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Effect of Social Distancing on Coronavirus Disease 2019 Spread Controlling: A Mathematical Modeling

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Abstract

Coronavirus disease 2019 (COVID19), the outbreak of the novel coronavirus, has posed an unprecedented public health threat to China and many other countries in the world at present, with a significant effect on health and public health systems, individual lives and national and world economic. COVID-19 has been declared by the WHO as a pandemic. The structures of public contact significantly determine spread of this infection and, in the absence of vaccines, the control of these structures through extensive social distancing measures have appeared to be the most effective means of mitigation. In this paper, to examine the impact of social distancing in COVID 19 distribution, we propose mathematical model using direct correlation between social exposure and reproduction number. We show that the calculation of social distance is an efficient way of monitoring the spread of COVID-19 in the absence of vaccines. In India, we have also calculated that the basic reproduction number is 2.5.

Keywords: Coronavirus, Coronavirus disease 2019, Mathematical model, Pandemic, Reproduction number, Social distancing

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Introduction

A large family of viruses known as coronaviruses may cause in humans, several coronaviruses ranging from the common cold to more brutal diseases such as Middle East respiratory syndrome and severe acute respiratory syndrome are known the basis of respiratory infections. The most newly revealed coronavirus causes coronavirus disease (COVID-19). COVID-19 was first reported in month of the December 2019, in the Wuhan city of China. COVID-19 has further spread from Wuhan city to other cities of China and various other countries in the world. COVID19 has wide and rapid spread in the community of most of the countries due to which WHO declared COVID-19 disease as a public health emergency of international concern in January 30, 2020. The global confirmed cases by April 28, 2020, have reached 3,132,312, with a death case of 221,436 and recovered cases of 953,309. COVID-19 epidemic is great harm to people's daily life and country's economic development. COVID-19 has experienced four stages since its reporting: Initial stage, local eruption, community spread, and widespread transmission. China witnessed the fourth stage of transmission earlier in February 2020 while countries such as Italy and the USA are in fact currently in the fourth stage.[1-3]

As per Indian Council of Medical Research, world second population country India is currently in Stage-2 of transmission. This is because of Indian government's sudden and strict enforcement of 21 days national lockdown from March 25, 2020, with further extended until May 3, 2020. In India, the initial case of COVID-19 was reported on January 30, 2020, originating from China. Further, India has reported 31,324 confirmed cases with a death case of 1008, and 7, 747 recovered cases as on April 28, 2020.[2,4] COVID-19 symptoms are very similar to flu such as cough, cold, fever, tiredness, nasal congestion, runny nose, sore throat, diarrhea, and breathing problem. COVID-19 infection increasing rapidly and until now there is no vaccine is announced or available. Hence, the governments of most countries advise to their peoples to use measures such as social distancing (1 m or 3 feet) with other people with partial or complete lockdown.[5] The intensity of an infection like COVID-19 pandemic is measure by reproduction number R0. Reproduction number represents the average number of people infected by a sick person during incubation period of pandemic and incubation period is the time after which the person feels the symptoms. The incubation period of COVID-19 is on average 5–6 days and may be up to 14 days. Thus, to take proper actions on the outbreak COVID-19, it is important for the scientist or the modeler to predict the role of social distancing on total number of confirmed infected cases, on total number of deaths, on reproduction number, and duration of the pandemic.[6-9]

Keeping the above in mind, through this research paper, we proposes a mathematical model using direct correlation between social exposure and reproduction number to predict the effect of social distancing in the spread controlling of COVID-19. Through our model, we formulate mathematical formula to measure total number of infected cases for three types of cases, that is, for the case without social distancing, for the case with social distancing

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measure of s percentage, and for a combination of both cases. Our model works like a generalized model for a pandemic like COVID-19 and can be used to predict total expected duration of disease, the number of expected cases.

We outline preliminaries in Section-2. In Section-3, related work is discussed. In Section-4, the concept of social distancing is briefly discussed. In Section-5, the proposed mathematical model is described. In Section-6, the result analysis of this research is presented; finally conclusion is described in Section-7.

Preliminaries

In this section, we have described data source and various notations used in the paper.

- Data source: All the data to COVID-19 pandemic for India have retrieved from Worldometer. We have used the total infected case data available on Worldometer in 5 days interval from March 2, 2020, to April 28, 2020[2]
- Notations: The various notations used in this paper are listed in the following Table 1.

Related Work

Mathematical modeling is a key tool on estimating and predicting the scale and time line of pandemics, evaluating usefulness of public health interventions, and informing public health policies. Mathematical modeling is used for theoretical analysis, quantitative analysis, and simulation of the spread chain of infectious diseases like COVID-19. Mathematical model on infectious disease prediction mainly includes differential equation prediction models based on dynamics,[10-18] time series prediction models based on statistics and random processes mainly including autoregressive integrated moving average model, exponential smoothing method, grey model, and Markov chain method[19] and others based on data-driven and reproduction number based mathematical modeling.[14,20-24] At present, there are very limited works that studied the impact of social distancing effect on COVID-19 transmission in India circumstances. In this paper, we present simple mathematical model using the statistics of social distancing effect on reproduction number.

Table 1: Notations used.

S. No.	*Name*	*Meanings*
1.	R0,IP	Basic reproduction number and Incubation period, respectively
2.	Sd, s	Social distancing and Social distancing percentage, respectively
3.	Who	World Health Organization
4.	N	Total population of Country
5.	n	Active population participated in exposure
6.	t, T	Time before lockdown and after lockdown, respectively, in time unit (5 days), respectively
7.	ec_{nsd}, EC_{Nsd}	One person infected case and Total infected cases, respectively, no with no Social distancing in t time unit respectively
8.	ec_{sd}, EC_{sd}	One person infected case and Total infected cases, respectively, with Social distancing in T time unit
9.	EC_{total}	Total infected case in t + T time units
10.	$R0^{t}$	One person active cases in t time units that further spread disease COVID-19

Social Distancing

There is currently no treatment for COVID-19 pandemic across the world except few suggestive treatments of use of hydroxychloroquine, azithromycin, antiretovirals drugs, and plasma therapy used in Indian Scenario. The significant results of these treatments in all patients of COVID-19 infections are questionable. Hence, the most of the countries including India suggested to their people prevention strategy as a treatment of COVID-19 pandemic. Preventive strategies include quarantines (home isolation) of suspected cases and those with mild illnesses and strict infection control trial at hospitals, contact tracing, masks, hand hygiene practices, adoption of social distancing measures, and national level partial or complete lockdown. Out of these strategies in worldwide mostly social distancing measures are used to reducing the spread of COVID-19 pandemic.[7,25] Social distancing is an important step to break the chain of physical interaction between humans in COVID-19 pandemic. Social distancing measures includes, to keep himself at least 6 ft apart from others, avoid non-essential gathering of crowds, limit contacts with those at higher risk, work from home whenever possible, greet with wave not handshake or hug, and avoid going out except for essentials. The major step in the direction of social distancing is to announce lockdown at national level. Indian government took this preventive measure seriously, and started this with the 1-day implementation of Janta curfew on March 22, 2020, and further announcing a 21-day lockdown till April 14, 2020, which is further extended till May 4, 2020.

Social distancing has some negative effects such as mental health and loneliness, in spite of this social distancing is mostly use because it reduces transmission of the virus effectively and lessens the impact on already stretched health-care services. The principle behind social distancing is to decrease the basic reproduction number R0 and a small reduction in R0 can have a profound effect in delaying the exponential growth and spread of a disease. Further, the value of R0 is the important parameter used in studying new cases. The value of R0 tells about contagiousness of disease. In simple terms, R0 determines an average of what number of people can be affected by a single infected person over a course of time. If the value of R0 <1, this signifies, the spread is expected to stop. If the value of R0 = 1, this signifies spread is stable or endemic. If the value of R0 >1 this signifies, spread is increasing in absence of intervention. Thus, calculating the value of R0 remains an important part.[25] In India, R0 value of COVID-19 has been calculated based on earlier data are reported in the range 1.5–4.[26,27] In our analysis, we have used total infected case data on March 24, 2020, for calculating basic reproduction number from date March 2, 2020, to March 24, 2020. Further, based on our calculation basic reproduction number in above duration is 2.5 and it further decreased due to social distancing effects in later duration based on our mathematical formulation.

Proposed Mathematical Model

Social distancing measures place an important role in controlling spread of COVID-19 pandemics only if carried out properly. These measures are in take place worldwide to reduce the spread of COVID-19. In this section first, we have described our model assumption and then we have described a mathematical approach on modeling the effect of social distancing for COVID-19 spread controlling based on three types of cases.

Model assumption: We have considered the following assumptions for our mathematical formulation:

- Incubation period is the time after which the person feels the symptoms, for COVID-19 the incubation period is on average 5–6 days and may vary up to 14 days.[28] We have taken the incubation period of the 5 days as reported on several studies the mean incubation period 5–5.2 days[29,30]
- We assume during the incubation period of the 5 day's a person will experience symptoms, that is, up to maximum 5 days the person (Active person) infects to others and after that become inactive or become hospitalized or in self-quarantine
- We assume a direct correlation between social exposure and basic reproduction numberR0
- As national level, lockdown with social distancing reduces reproduction number. Hence also reduced the probability that a given uninfected person will come into physical contact with an infected person. Hence, we have assumed 30 days (more than 2 × times to maximum incubation period[26]) continuous lockdown duration after which reproduction number R0 will decreases and new basic reproduction number is calculated by following equation: $R0' = (R0 \times (1-s))$. Here, s represents percentage of adopting social distancing.

Let us further assume N represent the total number of population of a country out of which say n% (active persons) populations (participated in chain of exposure) is infected by pandemic, t represent time delay in unit of 5 days (incubation period). It is the time after which measure of social distancing applied. Now formulation of the mathematical formula to measure the total number of infected cases for three types of cases described following:

Case-1 No Social Distancing

In this social, distancing measure is not applied. As we assume duration without social, distancing is t time unit. So for this duration using assumption of direct correlation between social exposure and R0, we deduce following Figure 1 for one-person infection exposure.

As per Figure 1, it is clear that by adding all cases, that is, $1+R0+R0^2+R0^3+\ldots R0^t$, we get the total infected persons with no social distancing by the one person say ec_{Nsd} in time t. hence, $ec_{Nsd}=1+R0+R0^2+R0^3+\ldots R0^t$

$$\Rightarrow ec_{nsd} = [\{R0^{t+1}-1\} \div \{R0-1\}] \quad (1)$$

Equation 1 represents infection chain by a single person without social distancing measure in time t. Now as at initial stage, there are n% number of infected person out of N so the total infected cases without social distancing in same times t say EC_{Nsd} is given by following equation:

$$EC_{Nsd} = \sum_{i=1}^{N*n/100} [\{R0 \wedge (t+1) - 1\} \div \{R0 - 1\}] \quad (2)$$

Further, above equations is not applicable for value of R0 = 1, for this value the total infected case= (t + 1). (N ∗ n/100).

Case-2 Social Distancing of s Percentage

In this case, social distancing measure is applied with s percentage. Its meaning can be understood by subsequent example:[8] Suppose 80% social distancing applied then it either mean -any person in one household could go out once in 5 days or one member per family of five could go out daily, but the other four stay at home all the time. Further, the value of s is in the range of [0, 1] (1-for 100%). Now using assumption of direct correlation between social exposure and R0, with s percent social distancing, we get subsequent Figure 2, which shows chain effect of one sick person with social distancing measure of s percentage, in time duration of T time unit:

Thus, it is clear from Figure 2, the number of cases infected by chain of one sick person with social distancing s, say ec_{sd}, given by adding all cases, that is, $ec_{sd}=1+\{R0(1-s)\}+\{R0(1-s)\}^2+\{R0(1-s)\}^3+\ldots \{R0(1-s)\}^T$

that is, $$\Rightarrow ec_{sd}=[\{(R0(1-s))^{T+1}-1\} \div \{(R0(1-s))-1\}] \quad (3)$$

Further, with value of initial infected active persons n% out of total population N. The total infected cases say (EC_{sd}) with social distancing measure of s percent is represented by following equation:

$$EC_{sd} = \sum_{i=1}^{N*n/100} [\{R0' \wedge (T+1) - 1\} \div \{R0' - 1\}] \quad (4)$$

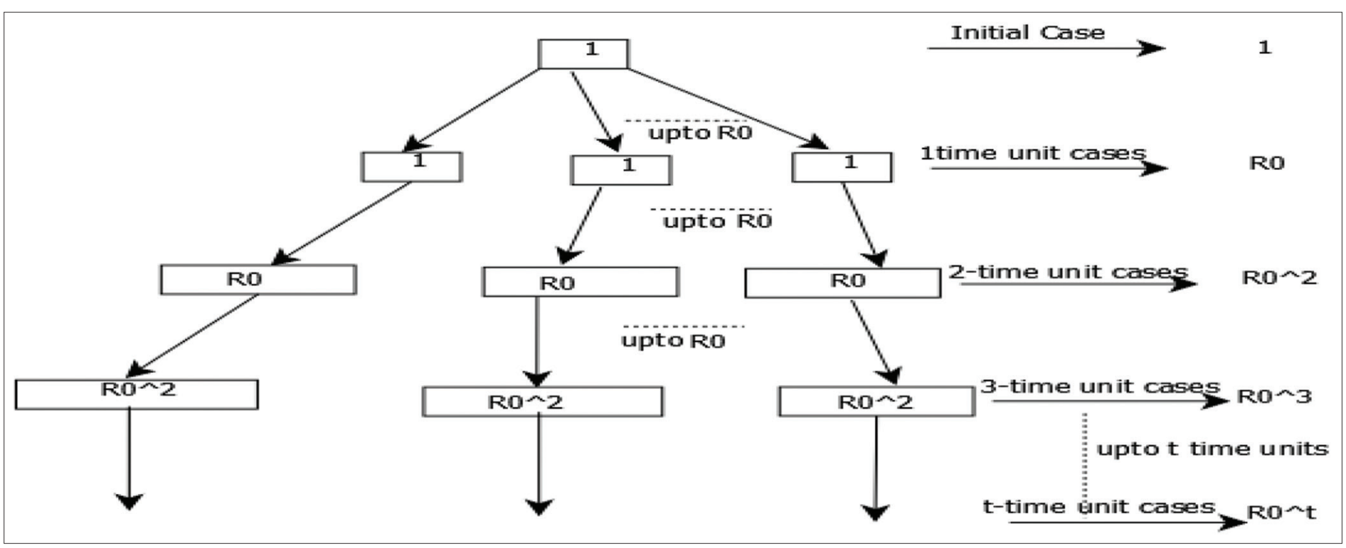

Figure 1: Infection chain by the one person without social distancing measure in t time units

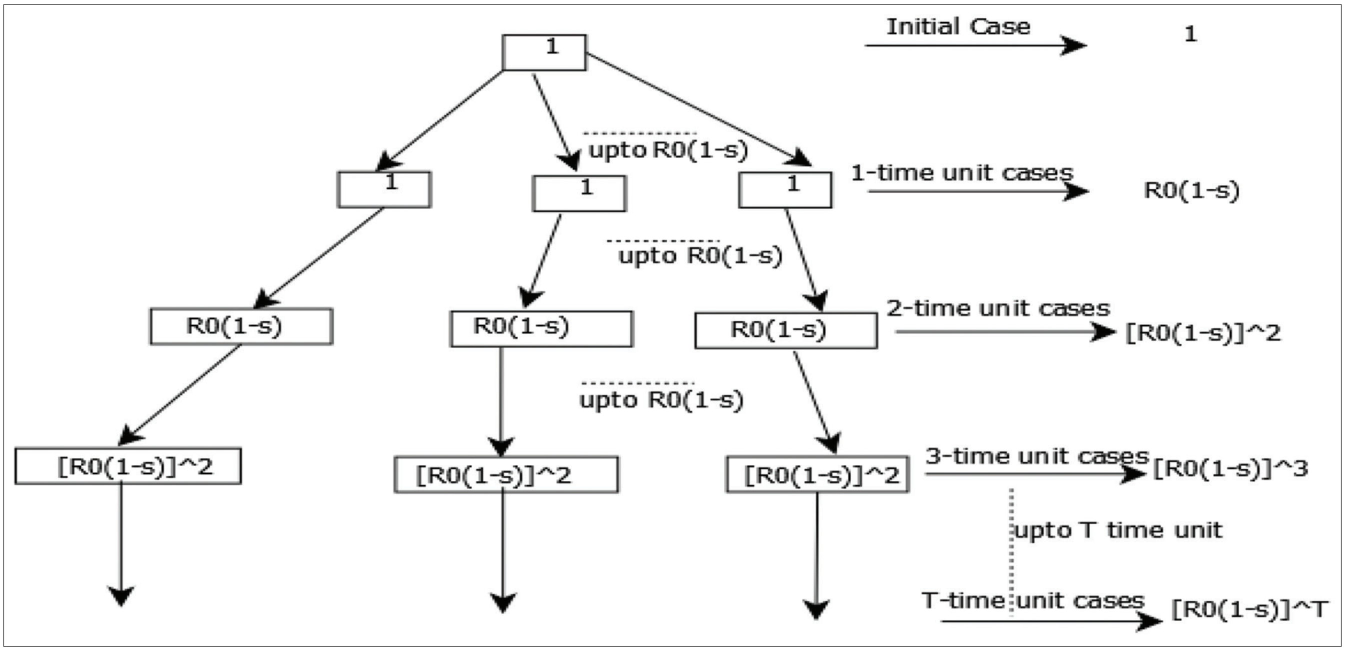

Figure 2: Infection chain by one person with s percent social distancing measure in T time unit

Where R0′ =(R0 ∗ (1−s)) and N∗n/100 are number of active persons spreading COVID-19. Now, As per our assumption, if the duration of continuous lockdown (or Sd) is more than 30 day's (i.e., T >6) then we divide all duration in 30 days slots (T = 1 to 6). Further, we calculates infected cases for each slots with new active cases and reproductive number R0′ (here R0′ =(R0 ∗ (1−s))).

Case-3 Hybrid Case

In this case, social distancing measure is applied after t time units for T time unit duration. Hence, using equations 2 and 3 the total infected cases in Hybrid situation, say (EC_{total}) in time t + T, given by following equation:

$$EC_{total} = EC_{nsd} - (N*n/100)R0^t + \sum_{i=1}^{(N*n/100)R0^t} ec_{sd} \qquad (5)$$

Further, like in case-2 discussed above, if in this case T >6 then divide whole duration (lockdown or sd) into slots of 30 days. Then, infected cases are calculated with new reproduction number (R0′) and active persons [(N ∗ n/100)$R0^t$] for each slots (here R0 is taken as per corresponding slots). Through equations 5, it is cleared that number of infected cases are less when decision of social distancing measure taking as early as possible with high percentage of s.

Result Analysis

Using our mathematical model, in this section, we have presented our analysis on spread of COVID-19 disease in India. In India COVID-19 is in Stage-2 and there is no community transmission, but we have been observing an increase in the number of patients each day. We have predicted basic R0. We have presented effect of social distancing by comparing one person infected cases for both no social distancing measure and with different percentage social distancing measures.

Prediction of Basic R0

We have estimated R0 for the duration of March 2, 2020, to March 24, 2020 (i.e., before lockdown March 24, 2020). In the estimation of R0, we have used the infected case data from March 2, 2020, because before this date the infected case is constant, that is, total 3 was the number of infected cases. As after March 24, 2020, lockdown was started and we know in lockdown due to social distancing the reproduction number must be less than R0. So for the estimation of R0, we have applied mainly formula-1, with total infected case data on March 24, 2020 (i.e., 536) and time t = 4.4 unit (As time taken in 5 days unit and March 2, 2020, to March 24, 2020, total days 22, so t=4.4). Further, using above procedure, we obtained R0 as 2.5.

Analysis of Social Distancing

We presented the effect of social distancing using the number of infected cases. For this, we have depicted the number of cases by one infected person in both the case of without Sd and Sd with percentage s. Further, following Table 2 represent effect of social distancing in terms of the number of infected cases of one infected person with value of s in the range of [0, 1], time say 30 days, that is, t=6 time unit and R0=2.5.

Moreover, based on Table 2, we have obtained the following Figure 3 that clearly shows the effect of social distancing in the number of infected cases.

Table 2: Analysis of social distancing effect by one infected person

S. No.	*Methods*	*Number of infected cases*
1.	No social distancing	407
2.	Social distancing with s=0.2	127
3.	Social distancing with s=0.4	33
4.	Social distancing with s=0.6	7
5.	Social distancing with s=0.8	2
6.	Social distancing with s=1	1

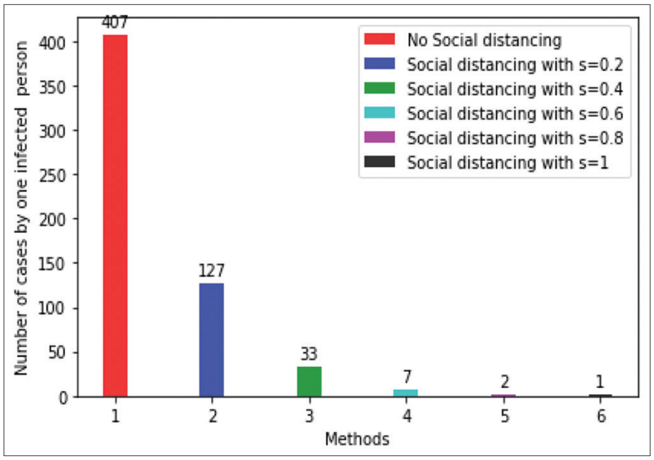

Figure 3: Social distancing effect using the number of infected cases by one person

Conclusions

Our study focused on COVID-19 disease in India. We have proposed a mathematical model using direct correlation between social exposure and reproduction number to analyze the effect of social distancing. Under our model, we have demonstrated the formulation of infected cases on three situations (a) without social distancing case, (b) with s percentage social distancing, and (c) Hybrid case. Through these formulations, we have analyzed the effect of social distancing and found that social distancing results continued reductions of reproduction number, hence used in spread controlling of COVID-19 disease. Further, we have estimated that basic reproduction number for India is 2.5.

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