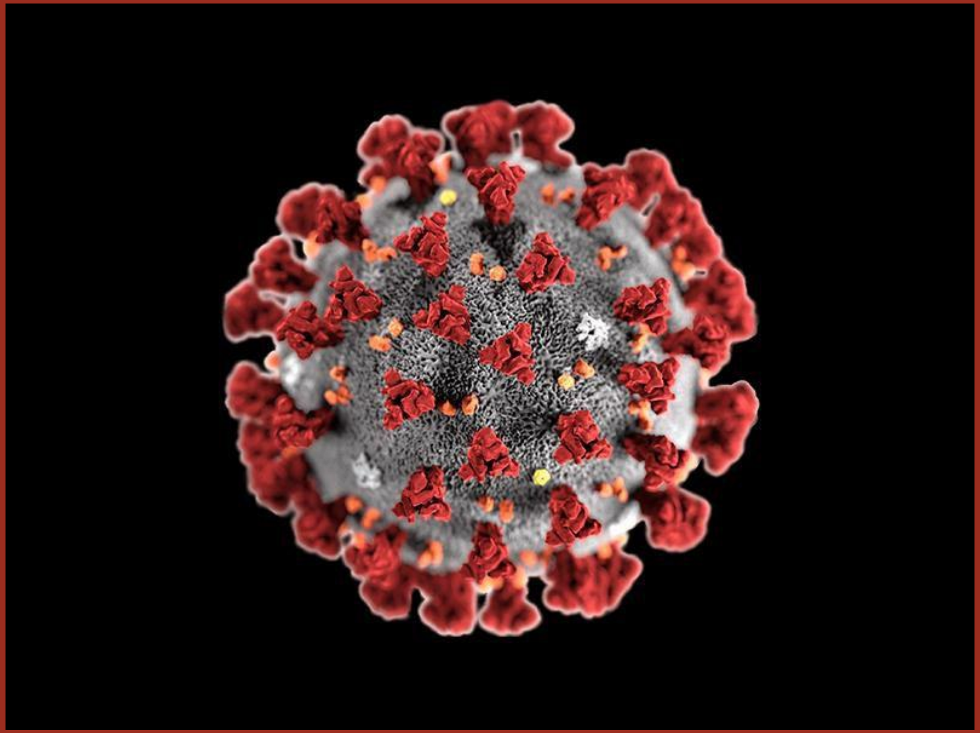


A PANDEMIC STUDY OF ***INDIA*** – AN ACTUARIAL APPROACH TO ANALYSIS

Hrishita Bapuram
Maryam Amir Ahmed
Shraddha Kodavade

Mentored by:
Prof. Akash Nakashe

OBJECTIVES

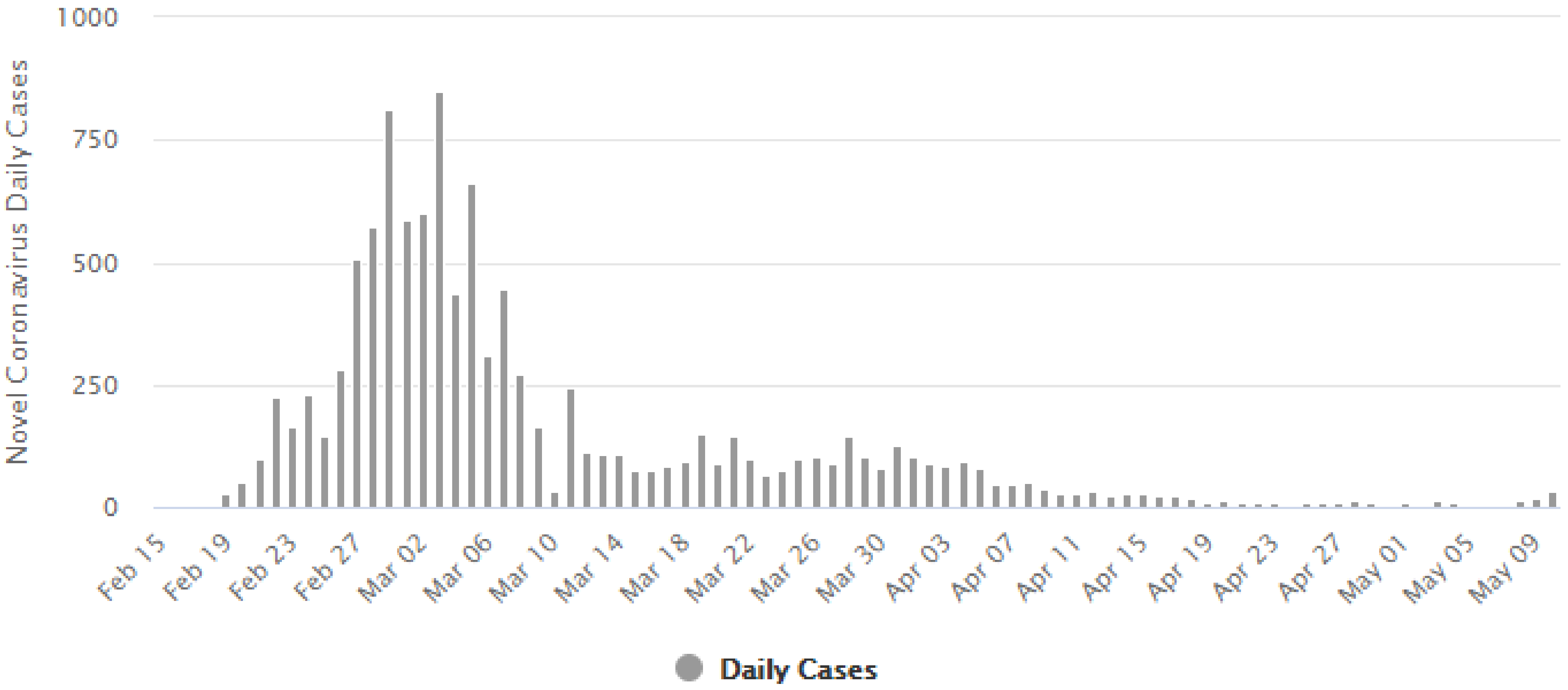
1. To analyze the existing statistical information regarding the global status and experience under different conditions throughout the Pandemic.
2. To analyze and interpret the statistical models developed for projecting COVID-19 scenario of India. (Expected number of cases, deaths, recoveries)

GLOBAL SCENARIO

We have considered five important and relevant countries

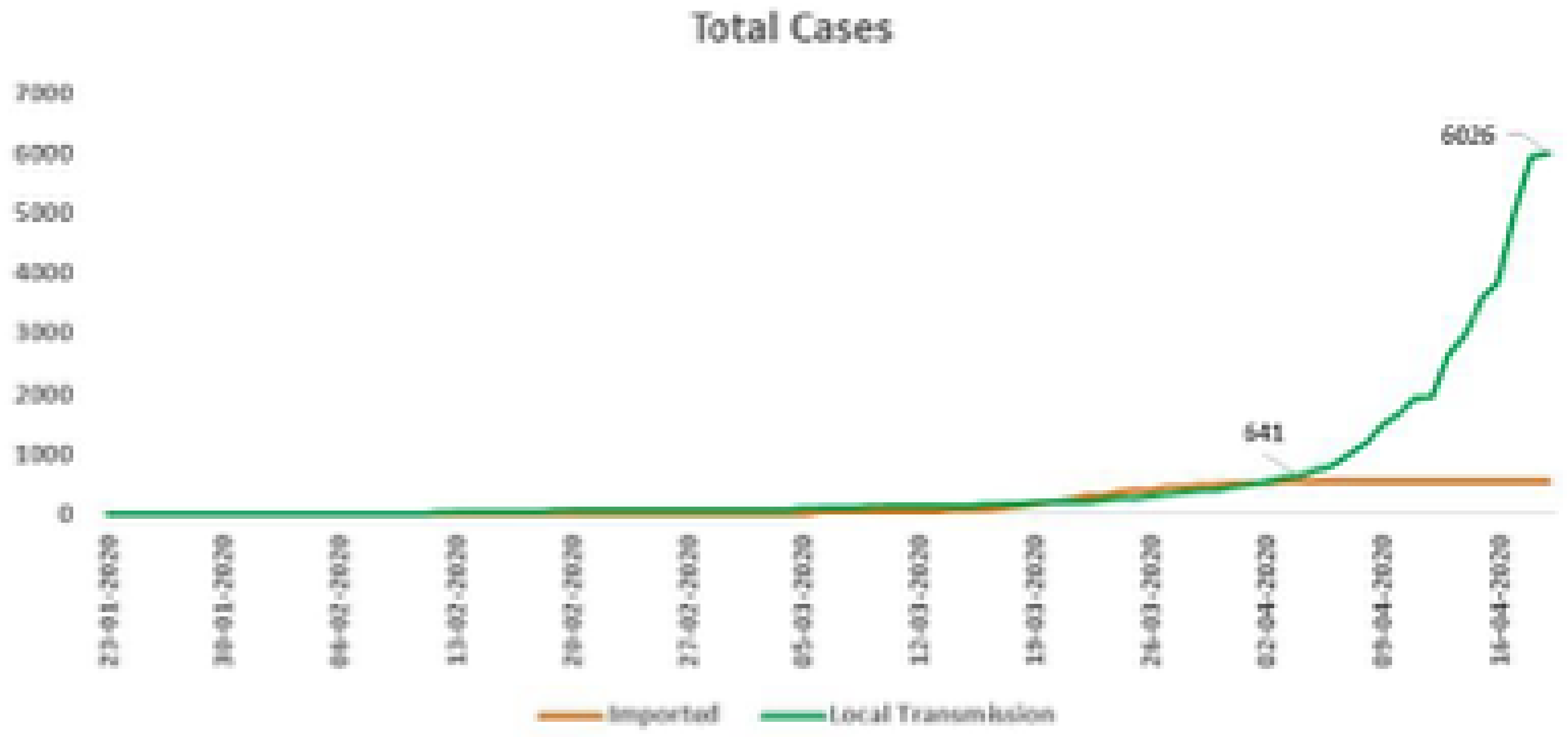
South Korea, Singapore, Italy, Germany, USA

SOUTH KOREA

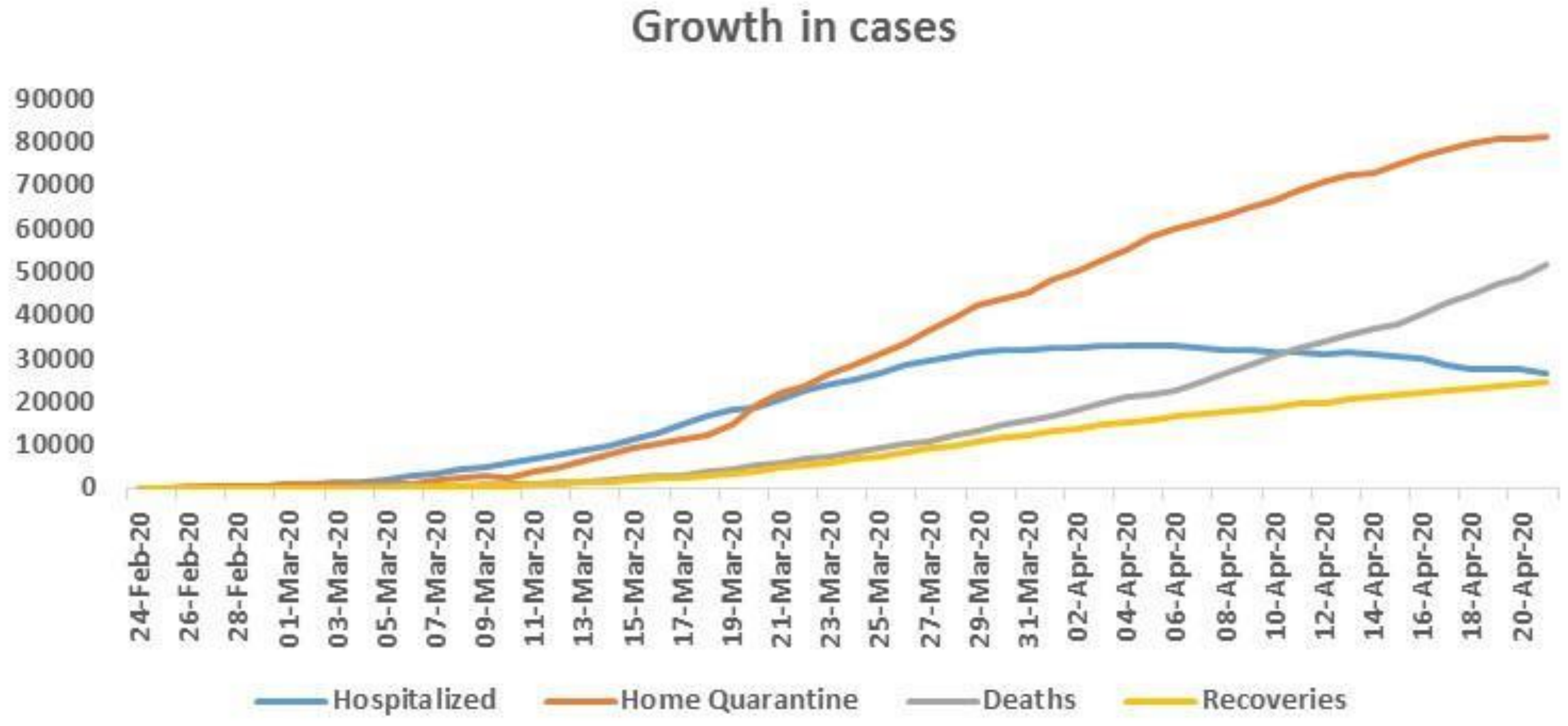


Novel Coronavirus Daily Cases
1000
750
500
250
0
Feb 15
Feb 19
Feb 23
Feb 27
Mar 02
Mar 06
Mar 10
Mar 14
Mar 18
Mar 22
Mar 26
Mar 30
Apr 03
Apr 07
Apr 11
Apr 15
Apr 19
Apr 23
Apr 27
May 01
May 05
May 09
Daily Cases

SINGAPORE

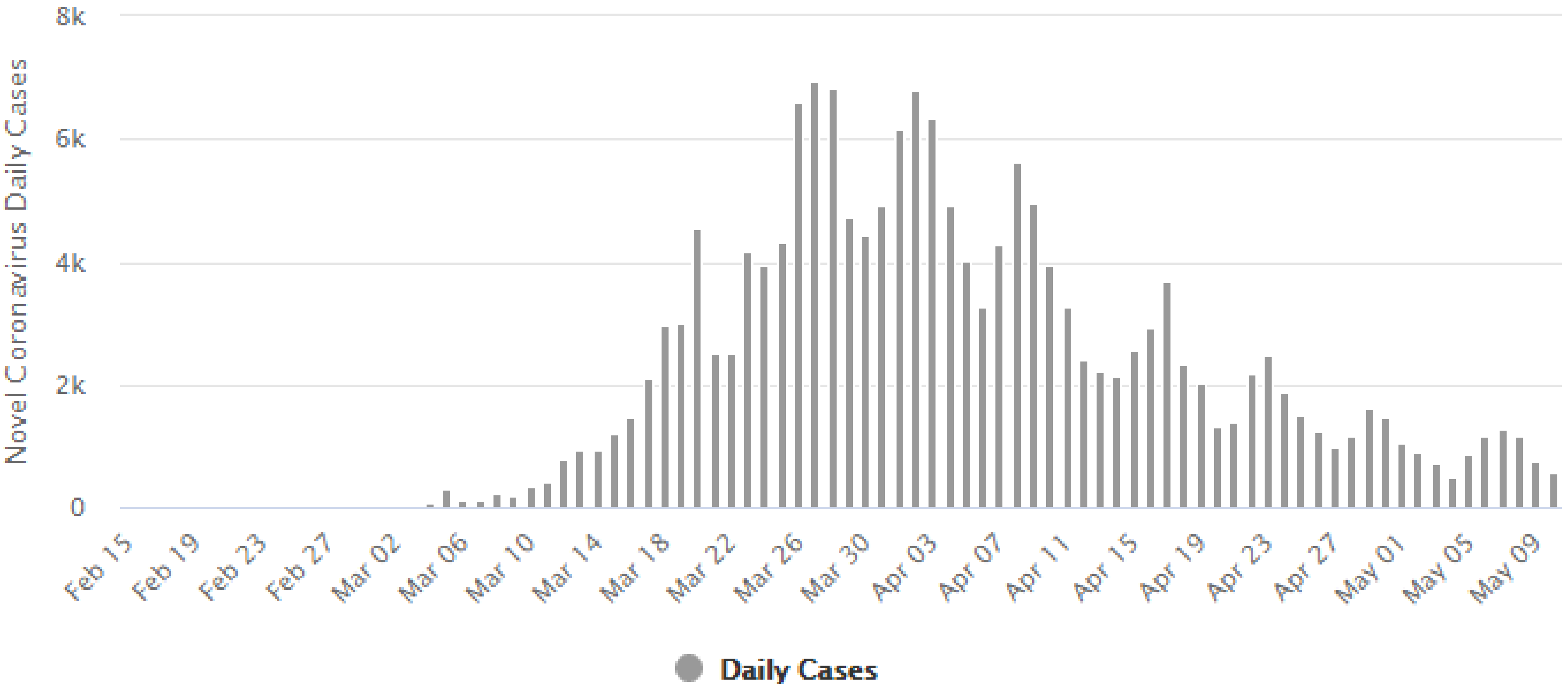

Total Cases
7000
6000
5000
4000
3000
2000
1000
0
6026
641
Imported
Local Transmission

ITALY



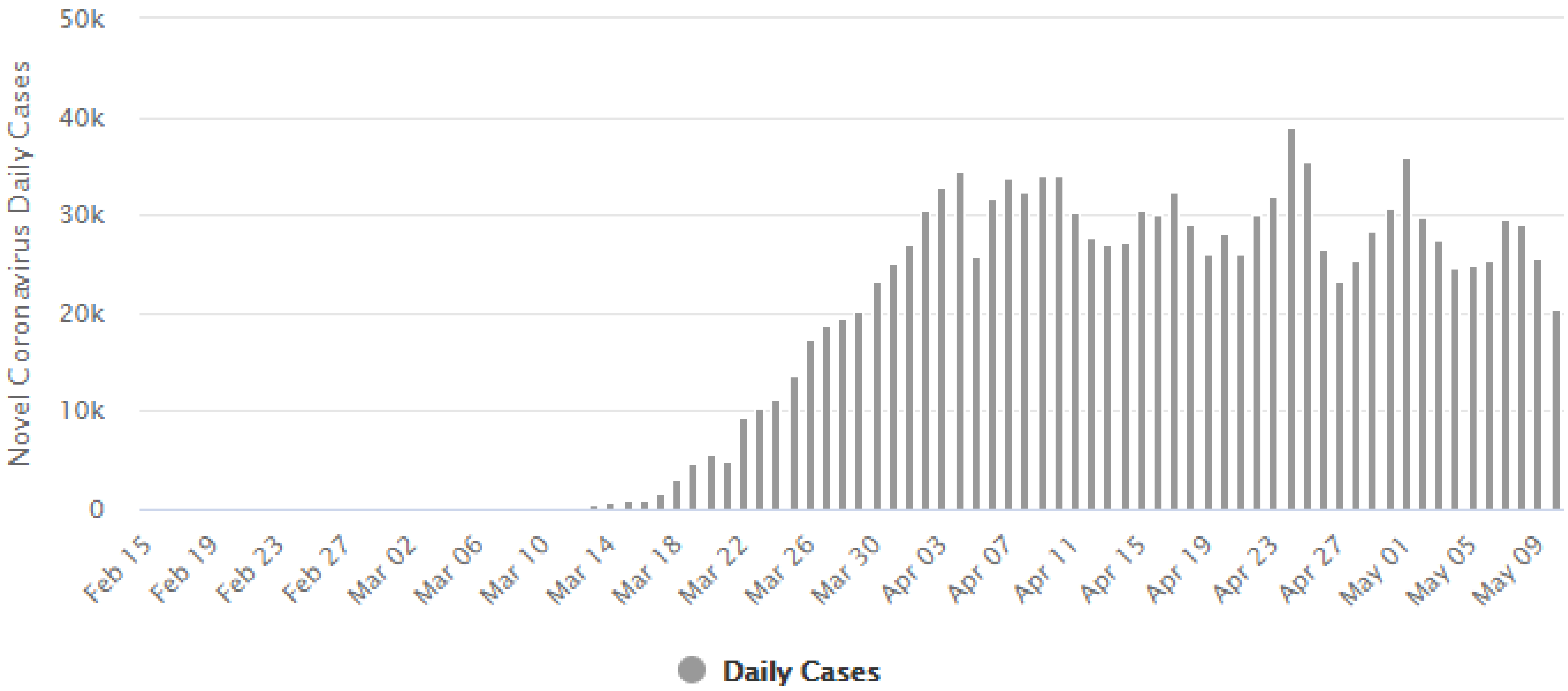
Growth in cases
90000
80000
70000
60000
50000
40000
30000
20000
10000
0
24-Feb-20
26-Feb-20
28-Feb-20
01-Mar-20
03-Mar-20
05-Mar-20
07-Mar-20
09-Mar-20
11-Mar-20
13-Mar-20
15-Mar-20
17-Mar-20
19-Mar-20
21-Mar-20
23-Mar-20
25-Mar-20
27-Mar-20
29-Mar-20
31-Mar-20
02-Apr-20
04-Apr-20
06-Apr-20
08-Apr-20
10-Apr-20
12-Apr-20
14-Apr-20
16-Apr-20
18-Apr-20
20-Apr-20
Hospitalized
Home Quarantine
Deaths
Recoveries

GERMANY



8k
6k
4k
2k
0
Novel Coronavirus Daily Cases
Feb 15
Feb 19
Feb 23
Feb 27
Mar 02
Mar 06
Mar 10
Mar 14
Mar 18
Mar 22
Mar 26
Mar 30
Apr 03
Apr 07
Apr 11
Apr 15
Apr 19
Apr 23
Apr 27
May 01
May 05
May 09
Daily Cases

USA


50k
40k
30k
20k
10k
0
Novel Coronavirus Daily Cases
Feb 15
Feb 19
Feb 23
Feb 27
Mar 02
Mar 06
Mar 10
Mar 14
Mar 18
Mar 22
Mar 26
Mar 30
Apr 03
Apr 07
Apr 11
Apr 15
Apr 19
Apr 23
Apr 27
May 01
May 05
May 09
Daily Cases

DISTRIBUTIONS USED

An Introduction

POISSON DISTRIBUTION

Poisson Distribution Formula

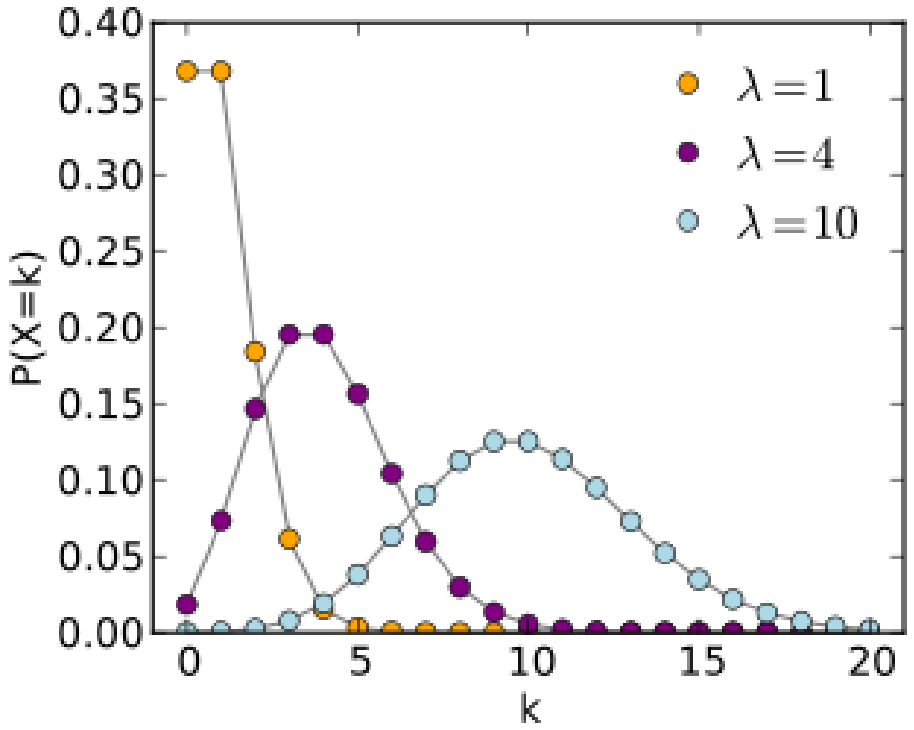
$$P(X = x) = \frac{\lambda^x e^{-\lambda}}{x!}$$

where

x = 0, 1, 2, 3, …

λ = mean number of occurrences in the interval

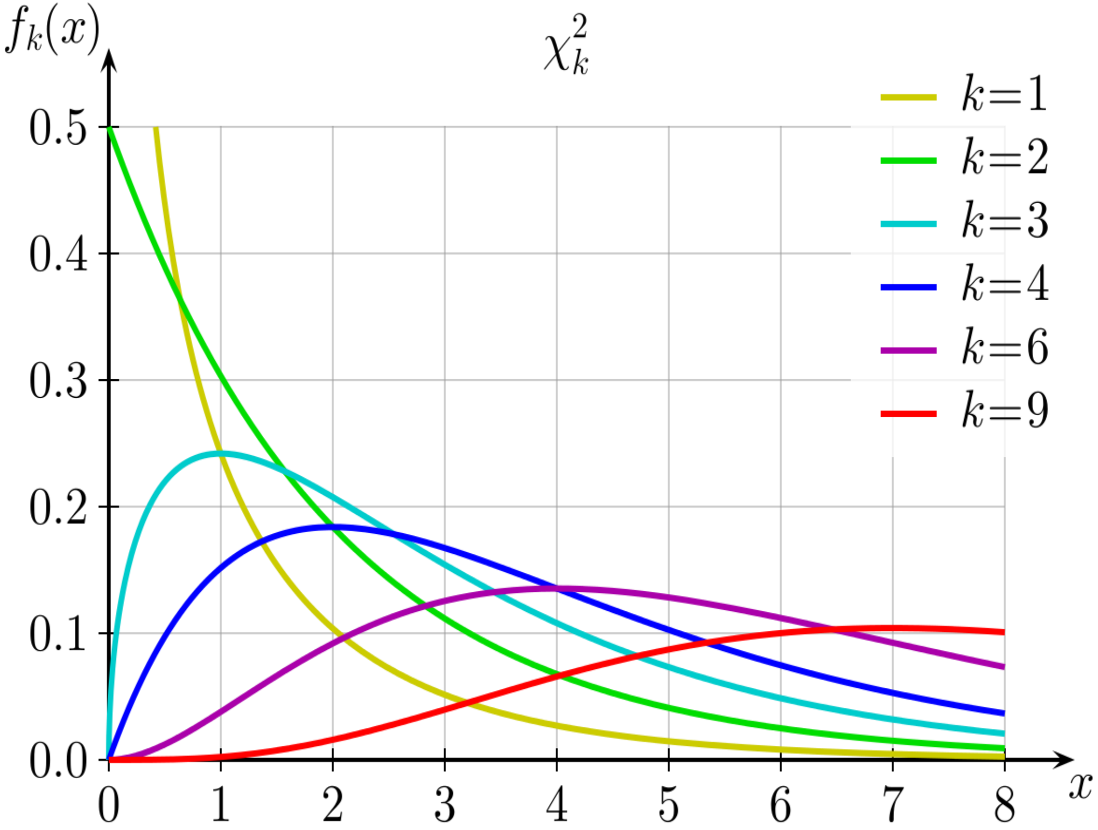
e = Euler's constant ≈ 2.71828



CHI SQUARED DISTRIBUTION

The pdf of the χ^2 distribution with k degrees of freedom:

$$f(x) = \begin{cases} \dfrac{x^{k/2-1}e^{-x/2}}{2^{k/2}\Gamma(k/2)} & \text{for } x \geq 0 \\ 0 & \text{otherwise} \end{cases}$$



HIRD MODEL

(Healthy, Infected, Recovered & Dead)

APPROACHES & ASSUMPTIONS

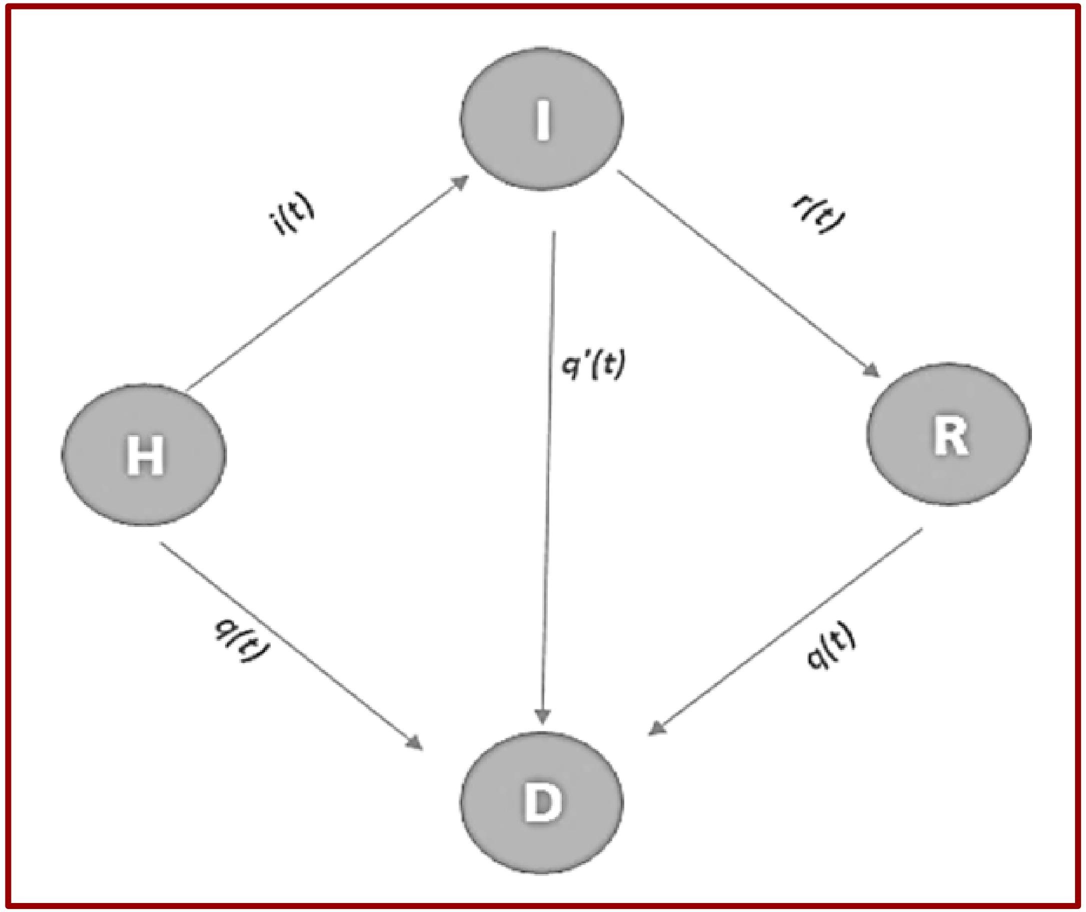
The HIRD model is a **multi-state Poisson model.**

Compared to the SEIR model, the HIRD model in addition to the total confirmed cases, also projects **expected recovery** as well as **expected deaths.**

In this model, 4 states are considered, namely:

1. ***Healthy (H)***
2. ***Infected (I)***
3. ***Recovered (R)***
4. ***Dead (D)***

STRUCTURE OF MODEL



Where,

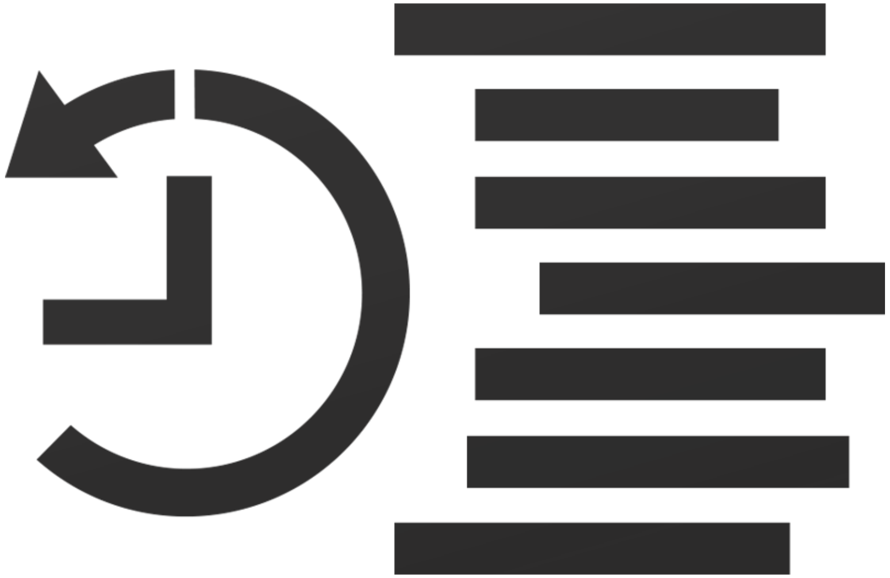
i(t) -> Probability of getting infected

r(t) -> Probability of getting cured

q(t) -> Population Mortality

q'(t) -> Case Fatality Rate (Death due to COVID 19)

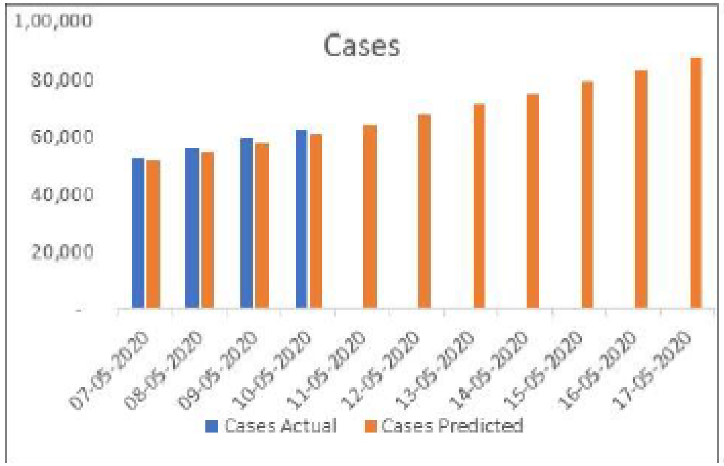
APPROACHES & ASSUMPTIONS

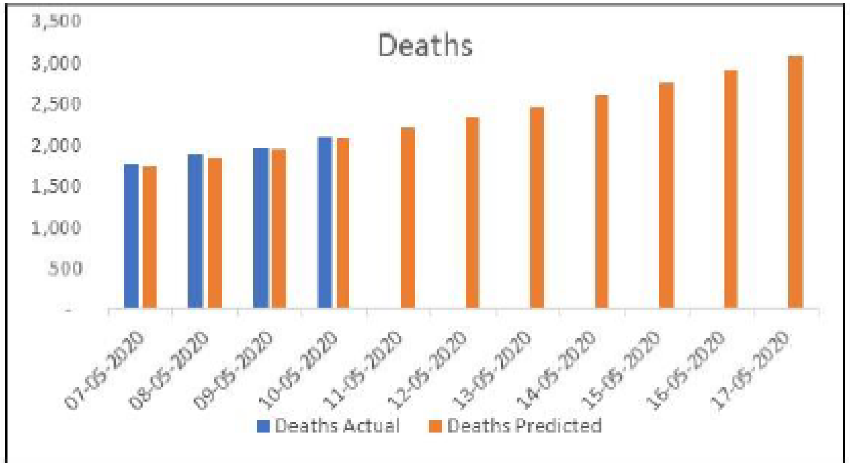


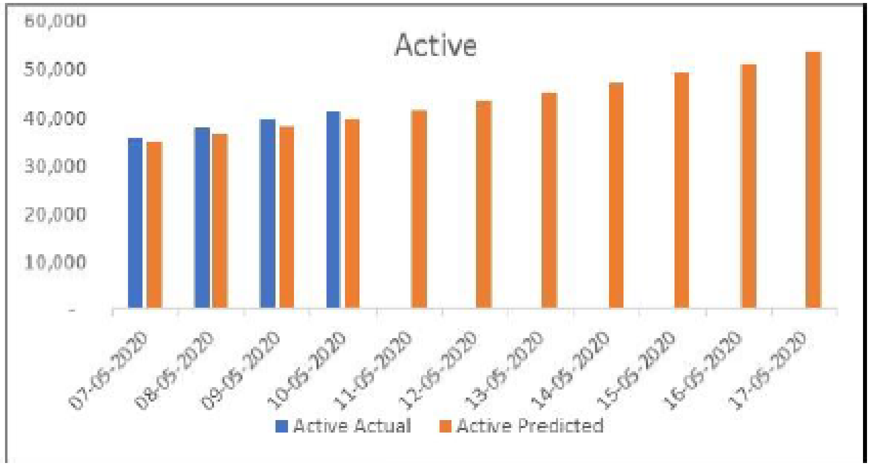
- It is a basic construct developed from an **intuitive perspective**.
- But at the same time, it is difficult to obtain the **underlying data of transition** from healthy state to infected state
- Hence there is reliance on **back testing** and **calibration**, while determining the **state transition probabilities**.
- What adds credibility to the whole process is the result of back testing that showed a remarkable accuracy.

BACKTESTING RESULTS

Projections	Date	11-May-2020		12-May-2020	13-May-2020	14-May-2020	15-May-2020	16-May-2020
		Actual	Projected	Projected	Projected	Projected	Projected	Projected
	Cases Confirmed	-	64,520	68,010	71,652	75,452	79,417	83,555
	Deaths	-	2,211	2,341	2,477	2,619	2,767	2,922
	Recoveries	-	20,692	22,242	23,858	25,545	27,305	29,141
	Active	-	41,617	43,427	45,316	47,288	49,345	51,492







CALIBRATION METHODOLOGY

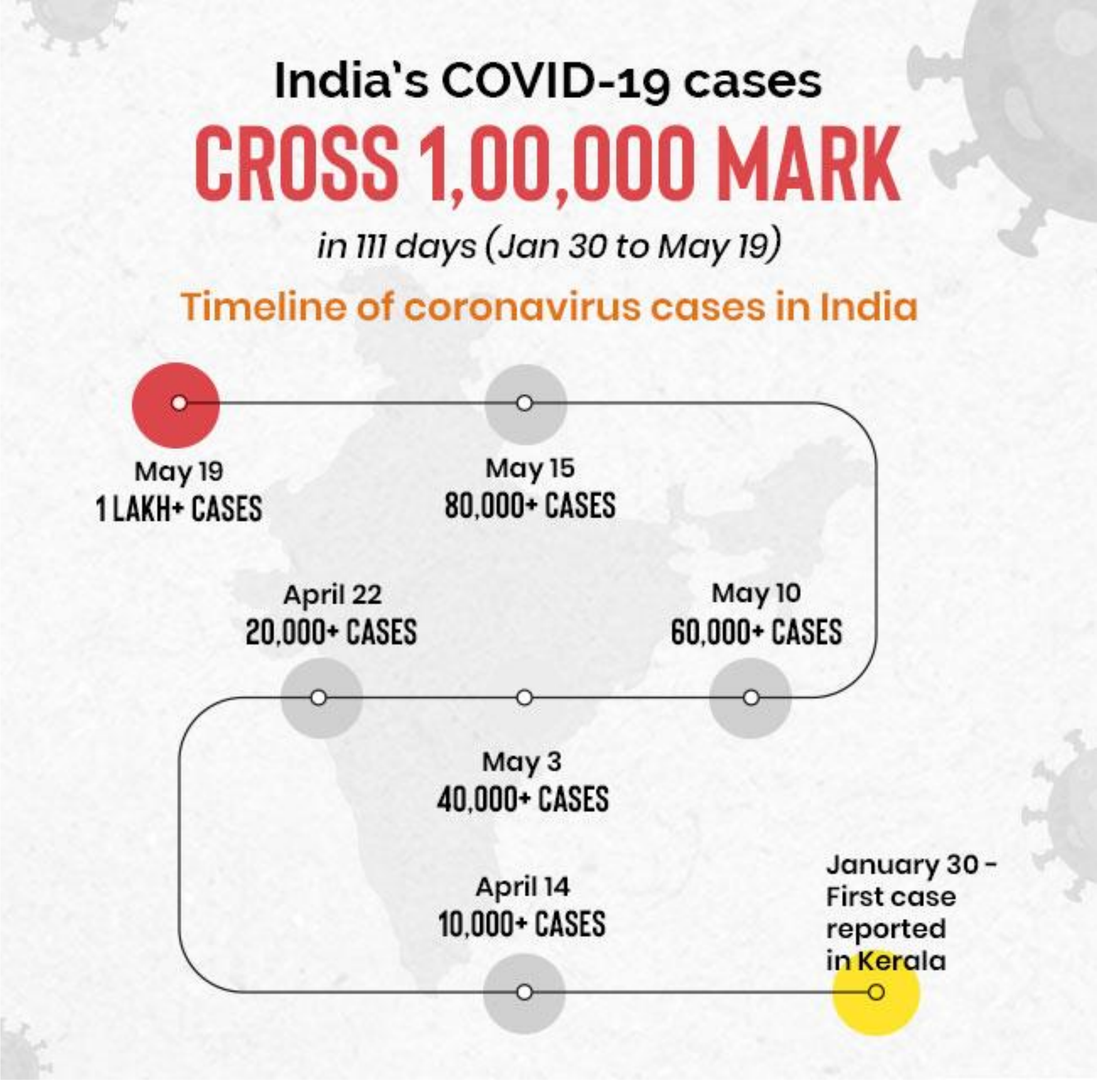
The following **assumptions were required in order to generate the results.** *Where possible, data was used to derive the assumptions.*

However, significant **actuarial judgement** was required to fine-tune and project most of the assumptions listed below.

1. *START DATE*
2. *TRANSMISSION RATE*
3. *DETECTION OF INFECTION*
4. *MORTALITY / RECOVERY*

START DATE

Although the first case in India was observed on **January 30, 2020**, for the purposes of the model, the **start is assumed from February 29**, 2020, when the **number of cases started to increase** in India.



TRANSMISSION RATE

This is the ***rate*** at which an <u>infected individual</u> could end up infecting another set of healthy individuals daily.

While this state is intuitive, <u>no direct data is available</u> to calibrate the parameters.

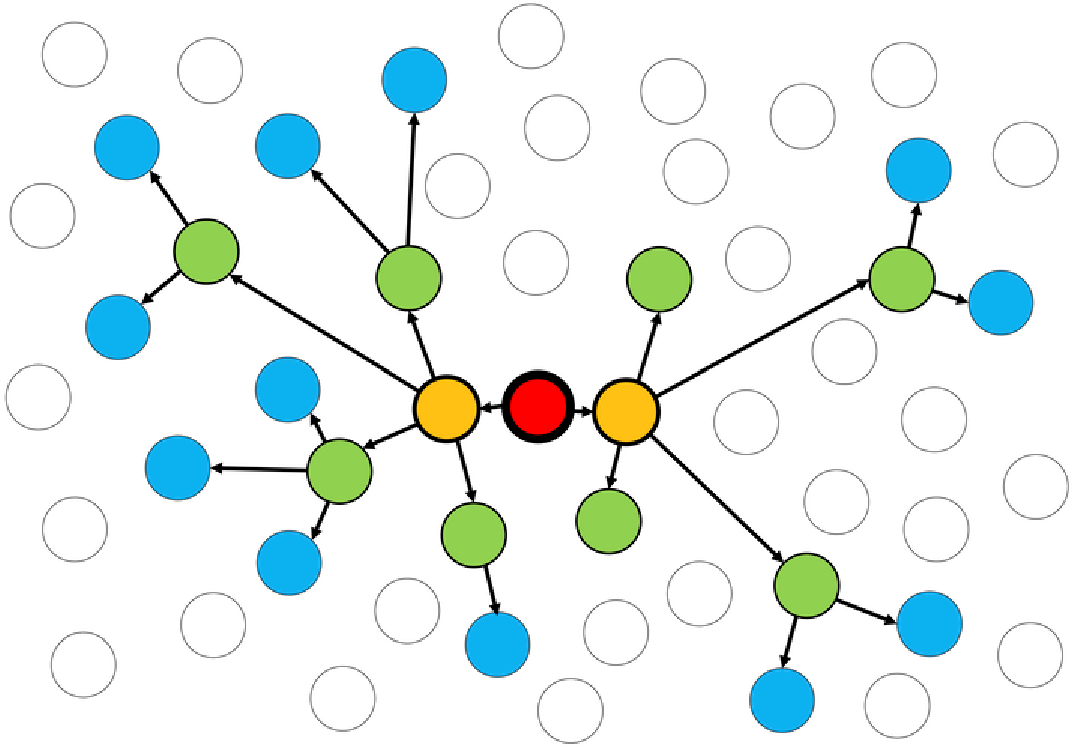
Infected (t+1) = Infected (t) * (1+ Transmission Rate (t))

TRANSMISSION RATE

However, **extraneous factors:**

- prevailing social distancing norms,
- active communication from various stakeholders,
- alertness from the government,
- lockdown measures taken, etc.

would have a **significant bearing on the rate of transmission.**



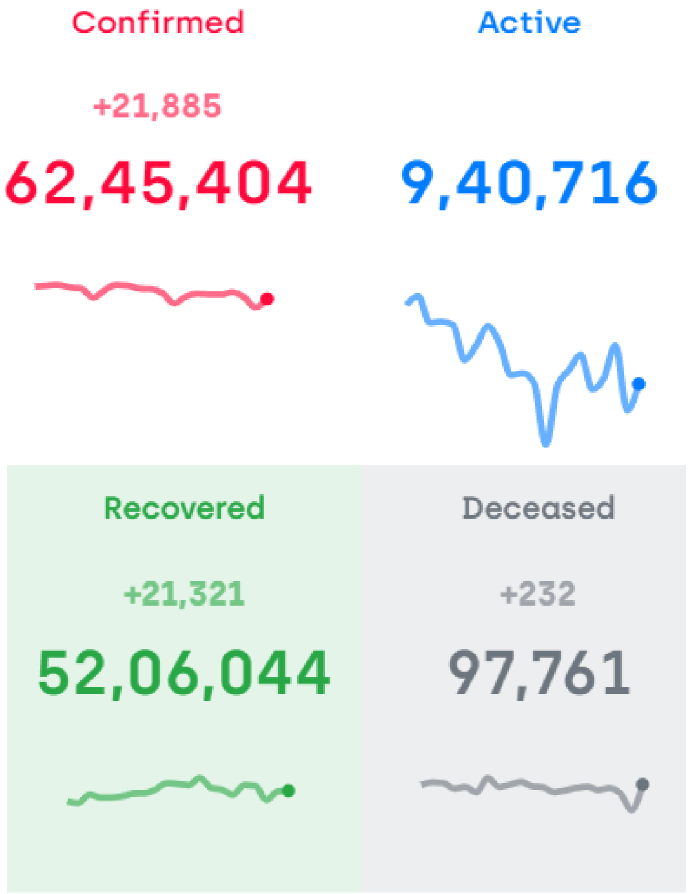
DETECTION OF INFECTION

Proportion of Asymptomatic Cases	70% of infected population
Average time for Asymptomatic Cases to stop being Infectious	Probability of being infectious after 14 days is 8%
Incubation period for the Symptomatic Lives	Poisson Distribution with mean of 5.5

MORTALITY / RECOVERY

Given limited information from our market, A ***single death rate*** is being for now.

The ***remaining lives*** are assumed to ***recover***.



PARAMETERS ESTIMATED

Transmission rates:

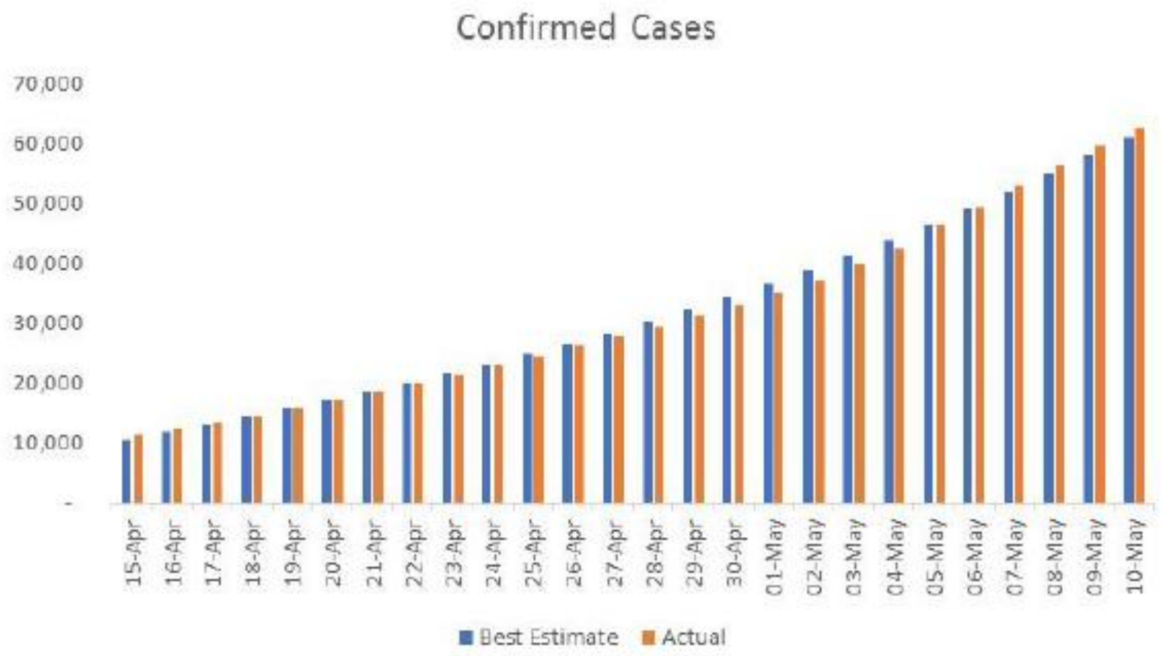
Day (from 29 February,2020)	1 - 9	10 - 24	25 - 44	45 - 63	64 - 77	17 May till end May	June '20
Best Estimate	1.737	1.291	1.178	1.132	1.132	1.120	1.100

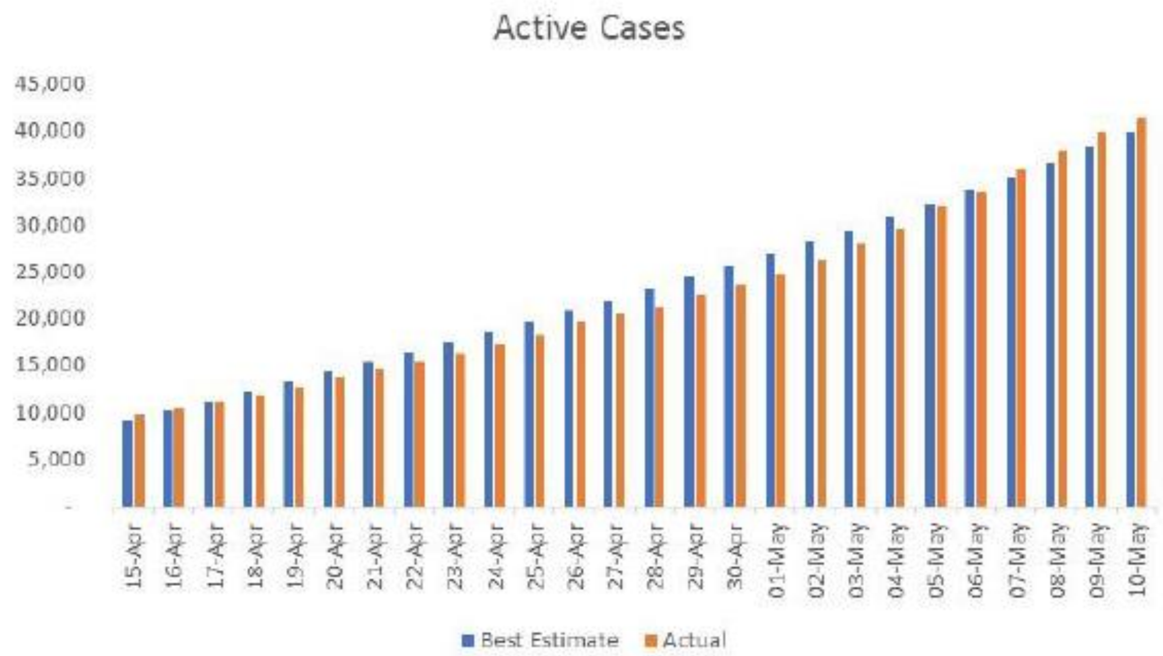
Death and Recovery Rates:

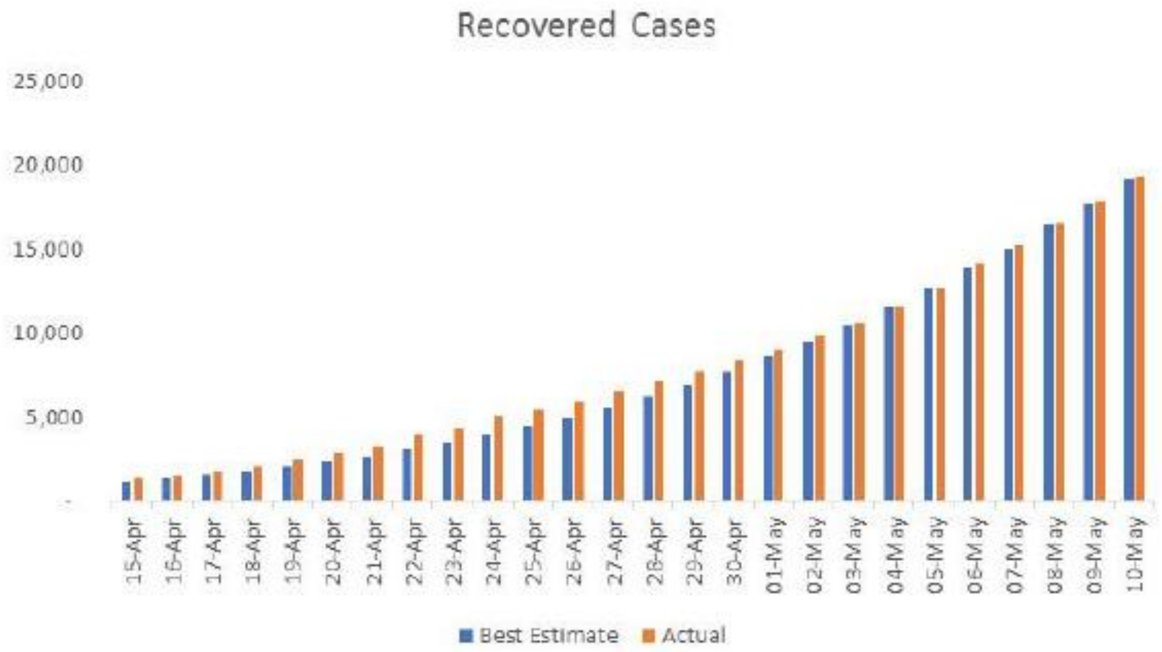
Death Rate	5%
Recovery Rate	95%

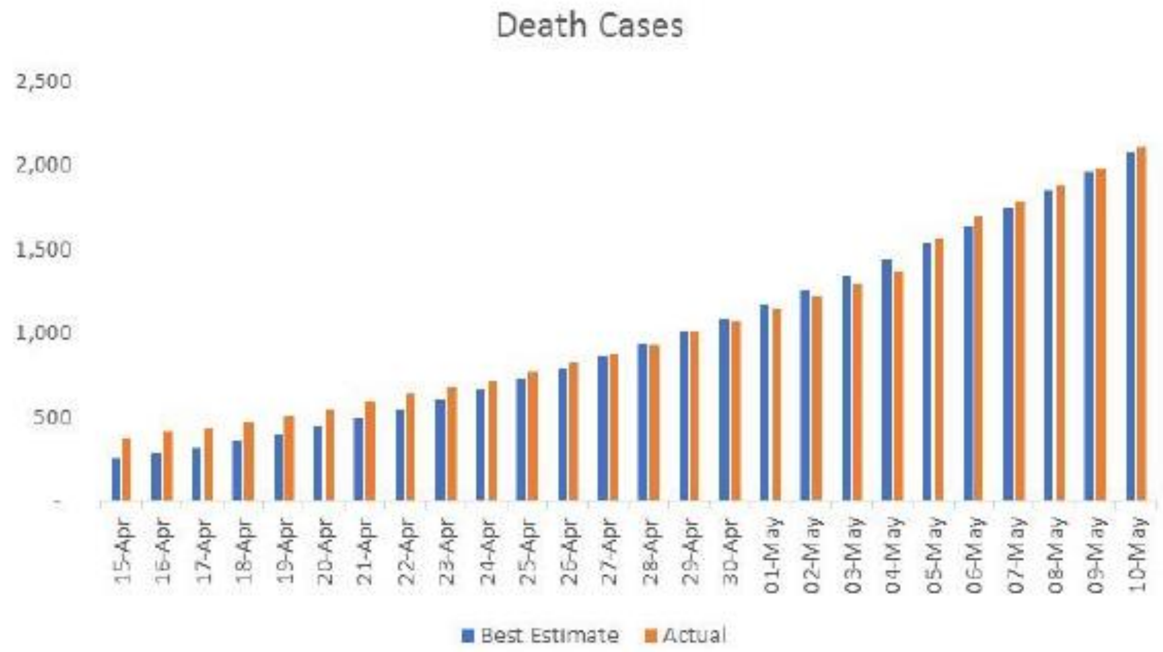
TIME-LAG DISTRIBUTIONS

- Time-lags such as Incubation Period, Time to Recovery & Time to deceased are ***not assumed to be constant.***
- Instead it was assumed that all these follow Poisson distribution with **different means.**
- All these lambda values have been derived using excel solver by minimizing the respective chi squared totals and then adjusted with the actual scenarios / numbers.
    - Recovery Period (Asymptomatic) ~ Poisson(10)
    - Incubation Period ~ Poisson (5.5)
    - Recovery Period (Symptomatic) ~ Poisson(18.25)
    - Time to Deceased ~ Poisson (7)


Confirmed Cases
70,000
60,000
50,000
40,000
30,000
20,000
10,000
-
15-Apr 16-Apr 17-Apr 18-Apr 19-Apr 20-Apr 21-Apr 22-Apr 23-Apr 24-Apr 25-Apr 26-Apr 27-Apr 28-Apr 29-Apr 30-Apr 01-May 02-May 03-May 04-May 05-May 06-May 07-May 08-May 09-May 10-May
Best Estimate
Actual


Active Cases
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
-
15-Apr 16-Apr 17-Apr 18-Apr 19-Apr 20-Apr 21-Apr 22-Apr 23-Apr 24-Apr 25-Apr 26-Apr 27-Apr 28-Apr 29-Apr 30-Apr 01-May 02-May 03-May 04-May 05-May 06-May 07-May 08-May 09-May 10-May
Best Estimate
Actual


Recovered Cases
25,000
20,000
15,000
10,000
5,000
-
15-Apr 16-Apr 17-Apr 18-Apr 19-Apr 20-Apr 21-Apr 22-Apr 23-Apr 24-Apr 25-Apr 26-Apr 27-Apr 28-Apr 29-Apr 30-Apr 01-May 02-May 03-May 04-May 05-May 06-May 07-May 08-May 09-May 10-May
Best Estimate
Actual


Death Cases
2,500
2,000
1,500
1,000
500
-
15-Apr 16-Apr 17-Apr 18-Apr 19-Apr 20-Apr 21-Apr 22-Apr 23-Apr 24-Apr 25-Apr 26-Apr 27-Apr 28-Apr 29-Apr 30-Apr 01-May 02-May 03-May 04-May 05-May 06-May 07-May 08-May 09-May 10-May
Best Estimate
Actual

SEIR MODEL

(Susceptible, Exposed, Infected & Removed)

INTRODUCTION

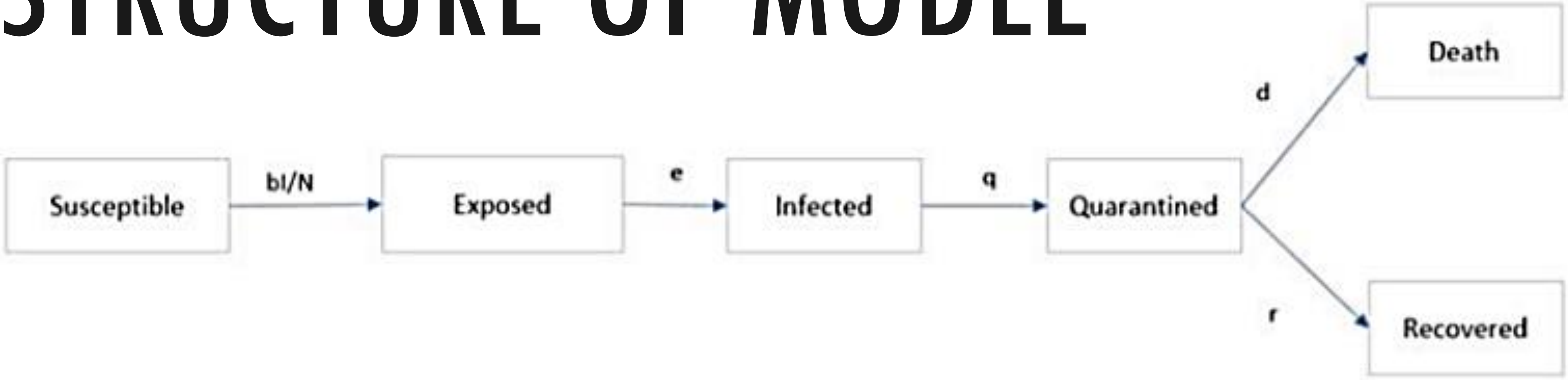
A **compartmental model** that is **a mathematical modeling** of an infectious disease, which in this case is COVID-19.

It is a multistate model which models the flows of lives between the four states mentioned. But for COVID-19, an additional state namely, **Quarantined** was also used.

<u>**IT HAS FOUR STATES, NAMELY :**</u>

i. ***Susceptible (S)***
ii. ***Exposed (E)***
iii. ***Infected (I)***
iv. ***Removed (R)***
   - ***Recovered (R)***
   - ***Death (D)***
v. ***Quarantined (Q)***

STRUCTURE OF MODEL



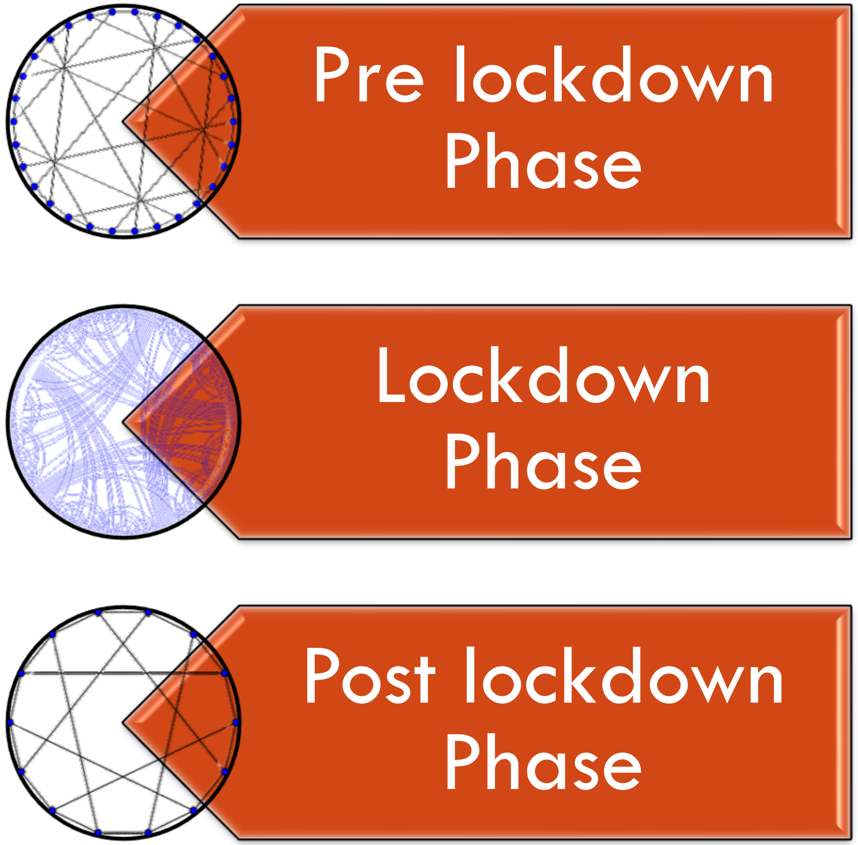
- N: total population in which the disease can spread
- S_t: Number of susceptible individuals on day t
- E_t: Number of exposed individuals on day t
- I_t: Number of infected individuals on day t
- Q_t: Number of quarantined individuals on day t
- R_t: Number of recovered individuals on day t
- D_t : Number of individuals died on day t

- b: expected number of people an infected person infects per day (R0 per day). Hence, b= number of contacts per infected person per day * probability of transmission
- e: Proportion of exposed being infectious per day, e= (1/incubation period),
- q: Proportion of infected quarantined per day. q= (1/number of days between a person getting infected and diagnosed).
- r: Proportion of quarantined recovered per day. r = (1/time to being recovered).
- d: Proportion of quarantined died per day. d = (1/time to die).
- R0: the total number of people an infected person infects. R0= b*duration of infection = b/q

KEY ASSUMPTIONS

- A person is in exposed state for the duration of **incubation period.**
- All **demographic** changes in the population (i.e., births, deaths, and ageing) are ignored.
- This is a closed system with a **constant population size.**
- As a person enters the “**Recovered**” stage, he/she cannot be under “**Susceptible**” again.
- **Exposed, Infected** and **Quarantined** migrate at a **constant rate.**

TIMEFRAME



CALIBRATION METHODOLOGY

$$S_{t+1} = S_t - \frac{bSI}{N}$$

$$E_{t+1} = E_t - \frac{bSI}{N} - eE_t$$

$$I_{t+1} = I_t - eE_t - qI_t$$

$$Q_{t+1} = Q_t + qI_t - rQ_t - dQ_t$$

$$D_{t+1} = D_t - dQ_t$$

$$R_{t+1} = R_t - rQ_t$$

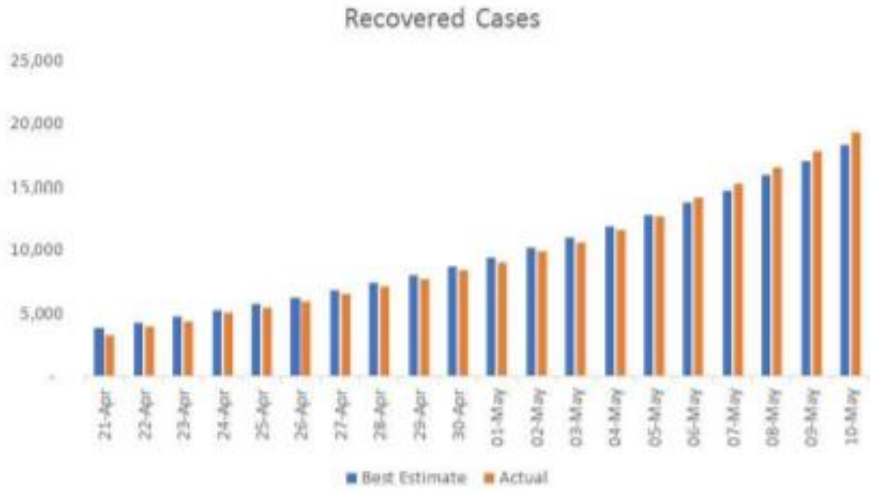
PARAMETERS ESTIMATED

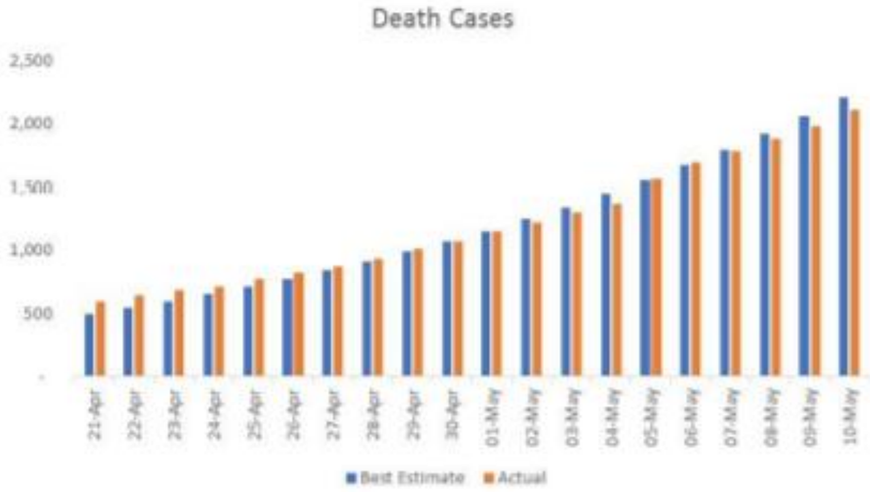
Following parameters have been estimated for the model (While estimating the parameters, it has been ensured the **Mean Absolute Percentage Error (MAPE)** is within **5%** over the modelling period)

Phase	**Pre-Lockdown**	**Lockdown**	**Post Lockdown**
Dates	30th January – 23rd March	24th March – 17th May	18th May Onwards (assumed)
Transmission rate per day	0.9	0.72	0.8
Average incubation period (days)	5	5	5
Average lag between infectious & Testing (days)	3	2	1.1
Daily recovery rate	1.43%	3.03%	3.33%
Daily death rate	0.50%	0.36%	0.29%

MODELLED VS. ACTUAL

Model was fitted using data until April 20, 2020 and was validated against the actual data until May 10, 2020. Given the validation results, model calibration seems reasonable

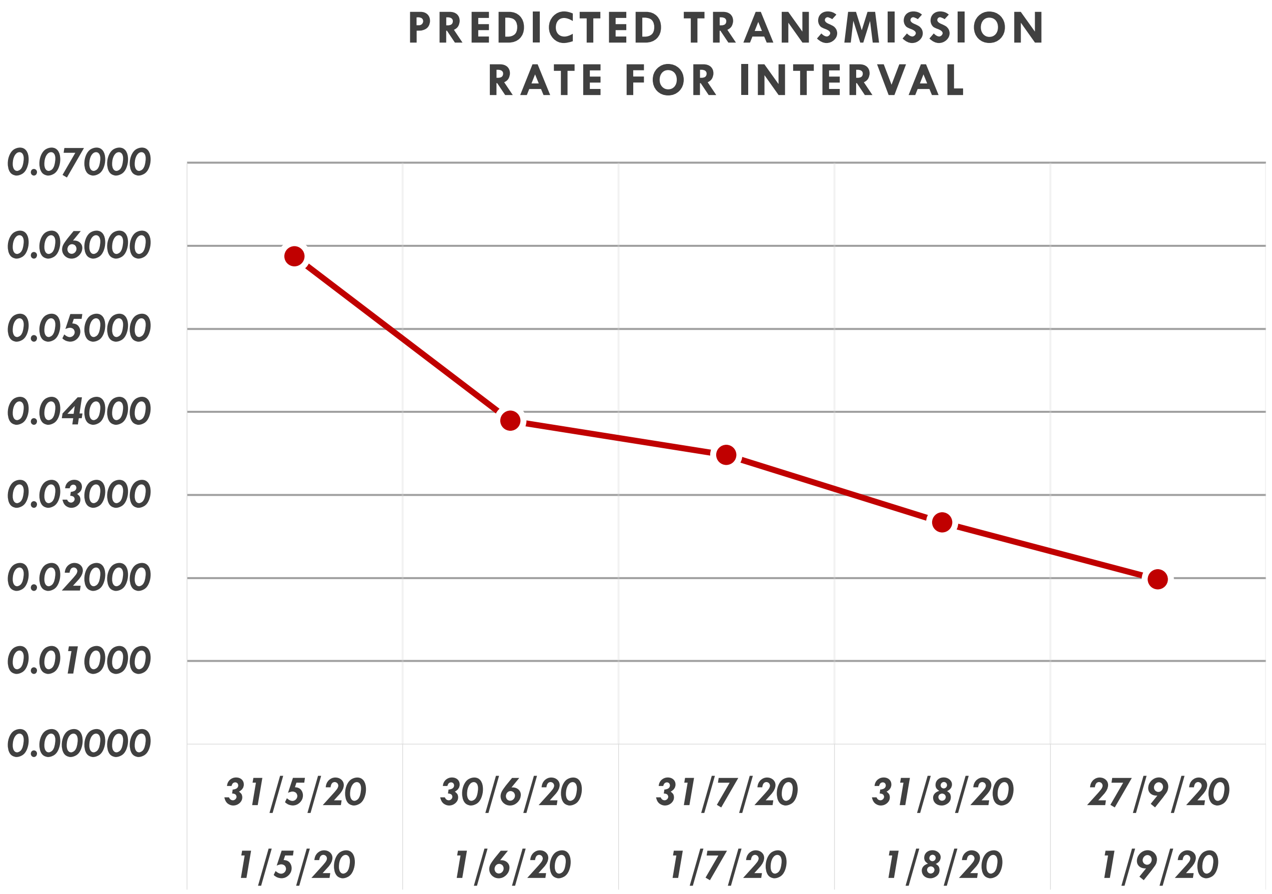


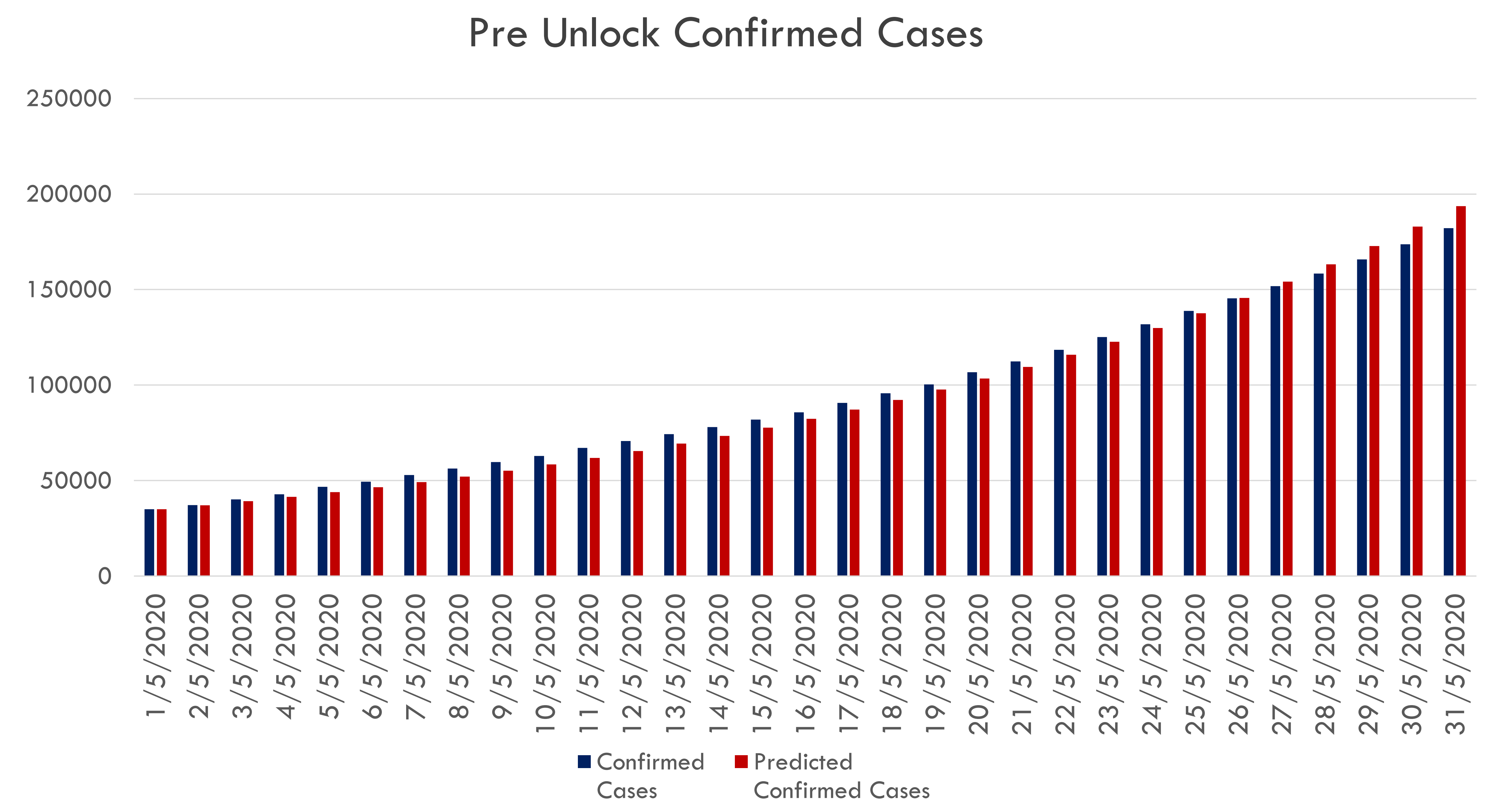


IMPLEMENTATION »

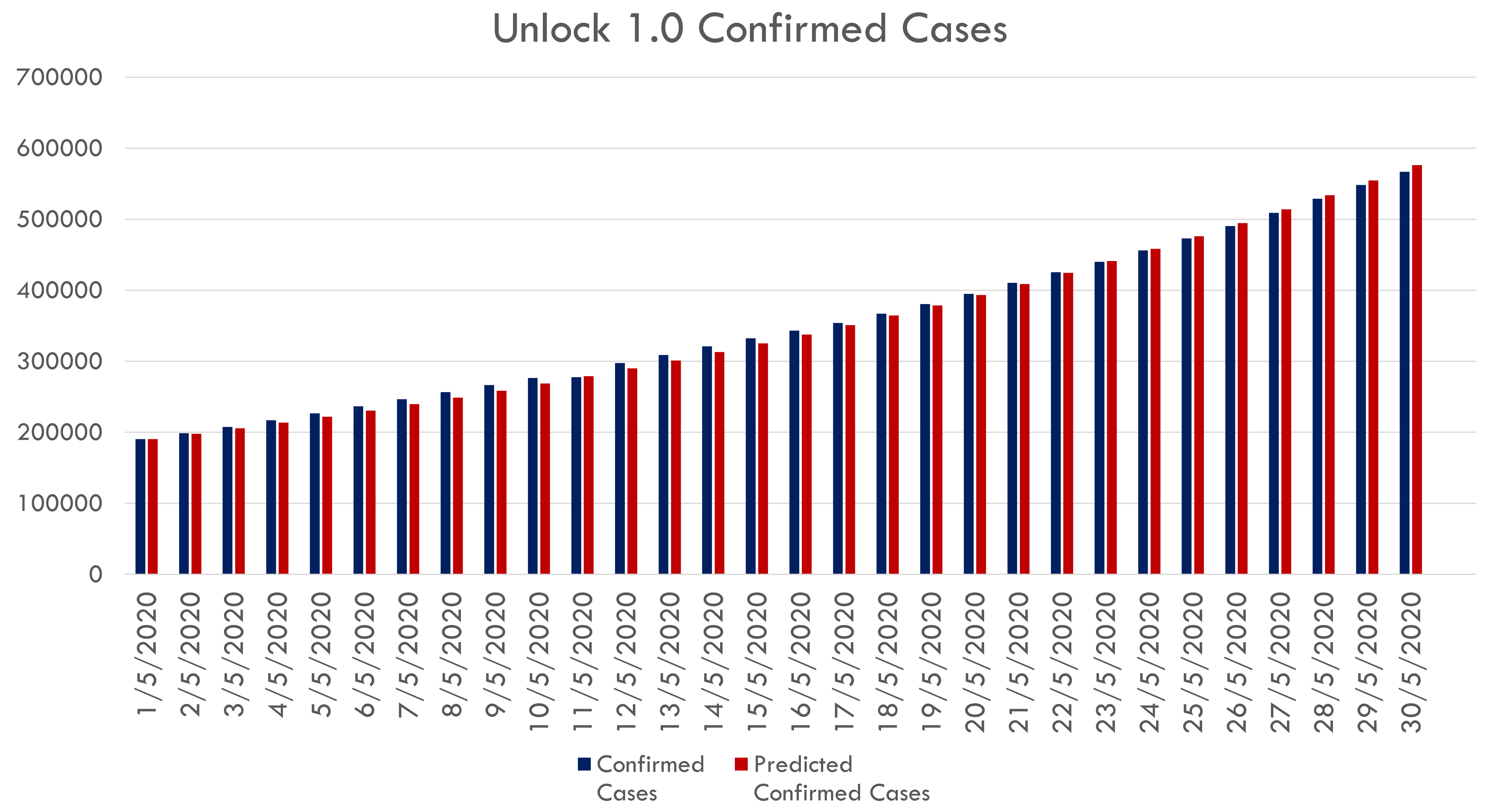
IMPLEMENTATION

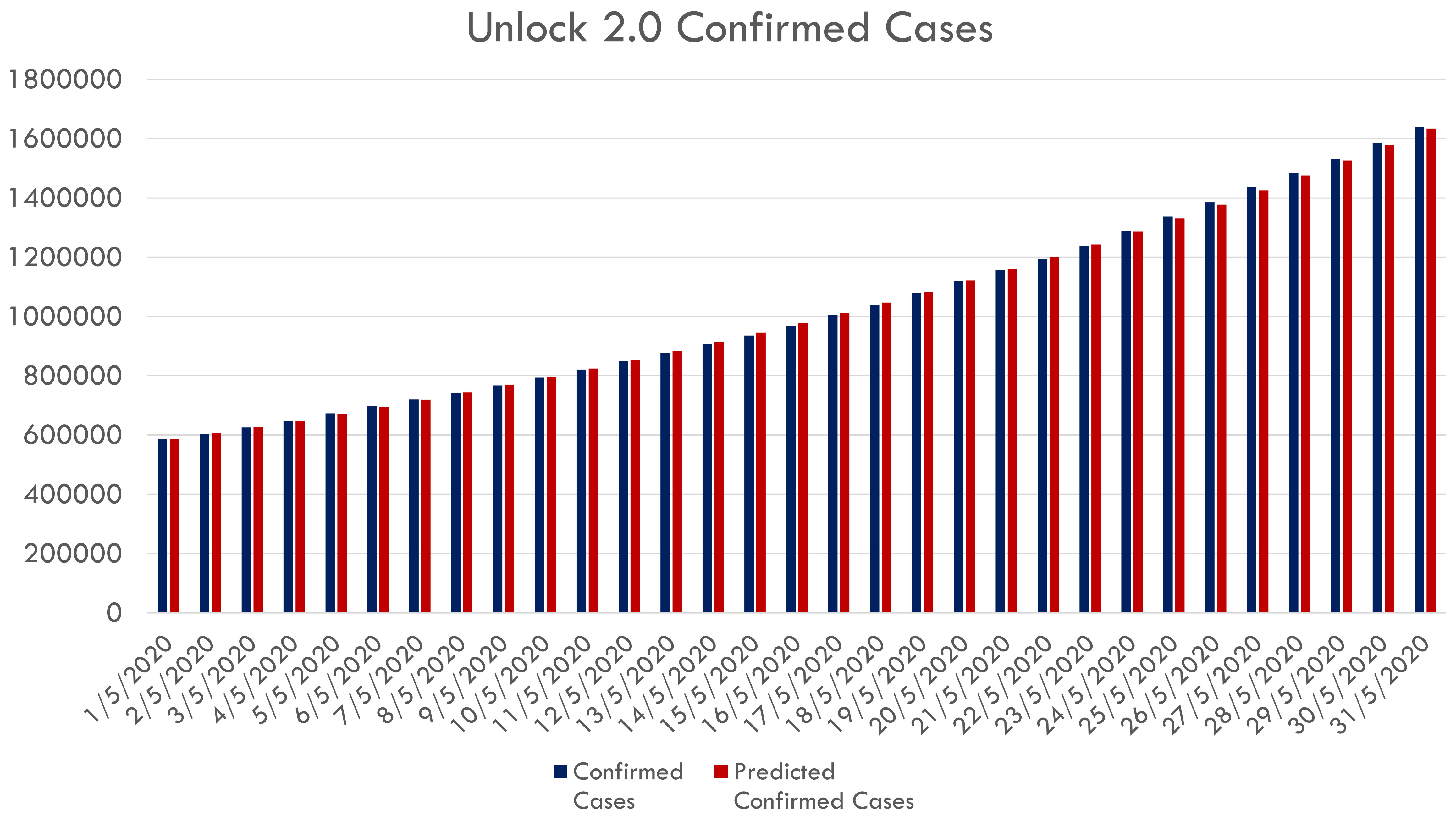
Interval Start Date	Interval End Date	Number of days	Predicted Transmission Rate for Interval
1/5/20	31/5/20	31	0.05872
1/6/20	30/6/20	30	0.03890
1/7/20	31/7/20	31	0.03481
1/8/20	31/8/20	31	0.02666
1/9/20	27/9/20	27	0.01982

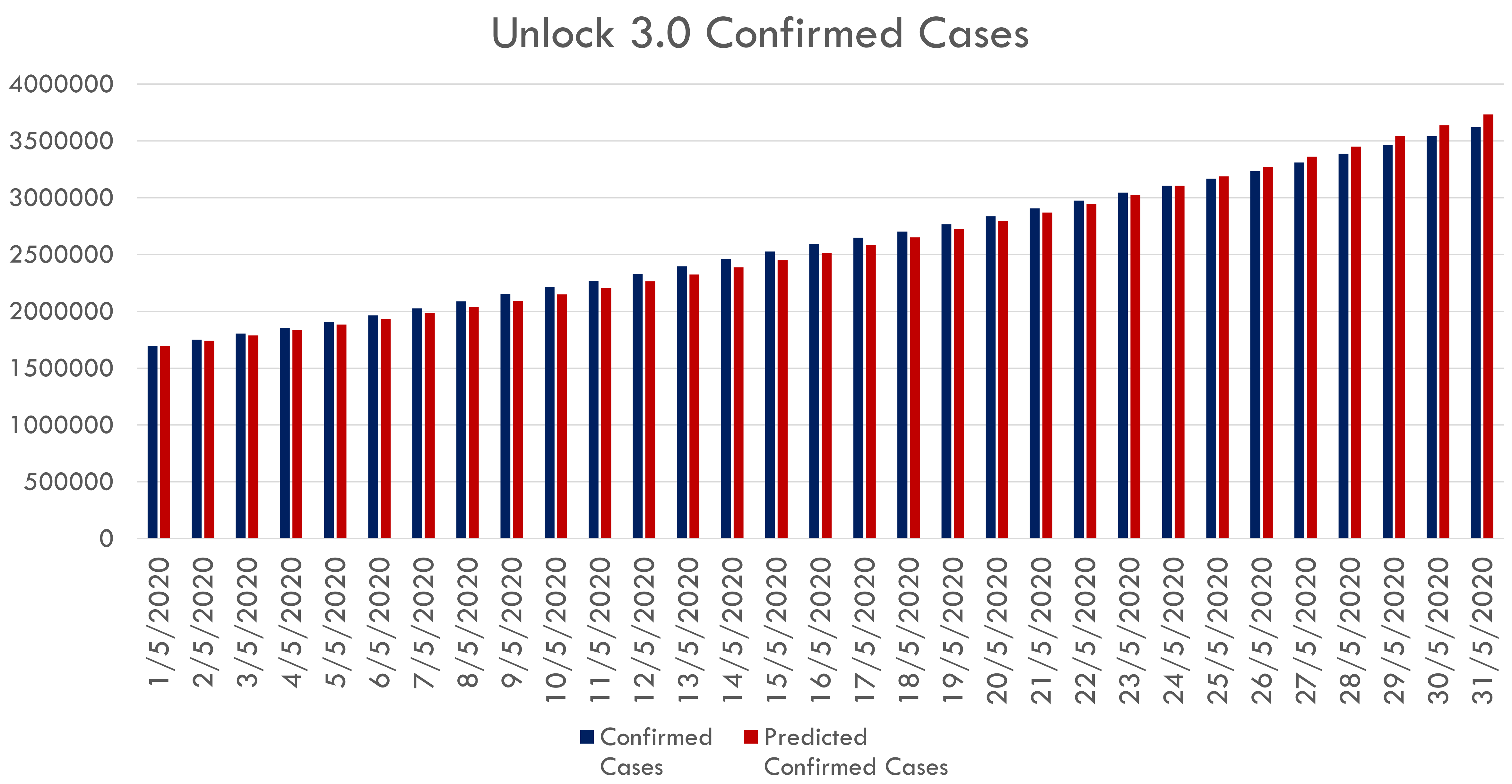


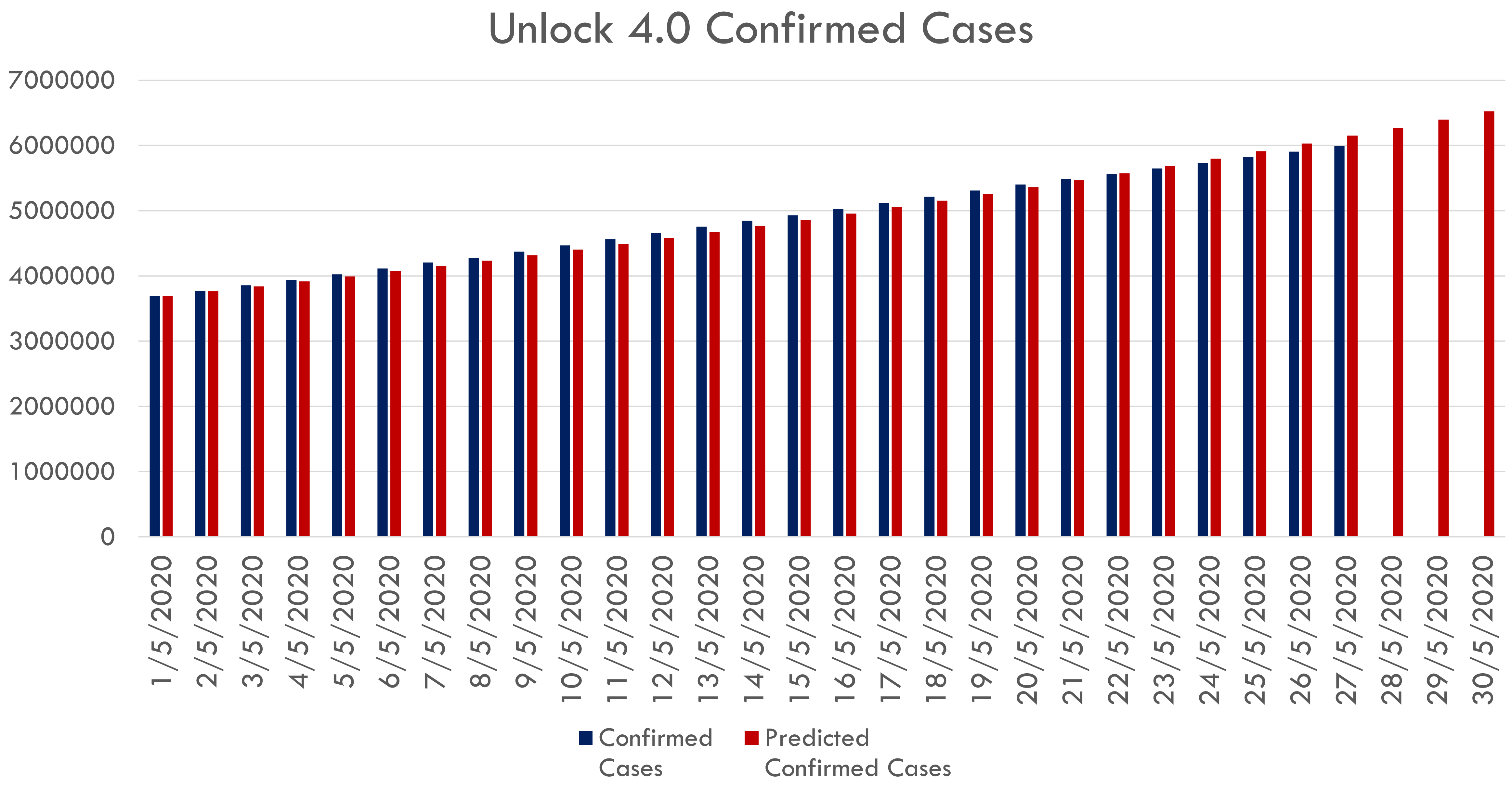


Pre Unlock Confirmed Cases
250000
200000
150000
100000
50000
0
1/5/2020
2/5/2020
3/5/2020
4/5/2020
5/5/2020
6/5/2020
7/5/2020
8/5/2020
9/5/2020
10/5/2020
11/5/2020
12/5/2020
13/5/2020
14/5/2020
15/5/2020
16/5/2020
17/5/2020
18/5/2020
19/5/2020
20/5/2020
21/5/2020
22/5/2020
23/5/2020
24/5/2020
25/5/2020
26/5/2020
27/5/2020
28/5/2020
29/5/2020
30/5/2020
31/5/2020
Confirmed Cases
Predicted Confirmed Cases


Unlock 1.0 Confirmed Cases
700000
600000
500000
400000
300000
200000
100000
0
1/5/2020
2/5/2020
3/5/2020
4/5/2020
5/5/2020
6/5/2020
7/5/2020
8/5/2020
9/5/2020
10/5/2020
11/5/2020
12/5/2020
13/5/2020
14/5/2020
15/5/2020
16/5/2020
17/5/2020
18/5/2020
19/5/2020
20/5/2020
21/5/2020
22/5/2020
23/5/2020
24/5/2020
25/5/2020
26/5/2020
27/5/2020
28/5/2020
29/5/2020
30/5/2020
Confirmed Cases
Predicted Confirmed Cases


Unlock 2.0 Confirmed Cases
1800000
1600000
1400000
1200000
1000000
800000
600000
400000
200000
0
1/5/2020
2/5/2020
3/5/2020
4/5/2020
5/5/2020
6/5/2020
7/5/2020
8/5/2020
9/5/2020
10/5/2020
11/5/2020
12/5/2020
13/5/2020
14/5/2020
15/5/2020
16/5/2020
17/5/2020
18/5/2020
19/5/2020
20/5/2020
21/5/2020
22/5/2020
23/5/2020
24/5/2020
25/5/2020
26/5/2020
27/5/2020
28/5/2020
29/5/2020
30/5/2020
31/5/2020
Confirmed Cases
Predicted Confirmed Cases


Unlock 3.0 Confirmed Cases
4000000
3500000
3000000
2500000
2000000
1500000
1000000
500000
0
1/5/2020
2/5/2020
3/5/2020
4/5/2020
5/5/2020
6/5/2020
7/5/2020
8/5/2020
9/5/2020
10/5/2020
11/5/2020
12/5/2020
13/5/2020
14/5/2020
15/5/2020
16/5/2020
17/5/2020
18/5/2020
19/5/2020
20/5/2020
21/5/2020
22/5/2020
23/5/2020
24/5/2020
25/5/2020
26/5/2020
27/5/2020
28/5/2020
29/5/2020
30/5/2020
31/5/2020
Confirmed Cases
Predicted Confirmed Cases



Unlock 4.0 Confirmed Cases
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
1/5/2020
2/5/2020
3/5/2020
4/5/2020
5/5/2020
6/5/2020
7/5/2020
8/5/2020
9/5/2020
10/5/2020
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24/5/2020
25/5/2020
26/5/2020
27/5/2020
28/5/2020
29/5/2020
30/5/2020
Confirmed Cases
Predicted Confirmed Cases

S015 | 75252019004

Hrishita Bapuram

S017 | 75252019003

Maryam Ahmad

S027 | 75252019011

Shraddha Kodavade

THANK YOU