MTH301 Final Year Project
Modelling of COVID-19 transmission dynamic in India
印度新冠传播率的动态建模分析

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1 Abstract

The prevention and control of COVID-19 epidemic is a great challenge for governments around the world today. In this study, we developed an epidemiological model based on dual-case segregation with mild and severe symptom classifications and simulated it to estimate changes in transmission capacity and transmission advantage across cases and we solve the proposed differential equations model. Then we match relevant policies corresponding to time with different pattern nodes of weekly growth of confirmed COVID-19 cases and analyze COVID-19 on a modified SEIR model with different parameters, which can provide theoretical support for deciding rational public health policies and preparing important resources for epidemic prevention.
预防和控制 COVID-19 疫情是当今世界各国政府面临的一个巨大挑战。在这项研究中，我们建立了一个基于轻重症双情况分隔的流行病模型，并对其进行了模拟，以估计各情况的传播能力和传播优势的变化，并解决所提出的微分方程模型。我们根据 COVID-19 确诊病例每周增长的不同模式节点，匹配与时间相对应的相关政策，在不同参数的修正 SEIR 模型上分析 COVID-19，这可以为决定合理的公共卫生政策和准备重要的防疫资源提供理论支持。

2 Keywords

SEIR model; COVID-19; Reproduction number
关键词：新冠病毒；基本传染率；SEIR 模型

3 Introduction

COVID-19 is the novel corona virus that has spread among human, and has caused serious global crisis that threatens to overwhelm public health care systems. The daily lives of billions have been impacted by the unprecedented social controls imposed by governments to control the spread of the virus.

In the struggle against COVID-19, a lot of studies on the epidemic spread prediction and the prevention and control policies of government have been carried out by researchers based on the actual situation of the epidemic and previous epidemiological models. One of the most popular epidemiological models, Susceptible-Infected-Recovered (SIR), was proposed by Kermack and McKendrick' s remarkable work in 1927 [1]. In the SIR model, society is divided into three compartments:susceptible (S),infected (I),recovered (R). The disease spreads from the affected to the unaffected by contact infection. Each infected person runs through the course of his sickness, and finally is removed from the number of those who are sick, by recovery or by death. And the chances of recovery or death vary from day to day. The rates that the affected may convey infection to the unaffected are like wise dependent upon the stage of the sickness.The experience with the SIR model has motivated many variations, with new compartmental states, such as SEIR, SEIRS, SIRS, SEI, SEIS, SI, and SIS [2]. Many of these models incorporate an additional compartment - exposed (E). In this state, individuals are infected but not yet infectious during a latent period. In general, the compartments and related state transitions are selected based on the characteristics of a specific disease and the purpose of the model.Researchers have previously used the SIR model and its extensions to estimate the parameters of diseases. Zhang et al. [3] used the improved SIR model and the Runge-Kutta method to predict the spread trend of the epidemic in China. Zhang et al. [4] established a novel stochastic dynamics model based on the transmission mechanism of COVID-19 and characteristics of epidemic prevention measures of COVID-19, and realized the effective prediction of the time of occurrence, development, and control for overseas epidemics. Liu,Gayle, Wilder-Smith, and Rocklöv(2020)[5]and You et al. (2020) [6]focus on estimating the basic reproduction number R0. Shen et al. [7] estimated the basic and effective reproduction number of COVID-19 on the basis of infectious disease dynamics, and predicted the peak time and epidemic scale.

Closer to this work, another stream of literature examines the impact of policy-related control measures on economic cost and the spread of COVID-19. Many efforts have been made to investigate the impact of different levels of prevention and control measures on the epidemic propagation based on the traditional SIR/SEIR models or their improvement versions.Atkeson (2020)[8] use the SIR model to predict the spread of COVID-19 in the United States over over an 18 month horizon by varying the level of mitigation measures from mild to severe and its economic impact. Acemoglu, Chernozhukov, Werning, and Whinston (2020)[9] extended the standard SIR model by including multiple demographic-based risk groups. They quantitatively investigate the optimal policy by analyzing the trade-off between efforts needed to save lives and improve economic indicators. In the Indian context, Kumar, Priya and Srivastava (2021)[10] found that Indian government have helped in slowing down the spread of COVID-19 inthe initial phases; however, our model shows that similar results could also have been achieved with moderate level of interventions.

The control of COVID-19 requires the knowledge of the driven factors that may affect the transmission process. It is unclear how and to what extent various infection prevention and control policies affect the spread of an epidemic. In this work, we aim to estimate the impact of interventions and related control measures that might be used to slow the contagion in India, and thereby provide optimal evidence-based policies to enhance health care resources and develop effective immunological defenses under different scenarios.

3.1 The Indian context

As the second most populous country in the world, the COVID-19 pandemic has spread to all states of India and has become a health threat that cannot be ignored in India, where there is a shortage of health personnel, beds and ventilators in hospitals amidst the current situation of explosive and exponential growth in the number of infections. From March 2020 to November 2020, the Indian government and administration have taken several policy measures and steps to prevent the spread of coronavirus disease infections in 2019 and reduce mortality and numbers. The overlap of administrative activities and areas between the states and the federal government has created a degree of confusion and led to a degree of medical crowding out. Initially, the Indian government was watching the development of coronavirus disease around the world in 2019 and preparing for this scenario. the government was still holding large public gatherings and events during the final phase in February and initial phase in March 2020. At this time, India was already experiencing infections caused by international travel-related infections. Later, the mainstream media told about the sudden increase in cases through the news, lacking any scientific basis or justification, creating panic among the government and citizens. In the absence of real-time scientific data, reliable policy and public health statistics, the Indian government also seemed to react quickly by proposing a severe embargo. According to the government notification, the embargo was declared to prevent the spread of the virus in March 2020, when the total number of infected people in the country was about 600 and only a few states were affected, not the entire country of about 1.3 billion people living in a different geographical and cultural system. After the announcement of the embargo, the government declared a temporary closure of all economic activities, commercial establishments, educational institutions, etc. India also halted all aviation activities at the end of March 2020 due to the spread of the virus through international travel. State law and order departments and the central government imposed curfews and lockdowns in cities and villages to stop the spread of the virus in communities through a number of strict measures. On the health and infrastructure front, the Indian government started publishing information related to the 2019 coronavirus disease and its mitigation and treatment strategies through the press. But the government has no viable plan on the administrative side: for example, increased testing and contact tracing facilities and increased bed availability. It was presumed that the blockade alone would be effective in reducing the number of infections and reducing the transmission routes of the virus in 2019 coronavirus disease, but the initial closure policy was not particularly successful due to lack of skilled human resources and lack of infrastructure, laboratory equipment, and testing tools. With a steep decline in GDP and an increase in the number of new COVID-19 cases per day globally, India is at great risk. Recovery will depend in large part on a series of policy measures taken by the Indian government. As the country relaxes its strictest COVID-19 embargo, the movement of workers in the workplace will affect the spread of the virus and the recovery of the country's economy. The negative impact of the embargo is reflected in the situation of workers. These workers and laborers travel to industrialized cities to earn a living and employment. Their standard of living is below that which sustains their mouths and they are the citizens with the lowest social security. The government's decision to blockade the country without much thought has wreaked havoc on the lives of laborers. The government assured the workers that they would receive food and shelter, but the food and shelter never reached them, forcing them to face death from starvation or infection. Due to the blockade and the collapse of economic activity, small and medium sized business owners were forced to fire their employees. The whole process of the government working and dealing with this situation was backward, which could have been avoided considering the inclusiveness and medical ethics in the policy and the evidence based on science and data.

Recently, researchers and economists have proposed models and reports to predict the number of COVID-19 cases. This study lies in testing specific government interventions, such as lockdown or quarantine, to control the spread of COVID-19 using the SEIR epidemiological model. Our goal is to provide a quantitative estimate of the impact that each policy will have. Such estimates can help policy makers design an optimal policy with reasonable estimates and predictions of the impact that a policy change will have. Using the designed model, we can answer which interventions perform better.

4 Material and methods

4.1 Model formulation

4.1.1 The standard unforced SIR model

In 1927, W. O. Kermack and A. G. McKendrick[1] created a model in which they considered a fixed population with only three compartments:
Susceptible(S(t)): individuals who have no immunity to the infectious agent, so might become infected if exposed. As COVID-19 is a newly identified pathogen, there is no known pre-existing immunity in humans.Based on the epidemiologic characteristics observed so far in China, everyone is assumed to be susceptible, although there may be risk factors increasing susceptibility to infection.
Infectious(I): individuals who are currently infected and are capable of transmitting the disease to susceptible individuals who they contact.
Removed(R): individuals who are immune to the infection, and consequently do not affect the transmission dynamics in any way when they contact other individuals.The recovered individuals are presumed to have acquired some level of immunity to the disease, such that they have a lower probability of reinfection compared to susceptible individuals.Those in this category are not able to be infected again or to transmit the infection to others.
And the total population size is $N = S + I + R$.
If we scale the state variables by the population size ($S \to S/N$, $I \to I/N$, $R \to R/N$) and derive equations for these scaled variables, then the standard SIR model, originally investigated by Kermack and McKendrick (1927), can be written as

$$\frac{dS}{dt} = -\beta\ S\ I \tag{4.1}$$

$$\frac{dI}{dt} = \beta\ S\ I - \gamma\ I \tag{4.2}$$

$$\frac{dR}{dt} = \gamma\ I \tag{4.3}$$

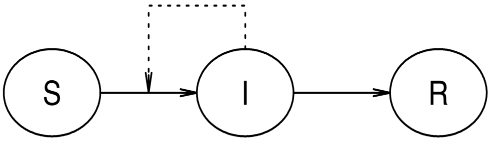


Figure 4.1: SIR

The epidemiological parameters are the transmission rate β which is the average of contacts per person per time and the recovery rate γ (i.e. the average latency period γ^{-1}).Then we introduce two demo- graphic parameters, the per capital birth and natural death rates, which are given by v and μ, respectively. Then we arrive at the system with vital dynamics:

$$\frac{dS}{dt} = v - \beta\ S\ I - \mu\ S \frac{dI}{dt} = \beta\ S\ I - \gamma\ I - \mu\ I \tag{4.4}$$

Since the population has no prior exposure, everyone is initially susceptible (S(0) = N), then a newly introduced infected individual can be expected to infect other people at the rate during the expected infectious period $1/\gamma$. Thus, the number of first infective group can be expected to infect $\mathbb{R}_0 = \beta * N/\gamma$. The number $\mathbb{R}_0$ is called the basic reproduction number and is unquestionably the most important quantity to consider when analyzing any epidemic model for an infectious disease. In particular, $\mathbb{R}_0$ determines whether an epidemic can occur at all; to see this for the basic SIR model, note in (4.1) and (4.2) that I can never increase unless R0 > 1. Taking (4.1) and (4.2), we obtain

$$\frac{dI}{ds} = -1 + \frac{1}{\mathbb{R}_0\ S} \tag{4.5}$$

$$I = I(0) + S(0) - S + \frac{1}{\mathbb{R}_0} ln[S/S(0)] \tag{4.6}$$

This is an solution to I as a function of S, not as a function of t. Over a sufficiently small time interval t, we can make the approximation $dS/dt = \Delta S/\Delta t$, where $S = S(t+t)S(t)$. If we now solve for the number of susceptibles a time t in the future, we obtain

$$S(t + \Delta t) = S(t) - \beta S(t) I(t) \Delta t \tag{4.7}$$

$$I(t + \delta t) = I(t) + \beta S(t) I(t) \Delta t - \gamma I(t) \Delta t \tag{4.8}$$

In order for computers to carry out the calculations specified by (4.8) and (4.9), we need to tell it the parameter values (β and γ, or $\mathbb{R}_0$ and N) and initial conditions (S(0) and I(0)).

4.1.2 Classic SEIR model with development

The experience with the SIR model has motivated many variations, with new compartmental states, such as SEIR. Many of these models incorporate an additional compartment - exposed (E). In this state, individuals are infected but not yet infectious during a latent period. In general, the compartments and related state transitions are selected based on the characteristics of a specific disease and the purpose of the model.

For our new SEIR model with development, the susceptible population is denoted by S. This model is more complex than the classical SIR model, but its structure remains simple. Indeed, all individuals are assumed to react on average in the same way to infection (there are no differences in age, sex, contacts). Moreover, there is no spatial structure in the model where everyone is potentially in contact with everyone. The infections are divided into 2 stages including exposed (E) and infectious (A and I) cases. Specifically,all infected individuals join class E immediately after infection, and then become infectious by leaving E during latent period (σ^1). After the latent period, we consider 2 classes of infectious cases including asymptomatic or with asymptomatic conditions (A), and symptomatic (I) cases, both of whom are infectious. The removed (by recovery or death) population is denoted by R. In practice, we will assume that a fraction p of infections are mild and a fraction (1−p) are severe and require hospitalization. For the effective contact rate β, we consider the same effective contact rate for the asymptomatic and symptomatic cases merely for simplicity. For the cases, i.e., those in E, A, or I classes, we consider 2 types of symptoms that are denoted by subscript '1' for the mild cases, and '2' for the severe cases. Comparing against the original type, we consider several epidemiological characteristics of mutated variants that different from the original. They include

$$\begin{aligned}
\frac{\mathrm{d}S}{\mathrm{d}t} &= -\lambda\ S && (4.9)\\
E_1 &= p\ \lambda\ S - \epsilon\ E_1 + p\ \nu && (4.10)\\
A_1 &= \epsilon\ E_1 - \sigma\ A_1 && (4.11)\\
I_1 &= \sigma\ A_1 - \gamma_1\ I_1 && (4.12)\\
R_1 &= \gamma_1\ I_1 && (4.13)\\
E_2 &= (1-p)\ \lambda\ S - \epsilon\ E_2 + (1-p)\ \nu && (4.14)\\
A_2 &= \epsilon\ E_2 - \sigma\ A_2 && (4.15)\\
I_2 &= \sigma\ A_2 - (\gamma_2 + \alpha)\ I_2 && (4.16)\\
R_2 &= \gamma_2\ I_2 && (4.17)\\
M &= \alpha\ I_2\\
\text{with } N &= S + \sum_j (E_j + A_j + I_j + R_j)\\
\text{and } \lambda &= (1-c)\,(\beta_A\ A + \beta_I\ I)
\end{aligned}$$

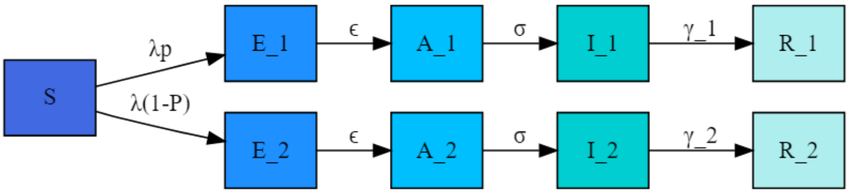


Figure 4.2: SEAIR

4.1.3 Calculation of Reproduction number

The basic reproductive number $\mathbb{R}_0$ is central to our understanding of epidemic spread which is defined as the mean number caused by an infected individual in a susceptibel population.[11]

$$\mathbb{R}_0 = \frac{\beta_1\ S_0}{\sigma} + p\ \frac{\beta_1\ S_0}{\gamma_1} + (1-p)\ \frac{\beta_2\ S_0}{\alpha + \gamma_2} \tag{4.18}$$

$$\mathbb{R}_1 = \frac{\beta_1\ S_0}{\sigma} \tag{4.19}$$

$$\mathbb{R}_2 = p\ \frac{\beta_1\ S_0}{\gamma_1} \tag{4.20}$$

$$\mathbb{R}_3 = (1-p)\ \frac{\beta_2\ S_0}{\alpha + \gamma_2} \tag{4.21}$$

$$\mathbb{R}_0 = \mathbb{R}_1 + \mathbb{R}_2 + \mathbb{R}_3 \tag{4.22}$$

The three terms of this expression have an intuitive interpretation because they correspond to a fraction of the secondary infections generated by an infected person during the course of his or her infection (which is the definition of $\mathbb{R}_0$). The $\mathbb{R}_1$ to infections caused by asymptomatic people A_1 and A_2 (in fact, $1/\sigma$ is the average time spent in the asymptomatic state). The $\mathbb{R}_2$ corresponds to infections caused by symptomatic mild infections I_1 (the duration of this phase can be found through $1/\gamma_1$ as well as the proportion of mild cases p). Finally, the $\mathbb{R}_3$ corresponds to secondary infections caused by severe and symptomatic cases I_2. With this expression, we can see that there are several ways to lower $\mathbb{R}_0$ and thus control the epidemic. For example, the number of susceptible people and the rates of transmission can be reduced (by confining the population, reducing contacts and wearing masks). One can also increase the recovery rates by isolating symptomatic people (from the point of view of the virus, a person who no longer has contacts is equivalent to a recovery, since he or she no longer transmits the virus).

4.2 Data sources

4.2.1 Confirmed and death cases

All analyses were performed with R software (version 4.1.1), using the "COVID19.Analytics" package developed by Marcelo Ponce. COVID-19 death and confirmed diagnosis data from https://api.covid19india.org.Cumulative for new coronary pneumonia in all states Confirmed cases are from the crowdsourced data platform covid19india.org, which uses official announcements and government information to provide up-to-date data and has verified the data collected on confirmed cases in the data available on the website of the Ministry of Health and Family Welfare, Government of India. The cumulative confirmed cases of COVID-19 measure the total number of patients testing positive in each state.

4.2.2 Parameters

$$\alpha = \gamma_2\ \frac{\theta}{1-\theta}. \tag{4.23}$$

$$\beta = \frac{R_0}{S_0}\gamma_1\sigma\frac{\alpha+\gamma_2}{(\gamma_1+p\sigma)(\alpha+\gamma_2)+b\gamma_1\sigma(1-p)}. \tag{4.24}$$

Notation	Description	Default	Range	References
ϵ	rate of end latency	1/4.2 day^{-1}	[0.21;0.27]	[12])
σ	rate of symptoms onset	1 day^{-1}	[0.9;1.1]	[13]
γ_1	recovery rate of mild cases	$1/17\ day^{(} - 1)$	[0.025;0.1]	[14]
γ_2	recovery rate of severe cases	$1/17\ d^{(} - 1)$	[0.025;0.1]	[14]
$\mathbb{R}_0$	basic reproduction number	2.5	[2;3]	[15]
p	proportion of infections that do not require hospitalization	0.9	[0.85;0.95]	[15]
θ	case fatality ratio of hospital patients	0.15	[0.135;0.165]	[15]
α	mortality rate of severe infections	-	-	see the calculation
ν	migration rate	$10^{-6}day^{-1}$	-	[15]
b	decrease in transmission due to hospitalization	0.2	-	[15]
c	fraction of the R0 deceased by public health policies	-	-	variable

Table 1: Parameters

5 Scenario building

In these simulations, we normalized the total population size and represent the percentage of the population infected. This is voluntary because this model has no structure and therefore cannot be applied directly to an entire country but rather to a small town or village.We present in Figure 5.5 the control measures taken by the Indian government in response to COVID-19. Based on the government control measures, we consider five scenarios, namely: 1. no intervention, 2. light intervention, 3. moderate intervention, 4. strict intervention, and 5. actual intervention. We explain these scenarios in the following.

5.1 No intervention

There is no intervention by the policy makers to either suppress or mitigate the impact of COVID-19. No lockdown or restriction on mass gathering is imposed. In this scenario,in the absence of any control, the epidemic is growing exponentially over time.In this scenario, we expect to observe a significant increase in the number of cases infected (Figure 5.1). In this case, after a long period without disturbance, it converges to the herd immune state of the SIR model (Figure 5.2) In Figure 5.1, we can see that most of the hosts are in I1 status, since most of the infected individuals do not have severe infections requiring hospitalization and this is the longest-lasting life cycle stage. Finally, we also remark that the percentage of infected individuals requiring hospitalization (I2, the lime green line) quickly exceeds the percentage of hospital beds (the dashed line). If we further lengthen the duration of uncontrolled infection, we find that the epidemic peaks 150 days after the start of the epidemic in the absence of any intervention. This is approximately equivalent to the intersection of the curves for those who remain susceptible (S yellow) and those who recover and become immune (blue). Finally, we see that the epidemic does not stop once the threshold of herd immunity (indicated by the black dashed line) is reached.

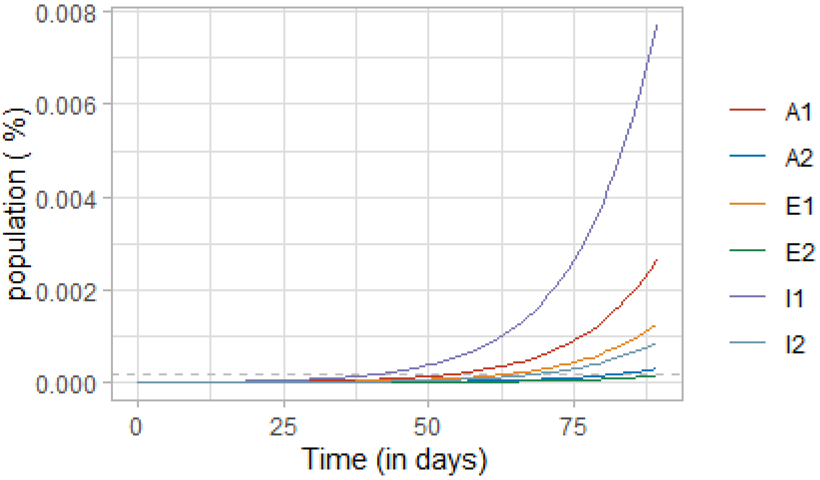


Figure 5.1: No intervention in short time

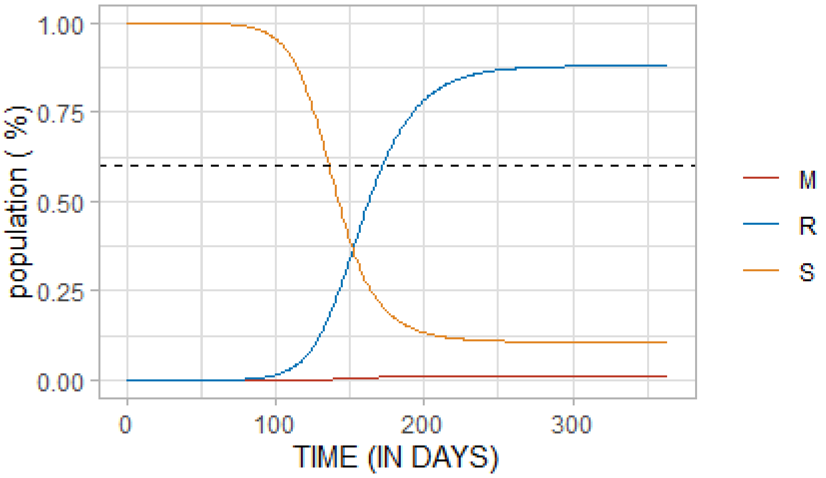


Figure 5.2: No intervention in long time

5.2 Strict intervention

A strict intervention scenario is one in which policymakers will intervene in order to control COVID-19. A strict intervention is a situation in which a complete lockdown is imposed for an extended period of time, local businesses are closed, and people's movement is highly restricted. We observed that the Indian government started a strict 21-day nationwide city closure and quarantine policy on day 60 of the outbreak. In this case, in order to simulate the implementation of this public health policy aimed at strongly cutting off the spread of the virus, we implemented this policy starting from day 60 of the outbreak for 30 days, as shown by the shaded rectangle in Figure 5.3. As expected, during the implementation of the control policy, the number of infected people was controlled in both mild and severe cases. As can be seen, the curve of people requiring intensive care (turquoise I2) remains well below the threshold of the number of available beds (gray dashed line). What can be observed is that once containment measures cease, the number of infected people grows rapidly, and the number of available beds quickly runs out due to the rapid increase in the number of seriously ill.

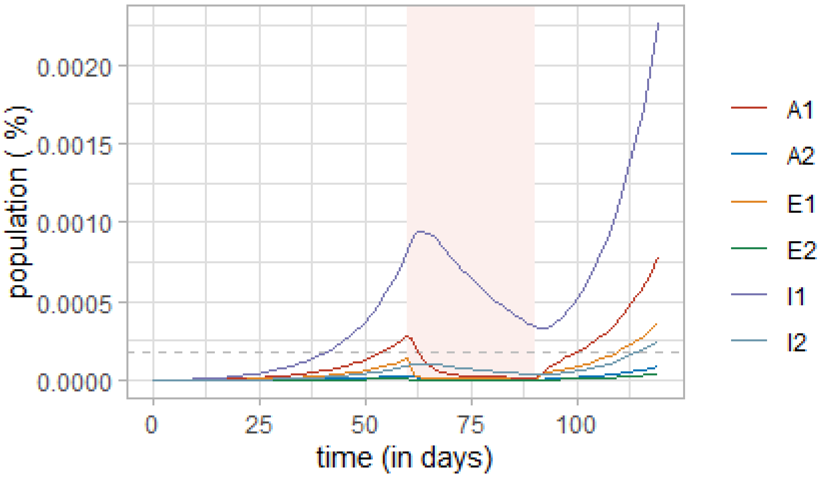


Figure 5.3: Strict intervention in short time

5.3 Moderate intervention

In the case of moderate interventions, we modeled the restrictions proposed by policymakers as more stringent compared to non-interference or mild interventions including partial blockade, movement restrictions or some countries advocated as slowing the growth in the number of daily infections, but not stopping the spread of the virus. We observed that in India, the government started with mild warnings and precautions against COVID-19 (late February to early March 2021), which turned into a very strict lockdown, closing businesses, restricting movement of people, and suspending all international flights (late March to mid-May), and then the government slowly allowed businesses to open and also eased the movement of people. This approach can be achieved by modeling it as follows: limiting the spread of the virus to only c=40 percent for 365 days. As shown in the figure 5.4, this strategy does not stop the spread of the epidemic, but only slows down the daily growth of the number of infections. It can also be seen that the number of severe I2 cases is dramatically rising above the threshold of the proportion of available intensive care and resuscitation beds. In the final phase, moderate interventions are very similar to the uncontrolled situation, but we can observe that the peak of the epidemic appears much later. In addition, the total proportion of the infected population is much lower than in the uncontrolled case and we approach the threshold for herd immunity (black dashed line). However, at the time of cessation of the measures, we observe that the number of susceptible populations is decreasing.

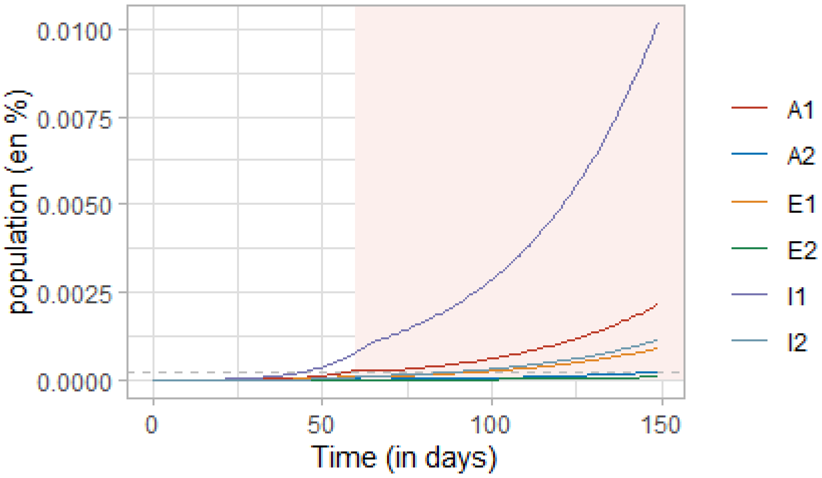
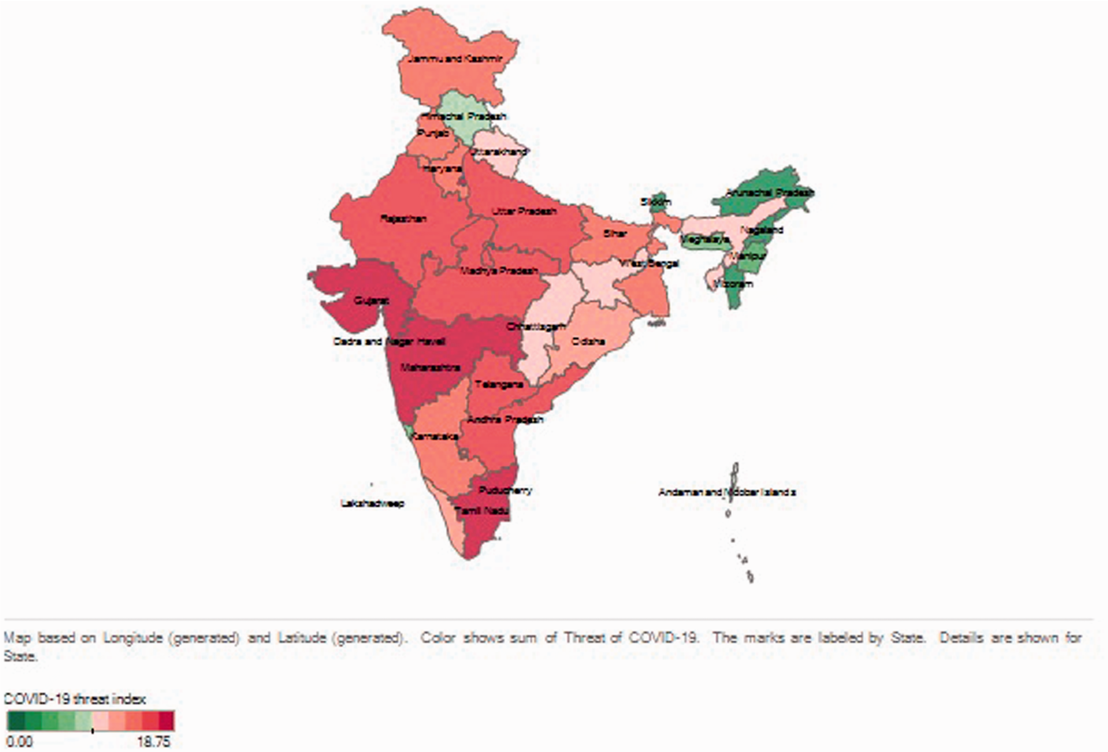


Figure 5.4: Moderate intervention in long time

5.4 Actual intervention



Map based on Longitude (generated) and Latitude (generated). Color shows sum of Threat of COVID-19. The marks are labeled by State. Details are shown for State.

Figure 5.5: Map of COVID-19 in India by State

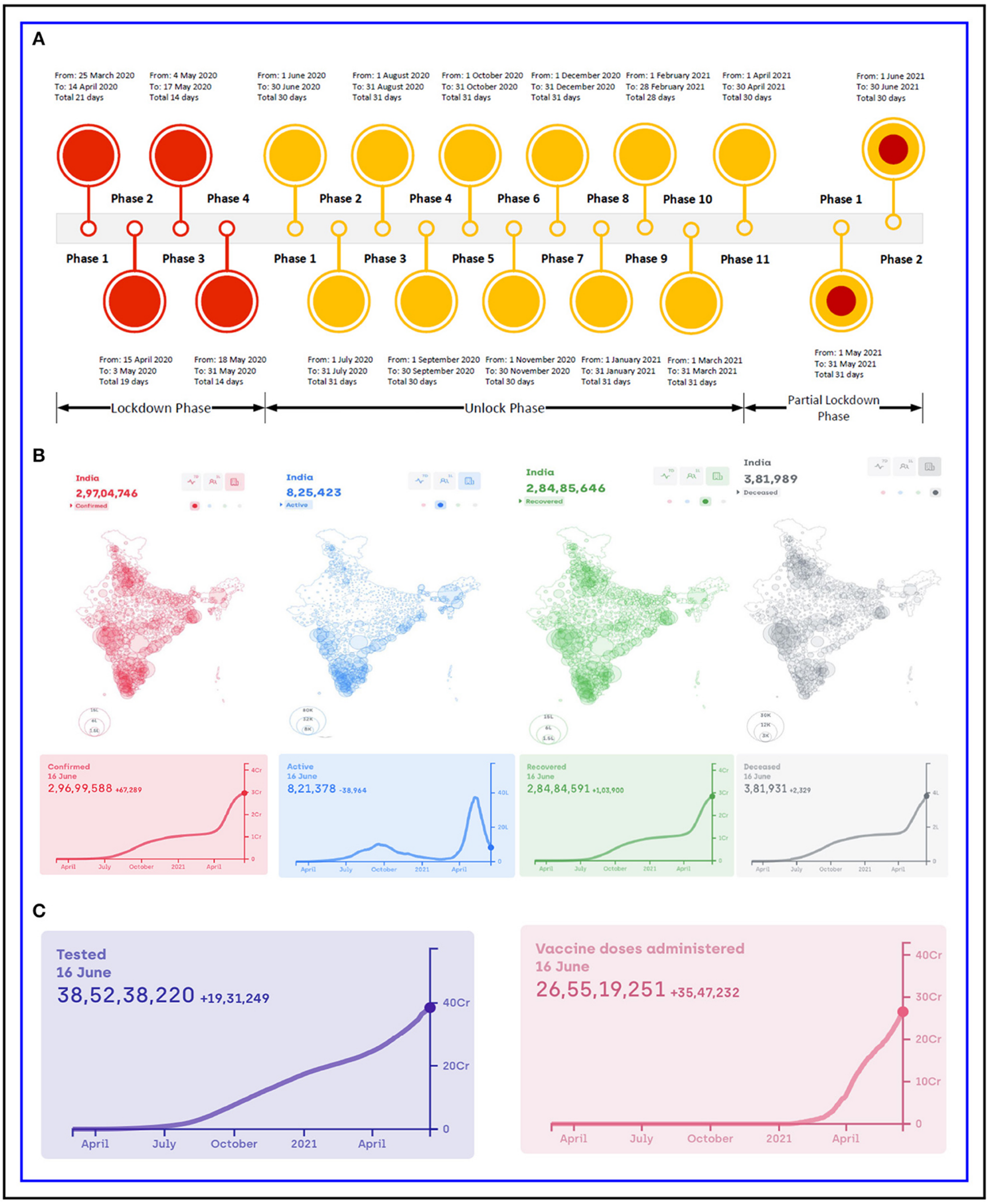


Figure 5.6: Real intervention in India

In reality, the Indian government declared a 14-hour public curfew on March 22, 2020, and a complete 21-day nationwide phase I lockdown on March 25, with mandatory social distancing of crowds. The Indian government is also periodically revising the guidelines for the lockdown measures as the outbreak develops. The second phase of the lockdown was implemented on April 15 for 19 days when the number of positive cases of infection was found to exceed 10,000. The Government of India then extended the embargo for an additional 2 weeks from May 4 (Phase III embargo). During this period, different geographical locations were divided into red, green and orange zones based on the threat level of the new crown. Based on the growth rate of confirmed cases, these areas were marked as red zones, while green zones were based on the criteria of no confirmed cases so far or no confirmed cases in the last 21 days, and other areas

were considered orange zones. The green and orange zones allow for some relaxation.
The most sensitive areas in India are designated as blocked areas. Lockdown Phase 4 began on May 18 and lasted 14 days of strict closures, allowing only certain activities to take place, such as sports and interstate travel for specific purposes only. Nationwide, the government advised educational institutions to continue online learning, banned public gatherings and allowed little international travel. The blockade area remains under strict perimeter control.
On Sept. 1, Phase IV relaxed additional restrictions outside the blockade area. Students and research scholars were allowed to visit schools/colleges in case of emergency, while 50 percent of teaching and non-teaching staff were allowed to teach online. Similarly, certain public gatherings of up to 100 people were allowed in training institutions, subways and, from September 21, wards.
Unlocking Phase V began on October 1, and on October 15, MoHFW and the Department of Commerce issued new SOPs to allow additional businesses such as athletic training fields, 50 percent capacity movie theaters/theaters/complexes, recreational parks, business-to-business exhibitions outside of closed areas, and intrastate and interstate sports.
No changes were made to the implementation of the policy for the phase that began on November 6 and the seventh phase that began in December. As an effect of the strict implementation of the strategic embargo, active new cases of coronary pneumonia dropped to 45,000 from 100,000 on Sept. 18. The unlocking policy for Phase X, which runs through March 1, 2021, continues to follow the same provisions as the earlier phases. Despite several commendable measures taken by the government to curb the increase in the number of infected cases for five months, the number of infected cases spiked sharply from mid-March 2021, as shown in Figure 5.6. This was the beginning of the second wave of new coronary pneumonia in India, where close to 170,000 people were diagnosed with infection in a single day. Following this new wave of neo-coronary outbreaks, a new policy was announced on March 23, effective until April 30. Its program calls for strict adherence to a test-tracking treatment regimen. The program includes aggressive detection of early cases of neo-coronary pneumonia, timely isolation of positive cases, contact tracing, and delineation of cordoned off areas. In addition, the Indian government has launched a campaign to promote and vaccinate more than 100 million people in India who have been fully or partially vaccinated as of April 11, 2021, while 11 million have been fully vaccinated. Despite these strict protocols, India faced the worst surge of the epidemic from mid-April 2021. In this context, the Indian government announced a partial lockdown phase with updated scientific guidance policies and lockdown-like measures, which included extended curfews, bans on related large gatherings and parties, closure of shopping malls and places of worship, etc., while allowing essential services to operate as usual. In addition to this, public transport was instructed to operate at a maximum of 50 percent of capacity. Based on this, local governments in each state/UT are instructed to make further decisions, and each state can independently adopt additional lockdown measures, which may also vary from state to state. As can be seen in Figure 5.6, the number of infected persons still grows when strict blockade policies are implemented, but at a slower rate, effectively slowing the increase in the number of serious illnesses. At the time of the deconfliction policy and the corresponding public policy implementation, when the epidemic was better controlled, the only option was to return to the strict home quarantine and city closure policy after reaching the peak, when these measures

were effective in containing the explosive increase in the number of infected people.

5.5 Model validation

Modeling requires communication, testing, modification and validation of the developed models at each state. Model validation is primarily a test of the robustness and usefulness of the model. The first step is to test whether the model conforms to the common knowledge of the population in the system; this phase is called structural validation. The next step is to test whether the model accurately reproduces the dominant behavior patterns of the real system, and this phase is known as behavioral validation. We performed extreme conditions testing and dynamic simulation testing to determine the validity and realism of our model. Extreme Conditions Testing Models must be robust and behave appropriately in all possible situations, even extreme conditions that have never been observed in the real world. Extreme conditions tests are typically used to test the robustness of the model structure. They test whether the model behaves appropriately when the inputs are assumed to be extreme. The extreme conditions are set in terms of the number of initial infected individuals, taking the extreme value of ”0”, which is not possible in reality. It is assumed that there would be no cases of COVID-19 in India if there were no infected persons in India or no foreign infected persons entering India. When the initial number of cases was set to ”0”, the model did not show any cases during the simulation. Dynamic simulation testing The model provides a consistent basis for prediction and is an integration of judgment, experience and intuition. The predicted effects of implementing alternative policies are available in time through the testing of known historical evidence. If the model replicates long-term historical behavior, it shows that the model reproduces the real system, and confidence in the utility of the model increases. We test our model to check that the model's output roughly matches the historical data points (Figure 5.7). The base run is the initial 200 days (with actual data). We found an average deviation of 11,183 in the actual number of cases. up to day 200, all deviations were less than 2.5 percent of the corresponding totals, indicating that the model fit showed good data with little deviation and a high level of acceptance of the model's usefulness.

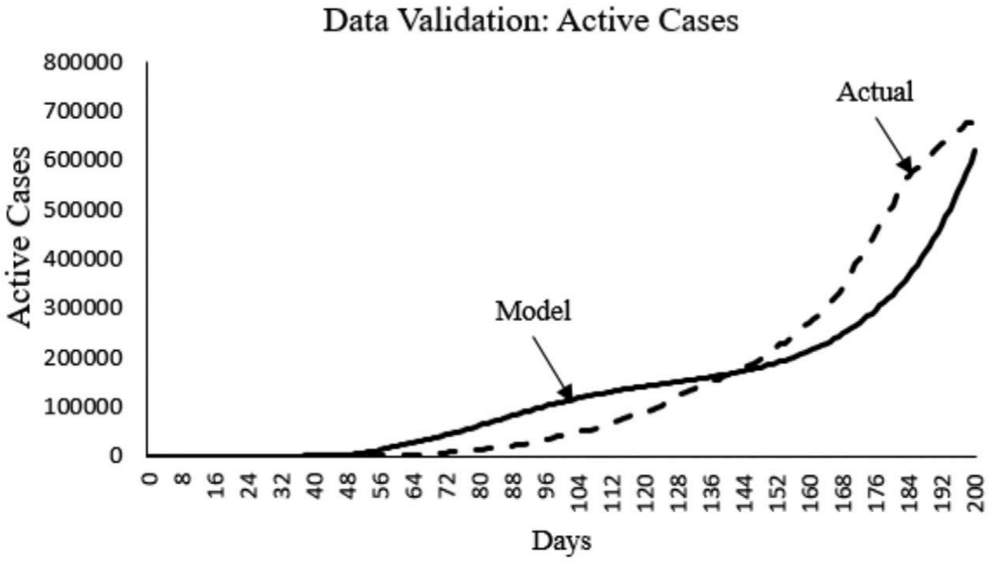


Figure 5.7: Model vs Actual

6 Limitations and future scope

R0 can be considered as the daily transmission rate, and if the transmission rate decreases, the number of infections decreases. Thus, our results clearly illustrate the importance of blockade and social distance to end this pandemic. Although we demonstrate important results for understanding the current status and reasonable prediction of COVID-19 in the Indian region, our study also has some limitations: 1. We chose a value for each parameter of the model, but these parameters are different in the a prior range and should be explored.
2. The model was not built on real data (especially the date of the first case and the number of recorded deaths). Therefore, the date of the peak of the epidemic has only relative values.
3. We ignore the indirect transmission by indirect transmitters such as handrails and door handles in public spaces, seats on public transport, etc., which may play an important role in transmission.
4. Although the mortality rate of COVID-19 infection is known to increase with age, there is no age structure in the population in our modeling.
5. We assume that only severely infected individuals (I2) die, whereas in reality, medical crowding and inadequate bed numbers are likely to increase mortality in these individuals, and complex realities and some specific policies are likely to increase mortality in uninfected individuals (S and R).
6. The control strategy in the model is uniform, while in reality it is the policy that changes over time and realities.
However, these limitations do not change the conclusion of this study that precautionary measures, blockades and social distance adopted can reduce R0, translating into a reduction in transmissibility and the emergence of new cases of COVID-19. In situations where a pandemic has already broken out, the implementation of strict lockdown and social distance measures can be effective in controlling the rate of severe illness and preventing excess mortality due to insufficient beds and medical crowding. In cases where the rate of severe illness is not high, a policy of mild or no interference with virus transmission under vaccine protection can be considered to achieve herd immunity on the SIR model (when there will not be more severe illnesses than beds). The New Coronavirus epidemic has brought significant changes to everyone and to governments around the world, but at the same time this epidemic has given us a learning opportunity to fight similar epidemics in the future, and we have accumulated many studies on the COVID-19 transmission model, and the basic theory of this study is relatively mature. This study is more difficult to study the classification of mild and severe diseases and to simulate realistic data. Although vaccination has been initiated in many parts of the world, COVID-19 and its variants are still causing some economic or health losses in different parts of the world at different times. Therefore, sustainable long-term strategies are something that governments need to consider. In the face of potentially more epidemics in the future, in addition to stronger measures such as lockdowns and vaccinations, everyone should consider putting self-protection against the virus into their daily lives

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