Statistical Inference of the Effectiveness of Lockdown for COVID 2019 in India

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Abstract - *The recent outbreak of COVID 2019 has led to lockdown in different countries in order to mitigate the spread of the virus. Although a similar strategy was followed in India, it has been reported multiple times that people in many states have not maintained the lockdown. Therefore, a significant increase in infection is observed in India even during the lockdown period. However, it is not possible to determine the effectiveness of lockdown in each state from the number of infections only. In this paper, we have used a curve fitting technique to study the rate of infection prior to and during the lockdown in different states of India, taking into consideration the at most two weeks of incubation period. The effectiveness of lockdown for different states of India has, thus, been quantified as the relative change in the rate of infection. Our results show that while for some states, the lockdown has indeed significantly reduced the rate of infection, for some other states it has not. From this observation, we have made an inference on how effectively different states of India have been able to implement the lockdown.*

***Key Words*: Coronavirus: SARS-CoV-2, COVID-19, Lockdown, Curve Fitting, Rate of Growth**

1. INTRODUCTION

In the late 2019, a novel form of Coronavirus, named SARS-CoV-2 (Severe Acute Respiratory Syndrome Coronavirus2), termed COVID-19 in short, started spreading in the province of Hubei in China [1], and claimed numerous human lives. Shortly after this incident The World Health Organization (WHO) declared the outbreak a Public Health Emergency of International Concern on 30th of January, 2020, and finally a pandemic on 11th of March. The virus is highly infectious, and primarily spreads between people during close contact, mainly via small droplets produced by coughing, sneezing, and talking. Two contrasting techniques for fighting this virus, as suggested by political leaders of various nations, are (i) to expose a large proportion of the population to it in order to create a herd immunity, or (ii) mitigation of human interaction so that the virus remains contained in a small set of the population. However, due to the mutating nature of the virus, herd immunity does not seem likely to be attainable in the near future. Therefore, in the absence of treatment or vaccine, ceasing human contact seems to be the only way to stop the spread of the virus. Therefore, social lockdown seems to be the only precautionary measure to mitigate the overall transmission, followed by rapid testing in order to identify and isolate the infected [2]. The first case of COVID-19 infection in India was reported on 30th January 2020, originating from China. The number of infected individuals started growing quickly across the country, and therefore, as a protective measure, a nationwide lockdown for 21 days was announced on 24th March 2020. However, since the number of infected patients was still growing at a significant rate, another nationwide lockdown till 3rd May 2020 followed the first phase.

Although the Government declared a complete lockdown, a general statement which followed in every newspaper and news channel was the lack of cooperation from the public in maintaining the lockdown. Furthermore, emergency services such as grocery, medical facilities needed to remain open, where people gathered frequently. Therefore, the lockdown was far from ideal, which reflected in the significantly increasing number of infections even during the lockdown period.

The goal of this paper is to try to infer how effectively each state has been able to implement the lockdown. This is not obvious from the number of infections alone. We have (i) collected the number of infections for each state in India prior to and during the lockdown, (ii) considered an incubation period of 14 days, (iii) fitted a continuous function to approximate the growth both prior to and during the lockdown, and (iv) studied the ratio of the rate of change of the growth before and during the lockdown. The relative change in the rate of growth gives a proper quantification of the change in infection rate due to lockdown. And this value of relative change signifies how effectively each state has been able to implement the lockdown. Our results show that while some states such as Telengana has been able to maintain the lockdown strictly, other states such as West Bengal and Gujarat have not been quite successful in doing so.

The rest of the paper is organized as follows: In Section2, we discuss the mathematical technique which we have used for deciding the infection growth prior lockdown. In Section 3, we have approximated the growth of infection before and during lockdown via continuous functions. Section 4 reports the technique to determine the relative change in growth as a measure of the effectiveness of lockdown and shows this value for different states. We conclude in Section 5.

2. APPROXIMATION OF THE SIR MODEL

The standard SIR (Susceptible, Infected, Recovered) model is often used to study the spread of epidemic [1, 3]. The spread of disease in any epidemiology model is governed by a system of differential equations. The system of equations for the SIR model are

$$\frac{dS(t)}{dt} = -\beta S(t).I(t)$$

$$\frac{dI(t)}{dt} = \beta S(t).I(t) - \gamma I(t)$$

$$\frac{dR(t)}{d(t)} = \gamma I(t)$$

where β and γ are constants. However, for the COVID-19 scenario, we have made some approximation to this method. The change in the number of infected is governed by the equation

$$\frac{dI(t)}{dt} = \beta S(t).I(t) - \gamma I(t)$$

$$\frac{dI(t)}{I(t)} = (\beta S(t) - \gamma)dt$$

In India, till date, the number of infected is extremely less compared to the population of India (according to the data from covid19india.org). Therefore, for small values of t, we assume $S(t)$ to be constant. Integrating the differential equation under this assumption gives

$$I(t) = a.e^{b.t} \qquad (1)$$

where $a,b \in \mathbb{R}$. Although this may initially appear to be an unjustified approximation of the SIR model, we have shown in Fig. 1 that the pre-lockdown scenario in the top ten states of India indeed follow such an exponential growth in the number of infections. Therefore, this approximation seems justified for the current COVID-19 scenario of India but may not hold good in the future (in fact, we show in this letter that this exponential rate of growth does not always hold good in the lockdown period itself).

3. CURVE FITTING FOR INFECTIONS PRIOR TO AND DURING LOCKDOWN

3.1 Pre-Lockdown period

Lockdown in India was announced on 24th March, 2020. However, the incubation period for the disease is a maximum of 14 days [4], which means that it can take up to 14 days for a person to report positive for COVID-19 after being exposed. Therefore, any person, who was exposed before the lockdown, may still show the symptoms of COVID-19 well beyond the beginning of the lockdown. We have taken this 14 days of incubation into the pre-lockdown period to take into account any infection which was caused prior to the lockdown. Therefore, for this study, the pre-lockdown period is considered up to 7th April, 2020 instead of 24th March.

The states that we took into account were Delhi, Telangana, Andhra Pradesh, Gujarat, Rajasthan, Tamil Nadu, Madhya Pradesh, West Bengal, Maharashtra and Uttar Pradesh. These are the top ten infected states in India as of 30th April 2020 (refer to covid19india.org). We did not consider the other states since the number of infections in those states are quite low for any statistical inference. Infections in different states of India has been reported from 14th March at covid19india.org. For each of the ten states we have used the optimize package of scipy in order to obtain the values of a and b such that Eq. 1 fits the number of infections from 14th March to 7th April, 2020. In Fig. 1 we show the actual growth of infection and the fitting exponential curve for West Bengal, Rajasthan, Maharashtra and Delhi.

3.2 Lockdown period

The first 14 days of the lockdown have been included in the pre-lockdown scenario to account for incubation period. But, after that, the affect of a lockdown should be immediately noticeable. Therefore, the cases beginning from 8th April, 2020 should represent the affect of lockdown. The lockdown curve, therefore, considers the number of infections from 8th to 30th April, 2020. In this period, the growth of infection does not follow the exponential rate for all the states. We have used trial and error to fit the best possible curve for each state, while using the optimize package of scipy in order to obtain the values of the parameters.

During this period, some of the states, such as Delhi, West Bengal still showed exponential growth. Some states, such as Rajasthan, showed a linear growth *(I(t) = a.t + b)* and some states, such as Maharasthra, showed a quadratic growth *(I(t) = a.t^b +c)* in the number of infected. In Fig. 2 we show the actual growth of infection and the fitting curve for West Bengal, Rajasthan, Maharashtra and Delhi. This curve fitting technique essentially approximates a set of discrete data points with some continuous function.

3.3 Effect of population on the growth of infection

It is obvious that the growth of infection is a function of interaction in a population. However, it does not answer the question whether, in India, the interaction increases with the increase in population. A natural instinct is that although the population of Maharashtra is lesser than that of Uttar Pradesh, the interaction among people is expected to be much higher in Maharashtra, where the business capital of India, Mumbai, is located. We study in Fig. 3 whether the growth of infection in the pre-lockdown period is related to the population of the state.

For the pre-lockdown scenario, the growth of infection can be modelled using Eq. 1 for all the states. The growth of an exponential function is primarily dictated by the value of *b*, and the value of *a* applies a shift to the curve. In Fig. 3 we plot the values of *b* for different states with respect to their population, arranged in an ascending order of population. This figure clearly shows that the interaction in the population is not a function of the population of the states.

Therefore, any relative decrease in the growth of infection in a state during the lockdown, can be considered solely as the effect of lack of interaction among the mass, without any consideration of the population of that state.

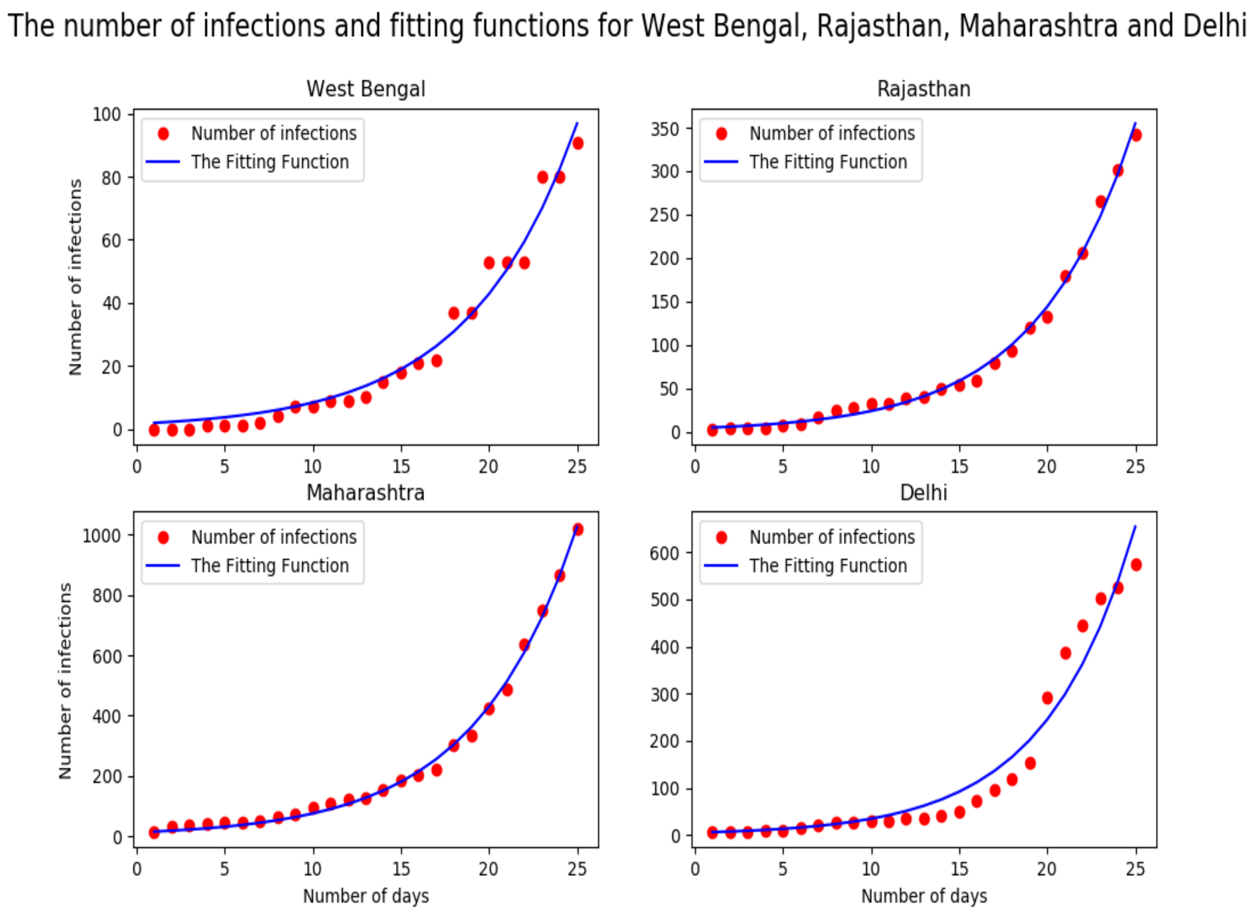

Fig-1: Growth of infection and fitting function for Pre-Lockdown period

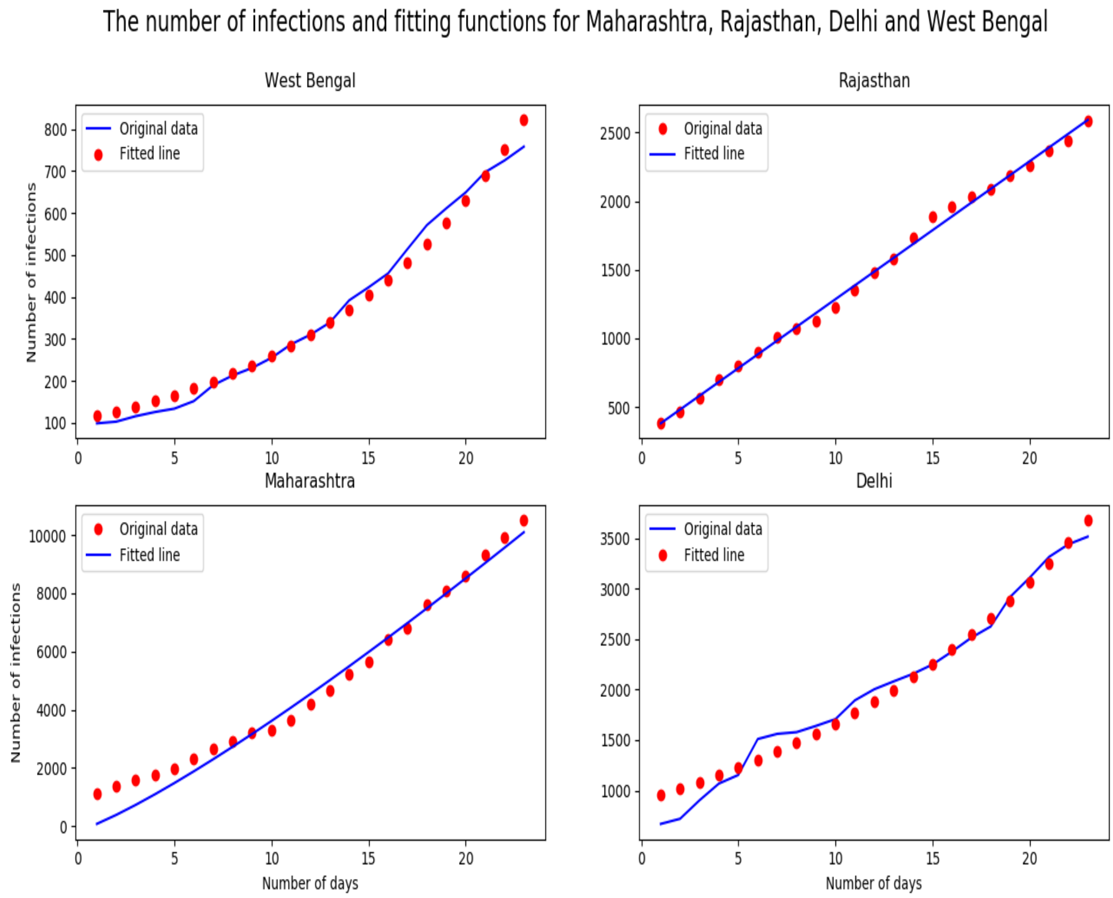

Fig-2: Growth of infection and fitting function for Lockdown period

4. RELATIVE CHANGE IN GROWTH AS A MEASURE OF EFFECTIVE LOCKDOWN IMPLEMENTATION

We have already shown in Fig. 3 that the population of the states does not seem to a determining factor in the spread of infection. Furthermore, it can be a safe assumption that the interaction among the people during lockdown is not greater than that prior to lockdown. Let, for a state S, the fitting function for the growth of infection prior to and during lockdown be S_{pre} and S_{post} respectively. Therefore, if the interaction is less during lockdown, then it is expected that

$$\frac{dS_{post}}{dt} \leq \frac{dS_{pre}}{dt} \qquad (2)$$

Renaming $dS_{pre}/dt = A$ and $dS_{post}/dt = B$, the relative change in the growth of infection due to lockdown is obtained as

$$Change_R = 1 - \frac{B}{A} \qquad (3)$$

Note that, from the assumption of Eq. 2,

$$0 \leq Change_R \leq 1$$

where 1 implies a perfect lockdown with no interaction, and 0 implies no lockdown, i.e., the rate of growth of infection during lockdown is same as that prior to lockdown. Therefore, the value of $Change_R$ is a good indication of the effectiveness of lockdown in a particular state.

From the fitting functions prior to the lockdown and during lockdown, we calculated the value of $Change_R$ for each of the top ten infected state for t = 48 (14th March to 30th April) which is compiled in Fig. 4. and Fig. 5.

We note from Fig. 4 and Fig. 5 that states like Telengana, Tamil Nadu and Rajasthan has shown significant effectiveness in the implementation of lockdown. Although the number of infected is still growing for Maharahstra at an alarming rate, they have also been able to control the rate of growth through effective implementation of lockdown. Our result indicates that one of the worst lockdown implementation is seen in West Bengal. And this result is indeed supported by various news regarding the noncooperation of the general mass in maintaining a strict lockdown in West Bengal, despite the repeated request of the Government.

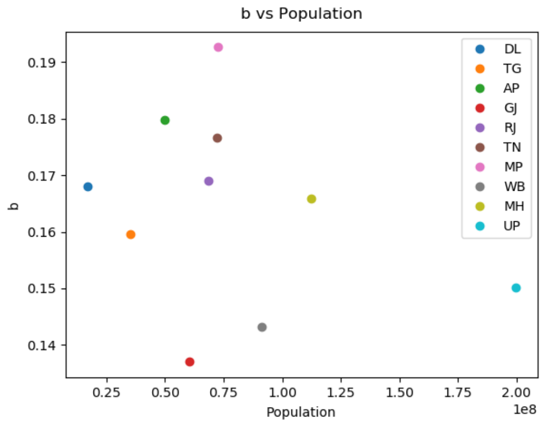

Fig-3: Value of *b* as a function of population

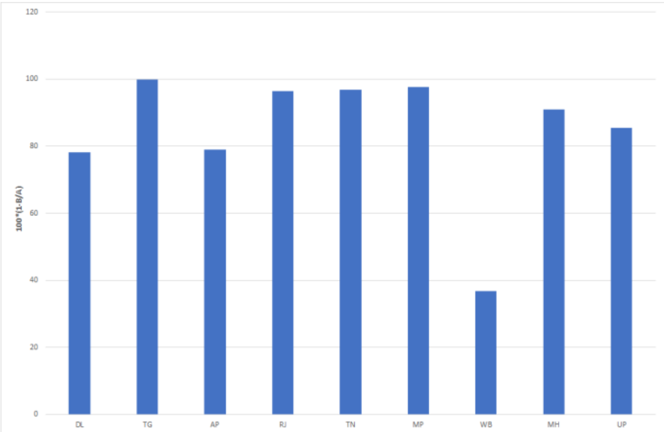

Fig-4: Relative change in the growth of infection in different states of India

State	$1 - \frac{B}{A}$
Delhi	0.78118
Telangana	0.99807
Andhra Pradesh	0.78936
Gujarat	-0.78515
Rajasthan	0.96388
Tamil Nadu	0.96910
Madhya Pradesh	0.97683
West Bengal	0.36720
Maharashtra	0.90916
Uttar Pradesh	0.85419

Fig-5: Relative change in rate of growth for the states

4.1 The curious case of Gujarat

Fig 5. shows that the assumption of Eq. 2 does not hold true for Gujarat. In fact, it seems, that the growth of infection in Gujarat has increased during the lockdown. Indeed, from the data of covid19india.org, it can be seen that while for most other states, the cumulative growth in the number of infections is a more or less non-decreasing function with minute perturbations at times, the infections in Gujarat has seen a sudden surge during April 19, 2020. Indeed, a Gaussian like structure is observable around that time, beyond which a more or less non-decreasing growth is observable. The aberrant value of $Change_R$ for Gujarat is most likely due to this reason.

5. CONCLUSIONS

Although complete lockdown was announced by Indian Government, such an ideal implementation is not possible. Furthermore, it was seen that despite the lockdown, the number of infection due to COVID-19 was growing in an alarming rate. It is not possible to determine how well the lockdown was implemented merely from the number of infections. In this paper, we have studied the rate of change of growth in infections prior to and during the lockdown and have determined the relative change in the growth for each state. The value of relative change provides a quantification of the effectiveness of the implementation of lockdown in each state of India. Our results show that while some of the states have indeed done a good job in implementing the lockdown, there are some states where lockdown was far from ideal.

The future scope of this research is the inclusion of other parameters such as the number of testing, average age of citizens in each state, average personal hygiene etc. to determine in more detail how effectively each state is trying to fight this pandemic, and thus try to predict how long India is expected to suffer from this.

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BIOGRAPHIES

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Sanjib Halder was awarded his 1st Master Degree (Master of Computer Application) from Indian Institute of Engineering Science and Technology, Shibpur, West Bengal, India and his Second Master Degree (M. E. in Software Engineering) from Jadavpur University, West Bengal, India. He worked in the Software industry for one year and then came to the academic world. He is teaching in the Computer Science Department of The Bhawanipur Education Society College for the last 19 years. His area of specialization is software Engineering and his research interest includes Software Engineering, mobile computing, System Security, etc.