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FUZZY LOGIC-BASED DECISION SUPPORT SYSTEM FOR COVID-19 EMERGENCY STATE DETERMINATION

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ABSTRACT

The World Health Organization defined the COVID-19 outbreak as a global epidemic (pandemic) on March 11 due to the occurrence of COVID-19 cases in 113 countries outside China where the first epidemic started, and the spread and severity of the virus. The virus epidemic, which emerged in Wuhan, the capital of the Hubei region of China on 1 December 2019, has spread throughout the world.
The number of cases has exceeded 200 million and the number of deaths has exceeded 4 million. In this study, the symptoms and results of covid-19 were modeled with fuzzy logic and evaluated. In the model, the symptoms of the virus such as fever, dry cough, fatigue, loss of taste and smell, permanent pain in the chest, travel history, and sore throat were identified as input. The risk situation, quarantine situation, and isolation situation were determined as output, decision rules were created. These rules will make it easier to understand and use a model that cannot be built mathematically by building on natural languages and showing it with graphics as well as a rule table. With this study, it is predicted that it will be a model for decision-makers in the field of health.

1. INTRODUCTION

Coronaviruses are single-stranded, positive polarity enveloped RNA viruses. Since they have positive polarity, they do not contain RNA-dependent RNA polymerase enzyme but encode this enzyme in their genome. They have rod-like extensions on their surfaces. Based on the Latin meaning of these protrusions "corona", in other words, "crown", these viruses are named Coronavirus (crowned virus), and the schematic structure of the coronavirus is shown in Figure 1 [1]. Covid 19 symptoms are often variable, but symptoms such as fever, dry cough, fatigue, loss of taste and smell, permanent pain in the chest, and sore throat are common symptoms. Symptoms appear within one to fourteen days of contact with the virus. The virus that causes Covid 19 is most often transmitted by an infected person coming into close contact with another person [2]. Small droplets and aerosols containing the virus can be emitted from the mouth and nose if the infected person breathes, coughs, sneezes, sings, or speaks. People become infected if the virus gets into the mouth, nose, or eyes [3]. Covid 19 is an infectious disease caused by severe acute respiratory syndrome coronavirus 2, and as of August 17, 2021, there are over 208 million confirmed cases in the world and over 4,38 million patients died due to the virus. [4].

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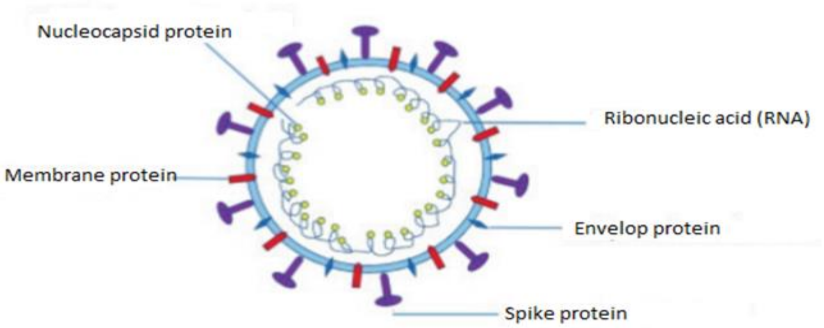

Fig 1. Schematic Structure of the Coronavirus [5]

Although artificial intelligence may seem like an effort to imitate the intelligent behavior observed in humans, the main goal is to produce technological tools that will help humanity. Fuzzy logic is an approach capable of processing ideas and information outside of classical binary logic theory. This approach provides mathematical answers to statistical uncertainties with logical analysis. Fuzzy set theory, in which multiple criteria decision-making tools are used, is an effective method to deal with the ambiguous situation in decision mechanisms in an environment where there are multiple contradictory goals, alternatives are complex and criteria are uncertain [6]. This study, it is aimed to find solutions to problems more easily by modeling common symptoms of Covid 19, risk situation, isolation, and quarantine processes with fuzzy logic.
This article is mainly structured as follows. The first section provides preliminaries on Covid 19 and fuzzy logic is given. The second section explains the modeling and evaluating Covid 19 with the fuzzy logic designer toolbox in the Matlab program in detail. The next section includes findings obtained from this study and discusses the advantageous and disadvantageous sides of the fuzzy logic model applied in this study. The last section discusses the results and presents references to further studies in the field.

2. METHODS

It is difficult to measure because most medical concepts are fuzzy[7]. In health, fuzzy logic was commonly used and applied in wide-ranging topics from disease diagnosis ophthalmic ultrasonography retinopathy diagnosis, and diabetes risk assessment [8]. So, important reasons for using fuzzy logic as a method to model Covid 19 are given below [9].

- The math concepts behind fuzzy logic are very simple. Its simplification of complexity with a naturalness approach is an important factor.
- Fuzzy logic creates a flexible environment in dealing with problems by offering different expressions.
- It offers a tolerant approach to imprecise data. Nothing is certain, everything can be expressed in relative values by making different approaches.
- It can model complex nonlinear functions. It can be expressed as a suitable fuzzy system by combining input-output data.
- It builds a system using the experience and knowledge of experts at a high level.
- When using fuzzy logic systems, known conventional techniques need not be neglected. In most applications, fuzzy logic and traditional techniques are easily used together.

The creation and editing processes of the fuzzy inference system were done with the fuzzy logic designer in Matlab software. To provide simplicity, comfort, speed, and efficiency in the definition and solution of the problem, a membership function should be selected ranging between 0 and 1 values. Although fuzzy logic designer includes 11 types of membership functions, in our model, are used trimf and trapmf, which have the advantage of simplicity since they have a linear structure. Fuzzification of the inputs and applying the fuzzy operator in Sugeno is the same as in Mamdani. The main difference between Sugeno and Mamdani is that the Sugeno output membership functions are constant or linear. In Sugeno, the result of the "if-then" rule is explained by a polynomial to the input variables. Accordingly, the output of each rule is defined as a single number. A weighting mechanism is then applied to obtain the final defuzzified output. While Sugeno avoids complex fuzzification, the work of specifying the parameters of polynomials is more inefficient and simpler than defining the extracted fuzzy sets for Mamdani. [9-13].

Dhiman and Sarma(2020) presented a fuzzy inference system for diagnosing the Covid 19 disease. They claim that if the atmospheric temperature is medium, more intake of ethanol and slightly higher body temperature then they will get a normal severity level of the infected patient[14].

Sharma ve et al developed a mediative fuzzy correlation method based on the parameters for Covid 19 patients from different parts of India. They specified that the presented approach to the prediction in Covid 19 based on mediative fuzzy logic has produced promising results for the continuous contradictory estimation in India[15].

Castillo and Melin suggest a hybrid intelligent approach for forecasting COVID-19 time series combining fractal theory and fuzzy logic. Publicly available data sets of 10 countries in the world were used to build the fuzzy model with time series in a fixed period. Forecasting average accuracy is 98%[16].

In our model, the covid-19 problem, which has 7 inputs-3 outputs and 21 rules, was addressed. The structure of the model is shown in Figure 2. Here it is seen that information flows from left to right from 7 inputs to 3 outputs. The fuzzy inference process in the fuzzy logic design box; consists of five stages: fuzzifying the input variables, application of fuzzy processors (and, or) to conditions, drawing conclusions from conditions, combining the results with the rules help defuzzification.

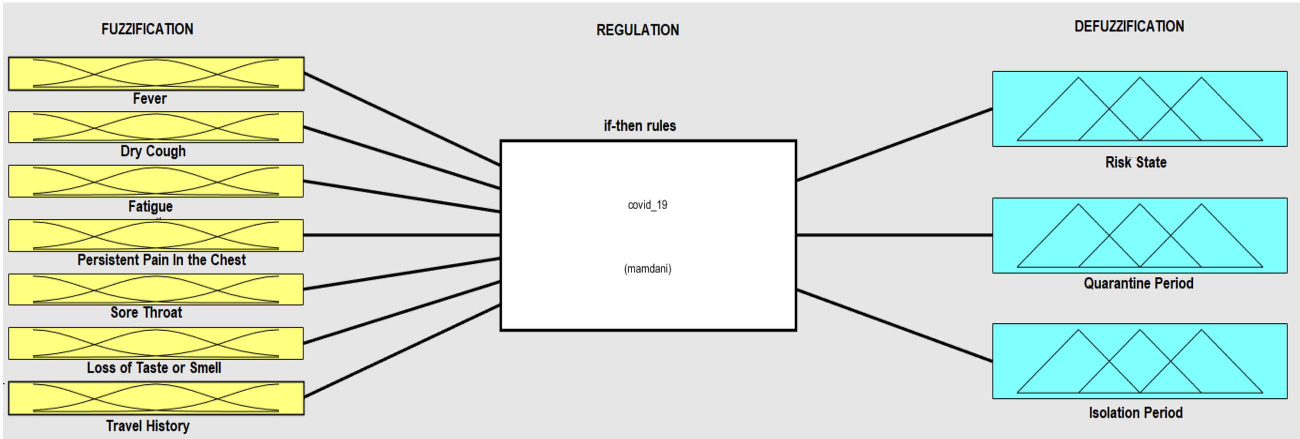

Fig 2. The structure of the model

2.1. Fuzzifying of the Inputs

First, the inputs are graded with the help of membership functions and converted into appropriate fuzzy sets by using linguistic variables against exact numerical values. In the fuzzy logic design box, inputs are always precise numerical values limited to the universal set values of input variables, and output is fuzzy membership degrees in linguistic sets. Fuzzifiying the inputs means the values in a table or the evaluation of a function.

Membership functions are determined for each value of the input parameters. The degree of an input belonging to a fuzzy set is represented by a membership function ranging from 0 to 1 and is symbolized as μ. Membership functions were created for each parameter with μ values[8].

The fever input variable supports 4 fever levels. Therefore fever input variable was divided into 4 fuzzy sets of linguistic ranges as low, medium, high, and very high. But other input values were divided into 3 fuzzy sets of linguistic ranges as low, medium, and high. For fever; the membership equations and μ values for each linguistic type are:

$$\mu\ low\ (\alpha) = \begin{cases} 1; \alpha < 35\ 0C \\ (36 - \alpha)/1; 35 \leq \alpha \leq 36\ 0C \\ 0; \alpha > 36\ 0C \end{cases}$$

$$\mu\ medium\ (\alpha) = \begin{cases} 0; \alpha < 35 \text{ or } \alpha > 37\ 0C \\ (\alpha-35)/1; 35 \leq \alpha \leq 36\ 0C \\ (37-\alpha)/1; 36 \leq \alpha \leq 37\ 0C \end{cases}$$

$$\mu\ high\ (\alpha) = \begin{cases} 0; \alpha < 36 \text{ or } \alpha > 38\ 0C \\ (\alpha-36)/1; 36 \leq \alpha \leq 37\ 0C \\ (38-\alpha)/1; 37 \leq \alpha \leq 38\ 0C \end{cases}$$

$$\mu\ very\ high\ (\alpha) = \begin{cases} 0; \alpha < 37\ 0C \\ (\alpha - 37)/1; 37 \leq \alpha \leq 38\ 0C \\ 1; \alpha > 38\ 0C \end{cases}$$

A value range of 0 to 10 was determined for dry cough, fatigue, persistent pain in the chest, sore throat, and loss of taste or smell variables. The membership equations and μ values for these variables for each linguistic type are:

$$\mu\ low\ (\alpha) = \begin{cases} 1; \alpha < 3 \\ (3-\alpha)/1; 3 \leq \alpha \leq 5 \\ 0; \alpha > 5 \end{cases}$$

$$\mu\ medium\ (\alpha) = \begin{cases} 0; \alpha < 3 \text{ or } \alpha > 7 \\ (\alpha-3)/1; 3 \leq \alpha \leq 5 \\ (7-\alpha)/1; 5 \leq \alpha \leq 7 \end{cases}$$

$$\mu\ high\ (\alpha) = \begin{cases} 0; \alpha < 5 \\ (\alpha-5)/1; 5 \leq \alpha \leq 7 \\ 1; \alpha > 7 \end{cases}$$

The travel history variable is related to the travel history of the patient in the last 14 days or being in close contact with a person having a travel history. The fuzzy sets of travel history include high, medium, and low risks[17]. The membership equations and μ values for traveling history record for each linguistic type are:

$$\mu\ high\ (\alpha) = \begin{cases} 1; \alpha < 13 \\ (14-\alpha)/1; 13 \leq \alpha \leq 14 \\ 0; \alpha > 14 \end{cases}$$

$$\mu\ medium\ (\alpha) = \begin{cases} 0; \alpha < 14 \text{ or } \alpha > 28 \\ (\alpha-14)/7; 14 \leq \alpha \leq 21 \\ (28-\alpha)/7; 21 \leq \alpha \leq 28 \end{cases}$$

$$\mu\ low\ (\alpha) = \begin{cases} 0; \alpha < 28 \\ (\alpha-28)/1; 28 \leq \alpha \leq 29 \\ 1; \alpha > 29 \end{cases}$$

2.2. Applying of the Fuzzy Processor

It is determined what degree of precondition every one rule has with fuzzification of the inputs. If the prerequisite of any rule has one or more parts, then a fuzzy processor is applied to obtain a number representing the result of the prerequisite of this rule. This number applies to the output function. The inputs of the fuzzy processor consist of two or more membership values of the fuzzy input variables that were fuzzified [18]. Output is one crisp value.

2.3. Applying of Result Inference Method

Before applying this method, the weights for each of the rules were determined to "1". By applying the inference method and the conditions in the rules were evaluated together and a fuzzy linguistic result was revealed. This process was applied for every one rule. The result inference structure is given in Figure 3.

Fig 3. The result to the fuzzy processor of the condition created by the inputs

The membership equations and μ values for risk situation for each linguistic type are:

$$\mu\ low\ (\alpha) = \begin{cases} 1; \alpha < 60 \\ (80-\alpha)/20; 60 \leq \alpha \leq 80 \\ 0; \alpha > 80 \end{cases}$$

$$\mu\ medium\ (\alpha) = \begin{cases} 0; \alpha < 60 \text{ or } \alpha > 100 \\ (\alpha-60)/20; 60 \leq \alpha \leq 80 \end{cases}$$

$(100-\alpha)/20;\ 80 \le \alpha \le 100$

μ high (α) =
$0;\ \alpha < 80$
$(\alpha - 80)/20;\ 80 \le \alpha \le 100$
$1;\ \alpha > 100$

The membership equations and μ values for isolation period for each linguistic type are:

μ low (α) =
$1;\ \alpha < 3$
$(3-\alpha)/1;\ 3 \le \alpha \le 10$
$0;\ \alpha > 10$

μ medium (α) =
$0;\ \alpha < 3$ or $\alpha > 14$
$(\alpha-3)/1;\ 3 \le \alpha \le 10$
$(14-\alpha)/1;\ 10 \le \alpha \le 14$

μ high (α) =
$0;\ \alpha < 10$
$(\alpha - 10)/1;\ 10 \le \alpha \le 14$
$1;\ \alpha > 14$

The membership equations and μ values for quarantine period for each linguistic type are:

μ low (α) =
$1;\ \alpha < 10$
$(10-\alpha)/1;\ 10 \le \alpha \le 14$
$0;\ \alpha > 14$

μ medium (α) =
$0;\ \alpha < 10$ or $\alpha > 21$
$(\alpha-10)/1;\ 10 \le \alpha \le 14$
$(14-\alpha)/1;\ 14 \le \alpha \le 21$

μ high (α) =
$0;\ \alpha < 21$
$(\alpha - 21)/1;\ 21 \le \alpha \le 28$
$1;\ \alpha > 28$

All these values were created in the light of the information in the covid-19 information guide of the World Health Organization (WHO).

2.4. Combining of Results

Since the decisions are based on the results of the rules in the fuzzy inference system, it is necessary to combine the results of the rules that make up the problem to obtain a single result. Thus, a single result is obtained by combining the fuzzy results of each rule. Combining can be done in three ways; Max, Probor, and Sum[9]. The integrated result obtained by evaluating the rules together is seen in Figure 4.

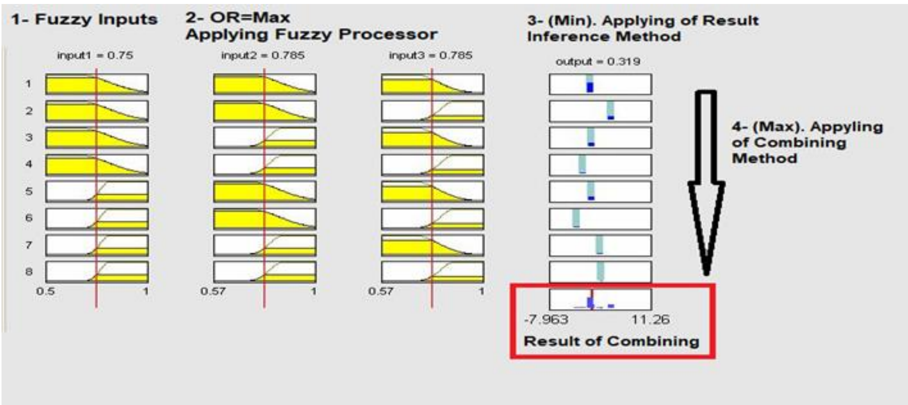

Fig 4. Membership functions of fever

2.5. Defuzzification

Defuzzification refers to fuzzy to crisp conversions. The fuzzy results generated cannot be used as been in applications, therefore it is necessary to convert fuzzy amounts into net quantities for further processing [19]. The input of the defuzzification process is the set of output from the combining. The output of the process will be a single number. However, in some cases, the outputs of the process may be numbers within a certain range. In such cases, it is desirable to obtain a single number in this set of numbers. In the defuzzification process, bisector, an average of maximums, largest maximum, smallest maximum, and centroid methods are used. In our practice, the centroid method was used, which is based on taking the value of the output area obtained from the merging process at the center.

3. EXPERIMENTAL

In this study, it was developed 7 input fuzzy set tables. Those fuzzy set tables of membership functions consisted of fever, dry cough, fatigue, persistent pain in the chest, sore throat, loss of taste or smell, and travel history. The fever input variable supports 4 fever levels and so it was divided into 4 fuzzy sets of linguistic ranges. Fuzzy sets have low, medium, high, and very high. Membership functions of the low, medium, high, and very high have triangular. Figure 5 shows fuzzy sets and membership functions for fever.

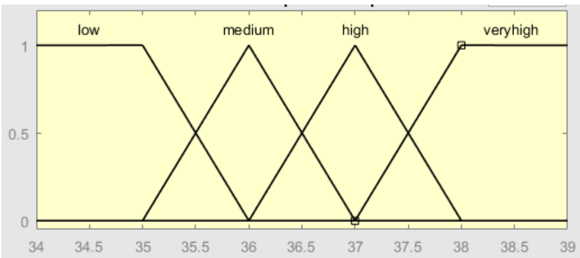

Fig 5. Membership functions of fever

Dry cough, fatigue, persistent pain in the chest, sore throat, and loss of taste or smell input variables support 3 levels and so these variables were divided into 3 fuzzy sets of linguistic ranges. Fuzzy sets have low, medium, and high. Membership functions of the low, medium, and high have triangular. Figure 6 shows fuzzy sets and membership functions for these variables.

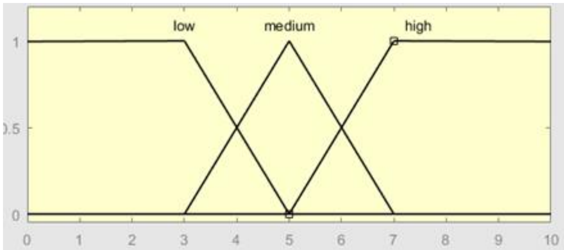

Fig 6. Membership functions of dry cough, fatigue, persistent pain in the chest, sore throat, and loss of taste or smell

The travel history input variable supports 3 levels and so it was divided into 3 fuzzy sets of linguistic ranges. Fuzzy sets have high, medium, and low. Membership functions of the high, medium, and low have triangular. Figure 7 shows fuzzy sets and membership functions for travel history.

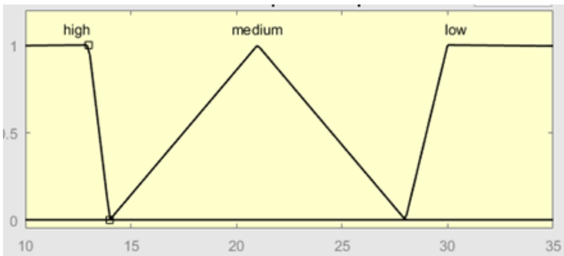

Fig 7. Membership functions of travel history

The risk situation output variable supports 3 levels and so it was divided into 3 fuzzy sets of linguistic ranges. Fuzzy sets have low, medium, and high. Membership functions of the low, medium, and high have triangular. Figure 8 shows fuzzy sets and membership functions for risk situations. To calculate the risk level according to Figure 8 ; the μ = 0.9 with the risk level of risk fuzzy sets (90) and the μ = 0.3 with the risk level of risk fuzzy sets (30). In this study, the result of the developed fuzzy system was obtained through the input of real parameter values, rules, and calculated using defuzzification.

$$risk\ level\ (\%) = \frac{\mu(\text{high})\ \text{x}\ \text{risk}(\text{high}) + \mu(\text{medium})\ \text{x}\ \text{risk}(\text{medium})}{\mu(\text{high}) + \mu(\text{medium})} = \frac{0{,}9\ \text{x}\ 90 + 0{,}3\ \text{x}\ 30}{0{,}9 + 0{,}3} = \%75$$

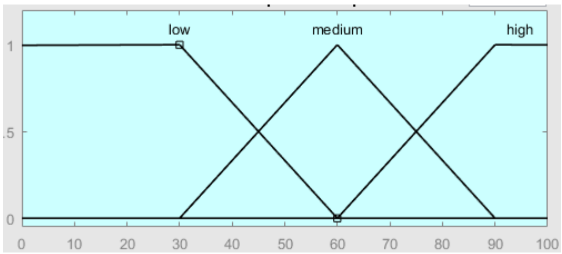

Fig 8. Membership functions of risk situation

The quarantine period output variable supports 3 levels. This variable was divided into 3 fuzzy sets of linguistic ranges. Fuzzy sets have low, medium, and high. Membership functions of the low, medium, and high have triangular. See Figure 9.

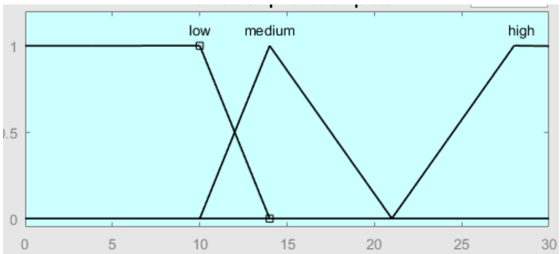

Fig 9. Membership functions of the quarantine period

The isolation period output variable supports 3 levels and so it was divided into 3 fuzzy sets of linguistic ranges. Fuzzy sets have low, medium, and high. Membership functions of the low, medium, and high have triangular. See Figure 10.

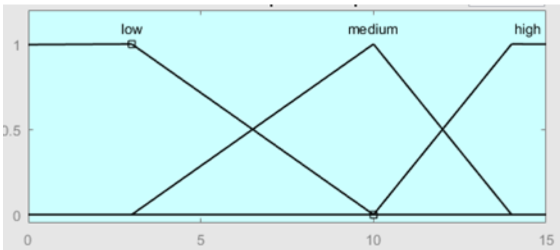

Fig 10. Membership functions of the isolation period

The rule viewer displays the roadmap that covers all the fuzzy inference process. The rule viewer for our model is given in Figure 11. The graphics in the first line of the figure show the inputs and outputs of the first rule. Similarly, the second line shows the second rule and the twenty-first line shows the twenty-first rule. The graphs shown in yellow in the first 7 columns show the membership functions that belong to the inputs of the rules, while the blue graphs in the other 3 columns show the membership functions based on the result values of the output. The graphs in the last row of the output columns, which are the last three columns, express the integrated weighted decision result of the fuzzy inference system.

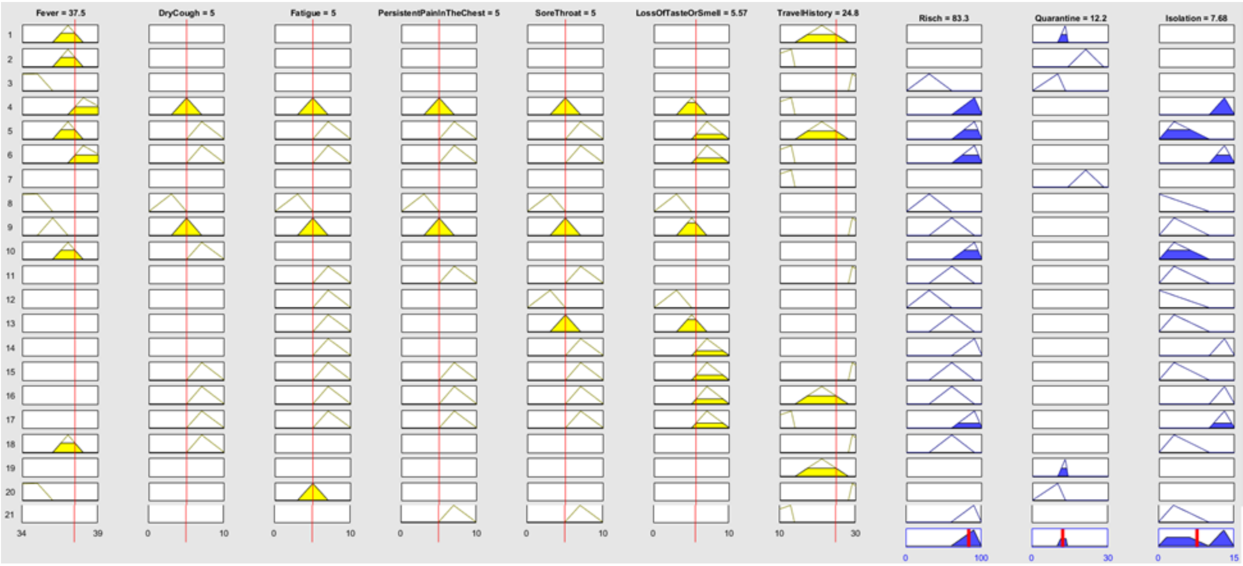

Fig 11. Rule Viewer in Matlab Software

In our model, combinations of rules were developed according to existing inputs and outputs. Twenty-one rules were constituted with seven input and three output parameters and these rules are given in Table 1.

Table 1. Combination of fuzzy rule

Rule Number	Rules
1	If (Fever is high) and (TravelHistory is medium) then (Quarantine is medium) (1)
2	If (Fever is high) and (TravelHistory is high) then (Quarantine is high) (1)
3	If (Fever is low) and (TravelHistory is low) then (Risk is low) (Quarantine is low) (1)
4	If (Fever is very high) or (DryCough is medium) or (Fatigue is medium) or (PersistentPainIntheChest is medium) or (SoreThroat is medium) or (LossOfTasteOrSmell is medium) or (TravelHistory is high) then (Risk is high)(Isolation is high) (1)
5	If (Fever is high) or (DryCough is high) or (Fatigue is high) or (PersistentPainInTheChest is high) (SoreThroat is high) or (LossOfTasteOrSmell is high) or (TravelHistory is medium) then (Risk is high)(Isolation is medium) (1)
6	If (Fever is very high) or (DryCough is high) or (Fatigue is high) or (PersistentPainInTheChest is high) or (SoreThroat is high) or (LossOfTasteOrSmell is high) or (TravelHistory is high) then (Risk is high)(Isolation is high) (1)
7	If (TravelHistory is high) then (Quarantine is high) (1)
8	If (Fever is low) and (DryCough is low) and (Fatigue is low) and (PersistentPainInTheChest is low) and (SoreThroat is low) and (LossOfTasteOrSmell is low) then (Risk is low) (Isolation is low) (1)
9	If (Fever is medium) and (DryCough is medium) and (Fatigue is medium) and (PersistentPainInTheChest is medium) and (SoreThroat is medium) and (LossOfTasteOrSmell is medium) and (TravelHistory is low) then (Risk is medium) (Isolation is medium) (1)
10	If (Fever is high) and (DryCough is high) then (Risk is high)(Isolation is medium) (1)
11	If (Fatigue is high) or (PersistentPainInTheChest is high) or (SoreThroat is high) or (TravelHistory is low) then (Risk is medium)(Isolation is medium) (1)
12	If (Fatigue is high) and (SoreThroat is low) and (LossOfTasteOrSmell is low) then (Risk is low)(Isolation is low) (1)
13	If (Fatigue is high) and (SoreThroat is medium) and (LossOfTasteOrSmell is medium) then (Risk is medium)(Isolation is medium) (1)
14	If (Fatigue is high) and (SoreThroat is high) and (LossOfTasteOrSmell is high) then (Risk is high)(Isolation is high) (1)
15	If (DryCough is high) and (Fatigue is high) and (PersistentPainInTheChest is high) and (SoreThroat is high) and (LossOfTasteOrSmell is high) and (TravelHistory is low) then (Risk is medium)(Isolation is medium) (1)

16	If (DryCough is high) and (Fatigue is high) and (PersistentPainInTheChest is high) and (SoreThroat is high) and (LossOfTasteOrSmell is high) and (TravelHistory is medium) then (Risk is medium)(Isolation is high) (1)
17	If (DryCough is high) and (Fatigue is high) and (PersistentPainInTheChest is high) and (SoreThroat is high) and (LossOfTasteOrSmell is high) and (TravelHistory is high) then (Risk is high)(Isolation is high) (1)
18	If (Fever is high) and (DryCough is high) and (TravelHistory is low) then (Risk is medium)(Isolation is medium) (1)
19	If (TravelHistory is medium) then (Quarantine is medium) (1)
20	If (Fever is low) and (Fatigue is medium) and (TravelHistory is low) then (Quarantine is low) (1)
21	If (PersistentPainInTheChest is high) and (SoreThroat is high) and (TravelHistory is high) then (Risk is high)(Isolation is medium) (1)

The solution surface in the fuzzy system of the problem addressed in the study is given in Figure 12. The surface in the graph helps us to interpret to what extent the output is related to which of the inputs and that are effective. When all the graphs are examined, it is seen that when the fever value is high and travel history is low, the risk is 70%, the quarantine period is 15 days, and the isolation time is between 8 and 11 days. In addition, when fatigue and dry cough values are high, it is seen that the risk situation increases to 80%, the quarantine period exceeds 12 days and the isolation period is around 7 days. Furthermore, in cases where persistent pain value in the chest is high and sore throat is high, the risk is between 70% and 80%, in addition, if the persistent pain value in the chest is high and the travel history value varies between low-high, the risk percentage varies between 65 and 85, the quarantine period from 12 days to 15 days.

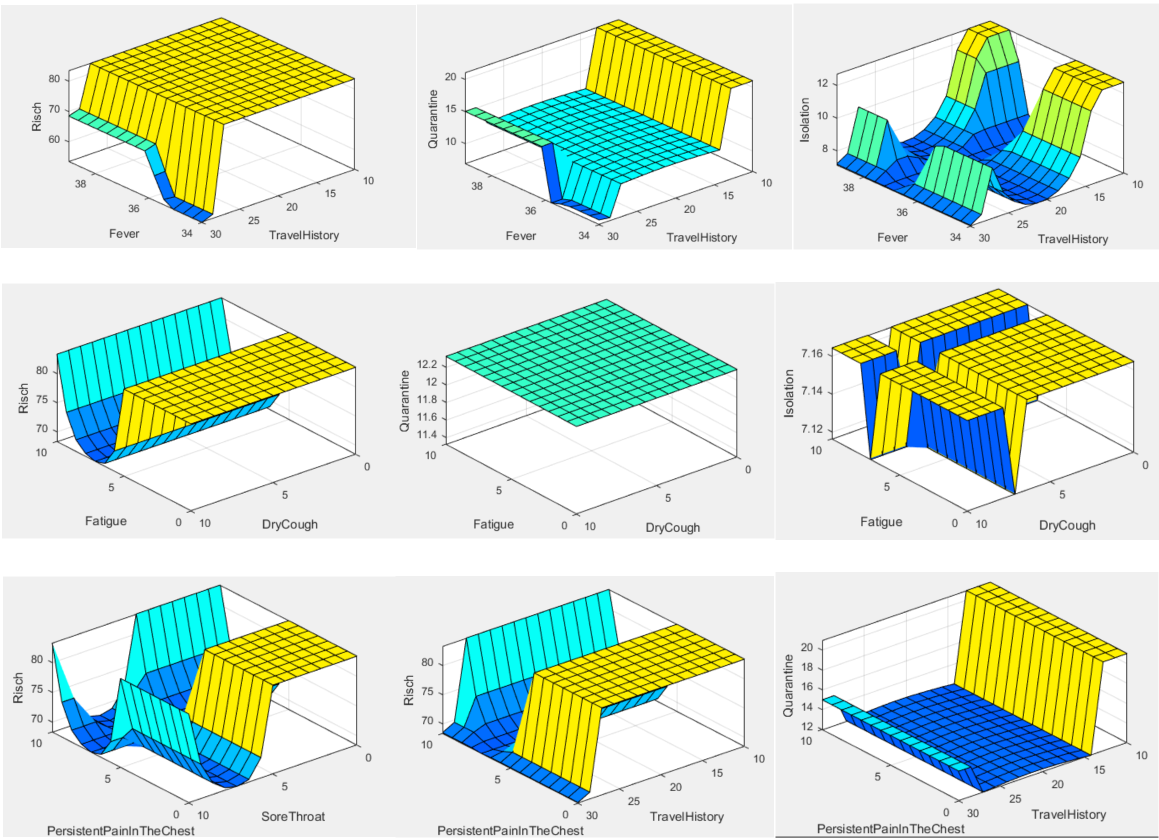

Fig 12. The solution surface in the fuzzy system

4. RESULTS

Covid 19 mostly happens when people were together for a certain period [20]. An infected person can infect others even two days before they show symptoms. In addition, Covid 19 can be transmitted from people who do not show symptoms. It is possible to remain infected for up to ten days in normal cases and two weeks in severe cases. For all these reasons, in addition to WHO's preventive measures, a model with the Covid 19 fuzzy logic approach is presented in this study. The presented model has a total of 21 rules with 7 inputs and 3 outputs. Unlike similar studies, quarantine and isolation situations were used as outputs in addition to risk situations. These rules will make it easier to understand and use a model that cannot be mathematically established by showing with graphics as well as the rule table, by building on natural languages. Finally, with this study, it is predicted that it will be a model for decision-makers in the field of health care.

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