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Mamdani Fuzzy Expert System for Online Learning to Diagnose Infectious Diseases

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Abstract

E-learning and expert systems can be implemented for learning in the health sector. Through the e-learning system, prospective health workers can analyze problems by exploring the material in the system. However, material learning alone is less effective, so case study-based learning using an expert system is needed to strengthen understanding. The research applies an expert system to online learning to diagnose several infectious diseases. The disease diagnosis process uses the backward chaining method and the Mamdani fuzzy inference system. The fuzzy Mamdani inference system determines the intensity of disease severity so that appropriate treatment recommendations can be made. The test findings on 15 test datasets yielded a backward chaining accuracy value of 100%. Three test scenarios were used to establish the test using the Mamdani fuzzy inference method. Scenario 1: Testing with the Center of Gravity defuzzification and Fuzzy Mamdani Min inference system Tests employing the Fuzzy Mamdani Min inference method and center average defuzzification are used in Scenario 2. Scenario 3 involves testing using the Fuzzy Mamdani Product Inference System with Center Average Defuzzification. The average outcome for the intensity of disease severity utilizing the Fuzzy Mamdani Min inference system with Center of Gravity defuzzification was greater than that of the two test scenarios that were suggested, which was 49.43%.

Keywords: *Expert System, Backward Chaining, Fuzzy Mamdani Min, Fuzzy Mamdani Product, Infectious Diseases*.

1. Introduction

The development of science and technology creates a new transition. The learning process that is usually done offline is now being done online. Online learning uses system support, such as e-learning and expert systems. E-learning and expert systems can be implemented for learning in the health sector. Paramedics widely use e-learning systems to get information quickly and precisely [1]. This is supported by the system's ease of access from any location as long as it is connected to the internet.

Several studies have made use of e-learning platforms, including those for learning Arabic [2], medical-surgical nursing [3], and the e-Sorogan system for basic nursing science [4]. Users of the system provided these studies with some excellent feedback. However, the developed e-learning system only focuses on aiding students in mastering the theories. To help students better comprehend problem-solving, case study-based learning is required.

Expert system technology can be used to conduct case study-based learning. Expert system technology is widely used in the medical field to diagnose various diseases. Research [5] applies the Dempster-Shafer method to diagnose several infectious diseases. The research conducted obtained an accuracy of 88.5%. Case-based reasoning and Dempster Shafer methods are used in research [6] to diagnose infectious diseases. The calculation of the case-based reasoning method using 3W-Jaccard obtained an accuracy value of 85.71%. Research [7] integrates expert systems with healthcare systems in diagnosing infectious diseases. The disease diagnosis process uses the Certainty Factor method, getting an accuracy value of 80%. These studies can provide a high level of accuracy in disease diagnosis. In addition, it also provides appropriate advice or recommendations for diagnosed diseases.

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These studies make it easy for users to choose the symptoms of the disease they are suffering from from the list of symptoms presented in the system. Learning through case studies using an expert system can also be implemented in the form of questions the user must answer to determine the type of disease suffered. This can be accomplished through the use of an expert system and a backward chaining inference system. The backward chaining method can be used as a control for the inference system [8].

The backward chaining method is used in several research studies to identify the illness. To identify COVID-19 disease, researchers [9] used the backward chaining approach. The backward chaining method was employed in the study [10] to identify many infectious illnesses in young patients. Anxiety problems in college students were identified using the backward chaining method in research [11]. A backward chaining and certainty factor approach is used in research [12] to identify a coronary heart disease risk early on. Determine the degree of confidence in the risk of coronary heart disease using the certainty factor approach. These investigations can identify the illness and offer suggestions for care. Determining the severity and intensity of the identified disease is still a necessary component of the system that has been developed.

The degree of disease severity cannot be accurately assessed. This is because every expert has a unique opinion regarding the disease's severity. Fuzzy logic can be used to model uncertainty in assessing the severity of a disease. Fuzzy logic can manage the language variables that represent uncertainty in assessing the disease's severity [13]. Several studies have used fuzzy logic to diagnose diseases. The Fuzzy Mamdani technique with nine input variables was used in research [14] to diagnose COVID-19 disease. In a study [15], the diagnosis of chronic kidney disease was made using a fuzzy inference method. Fuzzy logic was utilized in research [16] to identify metabolic syndrome and cardiovascular disease. The study's findings had an accuracy rate of 92%.

These studies can provide valuable confidence in diagnosing a disease. Based on this, the research will be conducted using the fuzzy Mamdani inference system and the backward chaining method to diagnose several infectious diseases. The fuzzy Mamdani inference system determines the severity of the type of disease suffered. In contrast, the backward chaining method is used to diagnose the type of infectious disease. Depending on the intensity and severity of the disease, recommendations for handling infectious diseases that are more appropriate can be determined. The research was implemented using infectious disease data from the Malang City Health Office in 2019 [17]. The diseases to be diagnosed consist of pharyngitis, diphtheria, and tuberculosis.

2. Research Methods

The research carried out is described in a chart presented in Figure 1.

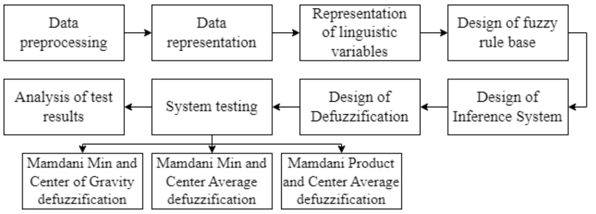

Figure 1. Research Method

According to Figure 1, the research begins with the data preprocessing stage. The data used is on infectious diseases at the Malang City Health Office in 2019. At this stage, the most specific symptoms are determined for each infectious disease: pharyngitis, diphtheria, and tuberculosis. Based on the data preprocessing stage, it was found that pharyngitis has five specific symptoms, diphtheria has five specific symptoms, and tuberculosis has six specific symptoms. The next stage is the data representation stage. Infectious disease data is represented in the decision table and decision tree representations. The form of representation using a decision tree is presented in Figure 2.

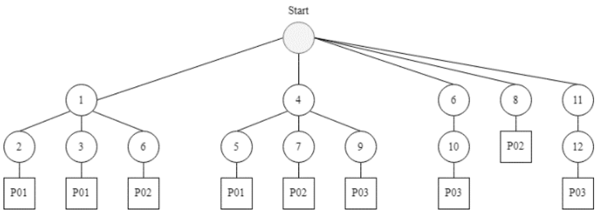

Figure 2. Decision Tree

According to Figure 2, node numbers 1 to 12 are nodes for symptom codes, while box P01 is pharyngitis, box P02 is diphtheria, and box P03 is tuberculosis. The research used a backward chaining approach with the depth-first search (DFS) method. In addition to representation in the form of a decision tree, the knowledge base is also represented using a decision table, as presented in Table 1.

Table 1. Decision Table

No	Evidence	A 1	A 1	A 1	A 2	A 2	A 2	A 3	A 3	A 3
S1	Sore throat	●	●		●					
S2	Throat feels dry	●								
S3	Oropharyngitis		●							
S4	Febris			●		●		●		
S5	Odynophagia			●						
S6	Dyspnea				●				●	
S7	Tonsilitis					●				
S8	Pseudomembrane						●			
S9	Hemoptisis							●		
S10	Chest pain								●	
S11	Wheezing									●
S12	Sleep hyperhidrosis									●

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According to Table 1, column A1 represents the type of pharyngitis disease, A2 represents diphtheria disease, and A3 represents tuberculosis. The next stage is the linguistic representation of the fuzzy system. This study uses two linguistic variables: the duration of symptoms that are felt or observed and the intensity of the severity of the disease. The duration of the symptoms felt or observed is used to determine how badly someone is diagnosed with a disease. The selection of linguistic variables and set domains was based on the knowledge and experience of infectious disease health experts. The set of linguistic values and the domains and units are presented in Table 2.

Table 2. Linguistic Variable

Linguistic variable	Set of linguistic	Domain	Unit
Long symptoms	Early	[1, 5]	
	Mid	[2, 8]	Days
	Late	[5, 10]	
Disease severity	Minor	[10, 50]	
	Critical	[20, 80]	%
	Fatal	[50, 100]	

According to Table 2, the long symptoms variable is utilized as an input variable, and the disease severity intensity variable is used as an output variable for the fuzzy system. The domain includes the long symptoms, including the earliest signs [1, 5]. Domain [2, 8] is the long symptoms, which includes intermediate symptoms, whereas domain [5, 10] is the long symptoms, which includes severe symptoms and delayed treatment. The varied intensity of disease severity within the domain is used to make a diagnosis of minor disease [10, 50]. Domains [20, 80] are critical illness diagnoses, while domains [50, 100] are fatal diseases that must be treated immediately. The severity of an infectious disease's linguistic variable influences the treatment recommendations. Given that the length of the patient's symptoms is inversely related to the intensity of the disease they are experiencing, the variable long symptoms falls within the same domain as the variable intensity of disease severity. The membership function for each input and output variable is represented in the subsequent stage. Figure 3 shows the input variable membership function.

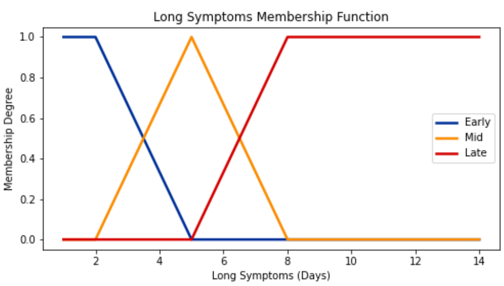

Figure 3. Long Symptoms Membership Function

According to Figure 3, the long symptoms input variable has three linguistic values: early, mid, and late. The membership function of the long symptoms input variable can be written using formula (1) to (3).

$$\mu_{Early}(\text{longSymptom}) = \begin{cases} 1, & 1 \le x \le 2 \\ \frac{5-x}{5-2}, & 2 < x < 5 \\ 0, & x \ge 5 \end{cases} \quad (1)$$

$$\mu_{Mid}(\text{longSymptom}) = \begin{cases} 0, & x \le 2 \text{ atau } x \ge 8 \\ \frac{x-2}{5-2}, & 2 < x < 5 \\ \frac{8-x}{8-5}, & 5 \le x < 8 \end{cases} \quad (2)$$

$$\mu_{Late}(\text{longSymptom}) = \begin{cases} 0, & x \le 5 \\ \frac{x-5}{8-2}, & 5 < x < 8 \\ 1, & 8 \le x \le 14 \end{cases} \quad (3)$$

The membership function of the disease severity output variable is represented in the membership function is presented in Figure 4.

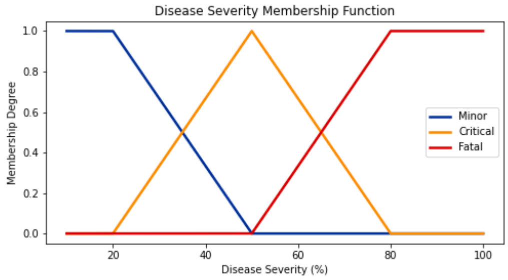

Figure 4. Disease Severity Membership Function

According to Figure 4, the disease severity output variable has three linguistic values: minor, critical, and fatal. The membership function of the disease severity output variable can be written using formula (4) to (6).

$$\mu_{Minor}(\text{Py}) = \begin{cases} 1, & 10 \le x \le 20 \\ \frac{50-x}{50-20}, & 20 < x < 50 \\ 0, & x \ge 50 \end{cases} \quad (4)$$

$$\mu_{Critical}(\text{Py}) = \begin{cases} 0, & x \le 20 \text{ atau } x \ge 80 \\ \frac{x-20}{50-20}, & 20 < x < 50 \\ \frac{80-x}{80-50}, & 50 \le x < 80 \end{cases} \quad (5)$$

$$\mu_{Fatal}(\text{Py}) = \begin{cases} 0, & x \le 50 \\ \frac{x-50}{80-20}, & 50 < x < 80 \\ 1, & 80 \le x \le 100 \end{cases} \quad (6)$$

The next stage is the fuzzy rule base design. The fuzzy rule base was formed based on interviews with infectious disease health experts. The fuzzy rule base consists of 75 rules, presented in Table 3.

Table 3. Fuzzy Rule Base

R	Long symptoms variable	Disease severity variable
R1	IF Sore throat is Early AND Throat feels dry is Early.	Pharyngitis is Minor
R2	IF Sore throat is Early AND Throat feels dry is Mid	Pharyngitis is Minor

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R3	IF Sore throat is Early AND Throat feels dry is Late	Pharyngitis is Critical
R4	IF Sore throat is Mid AND Throat feels dry is Early	Pharyngitis is Critical
R5	IF Sore throat is Mid AND Throat feels dry is Mid	Pharyngitis is Critical
R6	IF Sore throat is Mid AND Throat feels dry is Late	Pharyngitis is Critical
R7	IF Sore throat is Late AND Throat feels dry is Early	Pharyngitis is Fatal
R8	IF Sore throat is Late AND Throat feels dry is Mid	Pharyngitis is Fatal
R9	IF Sore throat is Late AND Throat feels dry is Late	Pharyngitis is Fatal
R75	…	…

According to Table 3, each rule will compare two symptoms so that the type of disease and the intensity of its severity can be determined. The next stage is the design of the fuzzy inference system. The inference system uses Fuzzy Mamdani Min and Fuzzy Mamdani Product. The implication process uses a Fuzzy Mamdani Min inference system with a min operator for the t-norm and a max operator for the s-norm [18].The equation for the fuzzy implication process using the Mamdani-Min inference system is presented in formula (7) [19].

$$\mu_{FMM}(x,y) = \min\left[\mu_{FP1}(x), \mu_{FP2}(y)\right] \quad (7)$$

According to formula (7), fp1 is the antecedent part of the rule, while fp2 is the consequent part. The implication process uses a Fuzzy Mamdani Product Inference System with an algebraic product operator for the t-norm and a maximum operator for the s-norm. The equation of the fuzzy implication process using the Mamdani Product Inference System is presented in formula (8) [20].

$$\mu_{FMP}(x,y) = \left[\mu_{FP1}(x) * \mu_{FP2}(y)\right] \quad (8)$$

According to equation (8), fp1 is the rule's antecedent, while fp2 is its consequence. The next stage is the design of the defuzzification process. In this study, the Mamdani Min Fuzzy inference system uses the maximum composition process [21] and the Center of Gravity defuzzification method. In contrast, the Mamdani Product inference system uses the singleton and the center average defuzzification methods. The Center of Gravity defuzzification method for discrete cases is presented in formula (9).

$$y^* = \frac{\sum_{k=1}^{n} \mu_{B'}(y_k) y_k}{\sum_{k=1}^{n} \mu_{B'}(y_k)} \quad (9)$$

The Center Average defuzzification method is presented in formula (10) [22].

$$y^* = \frac{\sum_{i=1}^{M} y^{-i} w_i}{\sum_{i=1}^{M} w_i} \quad (10)$$

According to formula (10), y^{-i} is the center of the i-th fuzzy set, while w^i is the height of the i-th fuzzy set.

3. Results and Discussions

The disease diagnosis process uses the backward chaining method and the calculation of the intensity of disease severity using a fuzzy inference system is implemented in the sample test data in Table 4.

Table 4. Test Data

S1	S2	S3	S4	S5
Y (4 Days)	N	Y (4 Days)	Y (3 Days)	Y (2 Days)

According to Table 4, column S1 is a symptom of a sore throat with a duration of symptoms felt for four days. Column S2 is a symptom of a throat feels dry but is not selected by the user. Column S3 is a symptom of an inflamed back wall of the mouth/oropharyngitis with symptoms that last for four days. Column S4 is a symptom of fever with symptoms felt for three days, while Column S5 is a symptom of painful swallowing/Odynophagia with symptoms that are felt for two days. The results of the backward chaining disease diagnosis, namely the diagnosis of pharyngitis with the disease code P01. The results of the disease diagnosis by the system are then determined by the intensity and severity of the disease using the Fuzzy Mamdani Min inference system and the Center of Gravity defuzzification. The first step is to determine the membership degree value of the input variable. The results of the calculation of membership degrees are presented in Table 5.

Table 5. The Result of Membership Degree

Linguistic Variables	Linguistic Set	Membership Degree
Long Symptoms (S1)	Early	0,333
	Mid	0,666
	Late	0
Long Symptoms (S3)	Early	0,333
	Mid	0,666
	Late	0
Long Symptoms (S4)	Early	0,666
	Mid	0,333
	Late	0
Long Symptoms (S5)	Early	0,97
	Mid	0
	Late	0

According to Table 5, the linguistic sets triggered for each input variable for the long symptoms (S1, S3, S4, and S5) are early and mid. The next stage is the process of determining fuzzy implications based on pharyngitis output variable rules. The rule bases triggered by the pharyngitis output variables are presented in Tables 6 and 7.

According to Table 6, the fuzzy rule bases triggered for the long symptoms S1 and S3 are R10, R11, R13, and R14. The fuzzy rule base triggered for long symptoms S4 and S5 is presented in Table 7.

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Table 6. Fuzzy Implication S1 and S3

R	Long Symptoms		Disease Severity
	S1	S3	
R10	Early (0,333)	Early (0,333)	Minor (0,333)
R11	Early (0,333)	Mid (0,666)	Critical (0,333)
R13	Mid (0,666)	Early (0,333)	Minor (0,333)
R14	Mid (0,666)	Mid (0,666)	Critical (0,666)

Table 7. Fuzzy Implication S4 and S5

R	Long Symptoms		Disease Severity
	S4	S5	
R19	Early (0,666)	Early (0,97)	Minor (0,666)
R22	Mid (0,333)	Early (0,97)	Minor (0,333)

Tables 6 and 7 show that the value of the α – Predicate for rules 10, 11, 13, and 22 is 0.333, while the value of the α – Predicate for rules 14 and 19 is 0.666. The next stage is the rule composition process using the maximum composition. The result of the composition process using the maximum composition is the intensity of the severity of the minor disease of 0.666 and the intensity of the severity of the critical disease of 0.666. The results of defuzzification on the output variable of pharyngitis are presented in Figure 5.

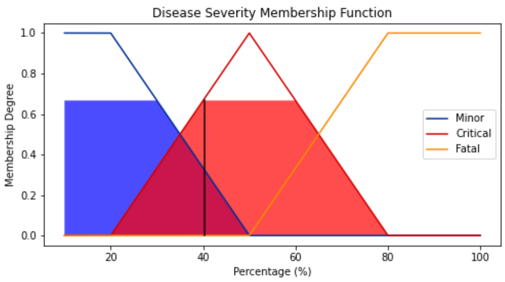

Figure 5. Defuzzification

According to Figure 5, the blue block represents the value of α – Predicate for the minor linguistic set, while the red block represents the value of α – Predicate for the critical linguistic set. The black line shows the result of defuzzification, with a crisp output value of 40.39%. The results of these calculations will be implemented using an expert system application. The results of the implementation of the expert system application on the test data in Table 4 are presented in Figure 6.

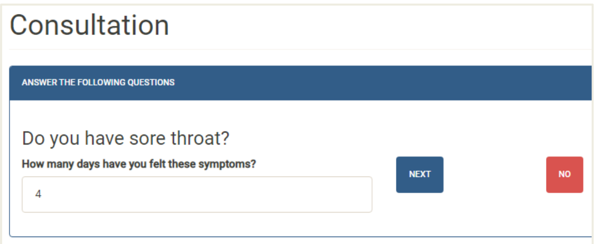

Figure 6. Display Symptom Question 1

According to Figure 6, the symptom consultation process is carried out using a question-and-answer model. The system will ask the user questions about several symptoms. If the user experiences these symptoms, the user must input the number of days to feel or observe these symptoms and then select the 'Next' button. The next question is presented in Figure 7.

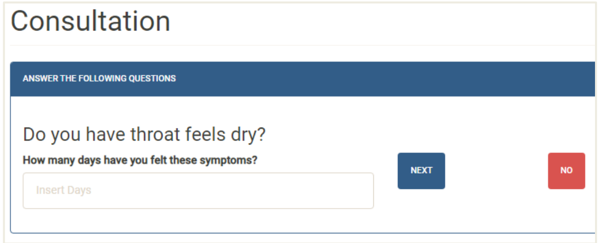

Figure 7. Display Symptom Question 2

According to Figure 7, the system will ask the user a question about the symptom of a dry throat. Based on Table 4, the patient's symptoms of 'throat feels dry' are not felt, so the 'No' button is selected in the expert system application. The next question is presented in Figure 8.

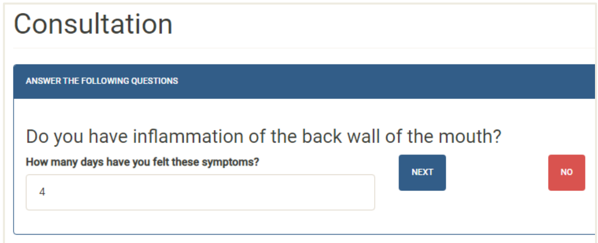

Figure 8. Display Symptom Question 3

According to Figure 8, the system will ask the user a question in the form of symptoms of an inflamed back wall of the mouth. Based on Table 4, the duration of symptoms of an inflamed back wall of the mouth is felt for four days, so the expert system application will input a value of 4. Then the user selects the 'Next' button. The next question is presented in Figure 9.

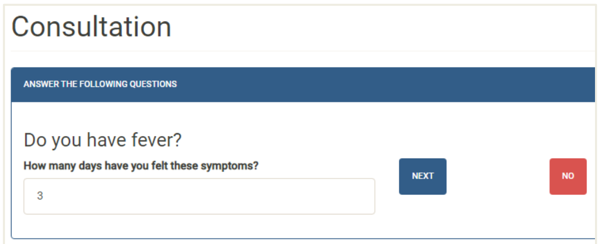

Figure 9. Display Symptom Question 4

According to Figure 9, the system will ask the user a question in the form of fever symptoms. Based on Table 4, the duration of fever symptoms is felt for three days, so the expert system application will input the value 3. Then the user selects the 'Next' button. The next question is presented in Figure 10.

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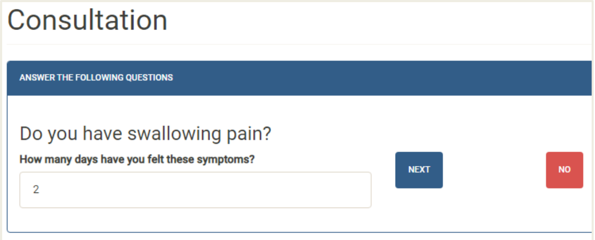

Figure 10. Display Symptom Question 5

According to Figure 10, the system will ask the user a question in the form of painful swallowing symptoms. Based on Table 4, the painful swallowing symptom is felt for two days, so the expert system application will input a value of 2. Then the user selects the 'Next' button. The final results of disease diagnosis using the Fuzzy Mamdani Min inference system and the Center of Gravity defuzzification method in the expert system application are presented in Figure 11.

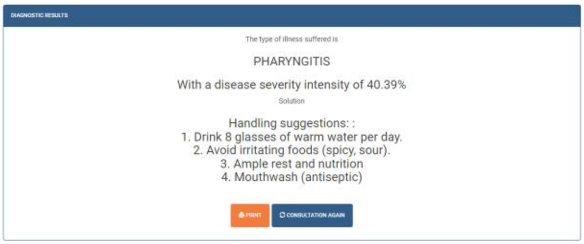

Figure 11. Display of Disease Diagnosis Results

According to Figure 11, the system will display the diagnosis results, consisting of the type of infectious disease diagnosed, the intensity of the disease severity, and recommendations for handling that must be made. The results of the history of questions answered by users are presented in Figure 12.

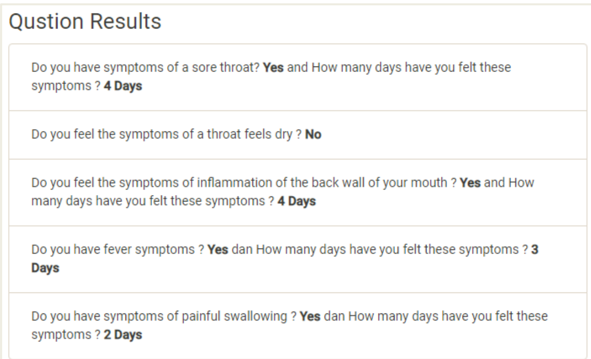

Figure 12. Questions history

According to Figure 12, the history of questions is a symptom displayed by the system to the user. The question history display is an answer to a question in the form of the duration of symptoms felt and symptoms that the user does not feel. Testing on the expert system application is implemented using 15 test cases. The results of testing the diagnosis of infectious diseases using the backward chaining method are presented in Table 8.

Table 8. Disease diagnosis test results

No	The selected symptom with the the number of days	System Diagnostic Results	Expert Diagnosis Results
1.	S1 = y (3 days), S2 = y (4 days), S3 = n, S4 = n, S5 = n	Pharyngitis	Pharyngitis
2.	S1 = y (2 days), S2 = y (4 days), S3 = y (2 days), S4 = n, S5 = t	Pharyngitis	Pharyngitis
3.	S1 = y (4 days), S2 = n, S3 = y (4 days), S4 = y (3 days), S5 = y (2 days)	Pharyngitis	Pharyngitis
4.	S1 = y (4 days), S2 = n, S3 = n, S6 = y (3 days), S4 = n, S7 = n, S8 = n	Diphtheria	Diphtheria
5.	S1 = n, S4 = y (6 days), S5 = n, S7 = y (3 days), S8 = n	Diphtheria	Diphtheria
6.	S1 = y (7 days), S2 = n, S3 = n, S6 = y (2 days), S4 = y (4 days), S7 = y (3 days), S8 = n	Diphtheria	Diphtheria
7.	S1 = n, S4 = y (8 days), S5 = n, S7 = y (4 days), S8 = y (4 days)	Diphtheria	Diphtheria
8.	S1 = n, S4 = n, S8 = y (8 days)	Diphtheria	Diphtheria
9.	S1= n, S4 = y (10 days), S5 = n, S7 = n, S9 = y (3 days), S6 = n, S11 = n	TB	TB
10.	S1 = n, S4 = n, S6 = y (6 days), S10 = y (7 days), S11 = n	TB	TB
11.	S1= n, S4 = n, S6 = n, S8 = n, S11 = y (3 days), S12 = y (2 days)	TB	TB
12.	S1 = n, S4 = y (10 days), S5 = n, S7 = n, S9 = y (2 days), S6 = y (7 days), S10 = y (7 days), S11 = n	TB	TB
13.	S1 = n, S4 = y (9 days), S5 = n, S7 = n, S9 = y (2 days), S6 = n, S11 = y (6 days), S12 = y (7 days)	TB	TB
14.	S1 = n, S4 = n, S6 = y (3 days), S10 = y (3 days), S11 = y (5 days), S12 = y (6 days)	TB	TB
15.	S1 = y (2 days), S2 = n, S3 = n, S6 = y (3 days), S4 = t, S6 = t, S8 = y (2 days)	Diphtheria	Diphtheria

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According to Table 8, the symptom column is recorded based on a list of symptom questions on the user interface. The questions that appear are recorded as answers in the form of 'y' representing the symptoms experienced by the user, or 'n' for symptoms that are not experienced by the user. In test data number 1, the question was answered 'y' namely symptom 1 with a duration of symptoms felt or observed for three days. Then comes symptom 2, with a four-day long of symptoms felt or observed. The questions on the user interface that were answered 'n' are symptoms 3, 4, and 5. Based on test data number 1, symptom 1 is a symptom of a sore throat, while symptom 2 is a symptom of a dry throat. The result of test data number 1 using the backward chaining method is pharyngitis. The results of the diagnosis match those of infectious disease experts.

The results of testing the diagnosis of infectious diseases on 15 samples using the backward chaining method were validated by infectious disease health experts. The results of expert system disease diagnosis on 15 test samples are the same as those of disease diagnosis by experts. Based on this, the accuracy value generated by the expert system is 100%. The next stage is determining the severity of the disease for each type of disease diagnosed. In the research conducted, several test scenarios were implemented. The test scenario aims to compare the performance of the fuzzy inference system on the intensity of disease severity. The first test scenario involves testing with the fuzzy Mamdani Min inference system and the center of gravity defuzzification method, while the second involves testing with the fuzzy Mamdani Min inference system and the center average defuzzification method. And the third test scenario, namely testing using the Mamdani product inference system and the center average defuzzification method, is presented in Table 9.

Table 9. Test Scenario Results

No.	The selected symptom with the the number of days	System Diagnostic Results	Mamdani Min and Centroid (Scenario 1)		Mamdani Min and Center Average (Scenario 2)		Mamdani Product and Center Average (Scenario 3)	
			Severity Linguistic	%	Severity Linguistic	%	Severity Linguistic	%
1.	S1 = y (3 days), S2 = y (4 days), S3 = n, S4 = n, S5 = n	Pharyngitis	Critical	37,03%	Minor	26,67%	Minor	29,01%
2.	S1 = y (2 days), S2 = y (4 days), S3 = y (2 days), S4 = n, S5 = t	Pharyngitis	Minor	23,99%	Minor	26,67%	Minor	26,67%
3.	S1 = y (4 days), S2 = n, S3 = y (4 days), S4 = y (3 days), S5 = y (2 days)	Pharyngitis	Critical	40,39%	Minor	32,91%	Minor	30,24%
4.	S1 = y (4 days), S2 = n, S3 = n, S6 = y (3 days), S4 = n, S7 = n, S8 = n	Diphtheria	Critical	44,91%	Minor	27,97%	Minor	22,59%
5.	S1 = n, S4 = y (6 days), S5 = n, S7 = y (3 days), S8 = n	Diphtheria	Critical	59%	Critical	44,67%	Minor	32,71%
6.	S1 = y (7 days), S2 = n, S3 = n, S6 = y (2 days), S4 = y (4 days), S7 = y (3 days), S8 = n	Diphtheria	Critical	44,91%	Minor	27,91%	Minor	25,18%
7.	S1 = n, S4 = y (8 days), S5 = n, S7 = y (4 days), S8 = y (4 days)	Diphtheria	Critical	60,13%	Critical	59,44%	Critical	59,44%
8.	S1 = n, S4 = n, S8 = y (8 days)	Diphtheria	Fatal	81,42%	Fatal	99%	Fatal	99%
9.	S1= n, S4 = y (10 days), S5 = n, S7 = n, S9 = y (3 days),	TB	Critical	58,88%	Critical	45,55%	Critical	45,55%

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	S6 = n, S11 = n							
10.	S1 = n, S4 = n, S6 = y (6 days), S10 = y (7 days), S11 = n	TB	Fatal	68,78%	Critical	56,67%	Critical	51,23%
11.	S1= n, S4 = n, S6 = n, S8 = n, S11 = y (3 days), S12 = y (2 days)	TB	Minor	25,55%	Minor	33,33%	Minor	33,33%
12.	S1 = n, S4 = y (10 days), S5 = n, S7 = n, S9 = y (2 days), S6 = y (7 days), S10 = y (7 days), S11 = n	TB	Critical	63,75%	Critical	54,16%	Critical	50,61%
13.	S1 = n, S4 = y (9 days), S5 = n, S7 = n, S9 = y (2 days), S6 = n, S11 = y (6 days), S12 = y (7 days)	TB	Critical	58,11%	Critical	39,99%	Critical	38,51%
14.	S1 = n, S4 = n, S6 = y (3 days), S10 = y (3 days), S11 = y (5 days), S12 = y (6 days)	TB	Critical	40,39%	Minor	24,16%	Minor	24,81%
15.	S1 = y (2 days), S2 = n, S3 = n, S6 = y (3 days), S4 = t, S6 = t, S8 = y (2 days)	Diphtheria	Minor	34,38%	Minor	27,77%	Minor	22,77%

According to Table 9, in test data number 1, S1 is a sore throat symptom with ‘early’ symptoms for a long time, while S2 is a dry throat symptom with ‘middle’ symptoms for a long time. The results of test data 1, using the Mamdani Min inference system and the centroid defuzzification method, indicate a pharyngitis disease with a severity intensity of 37.03% and a critical severity status. The results of the intensity of disease severity using the Fuzzy Mamdani Min inference system and the Center of Gravity defuzzification method (scenario 1) obtained a higher value than the results of the intensity of disease severity using scenarios 2 and 3. The disease severity status using scenario one was mostly diagnosed as ‘critical’ while scenarios 2 and 3 were mostly diagnosed as ‘minor’.

The results of the intensity of disease severity using the Fuzzy Mamdani Min inference system and the Center Average defuzzification method (scenario 2) obtained a higher value than the results of the intensity of disease severity using the Fuzzy Mamdani Product inference system and the Center Average defuzzification method (scenario 3). However, the disease severity status using scenarios 2 and 3 is almost the same, i.e., most of them are diagnosed as ‘minor’.

Tests using the Mamdani Product Fuzzy Inference System and the Center Average Defuzzification Method (Scenario 3) will give a smaller value if the results of the degree of membership in the fuzzy implication process are equally small. Based on the test results, the Fuzzy Mamdani Min inference system and the Center of Gravity defuzzification method are more appropriate and provide a disease severity status value based on the recommendations for proper treatment. These results are influenced by the defuzzification method used. It can be seen that the Center of Gravity defuzzification method provides a value that is close to the optimum compared to the Center Average defuzzification method [23]. Infectious disease health experts recommend analyzing the test results using the Fuzzy Mamdani Min inference system and the Center of Gravity defuzzification method (Scenario 1) based on the test results because it is more in line with the recommended recommendations for cases in the 15 tests used. The results of the comparison test using scenarios 1, 2, and 3 are presented in Figure 13.

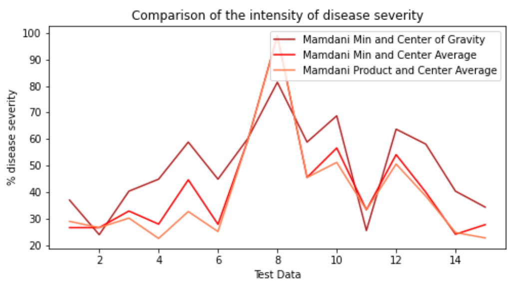

Figure 13. Comparison Graph of Disease Severity Intensity

Based on Figure 13, the x-axis is the number of test results, while the y-axis is the result of the prediction of the intensity of the severity of the disease. The results

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of the intensity of disease severity using the Mamdani Min inference system with the Center of Gravity defuzzification method (scenario 1) resulted in a higher value than the results of the intensity of disease severity using scenarios 2 and 3. Table 10 displays the findings of the three test scenarios and the average disease severity.

Table 10. The average of disease severity

Mamdani Min and Center of Gravity	Mamdani Min and Center Average	Mamdani Product and Center Average
49,43%	41,79%	39,44%

According to Table 10, the test results using the Center of Gravity defuzzification method and the Mamdani Min Fuzzy inference system yielded an average value of 49.43%, while the results using the Center Average defuzzification method and the Mamdani Min Fuzzy inference system yielded an average value of 41.79%. The lowest average value, 39.44%, was obtained by the Fuzzy Mamdani Product inference system and the Center Average defuzzification approach. The results indicate that the Fuzzy Mamdani Min method and the Center of Gravity defuzzification method are very well applied to determine the intensity of disease severity, as in [23] [24].

4. Conclusion

The conclusion obtained is that the expert system built aims to diagnose different types of infectious diseases and to determine the severity of the disease. The system built uses the backward chaining method to diagnose infectious diseases such as pharyngitis, diphtheria, and tuberculosis. In addition, the system uses a fuzzy inference system to determine the severity of the disease. The results of disease diagnosis using the backward chaining method on 15 test results give an accuracy value of 100%. The results of testing the intensity of disease severity using the Fuzzy Mamdani Min inference system and the CoG defuzzification method obtained the percentage value of the intensity of the severity of the disease, which was higher than the two proposed scenarios, which were 49.43%. Values that are more in accordance with professional recommendations are provided by the test results utilizing Fuzzy Mamdani Min and the Center of Gravity defuzzification approach.

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