Fuzzy Logic in Pandemic Prediction

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***Abstract*—With the Covid-19 taking over the world for past one year, the world has seen the worst. With the world coming to a stand still, the largest of economies shattered, businesses closed and livelihood ceased. The expensive decision of lockdown adversely affected almost everyone round the globe. We realise the need for a strong and sustainable model in order to cope with such unprecedented global natural circumstances. In this paper, we focus to study and compare different pandemic dynamics models[1], and utilizing fuzzy logic in predicting the spread to limit the spread and help in devising policies and mitigation measures to reduce the adverse effects. The paper tries to present and compare traditional modelling algorithms with fuzzy induced algorithms and try to improve them by taking into consideration mitigation strategies like social distancing and social mixing factors using various tools like pyFTS[1], Fuzzy rule based system for prediction[2]. The paper also tries to evaluate the efficiency of mitigation strategies in limiting the spread.**

***Index Terms*—pyFTS,pandemic,social mixing factor,fuzzy logic**

I. Introduction

Human kind has faced the wrath of nature time and again. Over the centuries, humans have faced catastrophic disasters such as deadly earthquakes, tsunamis, volcanic eruptions , cyclones , epidemics and pandemics. A natural disaster can be defined as catastrophic event which can cause a long lasting damage to living beings resulting from natural processes of earth and nature. Over the last century, floods and tsunamis alone have caused a large scale devastation in human lives. In 1931, floods in China caused largest recorded deaths of around 1,000,000–4,000,000 people. In 2004, Tsunami in Indian Ocean costed lives of around 227,898 people[11]. These disasters are natural disturbances while epidemic is an uncontrolled spread of disease occurring at a particular time in a particular community. Major epidemic examples include Malaria, Dengue Fever etc. A Pandemic can be seen as a global epidemic where spread of the infectious disease is not limited to a particular area or community but spreads worldwide. The pandemics can vary in terms of their spread rate, fatality rate, period of spread etc. History has seen various pandemics like Spanish Flu (1918-1920) which caused 1-5.4 % loss of global population, Third Plague Pandemic (1855-1960) and other ongoing pandemics like HIV/AIDS and COVID - 19.[12] The ongoing COVID-19 crisis is the pandemic, first reported in Wuhan, China in November 2019. COVID-19 is caused due to coronavirus SARS-CoV-2. The world has seen other such viral diseases in the past like Ebola Virus, H1N1 flu etc which not only have posed a threat to human lives but also the economic well being of the society. Pandemics are spontaneous and complex, risking human lives, environment and the global economy.[13]

Such pandemics require effective, efficient and spontaneous responses as the situation of spread needs to be controlled at the earliest. Each country in the world works together to fight back. But the fight against such pandemics requires efficient algorithms to predict the outcomes of the measures taken. We need proper models and algorithms to visualize the situation and plan a policy to mitigate the effects and stop the spread as soon as possible. Till date we can see that almost every country of the world is suffering from COVID-19. Many countries have successfully controlled the spread but many like India are still fighting back. The need of efficient models and algorithms comes into picture. A lack of proper pandemic management system has caused a grave effect on the economy as well as human well being. With the second and third wave in picture in India, we require robust models to deal with the situation which can effectively predict the outbreak and help in developing mitigation strategies.

In this paper we study different models generated so far for pandemic modelling and predicting the outbreaks in different regions which could help in devising policies and mitigation strategies. The paper also tries to study the effect of mitigation strategies followed, based on different dynamic pandemic models. We try to develop a prediction model based on Fuzzy Logic using pyFTS as Fuzzy time series model has been proved to give better and more accurate predictions.[14] The data used for analysis and developing fuzzy time series model is collected from WHO website ranging from January 2020 to April 2021.
The data set includes a date wise data in csv format for different countries with details of new cases, recovered cases and deaths per day.

The rest of the paper is arranged as follows: First the motivation and related work are discussed with their positive and negative aspects. Next, the methodology has been explained, discussing about the models analysed and worked upon in this paper. Then, the Fuzzy Time series model and its advantages over other models is discussed. Afterwards, we discuss the experiments conducted on the models for analyse the effects of strategies undertaken. Then, we compile the results. Finally, the paper is concluded along the Future Work.

II. Motivation and Related Work

The uncontrolled spread of COVID-19 and the world wide human suffering reflects the need of a robust pandemic management system where the spread can be predicted well in advance so that proper strategies could be laid out to control the pandemic without a major loss of human lives and without facing an economical crisis. The world should be prepared well in advance with a well structured plan to fight such biological disasters with proper norms and strategies. The computing world today has an edge because of the large scale data that is present round the globe. The major challenge that the world has witnessed is the uncertainty of the virus spread. For example: In India, the lack of accurate predictions of second wave and relaxations in COVID norms, led to tsunami of virus spreading like a wildfire to every household claiming thousands pf lives daily. Thus, there is a string need for a robust system to handle such pandemic situations, In our paper, we try to analyse the COVID precautions like social distancing and social mixing factor to understand the necessity in various vulnerable age groups. We also try to monitor the lockdown period and how it would affect the spread and help in controlling the spread. We try to study various models like SEIR[3], SIR[4] , Holts-Winter Time Series prediction model[5], SIS model[6] and try to develop a Fuzzy based time series prediction model to increase the accuracy of the studied models.

Next, we discuss the related work in the field of Pandemic Modelling. fSEIR[7] model tries to study the human behaviour and integrate it with the probability of transmission over the progression of the pandemic. The authors study the basic SEIR model and modify it to fSEIR model to inculcate the human behaviour in the study of H1N1 pandemic in Singapore to reflect the practical utility of their work[22]. A dynamic modelling approach named Fuzzified Richards Growth Model[8] to understand the dynamic behaviour of COVID-19 and perform the practical analysis on the data from USA,China and the top five countries with highest population in Europe and Turkey. The authors use lsqcurvefit in MATLAB to fit the data in Fuzzy Richards Model and study the dynamics of COVID-19[23]. To learn the dynamics of a pandemic and support robust decision making a hybrid model is inherited from three state-of-art modalities i.e. Fuzzy Rule Bases System(FRBS), Multi-Layer Perceptron (MLP) and Gaussian Mixture Model and a better hybrid model is proposed having an acceptable performance[21]. A Mamdani based Fuzzy Inference Model determines and analyses the impact of various clinical factors on COVID-19, broadly categorising the factors as risk and preventive factors. The model evaluates the susceptibility index based on the inferences of risk and preventive values.[18]
Adaptive neuro fuzzy inference system (ANFIS) is suggested to be taken as the primary consideration for predicting the contagion effect of COVID-19 pandemic.ANFIS has proven its optimal ability to deal with uncertainty and has been widely applied on forecasting systems. FIS and ANFIS models are compared to show the effectiveness of ANFIS.[9] The other related literature study the Machine Learning Algorithms in order to study and mitigate the effects and transmission of pandemic. The authors present a comprehensive study of various ML algorithms that can be applied in the pandemic situations effectively and various phases of disaster are identified where ML algorithms can be applied[20].A deep learning model to exploit the chest x-ray data set and identify the x-rays as covid or non-covid xrays is laid out using fuzzy color ans stacking approaches which tries to accurately identify the covid infection. The authors propose an approach to use mobile devices without the need of going to the hospital using MobileNetV2[19].

III. Pandemic Dynamic Models

SIR Model

An epidemiological model called SIR, computes the theoretical value of the number of people affected by the infectious disease in a closed population over time. The name these epidemiological models reflects that the models involve coupled equations relating the number of different categories of population[24] i.e.

S(t) : susceptible people
I(t): number of people infected, and
R(t): number of people who have recovered

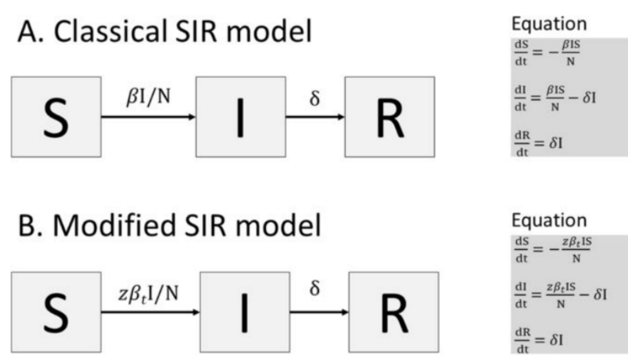


Fig. 1. SIR Model Flow and Equation

This model further has various variations, we are planning to go through some to better simulate COVID-19. The model is useful for disease which have long lasting immunity. For looking into which graphs we can use for real world simulation, we came across Erdos-renyi network. The advantage of using this model is ”each individual has identical probability of independently partnering with any other individual in the population”, which helps us generalizing the simulation.

In the Figure 2 we did put constraints to plot the graph, the constraints are gamma = 1, tau = 1.5, kave = 3. All these are parameters used in Poisson Degree Distribution followed to mimic the behaviour of epidemic.

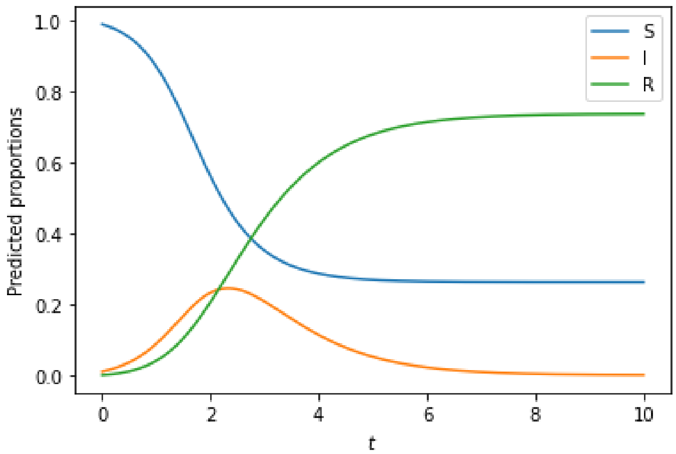


Fig. 2. Proportion of people in S,I and R

All the traditional model plots are simulated using Epidemics on Networks(**EoN**)[10], a python library which automates and helps in simulating epidemics based on constraints and graphs. The paper gives the template of code, and we can modify the parameters to plot accordingly.

SEIR Model

SEIR (Susceptible Exposed Infectious Removed) is an extension of SIR Model. Its a compartmental model which is a set of ordinary differential Equations that need to be solved in order to derive the dynamic behaviour of the system over time.State variables include the stock of susceptible and infectious population, and rate-related parameters include the probability of viral transmission and the “infectivity” of the cases over time.

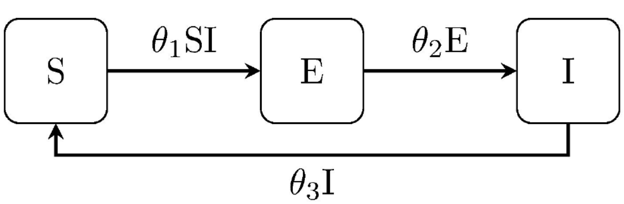


Fig. 3. Flow chart of SEIS Model

The **SEIS** model is a different variant of **SEIR** model, where the person who recovers from a disease is still susceptible. Covid is such a disease where you get immunity for a short period of few months, and you are susceptible again. The flow char of SEIS model is shown in Figure 3

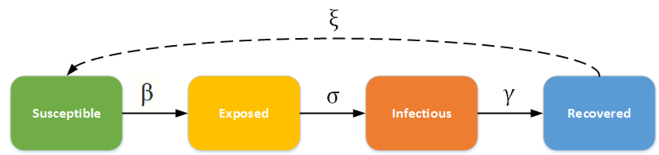


Fig. 4. Flow char of SEIR Model

The infectious rate, β, controls the rate of spread which represents the probability of transmitting disease between a susceptible and an infectious individual. The incubation rate, σ, is the rate of latent individuals becoming infectious (average duration of incubation is $1/\sigma$). Recovery rate, $\gamma = 1/D$, is determined by the average duration, D, of infection. For the SEIRS model, ξ is the rate which recovered individuals return to the susceptible state due to loss of immunity.[16]

$$\begin{aligned} \frac{dS}{dt} &= \mu N - \nu S - \frac{\beta SI}{N} \\ \frac{dE}{dt} &= \frac{\beta SI}{N} - \nu E - \sigma E \\ \frac{dI}{dt} &= \sigma E - \gamma I - \nu I \\ \frac{dR}{dt} &= \gamma I - \nu R \end{aligned} \tag{1}$$

For simulating **SEIR** model (Susceptible-Exposed-Infectious-Removed) model is the extension of SIR model, with Exposed introduced between Susceptible and Infectious. Covid-19 can be better represented by using this model. We also introduce some random transitioning rate of people from E to I(elder people, people with low immunity). Also we introduce the randomness factor in some relationships, where some relations have higher transfer rates than the other.

The number of people for simulation here are 1 lakh, the graph simulating the number of people at different time period in either of the four categories is shown in Figure 5

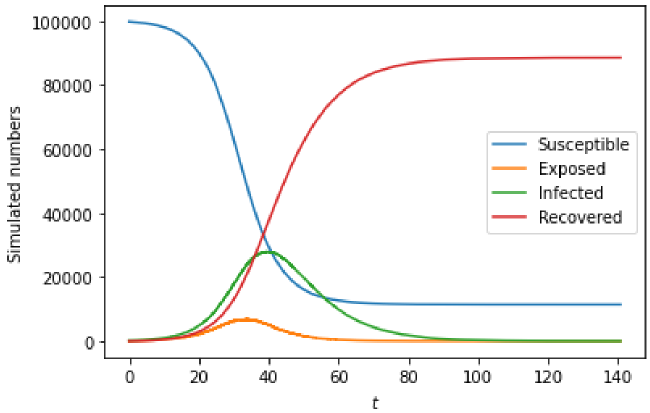


Fig. 5. SEIR Model Parameters with Time

SIS Model

Susceptible-Infectious-Susceptible model describes the dissemination of a single communicable disease in a susceptible population of size N. The transmission of the virus will occur if the infected host or carrier of the pathogen transmits or passes on the pathogen or the disease to a healthy susceptible individual. The period of infection will keep on extending throughout the pandemic until the susceptible individual recovers warrantying a two stage model: Susceptible or Infected.[1]7

Holts - Winter Model

Holts - Winter Model Captures the seasonality. The model has two variations that differ in the seasonality component: Additive and multiplicative Seasonality. Additive Seasonality is used when the seasonal variations are roughly constant while the multiplicative method is used when the seasonal variations are in proportion to the series and are constantly changing. In the analysis for this paper, for comparison purpose we have used only the additive seasonality.[25]
The graphs by using Holts-Winter model for time series forecast of 1. Cases 2. Deaths:

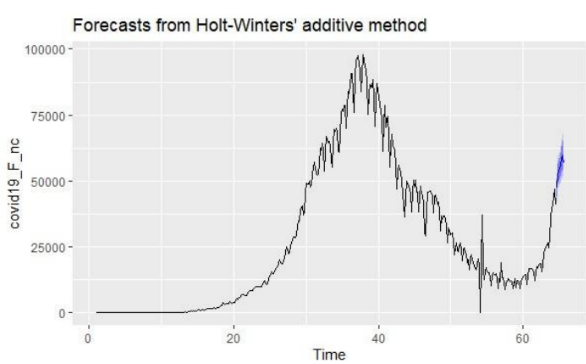


Fig. 6. Holt Cases

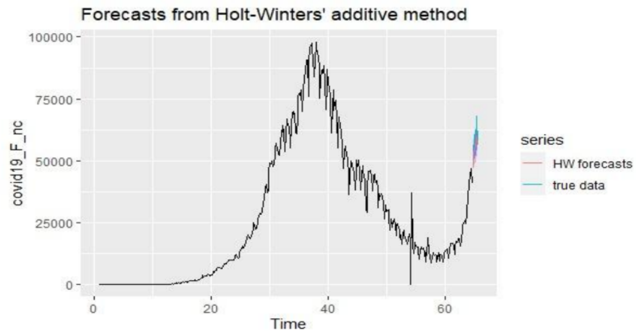


Fig. 7. Holt Deaths

IV. Fuzzy Time Series using pyFTS

Using Time series prediction methods, is a common way of analysing the pandemic spread and transmission rates according to time[towardsdatascience]. FTS: Fuzzy Time series is a non parametric method for time series forecasting based on Fuzzy Theory.

For Fuzzy Time Series prediction, we first declare linguistic variables A0-A9 , 0 being the lowest infection and 9 being the highest. Now, each record of the dataset is set to a fuzzy set by using "Maximizing" method. This process is called fuzzification.
Next step is rule generation. The rules are generated using Precedent $- >$ Consequent logic . For example: A1 $- >$ A2 means that we moved from A0 to A1. For the analysis, in our paper, we have generated rules for two scenarios: Number of Cases and number of deaths over time.

Rules for number of cases are:

$$
\begin{array}{c}
A0 - > A0 \\
A0 - > A1 \\
A1 - > A1 \\
A1 - > A2 \\
A2 - > A1 \\
A2 - > A2 \\
A1 - > A0 \\
A2 - > A3 \\
A3 - > A3 \\
A3 - > A4 \\
A4 - > A4 \\
A4 - > A5 \\
A5 - > A5 \\
A5 - > A6 \\
A6 - > A6 \\
A6 - > A7 \\
A7 - > A7 \\
A7 - > A8 \\
A8 - > A8 \\
A8 - > A7 \\
A8 - > A9
\end{array}
$$

A9 $->$ A9
A9 $->$A8

Rules for number of deaths are:

A0 $->$ A0
A0 $->$ A1
A1 $->$ A0
A1 $->$ A1
A1 $->$ A5
A5 $->$ A1
A1 $->$ A2
A2 $->$ A2
A2 $->$ A1
A2 $->$ A3
A3 $->$ A2
A3 $->$ A3
A3 $->$ A4
A4 $->$ A4
A4 $->$ A5
A5 $->$ A5
A5 $->$ A6
A6 $->$ A7
A7 $->$ A7
A7 $->$ A8
A8 $->$ A9
A9 $->$ A8
A8 $->$ A8

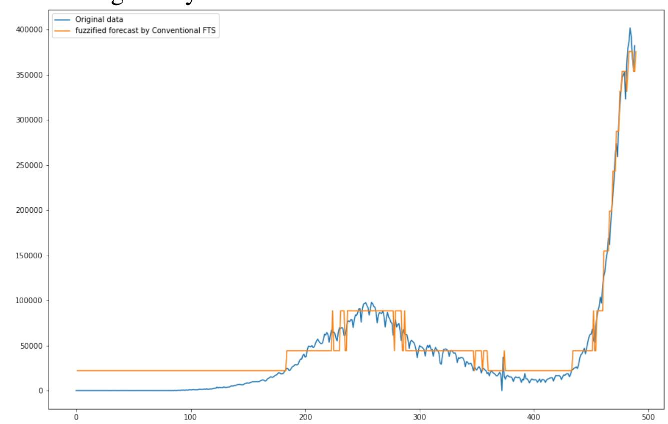
We use ConventionalFTS model to generate the fuzzy time series and fit the data for cumulative cases and cumulative deaths over time.The fuzzy rule based model for cumulative cases is :

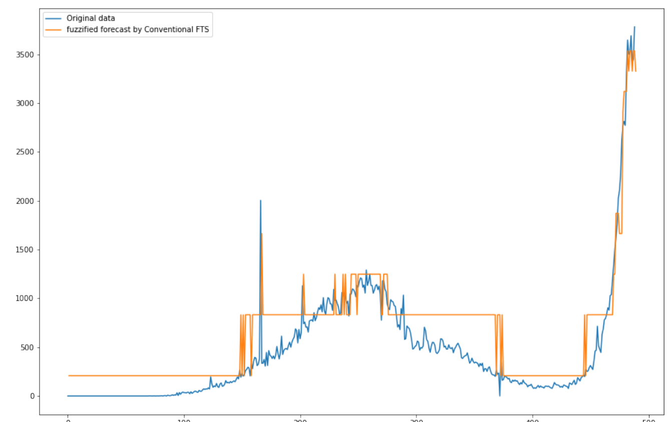
Conventional FTS for Cases:
A0 $->$ A0,A1
A1 $->$ A0,A1,A2
A2 $->$ A1,A2,A3
A3 $->$ A3,A4
A4 $->$ A4,A5
A5 $->$ A5,A6
A6 $->$ A6,A7
A7 $->$ A7,A8
A8 $->$ A7,A8,A9
A9 $->$ A8,A9

The fuzzy rule based model for cumulative number of deaths is :

Conventional FTS for Deaths:
A0 $->$ A0,A1
A1 $->$ A0,A1,A2,A5
A2 $->$ A1,A2,A3
A3 $->$ A2,A3,A4
A5 $->$ A1,A5,A6
A4 $->$ A4,A5
A6 $->$ A7
A7 $->$ A7,A8
A9 $->$ A8
A8 $->$ A8,A9

The graphs below show the prediction for 1. Cases and 2. Deaths using Fuzzy time series model:



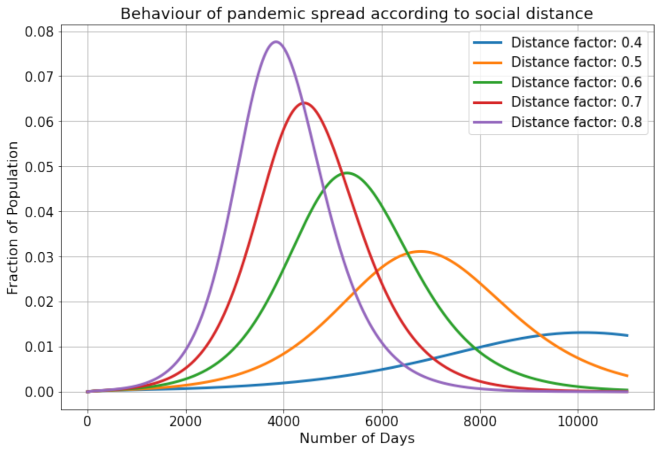


V. Experimentation and Analysis

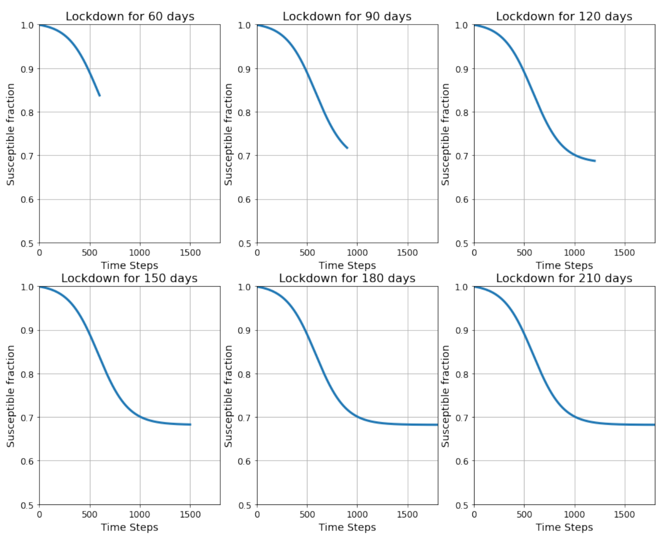
The major mitigation strategy that have been so far in this pandemic is Lock-Down and Social Distancing. The lockdown norms have been different in different countries. If we talk about India, the lockdown kept extending but after a little dip in number of cases, the lockdown rules were relaxed. People stopped following social distancing norms and as a result India has entered the second wave of COVID-19 pandemic.

Thus it makes it completely necessary to analyse the situation before making any decisions. We experiment on SEIR model by varying Social Distancing factor and Lockdown period and try to analyse the effect of relaxing or making the norms strict on the spread of the pandemic.

The social distancing values are taken as social mixing factor. Therefore higher the value means lower the social distance. We vary the social mixing factor between 0.4-0.9, 0.4 being the social distance to be highest and 0.9 being the lowest social distance. We try to figure out the transmission slope with the varying social distance[15].



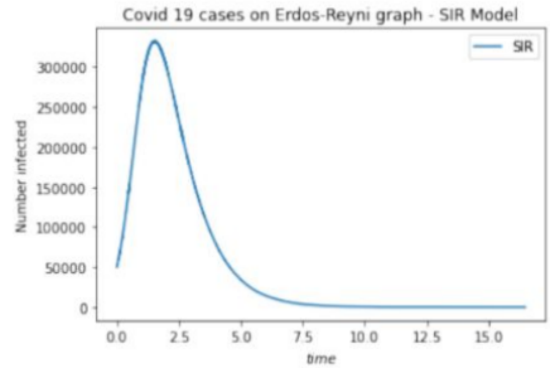
Next, we try to figure out the optimal period for lockdown by varying the number of lockdown days and try to analyse the transmission slope through time.

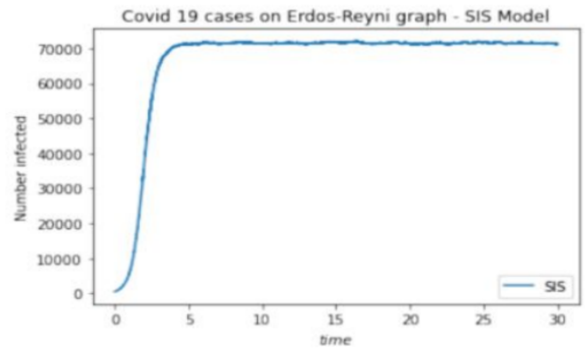


Therefore, in order to build a herd immunity, we need to find the optimal lockdown period as an extended lockdown might not be optimal and may cause no effects after a certain time.

VI. Results

The experimentation on dynamic models show that the precautions are necessary for limiting the spread. The transmission rate directly affects the fatality rate of a pandemic and tends o slow down the recovery rate. Generating Fuzzy time series model helps us to clearly analyse the situation as compared to Holts - Winter model where it can be clearly seen that the predictions are not up to the mark. The Fuzzy time series model is able to predict almost optimal results with low error. The graphs below show the effect on recovery rate, when precautions are taken(SIR) and when precautions are not taken(SIS)





All the experiments were performed on SEIR model, which show the importance of robust analysis of data in pandemic situation as it can help us to devise proper mitigation strategies and lay out a proper plan to be ready for the any unprecedented situation.

VII. Conclusion and Future Work

With the daily increase in death toll and degrading global economy, a robust analysis of dynamic pandemic models is necessary. In the paper, we provide a study of different pandemic models (SEIR,SIR, Holts - Winter etc) and try to find out a robust decision making model that could help us to lay out a proper plan to handle pandemic situation without major loss of human lives and without affecting the economy much. We develop a Fuzzy time series model using ConventionalFTS, which is supposed to give better prediction results and in turn, help in taking proper actions in such situation.

Considering the future aspects of the paper, we tend to perform a similar analysis on Fuzzy Model and verify the results. We also tend to look into some other models that could help in handling the pandemic situations well. We also would like to perform such analysis to understand the effect of mitigation measures like social distancing and lockdown on the global economy apart from the already done transmission rate.

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