Dynamic Modelling and Live Prediction of COVID-19 Using SIR-D model.

On quantative prediction of COVID-19 using simple spreadsheets for Pune region.

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***Abstract*—This report puts forth an approximate quantitative prediction of COVID-19 (coronavirus) counts i.e. affected, infected and dead population and suggestions on measures to be taken in Pune City in coming months. The effects of premature lifting of lockdown in the city are discussed regarding the above counts, the overall magnitude and time-wise progress of the pandemic. This document also provides some important suggestions to the bodies in execution as well as the individuals in the city. We have coarsely made an attempt as an individual to map the further cases and do the planning accordingly although there are various prestigious organizations working on this issue.**

Keywords—pandemic, prediction, SIR-D epidemic model, mathematical modelling, COVID-19, Pune City.

I. Introduction

With the outbreak of Coronavirus in Pune active since 9th of March, 2020, There has been a lot of strain on the health services, law enforcement, and the overall tolerance of people. This report provides a crude prediction and also a spreadsheet [1] which has SIR-D [2] epidemic dynamics implemented. The main motive of this analysis is to alert the bodies in execution to continue the lockdown mid till mid of August as of April end, 2019. The magnitude of the peak infected count may rise above lakhs if the lockdown is lifted considering the stabilized recovery, infection and death rate. In lockdown state the peak of infected count is expected around mid of August. In this model we have considered the previous ten stabilized counts for fitting our model to prevent the errors in curve parameters caused by the unstable rates till the havoc recedes and individuals stabilize. **We have given a live spreadsheet that calculates prediction for any other city/locality by just putting in the actual values at respective dates.**

II. Assumptions and Disclamers

A. *Source of data*

As given in references [3][4][5], the data was taken from official portals of Government of Maharashtra. The infected and death count was taken from [4] and recovered or discharged count was taken from [5]. The collective data was found at [3] with previous records before lockdown since 9th of March 2020, so as to record the rate of infection in pre lockdown state. But it is most important point to consider that how many tests are actually being carried out. Due to lack of testing the predicted data may seem overestimated. But according to the reports of Government of India around 69% [13] cases are asymptomatic i.e. they may not show symptoms but are still infectious and have ability to spread it further. It can happen that such population may not be tested and directly move to the recovered compartment after the incubation period i.e. when they have developed their immunity to do so. Such individuals may not come in actual counting and bypass our model. But this process can occur without hindrance only in lockdown period which is why lockdown is utmost necessary. Hence the predicted values cannot be absolutely ignored or discarded. Developing such herd immunity is an important factor that can safely drive the population through this outbreak safely without any strain on infrastructure.

B. *Accuracy*

The predictions made in this model are accurate with ±10% errors for next 15 days. The accuracy further cannot be guaranteed as errors build up after differentially aggregating the model with more number of rows. With given data [3][4][5] under consideration, the curve fitting considers that the parameters of the model [2]. The model is gives slightly volatile prediction as minute change in the curve parameters due to recent actions of the individuals or medical response on the active cases to be recovered can cause a huge deviation in predicted values. The prediction can be counter checked on [3][4][5]. Pune's death ratio and reproduction number is very higher compared to other cities. The early lockdown has kept us safe until now. The immunity has very slight or hardly any role here in initial stages. The virus will progress according to following dynamics.

C. *The intervention due to vaccination or immunisation*

According to the news [11], a confirmed vaccine for COVID-19 is expected around September or October, it will change the profile of prediction entirely. Thereafter we need to model the situation using SEIR-D with vaccination [7].

D. *The intervention due to premature lifting of lockdown*

The term premature here refers when the lockdown state is lifted before the peak or maxima of the pandemic. This may lead to sudden (mostly logistically [2]) change of reproduction number [2] which in turn can cause catastrophic spike of active cases in the magnitude of lakhs. In this position, the predictions in lockdown state may not apply. The detail discussion of this factor is discussed in the following section of this document.

E. Regarding the updates of the spreadsheet

We have attached a live spreadsheet which gives the prediction accordingly. This spreadsheet can also calculate the predictions of any other city/locality by changing the input data. As said previously that the model is highly volatile, and with incoming data, we may change the prediction model to advanced versions [2][7] which may as well in the metropolitan, we strongly suggest continuation of lockdown state till August start. However, the peak may occur earlier with steep slope and higher magnitude of order of lakhs near about first week of June. This prediction is made using the given [3][4] source of data and the parameters calculated considering the recent stable 10 days when lockdown was strictly followed.

From the statistics till now since 10 days the lockdown is appreciably followed in Pune City, a huge thanks to The Pune Police Department, the obedient citizens and their cooperation. But however the dynamics post premature lockdown are not so much in favor.

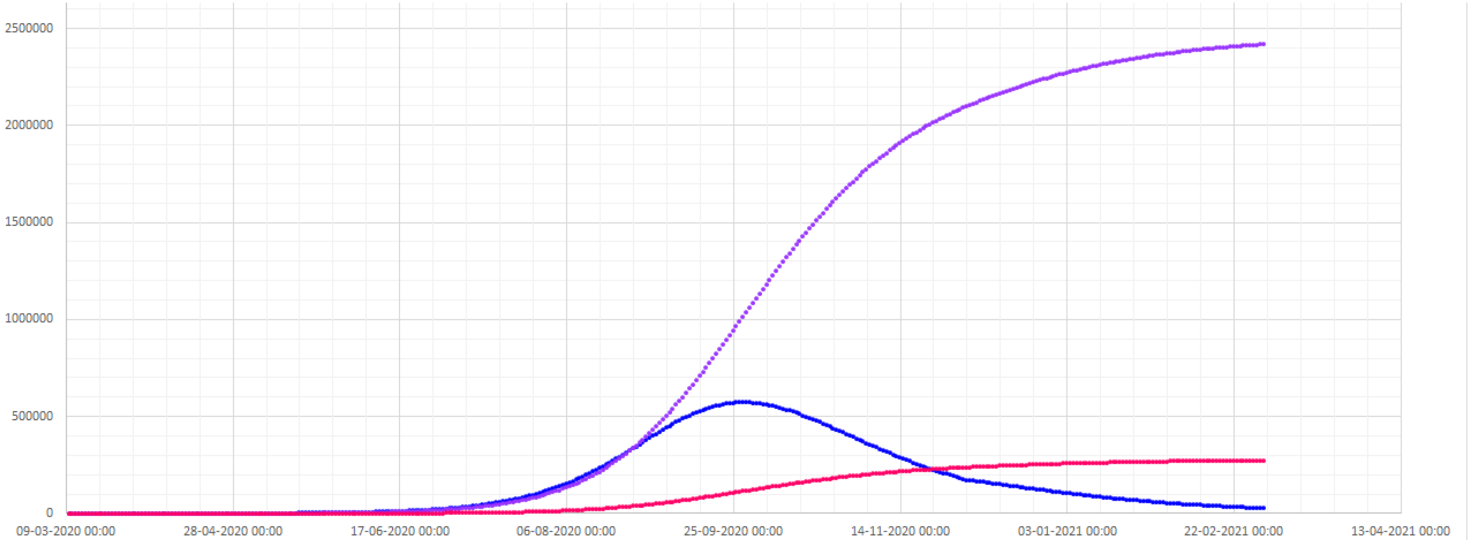

Figure 1: The Progression of COVID counts in lockdown state, blue = infected, purple = recovered, red = deaths.

drastically change the magnitude and time of predicted values. The updates of the same spreadsheet will be maintained on the site [1].

III. The Prediction and Actions

This section describes about the approximate future progress of the virus in the metropolitan and tries to give some suggestions to the bodies in execution and the readers of this document. The total population (N = 31,24,458) was taken from 2011 census reports [9].

TABLE I. PREDICTED COUNTS OF COVID-19 TILL 3RD OF MAY 2020

Date	Predicted COVID-19 Counts in Pune		
	Total Affected	*Recovered*	*Deaths*
29/04/2020	*1250*	*274*	*86*
30/04/2020	*1331*	*306*	*90*
1/5/2020	*1416*	*339*	*95*
2/5/2020	*1505*	*375*	*99*
3/5/2020	*1599*	*411*	*104*

a. The previous data was provided by [4][5] and predicted figures can have ±10% error

A. Lockdown Strategy

With constantly multiplying number of infected individuals

The population of the city is very high but is currently stabilized under lockdown. Due to sudden ramp up of infected population, the existing medical facilities can get overstrained and probably the situations may get out of control.

We definitely understand the economic crunch and loss of revenue which is very dependent on the mobility of individuals and their transactions, but however if infected count in thousands of magnitude can in turn infect them further and finally again there can be multiple loss of finance and infrastructure.

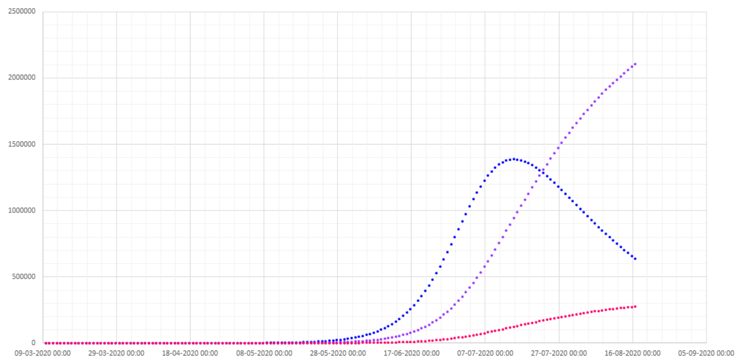

Figure 2: Progression of COVID if lockdown lifted in 3rd of May.

B. *Suggested Role of IT and Software Companies or other Industrial policies*

It has been observed that the current structures of the IT workplaces have poor ventilation, air conditioning and hygiene practices and external air exchange. This will not only promote the absolute spread of infection but also decrease the overall immunity of the employees. In this scenario, the premature lockdown lifting can infect the employees in mass scale which will dabble the entire predicted dynamics and as well the actual scenario will be pretty vulnerable. Frequent air exchange and better ventilation is highly suggested in these cases and hereafter. It is therefore suggested post lockdown to change the ventilation architecture if possible.

If we have to keep the human resources intact, then we have to actively participate in the planning of further strategies in accordance with the predictions which in turn we will have to make by tedious data analysis and which is why we would encourage such companies to draw certain conclusions and respond to the government and bodies in execution rather than blindly following the instructions. However, for now it is highly suggested not to put the human resources in immediate mobility and patiently wait for the peak to pass. After the situation calms down considerably, and if IT companies in Pune are able to maintain such disciplines, it may as well attract considerable potential investments in near future.

C. *Comparative analysis, best and worst case of coronavirus – Thailand and New York, and where Pune lies*

Since 8th of April, Thailand has observed a huge drop in COVID-19 active cases from start of outbreak on 15th of February. Till now at peak it had merely 1,451 active cases and only 54 are dead as of April 29 [10]. Due to strict restrictions, it seems that they have won the battle but they still consider the chances of second wave of outbreak. However, they are planning to lift things back to normal.

Since 15th of February, The New York city has 3,05,086 infected count and is now progressing near to peak. Daily around 3000+ cases are added and till now 23,474 are fatal cases as of April 29th [10]. Such may be the progress of COVID in the Pune city if by any chance there is mishandling of individual mobility, lack of medical facilities. In this case the accommodations of nearly 1 lakh beds is suggested.

Currently Pune is in the initial stages of the virus where even a slightest change in the infection and recovery factors i.e. even ±0.1% change deviates the prediction in magnitude of thousands.

D. *Measures and Mentality as an Individual*

The individuals are firstly requested to stabilize wherever they are and stay safe to prevent any knowing or unknowing transmission of disease. As said earlier that still Pune is in initial stages of outbreak a slight action can engrave entire future of the city. Next big factor is an individual's immunity. It is found that that the people aged 61-70 [12] have maximum mortality rate compared to teenagers or adults. Hence senior citizens have to take extra care while venturing out or rather forbid it.

According to a research [14] in NCBI, it is found that emotions and mental state of an individual play an active role in governing one's immune system. Therefore, it is necessary to slightly change the perspective we are looking at the situation. Instead of a war it has more to tune with nature and maintain a healthy wellbeing, mental and most importantly physical hygiene.

Individuals are also highly requested to follow the guidelines given by the Government and avoid as much physical contacts as possible for example, cash payment which was predominantly found to exchange the infection in a large mob and use online transactions wherever possible.

IV. Basis of Prediction - The SIR model with Fatalities

SIR, standing for Susceptible, Infected and Removed, modeling infectious diseases is as important as it has been in 1760, when Daniel Bernoulli presented a solution to his mathematical model on smallpox. It was however not until 20th century that mathematical models became a recognized tool to study the causes and effects of epidemics. In 1927, Kermack and McKendrick introduced their SIR-model based on the idea of grouping the population into susceptible, infected, and removed. The model assumes a constant total population and an interaction between the groups determined by the disease transmission and removal rates [6]. However, the Removed compartment contains both the recovered and death cases. We will derive these compartments as suggested in [2]. We will not actually solve this model analytically as their solutions are relatively complex and deriving the solution may require the reader to be proficient in solving the system of differential equations. But still if the reader is curious enough, one can refer [6]. We will try to fit an approximate curve formally known as state space fitting. In our case we will be using simple spreadsheet calculations to numerically solve by a variant of Euclid's method so that every reader can actually work with this model in their computers without installing any special software or programs like JRE, Python or other simulation runtimes.

A. *The Model*

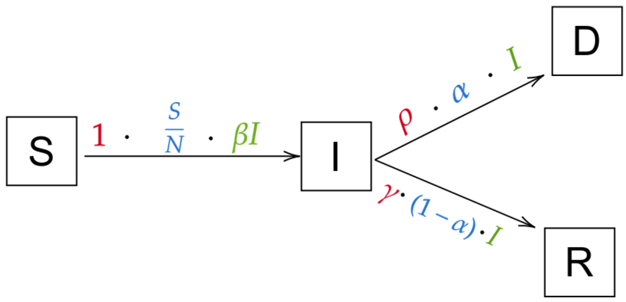

Figure 3: The SIR transitions with dead compartment. [2]

Every transition of the state is represented by three factors - The *rate(red)* describes how long the transition takes, *population(green)* is the group of individuals that this transition applies to, and *probability(blue)* is the probability of the transition taking place for an individual [2]. Where **β** is expected amount of people an infected person infects per day, **γ** is the proportion of infected recovering per day, **ρ** is rate at which people die (= 1/days from infected until death) and **α** is the fatality rate.

The differential system [2] for our model becomes,

$$\frac{dS}{dt} = -\frac{\beta}{N} IS \tag{1}$$

$$\frac{dI}{dt} = \frac{\beta}{N} IS - (1-\alpha)\gamma I - \alpha\rho I \tag{2}$$

$$\frac{dR}{dt} = (1-\alpha)\gamma I \tag{3}$$

$$\frac{dD}{dt} = \alpha\rho I \tag{4}$$

For our computation purposes, resolution of parameters α, β, γ and ρ is pretty tedious in the above forms and may as well lead to larger error in prediction. We need to derive simpler parameters of this ODE system to enable easy calculations. Let us define a, b and c as,

$$a = \beta \tag{5}$$

$$b = (1-\alpha)\gamma \tag{6}$$

$$c = \alpha\rho \tag{7}$$

Also, it must be noted that,

$$S + I + R + D = N \tag{8}$$

is constant, where N is constant. Furthermore, we do not have the Susceptible count, instead we have affected count A with us as sum of Infected, Recovered and Death population so,

$$A = I + R + D = N - S \tag{9}$$

Then our differential system becomes,

$$A = I + R + D \tag{10}$$

$$\frac{dI}{dt} = \left(a\left(1 - \frac{A}{N}\right) - b - c \right) I \tag{11}$$

$$\frac{dR}{dt} = bI \tag{12}$$

$$\frac{dD}{dt} = cI \tag{13}$$

B. Parameters Estimation and Tuning

To resolve our newly derived parameters a, b and c,

$$b = \frac{1}{I}\frac{dR}{dt} \tag{14}$$

$$c = \frac{1}{I}\frac{dD}{dt} \tag{15}$$

Now plugging in (14) and (15) in (11), we have,

$$\frac{dI}{dt} + \frac{dR}{dt} + \frac{dD}{dt} = a\left(1 - \frac{A}{N}\right) .$$

$$\frac{dA}{dt} = a\left(1 - \frac{A}{N}\right) \qquad \text{… from (9)}$$

$$a = \frac{1}{1 - \frac{A}{N}} \frac{dA}{dt} \tag{16}$$

However, it is to be noted that as reproduction number R_0 which is a measure of virus multiplication, clearly the number of infections an infected individual produces is given [2] by,

$$R_0 = \frac{\beta}{\gamma} \tag{17}$$

Depends on time with the lockdown measures, the properties of virus and its mutation, etc. factors. These all factors are the functions of time. Considering that γ is constant with time, (17) clearly implies that β is the function of time. And in turn a is the function of time. However, for our calculations in the predictions, we will consider its mean value constant over further period of time in constant conditions of lockdown and without lockdown. Let a_l be the mean value of a calculated from previous records using (16) and a_{nl} is the mean value of a since outbreak till lockdown start. We assume that after lockdown the mobility of individuals is same as that was before lockdown. Let t_l be the time at which there is lockdown. With this our parameter 'a' becomes as,

$$a = a_l \text{ if lockdown else } a_{nl} \tag{18}$$

It is true the fact that the parameters b and c are as well are the functions of time as the recovery rate or death rate may be influenced by the immunity response of individuals or the herd immunity concept. However, the recoveries and death count in the initial stages of outbreak are relatively small and may not give enough characteristic or deviation to fit their curves, especially after lockdown state. It is assumed that lockdown was taken immediately until the death and recovery count has not shown reasonable deviations. Hence we calculate the parameters b and c where they show a near constant trend and utilize their mean values for predicting the recoveries and deaths during and after lockdown. We will keep their values constant w.r.t time henceforth.

C. The Nature of Solution curves and brief explanation to pandemic dynamics

The infected count curve is a distorted bell shaped graph as shown in fig. 1 in blue, the maxima of curve gives the peak magnitude and the time at which it may occur. The inflection point of this curve has maximum rate of infection. Both the death and recovery curve has a logistic nature.

This follows because as the susceptible population is infected, simply stated will either live or die. If they show resistance or higher immunity, the recovered compartment gets filled with a rate proportional to the infected count and who cannot sustain the disease will go in dead compartment with the rate proportional to infected count. As these to compartments get filled with time, there is decrease in active cases or the infected population. But at the same time the virus keeps on infecting the new individuals. At some time when the rate of infection is in dynamic equilibrium with the recovery and death rate, the count of infections is at maximum which we here refer to as the peak of outbreak.

However, if we are having less initial data points, we cannot fit the curve with reasonable accuracy. This is because there is no characteristic deviation in parameters in initial stage. At this position it becomes very critical that even 0.1% change in curve parameters drastically affect the prediction.

D. *Sensitivity of parameters*

It is observed that even 0.1 % change in these parameters especially a causes around 30% change in predicted values. It implies that even 10% improvement in recovery or decrease in infection rate can cause volatile change in predictions.

Conclusion

From this report we have tried to put forward some quantitative prediction, given some suggestions to various bodies of the society and execution and as well given a live tool in the form of spreadsheet which will enable any individual or authority to analyze and predict the COVID-19 outbreak in their areas.

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