management holds significant promise for enhancing network performance. FDSS is anticipated to offer a more prompt and adaptable solution for managing and adjusting network utilization in response to network requirements. The anticipated outcome of this study is that it will enhance the efficiency and efficacy of bandwidth management, hence promoting equitable allocation of bandwidth among all users. Therefore, there is an expectation that the performance and quality of network services will experience a substantial improvement.

METHODS

The system that will be developed will use the Waterfall development model or known as the SDLC (Software Development Life Cycle), a method often used in software development to plan, build, and maintain a product/system. The Waterfall or "waterfall method" is a method developed by Winston W. Royce in 1970, where software development is done sequentially. This method has several phases, namely: analysis, design, implementation, testing, and maintenance [27]–[29].

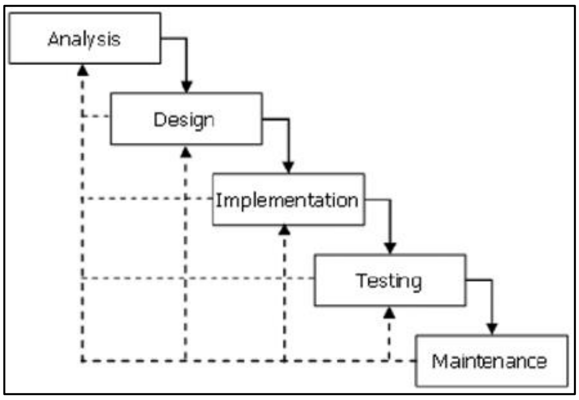


Figure 1. Waterfall Method

In accordance with the model used to develop the system, the initial phase is to analyze the needs such as identifying problems, goals, and system requirements through observation. Next is the design phase, where the system design is carried out according to the needs that have been determined in the previous stage. Then, the designed design will be implemented in the system coding (software development), in this case entering the implementation stage. After that, the system will be tested using black box testing which is a testing method that focuses on the functional aspect. At the final stage is system maintenance and improvement (if bugs or errors are found).

In the creation of Fuzzy Decision Support System using the Sugeno fuzzy method, the method introduced by Takagi-Sugeno Kang in 1985 introduces an output method (consequent) that is not in the form of sets, but in the form of equations (constants) or linear equations. Where the use of singleton as the membership function of the equation. Singleton is a fuzzy set that has a membership function at a specific point has a value and 0 outside that point.

This method consists of several parts; first of the formation of sets, application of fuzzy rule, and defuzzification as an output. Almost similar to the Mamdani method, but what differentiates the Sugeno method and Mamdani is the output membership function of the Sugeno method itself is in the form of a liner or constant[30].

RESULT AND DISCUSSION

The subsequent text outlines the structure of bandwidth management utilizing the Fuzzy Decision Support System (FDSS) employing Sugeno fuzzy logic. This entails the utilization of a decision support system that employs Sugeno fuzzy logic to effectively oversee and enhance the distribution of bandwidth within the network. The output variables utilized in this scenario are "Upgrade" and "Normal," which signify the different degrees of bandwidth allocation offered to users.

A. Formation of Fuzzy Sets

The system to be developed has three inputs and will produce one output, the inputs include Bandwidth, Number of Users and Network Quality. The fuzzy sets for each variable have 3 sets, namely ‘Sedikit/Buruk’, ‘Sedang/Cukup’, and ‘Banyak/Baik’. For membership function graph is shown in figure 2.

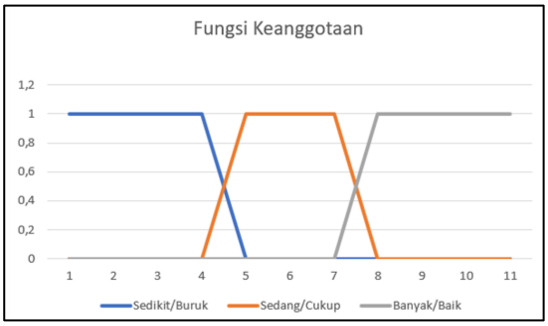


Figure 2. Membership Function Graph

The fuzzy set ‘Sedikit/Buruk’ has the highest degree of membership (=1) located at a value between 33.3. The membership function of ‘Sedikit/Buruk’ is shown in equation (1).

$$\mu Sedikit\ atau\ \mu Buruk\ (x) = \begin{cases} 1; x \leq 33{,}3 \\ \frac{(66{,}6-x)}{33{,}3}\ ; 33{,}3 \leq x \leq 66{,}6 \\ 0; x \geq 66.6 \end{cases} \quad (1)$$

The fuzzy set ‘Sedang/Cukup’ with the highest degree of membership (=1) is located between the values of 33.3 and 66.6. The membership function of ‘Sedang/Cukup’ is shown in equation (2).

$$\mu Sedang\ atau\ \mu Cukup(x) = \begin{cases} 0; x \leq 33{,}3\ atau\ x\ \geq 66{,}6 \\ \frac{(100-x)}{33{,}3}; 33{,}3 \leq x \leq 66{,}6 \\ \frac{(100-x)}{33{,}3}; 66{,}6 \leq x \leq 100 \end{cases} \quad (2)$$

Meanwhile, the fuzzy set ‘Banyak/Baik’ with the highest degree of membership (=1) is located at the value 66.6. The membership function of ‘Banyak/Baik’ is shown in equation (3).

$$\mu Banyak\ atau\ \mu Baik(x) = \begin{cases} 1; x \leq 66{,}6 \\ \frac{(x-66{,}6)}{33{,}3}\ ; 66{,}6 \leq x \leq 100 \\ 0; x \geq 100 \end{cases} \quad (3)$$

B. Formation of Fuzzy Rules

In fuzzy logic, the basic rule-based methodology for determining the placement of input and output is represented in the form of conditions and actions, commonly referred to as IF-THEN rules. This allows the fuzzy system to operate without the need for composition and decomposition[31]. The fuzzy rules established for optimizing bandwidth management using the Sugeno fuzzy method can be seen in Table 1.

Table 1. Fuzzy Rule

No.	Bandwidth	Number of Employees	Service Quality	Output
1	A little	A little	Poor	Upgrade
2	A little	A little	Fair	Upgrade
3	A little	A little	Good	Normal
4	A little	Some	Poor	Upgrade
5	A little	Some	Fair	Upgrade
6	A little	Some	Good	Normal
7	A little	Many	Poor	Upgrade
8	A little	Many	Fair	Upgrade
9	A little	Many	Good	Normal
10	Some	A little	Poor	Upgrade
11	Some	A little	Fair	Upgrade
12	Some	A little	Good	Normal
13	Some	Some	Poor	Upgrade
14	Some	Some	Fair	Upgrade
15	Some	Some	Good	Normal
16	Some	Many	Poor	Upgrade
17	Some	Many	Fair	Upgrade
18	Some	Many	Good	Normal
19	Many	A little	Poor	Upgrade
20	Many	A little	Fair	Upgrade
21	Many	A little	Good	Normal
22	Many	Some	Poor	Upgrade
23	Many	Some	Fair	Upgrade
24	Many	Some	Good	Normal
25	Many	Many	Poor	Upgrade
26	Many	Many	Fair	Upgrade
27	Many	Many	Good	Normal

C. Defuzzyfication

In the fuzzy process, the input for the rule-firming step is the fuzzy set obtained from the fuzzy rule composition, while the output generated is a fixed real number. Therefore, by given a fuzzy set within a certain range, a specific defuzzification value can be taken as the output[32]. In the Sugeno fuzzy method, the defuzzification process uses the Weighted Average method in equation (4).

$$WA = \frac{a_1 z_1 + a_2 z_2 + \cdots\ldots + a_m z_m}{a_1 + a_2 + \ldots + a_m} \qquad (4)$$

Description:

WA = Average value

a_n = Value of rule predicate – n and z_n

z_n = Output value index (constant) to – n

The output generated from the defuzzification process will be displayed using the following criteria: it will represent the fixed real value that is obtained from the composition of fuzzy rules, and it will be taken as the output within a certain range of fuzzy sets through the use of the Weighted Average (WA) method in the Sugeno fuzzy method.

Table 2. Range Fuzzy Output

Fuzzy Output	Range
Upgrade	$10 \geq N \leq 100$
Normal	$0 \geq N \leq 10$

D. Analysis and Design

The development of web-based decision-making using Fuzzy Sugeno goes through several stages, including: Analysis, in this stage the problem analysis is obtained from literature study, and if there is a theory that supports it, then in the analysis of the needs related in the development process of this system.

Then, the design stage begins, starting with the creation of a database that will be visualized in the form of an Activity Diagram, the creation of an Activity Diagram is an important factor in software development, as it provides a visual representation of the flow of activities in a system and can help to understand, document, communicate, and model a process. Additionally, it makes it easier for developers to identify areas that are potentially buggy[33]. The Activity Diagram will be presented in the form of UML (Unified Modeling Language), where the programming will be displayed in a visual diagram intended to be used in object interaction design[34].

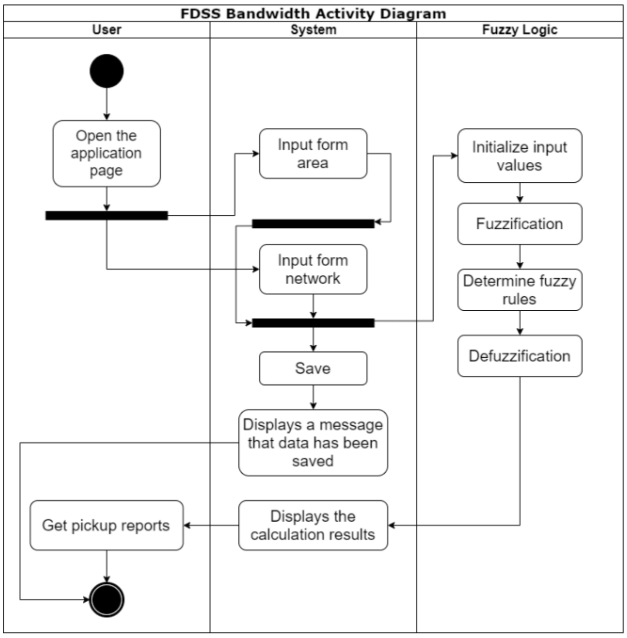


Figure 3. FDSS Bandwidth Activity Diagram

E. Application

The next step is to implement the previously designed implementation in a programming language, PHP (Hypertext Processor) is chosen as the programming language in the development of FDSS due to being a frequently used language for creating dynamic websites and being open-source. And using Sublime Text 3 as the text editor software.

1) *Landing Page*

The landing page that will be seen is the initial view of the web-based FDSS Sugeno model, as shown in Figure 4, where upon clicking the start menu, the user will be directed to the ‘Laporan SPK’ menu which is the output of the network bandwidth input.

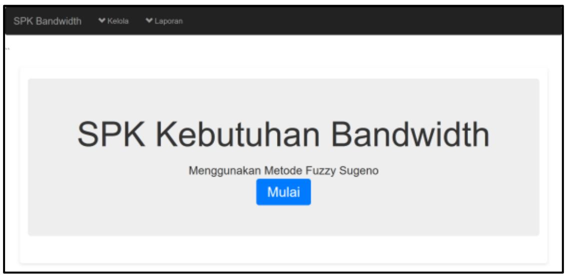


Figure 4. Landing Page

2) *Manage Page*

The management page is where users can add areas they want to assess the optimality of bandwidth distribution. The management page is divided into several sections, namely: area, network, and rules.

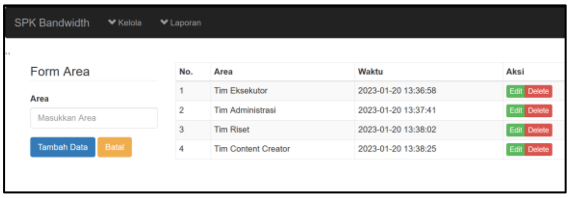


Figure 5. Area Management Page

Then in the management menu there is a manage rules page, its purpose is to input pre-determined rules and their sets in Table 1.

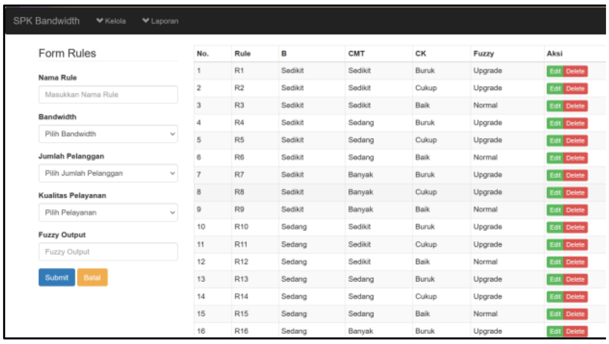


Figure 6. Manage Rules Fuzzy Page

3) *Input Page*

The input page is provided for users to input variables that will be calculated using the Sugeno fuzzy method in making decisions in optimizing the network according to the previously inputted area which can be seen in Figure 7.

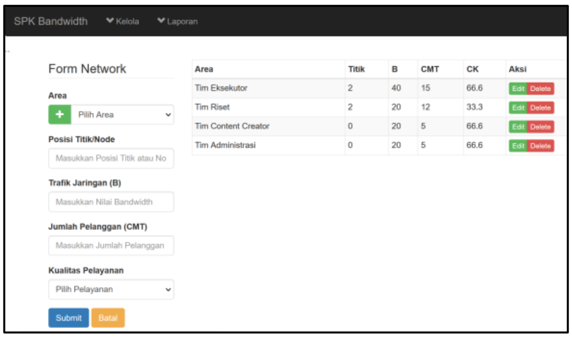


Figure 7. Input Network Page

4) *Monitoring Page*

After the variables are inputted on the input network page, the results of calculations using the Sugeno fuzzy method will be displayed on the monitoring page, the results will be issued in the form of 'upgraded' or 'normal' variables which can be seen in Figure 8, referring to the predefined fuzzy rules.

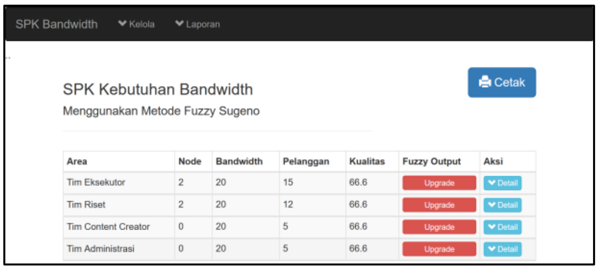


Figure 8. FDSS Output Page

For the 'details' feature provided to display fuzzy calculations, it can be seen in Figure 9.

Figure 9. FDSS Output Detail Display

F. Testing

After the system is developed, it will go through the testing phase. The purpose of the system testing is to evaluate the functionality of the application and to determine whether the program to be developed meets the expected results. It also ensures that the application has the best and maintained quality. In this case, the testing to be done is black box testing, which is a method for testing software without having to consider the detail of the software. The black box testing process consists of testing the program created by trying to input data into every form. This test is required to determine whether the program works according to its purpose[35], [36]. Table 3 is the test result of the black box.

Table 3. Test results from the black box

Testing Components	Testing Results
Click the 'Start' button	Valid
Click the 'Manage' menu bar	Valid
Click the 'Network Management' menu	Valid
Click the 'Area Management' menu	Valid
Click the 'Rules Management' menu	Valid
Click the 'Report' menu bar	Valid
Click the 'Decision Support Report' menu	Valid
Input data in the 'Network Management' menu	Valid
Edit data in the 'Network Management' menu	Valid
Delete data in the 'Network Management' menu	Valid
Input data in the 'Area Management' menu	Valid
Edit data in the 'Area Management' menu	Valid
Delete data in the 'Area Management' menu	Valid
Input data in the 'Rules Management' menu	Valid
Edit data in the 'Rules Management' menu	Valid
Delete data in the 'Rules Management' menu	Valid
Click 'Detail' in the Decision Support Report menu	Valid
Click 'Print' in the Decision Support Report menu	Valid

G. Implementations

After a meticulous application testing phase, the application was deployed at PT. Digdaya Monokrom Group, a company engaged in service and information technology. The company subscribes to a 100 Mbps WiFi service. However, within their existing network setup, there arose a pressing need to allocate bandwidth more judiciously among the various company divisions.

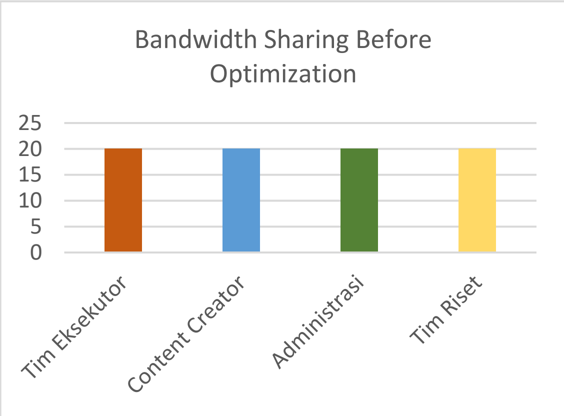


Figure 10. Bandwidth Allocation Before Optimization Using FDSS

Prior to adopting FDSS optimization, the distribution of bandwidth at PT. Digdaya Monokrom Group is evenly distributed, with each division receiving an allocation of 20 Mbps. The equitable allocation adheres to the notion of impartiality throughout the company's several departments. Nevertheless, it is recognized that this equitable allocation does not consistently cater to the particular requirements of every department. Furthermore, considering the ever-changing and progressive nature of the corporate environment, different divisions within a corporation have varying requirements for data transmission capacity. As the imprecise output calculation (illustrated in Figure 8) reveals, 'Upgrade' is suggested as an alternative, denoting modifications in the allocation of bandwidth within each division.

Hence, in order to attain a more efficient distribution of bandwidth, a resolution was pursued by implementing a Decision Support System (DSS) based on Fuzzy Logic, utilizing the Sugeno model. The implementation of FDSS optimizes the distribution of bandwidth based on predefined preferences, giving highest priority to the Execution Team for the greatest allocation. Subsequently, the Content Creator emerged, necessitating a substantial amount of bandwidth for marketing endeavors. Following that, an allocation was assigned to the Administration department, which is accountable for the company's daily activities. Lastly, the Research Team was granted an allocation specifically designed to meet their requirements in supporting research and development.

This strategy led to a more effective and customized distribution of bandwidth across different departments within PT. Digdaya Monokrom Group, meeting their specific needs and assuring a more streamlined operation.

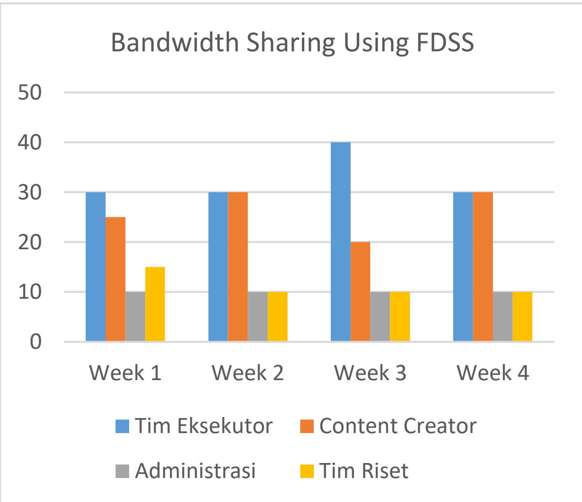
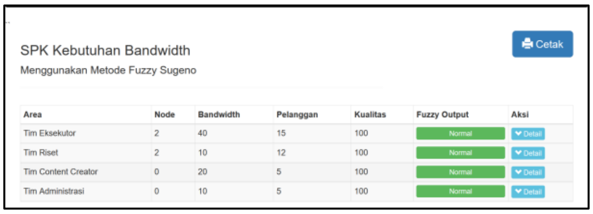


Figure 11. Bandwidth Allocation After FDSS Implementation

Figure 11 demonstrates that during the course of four weeks of monitoring, the allocation of bandwidth has been modified in response to the evolving preferences and requirements of each division. The entire bandwidth distribution remains consistent in accordance with the predetermined limit. These allocation adjustments allow the organization to more effectively meet the changing demands of each division over time, prioritizing the Execution Team with the greatest allocation, followed by the Content Creator, Research Team, and Administration. Consequently, the allotment of bandwidth is customized to fulfill the requirements of each division while staying within the limits of the current subscription capacity.


SPK Kebutuhan Bandwidth
Menggunakan Metode Fuzzy Sugeno
Cetak

Area	Node	Bandwidth	Pelanggan	Kualitas	Fuzzy Output	Aksi
Tim Eksekutor	2	40	15	100	Normal	Detail
Tim Riset	2	10	12	100	Normal	Detail
Tim Content Creator	0	20	5	100	Normal	Detail
Tim Administrasi	0	10	5	100	Normal	Detail

Figure 12. Fuzzy Output Results in the Third Week

The implementation of FDSS for bandwidth allocation provides numerous significant benefits. FDSS facilitates the allocation of bandwidth depending on the specific needs of each department, so enabling the organization to maximize the exploitation of network resources. By allocating resources wisely, FDSS helps the organization improve the quality of services provided by each department while maximizing the capacity of the available bandwidth subscription. This signifies a tactical maneuver in the administration of network resources that has the potential to improve the overall efficiency and production of the firm. Furthermore, Figure 12 visually illustrates the fuzzy output observed in the third week, indicating a 'Normal' allocation result. This exemplifies how FDSS effectively allocates bandwidth to satisfy departmental requests in various scenarios.

CONCLUSION

Optimal bandwidth allocation is essential for ensuring network efficiency. Poor usage of bandwidth can result in a decline in performance. The remedy for this issue involves creating a system that employs the FDSS Sugeno Model. The development process adheres to the systematic Waterfall methodology, which includes distinct stages such as analysis, design, implementation, testing, and maintenance.

After the system's development, black box testing is performed to evaluate its efficacy in managing bandwidth utilization. The test results are analyzed using Fuzzy Sugeno logic, resulting in an output of either 'Upgrade' or 'Normal' depending on predefined thresholds for bandwidth use.

To summarize, the developed system has the ability to make well-informed decisions in order to efficiently manage and regulate the utilization of bandwidth. This leads to a network that is more uniformly dispersed and optimized, in accordance with defined preferences and requirements. The evaluation of the network's performance pre and post bandwidth optimization using FDSS reveals substantial enhancements, hence emphasizing the efficacy of this strategy in augmenting network efficiency.

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