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A multi-criteria model for vaccine slot tracker using fuzzy logic

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***Abstract*---**The breakout of Covid has occurred in recent years which had a major impact worldwide. In this scenario, vaccination has proven to be highly successful. In a nation like India, vaccination of a big population is a difficult task. Individuals wait for hours for a vaccination slot, yet they are still unable to obtain one because information about the vaccination location and opening hours is unavailable. For this topic, we suggested a Vaccination Tracker algorithm that provides users with real-time information on vaccine openings, locations, available capacity, minimum age limit, Pin code and name of the organization, making vaccination registration a breeze. In this paper a model based of Multi-criteria Fuzzy technique is propose in which probability is generated to assign priority to the registered candidates. On the basis of the priority: Very High, High, Medium, Low, and Very low, the slot of the individual is informed regarding the availability of slots and slot is booked on the basis of the registration details. After successful vaccination, the countdown is started for the next dose, respectively.

***Keywords*---**COVID-19, economy, vaccination, application, healthcare, pandemic, fuzzy logic, slot.

Introduction

The world is currently undergoing a pandemic as a result of the widespread transmission of COVID-19, a novel coronavirus disease. It is an acute respiratory condition caused by the Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2), which was first discovered in late 2019 in Wuhan, China's Hubei province [1]. In March 2020, the World Health Organization (WHO) declared the COVID-19 a pandemic disease due to the exponential rate of infection and death.

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COVID-19 has infected about 18,142,718 people, according to a WHO study released on August 4, 2020. So far, 691,013 people have died among them. COVID-19 infection and fatality rates are rapidly rising due to the virus's high contagiousness [2]. In most cases, this disease is carried from person to person via respiratory droplets, which are communicated through the air or other surfaces. On a suitable surface at normal temperature, this virus can live for several hours to days [3]. To avoid the transmission of COVID, the patient should be isolated from others as soon as feasible, according to WHO recommendations. However, the COVID-19's wide maturation period, which ranges from 3 to 14 days, is a major concern. Fever, cough, dyspnea, loss of smell, loss of taste, diarrhea, and other symptoms are common with this disease. COVID-19 patients should go through a thorough, real-time, quick, and accurate screening process to ensure prompt treatment, isolation, and safety.

Governments, businesses, and a number of public and private organizations throughout the world are collaborating to discover a feasible solution to mitigate the risk of COVID-19 spreading globally. In this context, the employment of digital technologies is necessary since they are critical instruments for improving the population's health and providing essential services to them [4]. The World Health Organization (WHO) recently issued ten suggestions for using digital technology to improve healthcare quality and vital services. When it comes to technology and digitalization, more than 5 billion people are anticipated to use mobile phones globally; moreover, according to the "State of Mobile in 2019" study released in 2018, 194 trillion dollars' worth of applications were downloaded globally in 2018. As a result, applications are accessible to and used by a substantial proportion of the world's population, making them immensely popular. The historical background lacks knowledge of the depth and complexity of software linked to coronavirus illness (COVID19). Furthermore, there is no comprehensive list of all the apps designed to tackle the COVID-19 epidemic.

The immunization push was made feasible thanks to digitization, which helped schedule and maintain the essential measures. Now the issue arises: what is vaccination, why is it required, and how can vaccinations protect? The basic answer to all of these queries is that vaccination is the process of immunizing a person against a virus by delivering a vaccine. Vaccination stimulates the body's immunity, which protects people from future illnesses or diseases. When it comes to digitization and app creation, government agencies created more than half of the applications that were utilized during the epidemic. The graph in Figure 1 shows the total number of vaccines given in each month from 2021 to 2022. When compared to previous months, the immunization rate in January 2021 was just 191180. The initial poor response was owing to a lack of understanding and technical developments, as well as the country's large population.

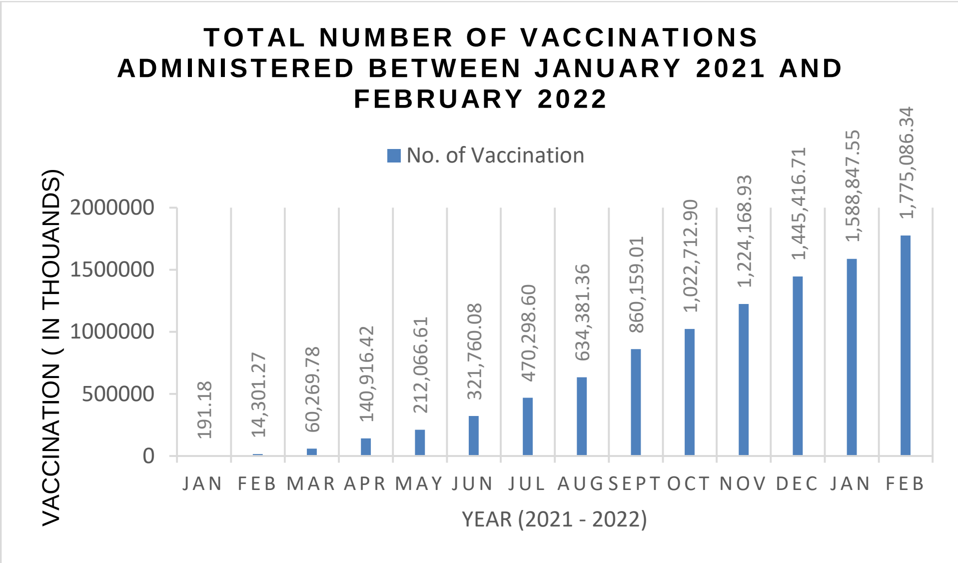

Fig. 1: Total no. of vaccinations administered between Jan 2021 & Feb 2022

Many nations have opted to install apps to help in the slowing of the COVID-19 virus's fast spread, which had a substantial and noteworthy part in the present worldwide pandemic. The remainder of the study is organized into six sections: section 2: related work; section 3: proposed model; section 4: Simulation result, section 5: comparative analysis, and section 6: conclusion & future work.

Related Work

In [5], the author mentions how the Covid proved to be a pandemic and proposes a fuzzy interference module for detection of the severity of Covid-19 on the basis of its symptoms like headache, diarrhea, cold, cough, fever, and vice versa. The module also considers the patients' travel history and contact with the infected person, respectively. In [6], the author performs the analysis and predicts the Covid-19 progression in some most affected states of India, such as Andhra Pradesh, Maharashtra, and Tamil Nadu. The methodologies used by the authors were: Susceptible Infective Removed, also known as the SIR model, and second, the Fb-Prophet model.

In [7], The author describes the use of the ARIMA machine learning model for Covid-19 outbreak forecasting. The MAPE achieved by the proposed model is 85% for the states of India as well as all the other countries. The analysis also shows the real infrastructure of the healthcare system's planning and infrastructure. In [8], the authors propose Covid 19 vaccine booking and management system using blockchain technology. The authors prefer blockchain technology as it maintains transparency and integrity of the entire process, i.e., from the inception of the vaccine. In [9], the author explains the vaccination drive in India under the supervision of honorable PM Mr. Narendra Modi. The author discusses the working of the COWIN platform and basic information regarding vaccines and vaccination with various head personnel of the Indian Govt. healthcare department.

In [10], the author mentions that the COVID 19 was declared a pandemic by WHO after it brought a worldwide crisis. The author explains the working of the COWIN application provided by the government of India for registering and booking slots for vaccination drives. In [11], the research analyses various sets of literature reviews on AHP and ANP methodology, knowing the mass applications of the same. The research concluded the fact that the AHP is a way more effective that ANP in terms of result delivery and efficiency. In [12], the study analyzes collaboration of evolution in AHP along with ANP, respectively. The study consists of various approaches towards AHP and suggests some upgradation in the existing model, leading towards achieving more accurate results.

Proposed Model

The proposed model suggests some advancements regarding the slot booking mechanism in the existing system, which can make the system more efficient and user-friendly. The steps to be followed are: For registration, the user has to fill up the sections mentioned on the homepage such as Name, contact number, Aadhar number – for authentication purpose, email id, date range, select state, select district, select pin code of the area user prefers for vaccination, select minimum age, select free or paid select availability, and select vaccine. Once the details are authenticated, the user is granted permission to access the slot tracking feature. Depending on the input given by the user regarding its vaccination status, i.e.

i. If the user is not vaccinated yet or it's the first dose, then the user is displayed the available slot at the particular PIN area based on the preferred date by the user. Based on the vaccination status of the user, the countdown for the second dose starts at the interval of 12 weeks from the date of the first dose vaccination.
ii. If the user has taken the first dose, it displays the available slot for the second dose.
iii. As soon as the user gets vaccinated, a countdown for a booster dose starts at the interval of 9 months.

After each phase, the user is sent a reminder for the available timeslot at the preferred location of the respective next dose via mail. The mail sent to the user is based on the information stored (such as preferred location PIN, email) in the database at the time of registration. For sending reminders regarding the available slot, we have applied a fuzzy logic approach which consists of three parameters: age, availability of vaccination slots, and vaccination status.

(a) Age: For implementing Covid 19 vaccination program, the priorities set by the government were in the order: citizens above 60 yrs., citizens above 45 yrs., and citizens above 18 yrs.
(b) Availability of vaccination slots: Availability of vaccination slots is a major factor in considering the individual's priority on the basis of these factors.
(c) Vaccination status: Here, we'll consider the vaccination status of the respective individual, i.e., the first dose, second dose, and the booster dose.

Here, a question arises: What is Fuzzy logic approach?

Fuzzy logic approach can be defined as a variable processing approach which processes multiple probable truth values via same variable. Fuzzy logic is a mathematical study of multivalued logic. It's a rule-based phenomenon that relies on artificial intelligence software, also known as AI. They are used in both engineering and non-engineering applications, such as medical diagnosis and stock trading; in general, they are used practically in all systems which consist of input and output logic. [13]

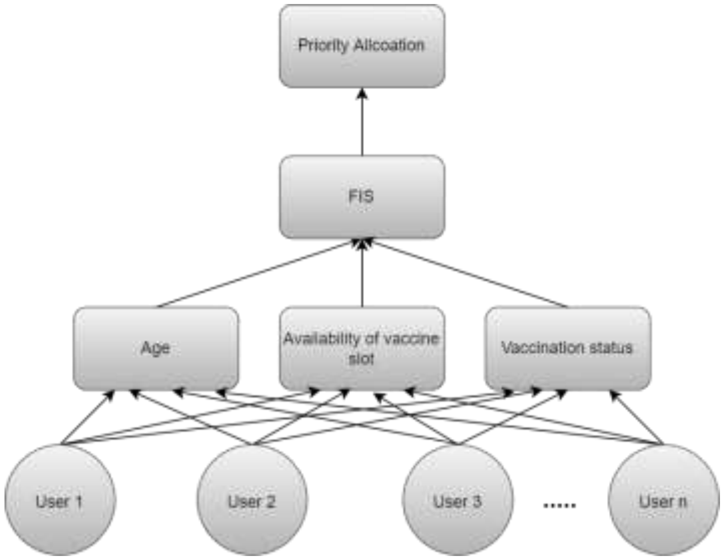

Fig. 2: Fuzzy based priority of slot availability notification mechanism

In this paper, the Fuzzy System is applied for sending the notification to the individuals regarding the availability of vaccination slots on the basis of three factors: Age, Availability of vaccine slots, and vaccination status of the individual, as shown in Fig. 2.

A. Proposed fuzzy based algorithm for slot tracking

The proposed slot availability reminder mechanism is based on fuzzy logic.

Algorithm: Fuzzy based algorithm for slot tracking
Ip: Input; Op: Output; MF: Membership Function; CV: Crisp value; FV: Fuzzy value; T1: Upper Threshold; T2: Lower Threshold 1: *Begin* 2: Ip and Op variables must be identified 3: *for* each variable: 4: Create MF of each 1,2,3,….n variable along with fuzzy sets; 5: *Define* the sets of fuzzy rules which relate to Ip and Op variable 6: Transform CV to FV using the MF:

7: MF=

$$\begin{cases} 1, \ \text{Input} \leq T1 \\ T1 - \text{Input}/T1 - T2, \ T1 < \text{Input} < T2 \\ 0, \ \text{Input} \leq T2 \end{cases}$$

8: In the rule base:
9: examine IF-ELSE rules
10: The outcome of each rule is added together
11: Transformation of Op values to CV
12: End

B. Fuzzification (for input)

In Fuzzification, the real or crisp value is converted into a non-crisp i.e. fuzzy value. According to crisp input, the range of fuzzy variables is defined, which ensures the proper implementation of any fuzzy program. The fuzzy sets used here are Low, Medium, and High. The three parameters considered for the simulation of output (as priority) are mentioned in Table 1.

Table 1: parameters considered for simulation of output (as priority)

Parameters	Low	Medium	High
Age	0 to 35	30 to 55	50 to 100
Availability of vaccination slots	23 to 31	13 to 25	01 to 14
Vaccination status	15 to 28 (Booster)	12 to 18 (Second dose)	0 to 14 (First dose)

Based on the parameters mentioned in Table 1, we'll decide the output in the form of priority. If the priority is:

- High- the user is notified at the earliest.
- Medium- the user is notified after those present in high priority.
- Low – the user is notified if any slot remains vacant in the particular area after the booking of high priority & medium priority groups.

In this paper, the fuzzy value of the first dose is 0 to 14, the second dose is 12 to 18, and the booster is 15 to 28. The membership function for input variables is shown in Tables 2 to 4. Table 2 represents the input range for the age factor on a scale of 18 to 150. The membership value, i.e., low, medium, and high, will be represented by fuzzy variable output, which will be employed in the simulation.

Table 2: Range of input for Age

No.	Range of Input (Crisp)	Name (fuzzy)
1	0 to 35	Low
2	30 to 55	Medium
3	50 to 100	High

Fig.3 is the representation of the respective fuzzy membership graph for the selected parameter ‘age’.

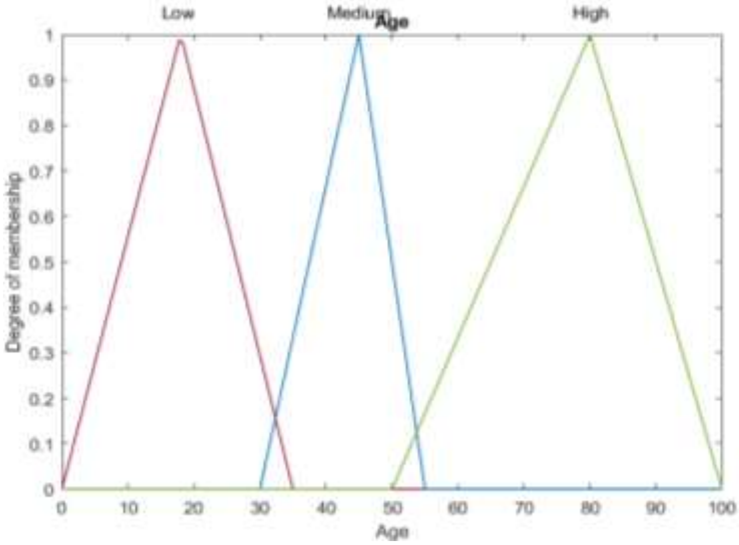

Fig.3. Age of person

Table 3 represents the input range for the availability of vaccination slots on a scale of 01 to 31. The membership value, i.e., low, medium, and high, will be represented by fuzzy variable output, which will be employed in the simulation.

Table 3: Range of Input for the availability of vaccination slots

No.	Input Range (Crisp)	Name (fuzzy variable)
1	23 to 31	Low
2	13 to 25	Medium
3	01 to 14	High

Fig.4 is the representation of the respective fuzzy membership graph for the selected parameter ‘availability of vaccination slots’.

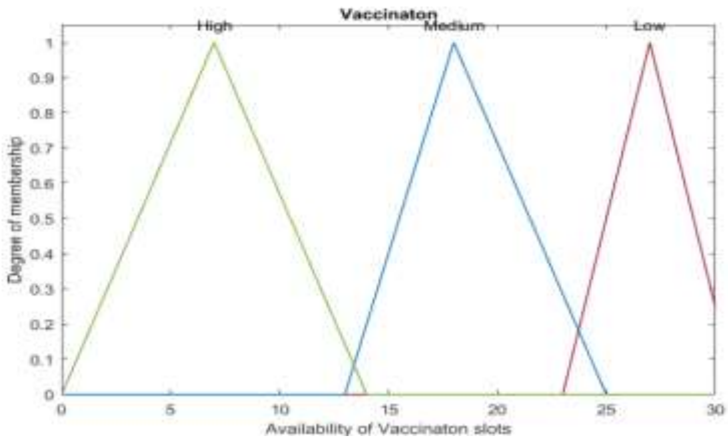

Fig.4. Availability of slots

Table 4 represents the input range for the date of input range on a scale of 0 to 28. The membership value, i.e., low, medium, and high, will be represented by fuzzy variable output, which will be employed in the simulation [14].

Table 4: Range of Input for Vaccination Status

No.	Input (Crisp)	Name (fuzzy)
1	15 to 28	Low
2	12 to 18	Medium
3	0 to 14	High

Fig.5 represents the respective fuzzy membership graph for the selected parameter ‘Vaccination Status ’.

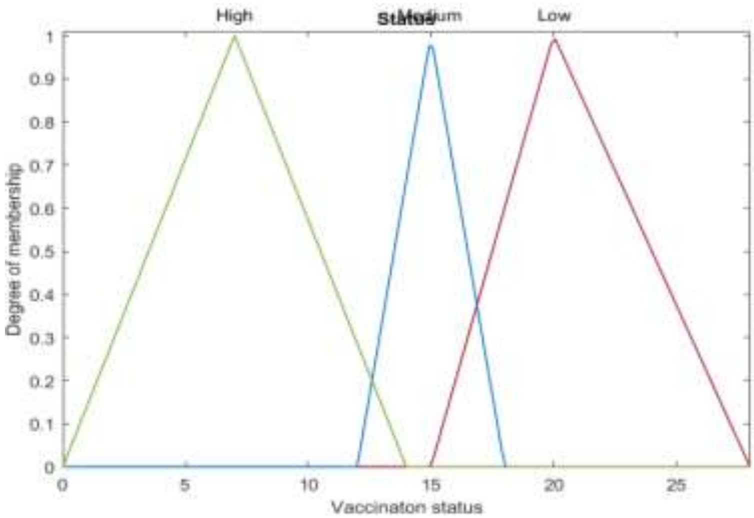

Fig.5. Status

C. Membership Function (for output)

For the input parameter, the membership functions are $\mu X(A_g)$, $\mu Y(D_a)$, and $\mu Z(V_s)$. Two thresholds are associated with these variables: the lower and the upper threshold. The values of these thresholds are T1, T2, T3, ... T6, respectively. These thresholds are employed to run the system since the lower threshold value indicates the system model's activation point, and between the upper and lower threshold values, the system model operates. Eq 1, Eq 2, and Eq 3 represents the membership function for the selected input parameters.

$$\mu_x(Age) = \begin{cases} 1, & Ag \leq T1 \\ T1 - Ag/T1 - T2, & T1 < Ag < T2 \\ 0, & Ag \leq T2 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\mu_Y(Availability\ of\ vaccination\ slots) = \begin{cases} 1, & Da \leq T3 \\ T3 - Da/T3 - T4, & T3 < Da < T4 \\ 0, & Da \leq T4 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$\mu_z(Vaccination\ status) = \begin{cases} 1, & Vs \leq T5 \\ T5 - Vs/T5 - T6, & T5 < Vs < T6 \\ 0, & Vs \leq T6 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Let us consider Ag, Da, and Vs as input variables for age, availability of vaccination slots, and vaccination status. The output variable depicts the priority of the slot booking reminder mechanism. The fuzzy sets used for setting the priority for notification and slot booking are defined as: Very high, high, medium, low, and very low.

Table 5: Fuzzy Output variables

Sr. no.	Output range fuzzy variable(Likelihood)	Fuzzy variable name
1	0 to 0.2	Very low
2	0.175 to 0.4	Low
3	0.35 to 0.6	Medium
4	0.5 to 0.8	High
5	0.7 to 1.0	Very high

Table 5 represents the fuzzy output variable through five membership functions on a scale of 0 to 1, in which the higher the number, the higher the probability of slot availability tracking notification.

Fig.6 represents the respective fuzzy membership graph for the output parameter 'Likelihood '.

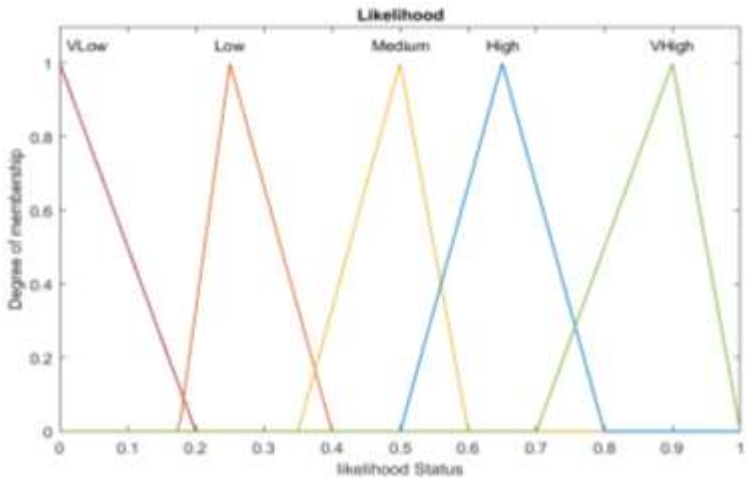

Fig.6. Vaccination Probability

The membership functions are selected on the basis of the defined fuzzy rule set. The order of the parameters (input) which are mentioned for the priority of the slot tracking and notification mechanism are:

$$Ag > Da > Vs \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where,
Ag: Age of the individual
Da: Availability of vaccination slots
Vs: Vaccination status

The input parameters: age of the individual, availability of vaccination slots, and vaccination status will only be entertained if their values are associated.

D. Fuzzy Rules

Rule 1. *If (Ag is High) and (Da is High) and (Vs is High) then (likelihood__ is Very High).*
Rule 2. *If (Ag is Medium) and (Da is Medium) and (Vs is Medium) then (likelihood__ is Medium).*
Rule 3. *If (If (Ag is Medium) and (Da is Medium) and (Vs is High) then (likelihood__ is High).*
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Rule 27. *If (Ag is Low) and (Da is Low) and (Vs is Low) then (likelihood__ is Very Low).*

Table 6: Fuzzy rule set for output, i.e., the priority of slot availability notification mechanism

Rule No.	Age	Availability of vaccination slots	Vaccination Status	Output
1.	L	L	L	VL
2.	L	L	M	VL
3.	L	M	H	VL
4.	M	M	L	L
5.	M	H	M	M
6.	M	H	H	VH
7.	H	L	L	M
8.	H	L	M	VH
9.	H	M	H	VH
10.	L	M	L	VL
11.	L	H	M	L
12.	L	H	H	H
13.	M	L	L	M
14.	M	L	M	H
15.	M	M	H	VH
16.	H	M	L	H
17.	H	H	M	VH
18.	H	H	H	VH
19.	L	L	L	VL
20.	L	L	M	L
21.	L	M	H	VH
22.	M	M	L	M
23.	M	H	M	H
24.	M	H	H	VH
25.	H	L	L	H
26.	H	L	M	VH
27.	H	M	H	VH

In Table 6. VL stands for Very low, L stands for low, M stands for Medium, H stands for High, and VH stands for Very high.

All the above-mentioned rules will be considered by the Fuzzy system in order to select the most appropriate and best match case for setting up the priority of slot availability notification mechanism.

Simulation Result

The different input parameters are used to get the probability of getting vaccination for the evaluation and allocation process. The in-built fuzzy toolbox of MATLAB is used to virtually create and allocate all the crisp inputs to the proposed model. Table 1 contains different parameters that are used in the simulation. In the simulation process, a registered person's age, availability of vaccination slot and vaccination status is taken as input to the model where U1 represents the individual user, and its respective instances are shown in table 7.

Table.7.Person slot tracking instance

Sr. No.	Person	Input	Likelihood
1	U1	[50, 15,14]	0.5
2	U2	[70, 08,15]	0.864
3	U3	[17, 05,15]	0.276

The result obtained by the proposed model, the likelihood of priority assignment for User 1 is 0.5, for User 2 its 0.864 and for User 3 the likelihood is 0.276 which indicates that User 2 has the highest priority, User 1 has a medium priority whereas User 3 has the low priority.

The three selected inputs depicted in Fig.7, where the Mamdani-FIS is used.

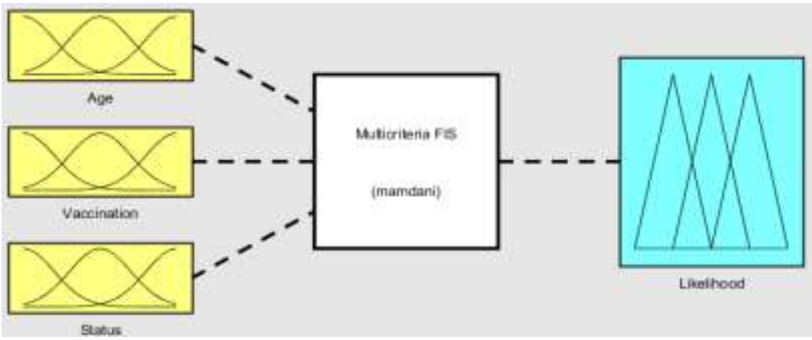

Fig.7.Fuzzy based vaccine slot tracker model

Fig.8 shows the likelihood (probability) of getting the vaccination slots for an individual user for the three selected key parameters.

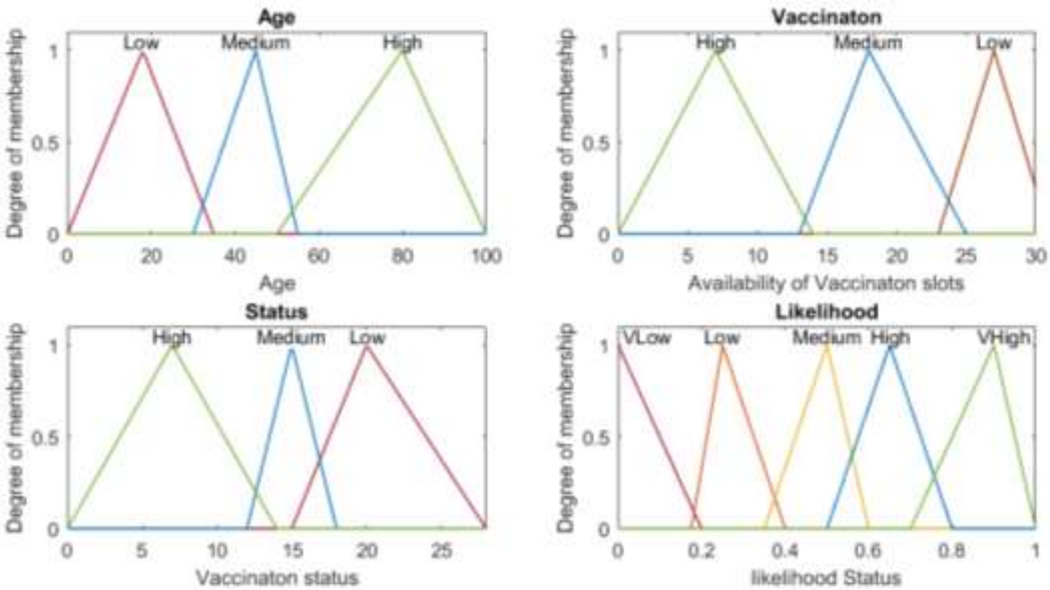

Fig.8. Probability of vaccination using selected parameters

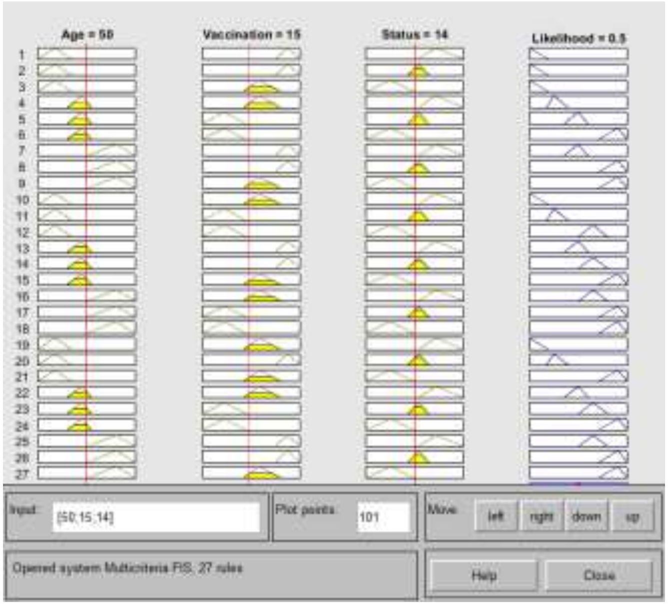

Fig. 9 Likelihood of User 1

As shown in Fig. 9, the Priority likelihood of User1 is 0.5, which depicts that its priority level is Medium. The value of different parameters mentioned for User 1 is: Age=50, Vaccination slot availability= 15 and Status of vaccination is 14.

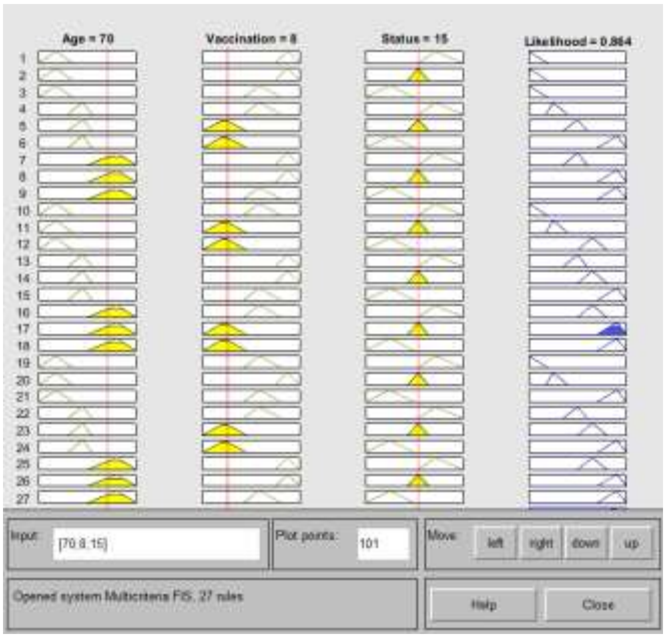

Fig. 10 Likelihood of User 2

As shown in Fig. 10, the Priority likelihood of User 2 is 0.864, which depicts that its priority level is Very high. The value of different parameters mentioned for User 2 is: Age=70, Vaccination slot availability= 08 and Status of vaccination is 15.

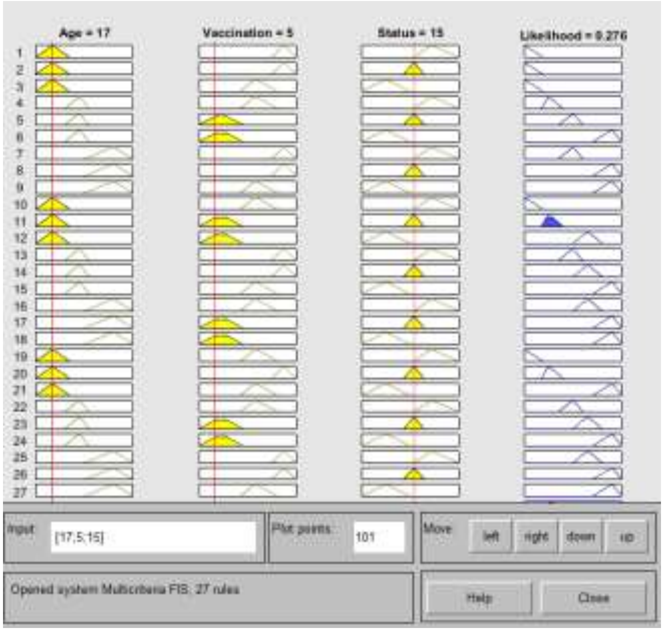

Fig. 11 Likelihood of User 3

As shown in Fig. 11, the Priority likelihood of User 3 is 0.276, which depicts that its priority level is Low. The value of different parameters mentioned for User 3 is: Age=17, Vaccination slot availability= 5 and Status of vaccination is 15.

Comparative Analysis

The Human judgement is utilized to measure fugitive utilizing the Analytic Hierarchical Process (AHP) and the Analytic Network Process (ANP). The AHP and ANP synthesis approaches are the most potent for combining decree and data to rank options and forecast outcomes. The ANP allows for complicated interdependencies among scales and attributes, whereas the AHP presents a framework with a unidirectional hierarchy relationship of AHP [15]. In the below mentioned Fig. 12 we have compared the data and observed the consistency of the efficiency of the previous techniques. The proposed technique's priority value are unexpectedly better with that of the AHP and ANP approach. Also, to be noted that the ranks obtained using the AHP and the ANP technique had a substantial coefficient of similarity.

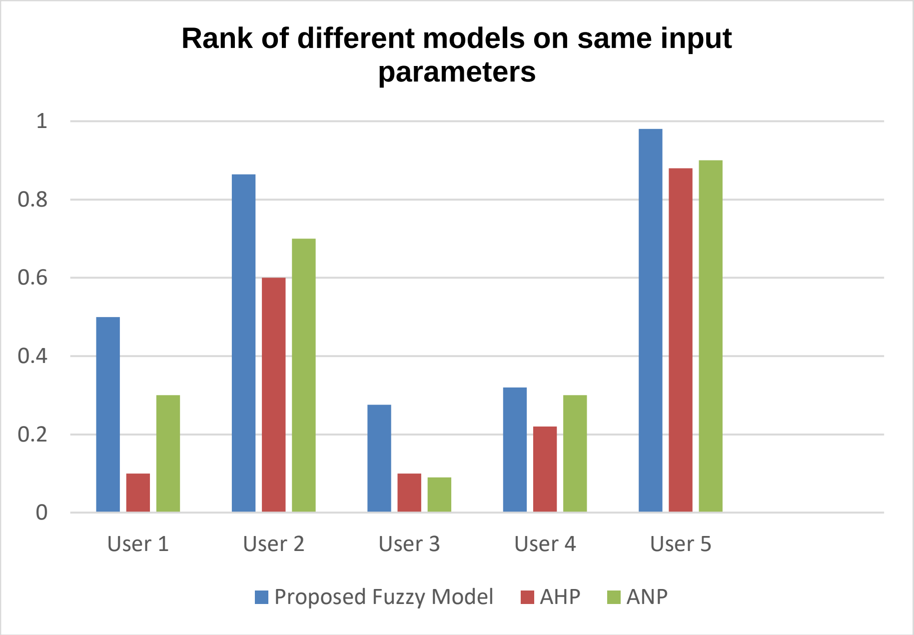

Fig. 12 Rank of different models on same input parameters

In Fig. 12, we have depicted the rank of different models using the same input parameters and test cases in which our proposed model has proved to be more efficient.

Conclusion & Future Work

The proposed approach evaluates the vaccination slot availability and registration based on the selected key parameters .The proposed model is evaluated, and tested for three random user instances where User 1 has a likelihood of 0.6, User 2 has the likelihood of 0.68 and User 3 got likelihood of 0.8. The framework assigns priority on the basis of the likelihood values. The higher the value, the higher the likelihood. In the above scenario, User 3 has got the high priority, User 2 has medium level priority and User 1 has low likelihood or probability. This approach can help to overcome various problems faced by the public during vaccination such as information regarding slot availability, slot tracking, registration and slot booking problems for the successful adoption of Vaccination drive nationwide with the implementation of Fuzzy logic approach in setting up of Priority. In future, we will extend the model capability using more number of criteria and sub-criteria with the incorporation of machine learning techniques.

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