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Rule Based Mamdani Fuzzy Inference System to Analyze Efficacy of COVID19 Vaccines

Poonam Mittal[1*], S P Abirami[2], Puppala Ramya[3], Balajee J[4] and Elangovan Muniyandy[5]

[1]Department of Computer Engineering, J.C Bose University of Science and Technology, Faridabad, India
[2]School of Computer Science and Engineering, VIT-AP University, Andhra Pradesh, Amaravati, India
[3]Department of Computer Science and Engineering, Koneru Lakshmaiah Education Foundation, Green Fields, Vaddeswaram, Guntur Dist., A.P., India
[4]Department of Computer Science and Engineering, Mother Theresa Institute of Engineering and Technology, Palamaner-517408, Chittoor, Andhra Pradesh, India
[5]Department of Biosciences, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Chennai, Tamil Nadu, India

Abstract

INTRODUCTION: COVID-19 was declared as most dangerous disease and even after maintaining so many preventive measures, vaccination is the only preventive option from SARS-CoV-2. Vaccination has controlled the risk and spreading of virus that causes COVID-19. Vaccines can help in preventing serious illness and death. Before recommendation of COVID-19 vaccines, clinical experiments are being conducted with thousands of grown person and children. In controlled situations like clinical trials, efficacy refers to how well a vaccination prevents symptomatic or asymptomatic illness.
OBJECTIVES: The effectiveness of a vaccine relates to how effectively it works in the actual world.
METHODS: This research presents a novel approach to model the efficacy of COVID'19 vaccines based on Mamdani Fuzzy system Modelling. The proposed fuzzy model aims to gauge the impact of epidemiological and clinical factors on which the efficacy of COVID'19 vaccines.
RESULTS: In this study, 8 different aspects are considered, which are classified as efficiency evaluating factors. To prepare this model, data has been accumulated from various research papers, reliable news articles on vaccine response in multiple regions, published journals etc. A set of Fuzzy rules was inferred based on classified parameters. This fuzzy inference system is expected to be of great help in recommending the most appropriate vaccine on the basis of several parameters.
CONCLUSION: It aims to give an idea to pharmaceutical manufacturers on how they can improve vaccine efficacy and for the decision making that which one to be followed.

Keywords: COVID19, COVID19 Vaccines, Side-Effects, Demographic Factors, Clinical Factors, Efficacy of COVID Vaccines, Medical History, Fuzzy Inference System, Mamdani Fuzzy Model

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*Corresponding author. Email: poonamgarg1984@gmail.com

1. Introduction

World Health Organization declared that more than 4.64 billion people worldwide are vaccinated with 1 dose of Covid Vaccine which stands equal to 60 percent of the world population. Out of which, more than 3.9 billion people are considered fully vaccinated, which stands equal to 50.3 percent of the world population.
There are another 182 candidate vaccines in pre-clinical development. As of 12 January 2022, the mentioned vaccines have obtained EUL: Pfizer/BioNTech, COVISHIELD and AstraZeneca vaccines, Janssen by Johnson Johnson, Mod- erna, Sinopharm, Sinovac-

CoronsVac, Bharat Biotech COVAXIN, Nuvaxovid [1]. For this study, nine vaccines are being considered, Pfizer, Moderna, AstraZeneca (Covishield), and Johnson Johnson, Covaxin, Sputnik V, Convicedea, Sino- vav, BBIP-Corv, which are being used rigorously to control the SARS-CoV-2 pandemic in various regions of the world. Table 1 represents vaccination record of various countries. Studies revealed that almost all the vaccines are at good safety profile [2] with some short-lived and self-limiting side effects. To analyze the performance of these vaccines there are several techniques which can be applied to see the impact of different parameters to see the performance of these vaccines but due to unavailability of crisp data there is a need of modelling tool which can work on fuzzy data. So, Fuzzy Inference System (FIS) can be a suitable tool that uses fuzzy set theory to map inputs (features) to outputs (classes). Mamdani Fuzzy Inference [1] is a type of FIS where fuzzy rules are a collection of linguistic statements. The performance of the Mamdani model [17] is a fuzzy membership inference [17,19,21] based on the rules generated. Mamdani Fuzzy Expert systems are considered to be intuitive and well-suited for human inputs. It has widespread acceptance and is used in Medical Sciences for effective future predictions.

Table 1. Vaccination Rates as per region

Region	Partially Vaccinated (in%)	Fully Vaccinated (in%)
U.S. and Canada	76	68
Latin America	72	63
Asia − Pacific	71	60
Europe	66	61
Middle East	51	40
Africa	14	11

The research content is organized as follows: introduction of the topic in given in section 1, section 2 covers the available research content of COVID'19 domain. Section 3 describes the factors affecting the performance of vaccines. Section 4 presents the proposal Mamdani fuzzy inference model. Section 5 presents the results and discussion of performance analysis of various vaccines in different scenarios with conclusion and findings given at the end.

2. Related Work

This section presents the throughput of research performed in different regions of the world to analyze the impact and aftereffects of COVID19 Vaccines. This study aims to calculate the efficacy of COVID19 Vaccines keeping multiple factors in consideration. The model is built using Mamdani fuzzy set theory. It was validated against available data on COVID19 Vaccines. Since the gap between model's predicted values and actual value is negligible, it could be claimed that the result of the study will provide valuable information for the drug manufacturer to improve the framework of vaccines for future clinical trials. The results will also be useful for public health authorities to procure more funds for the development of the vaccine and to acquire more vaccines for the public.

The creation of innovative vaccinations was made possible by the use of nucleic acid-based treatments and vaccines, which offered a stable and effective platform. According to the results of clinical studies of ChAdOx1 nCoV-19 (AstraZeneca/Oxford), giving the second dose after a 12-week gap could result in an efficacy of 78%. As a result, delaying the booster dosage for the AstraZeneca/Oxford vaccination would be beneficial. Hospitalization was reduced by 94 percent in the 28 to 34 days following the first dose of the vaccine. Phase -3 trials of Sinopharm were conducted in China [6]. For the age group of 18-60 years, the overall efficacy was calculated as 78%. Vaccine efficacy trials were not demonstrated for 60 years and above. After effects are mild to moderate and the most common reactions are pain at injection site, fever, fatigue, muscle pain [2]. A single dosage of this vaccine provides 66 percent efficacy against moderate to severe COVID-19 as per Johnson. The Janssen vaccine exhibited efficacy of 66% and 85% against moderate-to-severe and severe COVID-19 infection [5], respectively. Authors in [6] claim that Female participants had a greater efficacy rate than male participants, with 760 (70.4%) females and 320 (29.5%) males participating. It has been concluded that climatic circumstances [2] can be one of the elements affecting vaccine efficacy rate based on data from Brazil and Turkey. Participants aged 18 to 44 had a substantially greater effectiveness rate than those aged 45 and over. Participants having a lower immunity rate [18] and a history of chronic illness also had a lower effectiveness rate. Authors in [11] presented collective research from three randomized controlled trials conducted in the UK and Brazil on Pfizer and Covishield. The statistical analysis of these trails concluded that the overall efficacy of Covishield is 70.4%. The statistical analysis implemented in [8] aims to elucidate the impact of gender differences on efficacy of the vaccines. Authors claimed a significantly higher efficacy in Men.

3. Related Clinical and Demographic Factors

The efficacy of COVID19 Vaccines can vary greatly depending on a number of demographic factors. This section elaborates the various demographic factors that are taken into account to understand the vaccine's ability to protect against a variety of covid infections. Examples of such factors are gender, medical history including covid infection history [5], age, dose interval, immunity of the individual, side-effects observed post vaccination. In the following sections, we have discussed the impact of each parameter affecting the effectiveness of vaccines.

3.1 Age and Gender of Individual

The safety and efficacy of individual vaccines is critical to their success in the case of older people. According to the research, the rate of adverse events was slightly higher in young people whereas safety was worse than that of elder people. This could be claimed on the basis of symptoms observed post vaccination in both the age groups. The vaccine tolerance of different ages is being analyzed continuously. According to the study, it has been observed that the overall efficacy of vaccination is higher in the younger age group i.e. between 18 to 44 marks [14].

Most reactions of COVID19 vaccines are minor and a rare set of people re- ported severe reactions post vaccination. However, it has been observed that women experienced more side-effects as compared to male audience [8]. Though, this statement might vary from vaccine to vaccine. According to the study, vaccines like Pfizer (BNT162b2), Sputnik V (Gam-COVID-Vac) and Sinovac- CoronaVac showed almost equal or slightly higher efficacy in female candidates as compared to male ones [8]. On the other hand, efficacy of Convidicea was reported higher in men.

3.2 Immune Response from COVID Vaccines

Immune memory is used by vaccines to protect us from infection [5]. Immune memory might be the outcome of a previous infection or a successful vaccine [9]. There are 4 types of immunogens used in development of different COVID19 vaccines, namely, Inactivated virus, Viral subunit, Viral vector and RNA Based vaccines. It has been noticed that with the emergence of new variants like Omicron, the transmissibility of the infection has been increased. Furthermore, the vaccines that are less effective in preventing infection, have raised concerns among vulnerable groups whose immune responses may be insufficient in magnitude and quality. Due to weaker immune system, people aged 60 years or more and those with respiratory or cardiovascular disease are at high risk of serious disease.

3.3 Underlying Medical History

Severity of the medical history of a candidate plays an important factor in measuring the efficacy of a vaccine [6]. According to the findings, people who have a curable disease or no disease tend to show more effective responses to vaccines. It has been observed that people with previous medical history or those who are currently being diagnosed with any chronic disease such as cancer, cardiovascular disease etc., have shown comparatively low efficacy [6] as compared to the former category. Although the use of broad-spectrum antibiotics and antivirals to treat COVID patients has resulted in some improvement, many of them have experienced serious side effects [10].

It has also been noticed that the defense mechanism of those who have prior COVID infection has been found to persist for months. This has raised a question if two doses of mRNA and viral vector-based vaccines are needed in such cases.

3.4 Diversity of Adverse Events

According to the research, almost every vaccine has both systemic and localized side effects. The same has been reported in Pfizer. The statistical analysis performed on the clinical trial results of Sinopharm [7,13] investigated that after the first dose, participants aged greater than equal to 49 showed slightly higher percentage of local and systemic side-effects such as normal injection site pain, fatigue and headache as compared to people aged less than 49. The same was more common after the second dose of Sinopharm. The recipients of Moderna (mRNA-1273) [4,25] reported mild local reactions whereas around 50% of the candidates reported moderate to severe Systemic side-effects such as fatigue, myalgia, arthralgia, and fever [13]. Based on the Convidicea [20] trial results from Pakistan, Russia, Mexico and Argentine, it has been observed that the most prevalent significant adverse event was angina or myocardial infarction, which was reported by five subjects (two of whom died). Trauma was reported by four participants. Three candidates reported Appendicitis or bowel obstruction, one of whom died of sepsis [15].

4. Proposed Mamdani based Fuzzy Expert System

According to the reviewed research content, a number of demographic factors need to be considered in order to ensure relevant results of efficacy analysis. It is highly important to study the contribution of each factor in defining the effectiveness of the vaccine and to do the same a Mamdani based fuzzy inference system is implemented here to check the efficacy of different available COVID vaccines.

4.1 Objective

To predict the mutuality and domain of the factors, an integrated analytical approach is required. Therefore, there is a strong need for a model to assess the impact of various significant factors.

4.2 Proposal

The proposed model employs a Mamdani- fuzzy inference system for predicting the efficacy of the COVID vaccines based on various demographic factors as discussed in the previous section. Brief working of fuzzy expert system is modeled in figure 1.

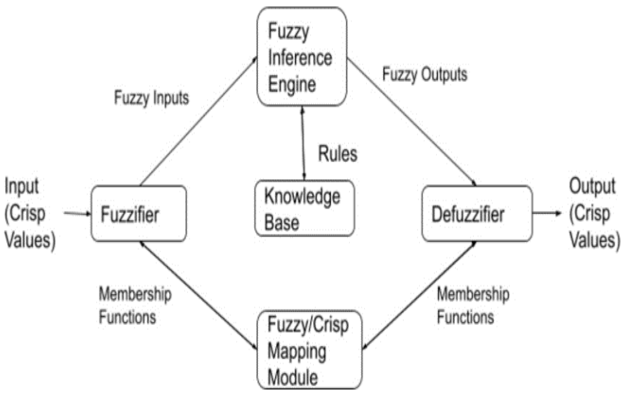


Figure 1. Block diagram of Mamdani Fuzzy Expert System

The proposed model is based on FES and implemented using MATLAB R2013b where the efficacy value is calculated through the base FES and outputs the results as shown in Figure 2.

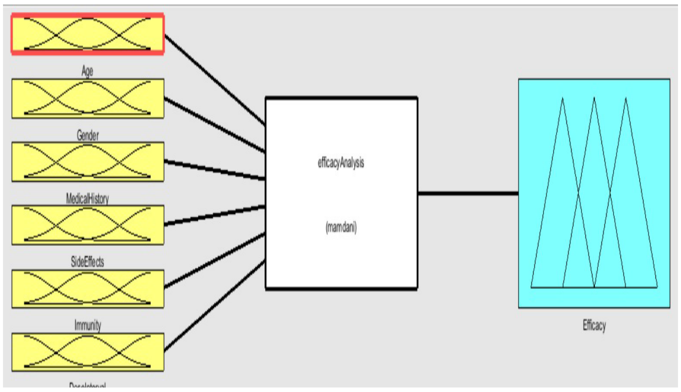


Figure 2. Fuzzy Inference system to calculate Efficacy Value

4.3 Efficacy Value Computation

To calculate the efficacy value of each vaccine, 6 major factors are considered. Fuzzy Pattern to calculate the efficacy rate of each vaccine is shown in Fig.3. Factors like medical history is a combination of a candidate's underlying disease history as well as COVID infection history. Immunity of the candidate determined by age, medical history and other related health factors [1]. Age is categorized in two major categories on the scale of 18 to 100 years. Gender of the person has been classified using binary values i.e., 0 for Male and 1 for Female. Underlying medical history, severity of side effects and immunity is scaled on Likert scale (0-10). Dose Interval varies from 15 to 85 days as shown in table 3. The crisp values of these variations are fuzzified onto linguistic variables as low, medium and high etc. [1]. 192 rules are prepared based on the variations of each input parameter.

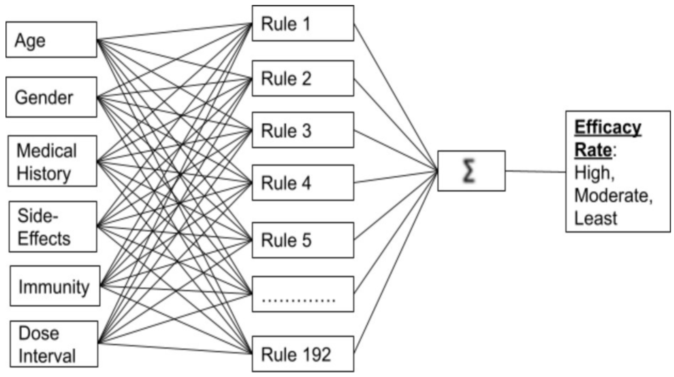


Figure 3. Proposed block diagram to calculate the Efficacy Value

On the basis of these rules, the efficacy of each and every vaccine is calculated. Design of FES is shown in Figure 3 where input variables are 6 parameters and output variable is named as Efficacy Rate [1]. All 192 rules for each of the vaccines are depicted in Tables 3(a-i).

Table 3(a): Rule Table for Moderna

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Severe	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Severe	65 above	Least efficient
Younger	Male	Chronic	Innate	Systematic	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	65 above	Least efficient
Younger	Male	Chronic	Innate	Local	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Local	45-65	Most efficient
Younger	Male	Chronic	Innate	Local	65 above	Least efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	local	65 above	Moderately efficient

Table 3(b): Rule Table for Janssen

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Severe	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Severe	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Local	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Local	45-65	Most efficient
Younger	Male	Chronic	Innate	Local	65 above	Moderately efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Moderately efficient

Table 3(c): Rule Table for Sputnik

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Severe	45-65	Least efficient
Younger	Male	Chronic	Innate	Severe	65 above	Least efficient
Younger	Male	Chronic	Innate	Systematic	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Local	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Local	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Local	65 above	Moderately efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Most efficient

Table 3(d): Rule Table for Sinovac

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Severe	45-65	Least efficient
Younger	Male	Chronic	Innate	Severe	65 above	Least efficient
Younger	Male	Chronic	Innate	Systematic	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Local	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Local	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Local	65 above	Moderately efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Moderately efficient

Table 3(e): Rule Table for Sinopharm

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Severe	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Severe	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	15-45	Most efficient
Younger	Male	Chronic	Innate	Systematic	45-65	Most efficient
Younger	Male	Chronic	Innate	Systematic	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Local	15-45	Most efficient
Younger	Male	Chronic	Innate	Local	45-65	Most efficient
Younger	Male	Chronic	Innate	Local	65 above	Most efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Most efficient

Table 3(f): Rule Table for Convidecia

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	15-45	Moderately efficient
Younger	Male	Chronic	Innate	Severe	45-65	Moderately efficient
Younger	Male	Chronic	Innate	Severe	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Systematic	15-45	Most efficient
Younger	Male	Chronic	Innate	Systematic	45-65	Most efficient
Younger	Male	Chronic	Innate	Systematic	65 above	Moderately efficient
Younger	Male	Chronic	Innate	Local	15-45	Most efficient
Younger	Male	Chronic	Innate	Local	45-65	Most efficient
Younger	Male	Chronic	Innate	Local	65 above	Most efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Most efficient

Table 3(g): Rule Table for Covishield

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	Frequent	Least Efficient
Younger	Male	Chronic	Innate	Severe	Moderate	Least Efficient
Younger	Male	Chronic	Innate	Severe	Scarce	Moderately Efficient
Younger	Male	Chronic	Innate	Systematic	Frequent	Least Efficient
Younger	Male	Chronic	Innate	Systematic	Moderate	Moderately Efficient
Younger	Male	Chronic	Innate	Systematic	Scarce	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Frequent	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Moderate	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Scarce	Most Efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Most efficient

Table 3(h): Rule Table for Covaxin

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	Frequent	Least Efficient
Younger	Male	Chronic	Innate	Severe	Moderate	Least Efficient
Younger	Male	Chronic	Innate	Severe	Scarce	Least Efficient
Younger	Male	Chronic	Innate	Systematic	Frequent	Moderately Efficient
Younger	Male	Chronic	Innate	Systematic	Moderate	Moderately Efficient
Younger	Male	Chronic	Innate	Systematic	Scarce	Least Efficient
Younger	Male	Chronic	Innate	Local	Frequent	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Moderate	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Scarce	Least Efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Most efficient

Table 3(i): Rule Table for Plizer

Input						Output
Age	Gender	Medical History	Immunity	Side Effects	Dose Interval	Efficacy
Younger	Male	Chronic	Innate	Severe	Frequent	Moderately Efficient
Younger	Male	Chronic	Innate	Severe	Moderate	Least Efficient
Younger	Male	Chronic	Innate	Severe	Scarce	Least Efficient
Younger	Male	Chronic	Innate	Systematic	Frequent	Moderately Efficient
Younger	Male	Chronic	Innate	Systematic	Moderate	Moderately Efficient
Younger	Male	Chronic	Innate	Systematic	Scarce	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Frequent	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Moderate	Moderately Efficient
Younger	Male	Chronic	Innate	Local	Scarce	Moderately Efficient
:	:	:	:	:	:	:
Elder	Female	None	Adaptive	Local	65 above	Moderately Efficient

Table 4: Membership function for input and output for Efficacy Values

Parameters		Membership Functions		
		L	M	H
	Age group	Younger [18 30 44]	Elder [38 65 100]	-
	Gender	Male [0 0 0]	Female [1 1 1]	-
INPUT	Medical History	None [0 0 4]	Curable [3 5 7]	Chronic [6 10 10]
	Immunity	Adaptive [0 0 6]	Innate [5 10 10]	-
	Side-Effects	Local [0 0 4]	Systematic [3 5 7]	Severe [6 10 10]
	Dose Interval	Frequent [15 30 45]	Moderate [38 51 65]	Scarce [57 72 85]
OUTPUT	Efficacy Rate	Least [0 0 4]	Moderate [3 5 7]	Best [6 10 10]

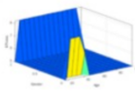
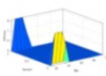
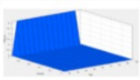
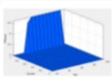
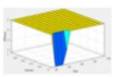
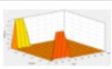
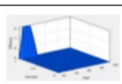
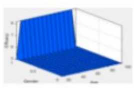
5. Result and Discussions

This section discusses the results obtained from Mamdani Fuzzy Expert System implementation of Clinical and Demographic factors. The output of the proposed system i.e., Efficacy Rate which has Best, Moderate, least effective as fuzzy results is converted to crisp values. Each of the individual factors such as age, gender, immunity, severity of side effects, underlying medical history of disease, and dose-interval are all altered to provide varied efficacy values. As observed by the surface view of various vaccines, the highest value of efficacy is 8.9 which is obtained for both Male and Female when Immunity is 5.1. Impact of each factor for each of the vaccines is discussed in below subsections. A surface view for each of the vaccines with two different parameters is demonstrated in Table 5 (a-e).

5.1 Impact of Age and Gender on Efficacy

Table 5(a) contains the surface view for each vaccine with respect to Age and Gender. Results of the same demonstrate that for Moderna, the highest efficacy is computed to be 8.2 (High), when the candidate's age is between 20-90 years irrespective of the Gender. Moderna and Sinopharm are found to be promising vaccines for young people irrespective of their gender.

Table 5(a): Surface view of vaccines based on Medical History and Gender

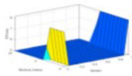
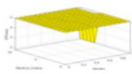
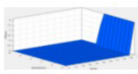
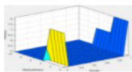
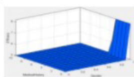
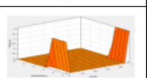
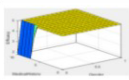
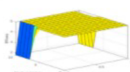
Vaccine	Gender	Age	Efficacy	Surface View
Moderna	1 and 0	20-90	8.2	
Sinopharm	1 and 0	20-40	8.2	
Sinovac	1	20-90	8.1	
Covishield	1	30-95	6.8	
Covaxin	1	45-100	5	
Pfizer	1 and 0	22-44	8.3	
Janssen	1	20-40	8.2	
Sputnik	1	20-85	8.2	

On the other hand, Covaxin is found to be moderately efficient in females of 44 above age group, with an efficacy rate as 5 (Medium). Jannesan shows higher efficacy in younger females i.e., between 20-40 years old, with efficacy of 8.2 (High). Both Sinovac and Sputnik [22] found to be equally effective for both Male and Female candidates of age 20 to 40.

5.2 Impact of Underlying Medical History and Gender of candidate on Efficacy

Surface view of FES results for each vaccine is represented in Table 5(b) which portrays the efficacy value with respect to 2 input parameters namely, Medical History and Gender of the person. The surface view for Pfizer depicts an efficacy of 8.3 when the candidate has no medical history, irrespective of gender. In case of Sinopharm, candidates with Chronic Disease history shows the efficacy value of 5 which is Medium. Sputnik [22] shows higher efficacy in Female candidates with curable or no underlying disease history. With the overall results, it could be concluded that candidates having either a curable or no medical history show higher efficacy value as compared to those with Chronic Disease such as blood clotting, cancer, HIV etc. Efficacy scale is observed to decline as the chronicity of the disease rises up.

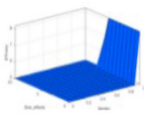
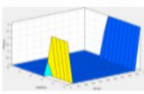
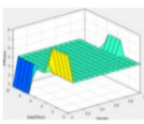
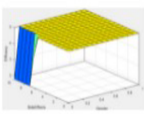
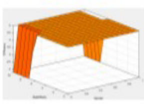
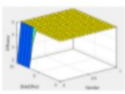
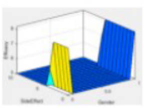
Table 5(b): Surface view of vaccines based on Medical History and Gender

Vaccine	Medical History	Gender	Efficacy	Surface View
Moderna	6	1 and 0	8.2	
Sinopharm	7	0	5	
Sinovac	5	1	8.2	
Covishield	6	1 and 0	8.2	
Covaxin	4	1	8.3	
Pfizer	4	0 and 1	8.3	
Janssen	7	1	5	
Convidecia	7	1 and 0	4	
Sputnik	6	1	8.1	

5.3 Impact of Severity of Side-Effects and Gender of candidate on Efficacy

All the vaccines show Systematic and Local Side effects to some extent. Vaccines show a decline in efficacy graph if the side effects are chronic. Table 5(c) shows the surface representation of the vaccine's efficacy with respect to severity of side effects. Based on these results it is concluded that in case of severe side effects i.e., having fuzzy values between 7 to 10, efficacy degrades. On the other hand, Efficacy of Covishield rises to 6.4 if almost no side-effects (0-4) were observed. Similarly, it is observed that efficacy of Pfizer depreciates for both Male and Female as the Severity scale rises up. i.e., between 7 to 10. Impact of severity is the same on Covaxin, Janssen and Moderna as well.

Table 5(c): Surface view of vaccines based on Side-Effects and Gender

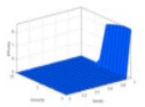
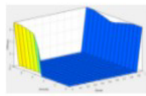
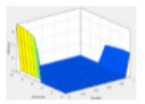
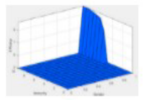
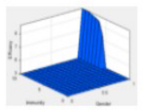
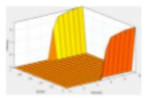
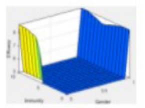
Vaccine	SideEffects	Gender	Efficacy	Surface View
Moderna	7	1	8.2	
Sinovac	5.5	1 and 0	8.1	
Covishield	6	1 and 0	6.5	
Covaxin	6	1 and 0	5	
Pfizer	7	1 and 0	5	
Janssen	6	1 and 0	5	
Sputnik	5.5	1 and 0	8.1	

5.4 Impact of Gender and Immunity of Candidate on Efficacy

Surface graph view of two different parameters taken at a time for each of the vaccines are shown in Table 5(d). The maximum efficacy value calculated is 8.9, which is for Pfizer.

The collective results for all the vaccines demonstrate that efficacy rises up when immunity ranges between 4 to 10 which is Innate. As per graphs, it is concluded that vaccines like Sinovac, Covishield, Pfizer and Sputnik show varied efficacy for Male and Female candidates [6]. Pfizer shows almost equal efficacy rate for both the Genders whereas Efficacy rate goes slightly higher for females in cases of Sinovac, Covaxin [22] and Janssen.

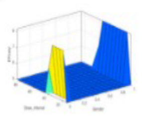
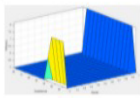
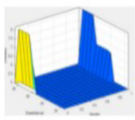
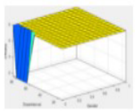
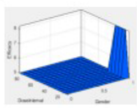
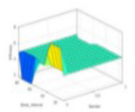
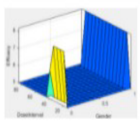
Table 5(d): Surface view of vaccines based on Gender and Immunity

Vaccine	Gender	Immunity	Efficacy	Surface View
Moderna	1	0-6	8.7	
Sinovac	1 and 0	5-10	8.8	
Covishield	1 and 0	4-10	8.8	
Covaxin	1	4-10	8.6	
Janssen	1	5-10	8.4	
Pfizer	1 and 0	4-10	8.9	
Sputnik	1 and 0	5.5-6	8.7	

5.5 Impact of Gender of candidate and Dose Interval of Vaccine on Efficacy

Dose interval of each vaccine varies between 18 to 84 days based on their rate of generating antibodies. Based on the surface graphs consolidated in Table 5(e), it is observed that Efficacy Rate jumps up as the gap between the vaccine dose expands. The highest efficacy value of 8.5 is discovered for Covishield since this vaccine has a comparatively larger gap between its two doses. Other vaccines like Pfizer, Moderna, Sinovac, Sputnik depict an efficacy rate greater than 8 which is considered as High.

Table 5(e): Surface view of vaccines based on Gender and Dose Interval

Vaccine	Gender	Dose Interval	Efficacy	Surface View
Moderna	1 and 0	18-45	8.2	
Sinovac	1 and 0	18-85	8.1	
Covishield	1 and 0	60-80	8.5	
Covaxin	1 and 0	15-60	5	
Janssen	1	15-35	8.1	
Convidecia	0	20-44	6	
Sputnik	1 and 0	20-80	8.3	

6. Conclusion

The research offers a Mamdani-based Fuzzy Expert System for determining and analyzing the influence of different clinical and demographic parameters on COVID'19 vaccination efficacy estimation. In this study, a total of 6 major factors are considered which has a great impact on the efficacy of the vaccines. Clinical factors such as underlying medical history of the person including COVID19 infection, severity of Side-effects observed post vaccination, immunity of candidate and dose interval plays a significant role in defining the efficacy. Along with that, demographic factors such as candidate's age and gender are also considered. The efficacy of each of the vaccines is estimated based on the inferences of these parameters.

- Moderna and Sinopharm are found to be promising vaccines for young people irrespective of their gender. On the other hand, Covaxin [22]is found to be moderately efficient in females of 44 above age group, with an efficacy rate as 5 (Medium). Jannesan shows higher efficacy in younger females i.e., between 20-40 years old, with efficacy of 8.2 (High). Both Sinovac and Sputnik found to be equally effective for both Male and Female candidates of age 20 to 40.
- Pfizer depicts an efficacy of 8.3 when the candidate has no medical history (4), irrespective of gender. In case of Sinopharm, candidates with Chronic Disease history shows the efficacy value of 5 which is Medium. Sputnik shows higher efficacy in Female candidates with curable or no underlying disease history.
- Efficacy of Covishield rises to 6.4 if almost no side-effects (0-4) were observed. Similarly, it is observed that efficacy of Pfizer depreciates for both Male and Female as the Severity scale rises up. i.e., between 7 to 10. Impact of severity is the same on Covaxin, Janssen and Moderna as well.
- Pfizer shows almost equal efficacy rate for both the Genders whereas Efficacy rate goes slightly higher for females in cases of Sinovac, Covaxin and Janssen.
- The highest efficacy value of 8.5 is discovered for Covishield since this vaccine has a comparatively larger gap between its two doses. Other vaccines like Pfizer, Moderna, Sinovac, Sputnik depict an efficacy rate greater than 8 which is considered as High.

The study concluded that the COVID19 vaccine is most effective in younger adults, people who don't have any COVID infection in the recent past, and those with high immunity. It is least effective in older adults, people who don't have any COVID infection in the recent past [27-33], and those with low immunity. The results obtained are quite promising thus can be successfully implemented to evaluate whether a particular vaccine is favorable in certain situations.

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