संगणक विज्ञान एवं अभियांत्रिकी विभाग
भारतीय प्रौद्योगिकी संस्थान मुंबई
पवई, मुंबई-400 076, भारत

Department of
Computer Science and Engineering
Indian Institute of Technology Bombay
Powai, Mumbai-400 076, India

Tel : (+91-22) 2576 7901
(+91-22) 2576 7902
Fax : (+91-22) 2572 0022
Email : office@cse.iitb.ac.in
Website : www.cse.iitb.ac.in

150 YEARS OF CELEBRATING THE MAHATMA

IIT Bombay

To
Shri Lav Agarwal, IAS
Joint Secretary, Ministry of Health and Family Welfare
Govt. of India
Nirman Bhavan, New delhi 110011

15th May, 2021

Subject: Index for computation and allocation of Liquid Medical Oxygen

Dear Shri Agarwal

This is subsequent to our online meeting with the National Task Force sub-committee, in the presence of Dr. Devi Shetty and others, on Thursday, 13th May, 2021. We had presented our suggestions on the computation of demand for oxygen and the logistics of its transport.

Please find attached the concerned submission on estimating oxygen demand, prepared by me and my colleague Alakhya Deshmukh. Given the absence of reliable data, our key conclusion is:

> Rather than Active Case numbers, the Daily Death Rate (DDR) is the most reliable index to determine total resource requirement for critical patients. For computing oxygen requirement, DDR*2.2 (in MT) is a good estimate of the demand for oxygen.

Thus, for Maharashtra with a current DDR of 700 deaths needs about 1540 MT per day. In my report, I have also suggested that states may add Covid-related but those audited as non-covid deaths occurring in Covid hospitals to the above number.

I believe this norm, if conveyed to the states and made public, will incentivise more accurate reporting and lead to more realistic assessments of other resource needs as well.

Let me know if you have any questions.

Regards,

Milind Sohoni
Professor

CC: Select members of the National Task Force.

Demand indices for Covid 19 Medical Resource Allocation

Milind Sohoni, IIT Bombay
Alakhya Deshmukh
10th May, 2021
Correspondence: sohoni@iitb.ac.in
(uses data as on 30th April, 2021)

1. Introduction

India is currently going through a public health crisis arising out of the second wave of the Covid-19 pandemic. This is accompanied by an acute shortage of critical care hospital beds and oxygen supply. With limited resources, the administration needs to make optimal allocation of resources based on an estimate of the need or the true demand for the resource. One approach is to construct a regional demand index which may be used to compare competing demands and arrive at a fair allocation of a resource. The most critical one, currently, is Oxygen.

Thus, the task is essentially of creating a **demand index** which may be used across states and districts for allocation of critical resources. Moreover, this index must be based on the limited suite of data sets available in the public domain or in a processed form, to individual states.

We first look at the ICMR guidelines applied to "active patient numbers" as an index which is being used right now. We point out a crucial lacuna and suggest improvements. However, this leads us to "hospitalization number" as the next best number to base our index on. A crucial correlation between these numbers and the Daily Death Rate (DDR) is next shown. This relationship also exposes other connections between resource scarcity, denial of service and deaths. This leads us to propose the DDR as a suitable index.

Finally, we analyse the questions of under-reporting and informality and problems of access, as limitations to index-based allocations.

2. The ICMR guidelines

ICMR has come up with some guidelines for determination of Oxygen demand based on the number of active patients. This is based on the following ICMR Patient Outcome Table (Table I):

Severity	Fraction	Oxygen Demand (Liters/Minute)
Mild	80%	0
Moderate	17%	-
Needing Oxygen	8.5%	0
Not Needing Oxygen	8.5%	10
Severe	3%	24

Table I: Patient Outcomes by Severity

The above break-up of patients is assumed as the severity spread for active patients to arrive at the estimated oxygen requirement as 3.16 kgs per active patient per day. This is then used to arrive at **316 MT/day for One Lakh active patients.**

There are a few problematic points in the above ICMR guidelines. These are:

1. **Durations.** The above table is a “longitudinal” patient outcome table and does not indicate the composition of active patients. In other words, if mild patients suffer for only 3 days, while the moderate and severe patients suffer for over 15 days, then most active patients will actually be moderate or severe patients. Moreover, even within the moderate and severe class of patients, the duration of illness makes a difference in the composition of active patients and as well as those in hospital. This patient mix will impact oxygen demand.

2. **Change with time.** The above fractions have changed with time as the epidemic has progressed. In the press release of 8th May, 2021, of the total active patients in the second wave, less than 7% needed critical care.

3. **Variations in patient profile across states.** Patients take some time to report their illness to designated centers. Moreover, the protocol to be taken off the active list is different across states and across districts. Finally, the availability of hospitals may be different in many locations and this may determine the profile of active patients.

All the same, let us look at the oxygen allocation for a selected set of states, by the order of 5th May 2021, as illustrated in Table II. The first two columns A and B show this allocation. Columns C,D and E are the active patients, the allocation according to ICMR guidelines and the actual allocation rate per lakh (compare with 316 MT/Lakh). We see that most states are under-provided and Goa, Kerala and J&K are severely so.

A	B	C	D	E	F	G
State	**Allocation**	**Active (Lakh)**	**As per ICMR**	**MT/Lakh**	**DDR (7 day average)**	**MT/Death**
MH	1779	6.39	2,023	278	790	2.25
KR	965	5.17	1,636	187	272	3.55
MP	643	0.88	279	731	91	7.07
HR	267	1.15	364	232	145	1.84
PB	227	0.66	209	344	152	1.49
KL	223	3.90	1,234	57	52	4.29
RJ	395	1.98	627	199	156	2.53
AP	500	1.82	576	275	74	6.76
UK	183	0.63	199	290	113	1.62
JK	41	0.42	133	98	44	0.93
GA	26	0.29	92	90	50	0.52
PY	40	0.12	38	333	15	2.67
OD	200	0.75	237	267	13	15.38

Table II: Analysis of Allocations

3. An improved version.

A possible improvement is to include In-hospital and Out-of-hospital durations. Let us put illustrative numbers for the same as in Table III below. Having the duration of illness and the specifics of the condition allow us to compute the active patient profile, the fraction in hospital and several other quantities. We see for example, that each patient is active for 8.58 days on the average and thus, in a steady state, the number of active patients will be roughly 8.58 times the number of new infections on that day.

Condition	Fraction (%)	Illustrative Durations		Oxygen demand (Liters/Minute)	Total Active Days	%-age of Active Patients	Total Hospital Days	%-age of those hospitalized
		Out of Hospital	In Hospital					
Mild	80	**8**	**0**	0	6.4	74.6	0.00	0
Moderate/ No Oxygen	8.5	**2**	**7**	0	0.765	8.9	0.60	33
Moderate/ Oxygen	8.5	**2**	**9**	10	0.935	10.9	0.77	43
Severe	3	**2**	**14**	24	0.48	5.6	0.42	24

Table III: Duration Based Analysis

The assumed numbers for the duration of stay in hospital, may be available with ICMR or MoHFW for different states. The above table allows us to summarize several other quantities as shown in Table IV.

Attribute	**Value**
Average duration of being active for a patient	8.58 days
Average duration of hospital stay for a patient	1.78
Fraction of active patients on any day who are severe and need oxygen at 24L/min.	5.6%
Fraction of active patients on any day who are moderate and need oxygen at 10L/min.	10.9%
Hospitalized patients as a fraction of those active on any day.	20.7%
Daily Oxygen Demand for 1 lakh active patients	**491 MT**
Daily Oxygen Demand per 1 hospitalized patient	**23.6 kgs**

Table IV: Key Quantities

There are several points to note:

1. Table IV gives us both - an estimate of hospitalization numbers and its severity profile, as well as the oxygen demand.
2. The duration of various stages of the illness are crucial to the computation. Given the medical infrastructure, this may change from state to state. An important determining factor is the number of days a mild patient is active, which we have taken as 8 days. This number depends on the tracking protocol of the state.
3. Hospitalization numbers, if reliably available side-step several issues of the treatment of mild patients and therefore will lead to better estimators.

4. The Daily Death Rate

As suggested above, a more direct metric of the oxygen demand is the count X(n) of the number of people hospitalized. But these numbers are not reliably available. Typically, it is D(n), the daily death rate (DDR), which is easily available. Let us conjecture that for a given region, we have the relationship D(n)= ***a****X(n)+***b***, where ***a*** is the mortality rate. We examine this hypothesis, and a more refined relationship, later in this section.

Assuming a constant mortality fraction for a given region, we see that the number of deaths D(n) is a simple proxy for X(n) and the oxygen demand. This is illustrated in Table II. The current allocation is compared with D(n), as shown in columns F and G of Table II. We see that the allocation is between 0.52 MT/DDR for Goa and 15.38 MT/DDR for Odisha. Most are in the range 1-4 MT/DDR. Note that the current national Daily Death Rate (DDR) of about 4000 and the available LMO of 8000 MT per day gives us a comparison value of 2 MT/DDR.

This number of **2-2.2 MT/DDR** has been found satisfactory for oxygen demand in Maharashtra during non-stressed times as well. Note that it is in line with the duration-based estimation of hospitalization numbers and oxygen demand in the following sense: The disease statistics of Table IV, gives us an expected consumption of 23 kg/day for a hospitalized patient, and this with an ***a***=1/95 (or 1 death per day per 95 patients in critical care) gives us 2 MT/DDR.

Regression analysis of Hospitalization and Deaths

Let us now verify the relationship between DDR D(n) and hospitalization data X(n). Unfortunately, X(n) is not available at the MoHFW site. We use the hospitalization data, X(n) as available at the crowd-sourced covid19india.org.

Method:

Our model analyzes the association between hospitalization numbers X(n) and the number of deaths D(n) caused due to the covid-19. For this we have sourced data on (1) the number of patients hospitalized X(n) and (2) number of deaths D(n) from covid19india.org. These numbers have been accessed via a suitable api.

We analyze the relationship between the number of patients hospitalized and the number of deaths by using a Multi-parameter Regression Model.

$$D_i = \beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + C$$

where; i= observations from 10th January to 30th April 2021

D_i : Number of deaths on a given day i

X_1: Number of patients hospitalized on a given day i (in other words, X(i))

X_2: Difference in the number of patients hospitalized [$X_2 = X_{1i} - X_{1(i-1)}$]

β_0: D-intercept

β_1: Coefficient of X_1

β_2: Coefficient of X_2

X_1 is merely the sequence X, the hospitalization numbers. The use of the difference X_2 as the (backward) difference allows for “de-trending” and the dependence of D(n) on historical data.

Results:

The Table V below presents the results of our multi-parameter regression model for a selected subset of states and Mumbai. We have tested the significance of our results at a confidence interval of 95%.

States	β_0	β_1	β_2	R^2	$1/\beta_1$	$1/\beta_2$	p-value* (β_1)	p-value* (β_2)
Delhi	-4.4	0.0123	-0.015	0.89	82	-67	6.98E-54	2.09E-06
Maharashtra	-16.43	0.0078	-0.001	0.72	128	-957	1.46E-31	7.09E-01
Mumbai	-0.95	0.0076	-0.009	0.8	132	-111	7.61E-40	9.16E-27
Haryana	-0.4	0.0061	-0.0042	0.94	163	-239	1.08E-62	3.96E-03
Karnataka	-0.82	0.0063	-0.0062	0.96	158	-161	5.50E-75	2.71E-15
Kerala	13.3	0.0007	-0.00001	0.75	1382	-58276	1.49E-31	9.25E-01
Madhya Pradesh	-0.45	0.0066	-0.0111	0.97	150	-90	3.47E-85	3.04E-14
Tamil Nadu	1.19	0.0052	-0.005	0.94	191	-201	1.22E-51	6.89E-02
Uttar Pradesh	0.9	0.0065	-0.0084	0.93	155	-120	6.10E-62	1.55E-06
Gujarat	-6.16	0.0119	-0.0182	0.99	84	-55	2.64E-92	3.88E-08

*alpha= 0.05

**The p-values highlighted in green and red are observed to be statistically significant and insignificant respectively at a C.I. of 95%

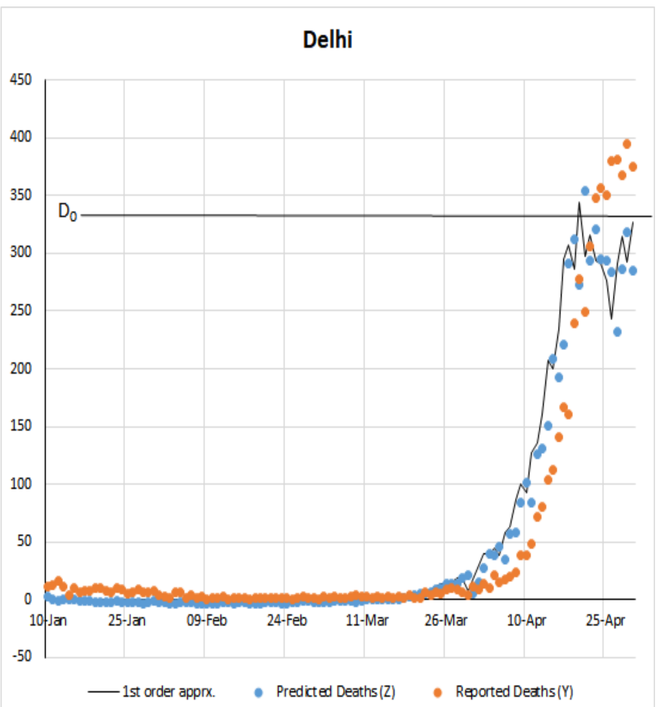
Table V: Hospitalizations and Deaths

Analysis:

We observe a strong dependence of the number of deaths that occur on (1) hospitalization numbers and (2) change in hospitalization numbers in all the regions mentioned above. A look at $1/\beta1$ values indicates out of how many patients hospitalized does 1 death occur. Delhi appears to be the worst hit of all regions with 1 death per 82 patients hospitalized, followed by Gujarat at 1 death per 84 hospitalizations. Kerala's score of 1 death per 1382 hospitalizations indicates that the state is well provisioned in terms of critical care medical facilities and that so far, it has managed the pandemic well. The mortality in other states is between 1/100 and 1/200.

A significant p-value for $\beta2$ indicates that there is a strong dependence of number of deaths on historical data of hospitalization. Its insignificance, as in Kerala, Tamil Nadu and Maharashtra, indicates negligible dependence or that the hospitalization numbers must be slow moving. Charts for Delhi are shown in Fig. 1 and Fig. 2 below. In Fig. 1, we plot the time series of D(i), the reported deaths (in orange dots), Y(i)), the prediction (in blue dots) , and the linear first order prediction as a black line. This is precisely $\beta_0 + \beta_1 X_{1i}$. which is essentially hospitalization scaled appropriately. We see that till D0=330 deaths per day, hospitalizations and deaths rose together. After D0 was breached, hospitalizations remained bounded but highly fluctuating, while deaths increased. In Fig. 2, we show the reported deaths (in orange) against the predicted deaths in blue. Again, we see that till C0, roughly the carrying capacity, deaths were lagging hospitalizations. Beyond C0, deaths and hospitalizations become uncorrelated. Thus the tuple (C0,D0) is the inherent turning point in service delivery. This phenomenon is seen in several states to different extents.

The remaining charts are presented in the Appendix. Of interest is Mumbai, where the historical dependency of deaths on hospitalization numbers clearly stand out. The severity mix within hospitalized patients has changed after April 20th, 2021 and excess deaths are observed.



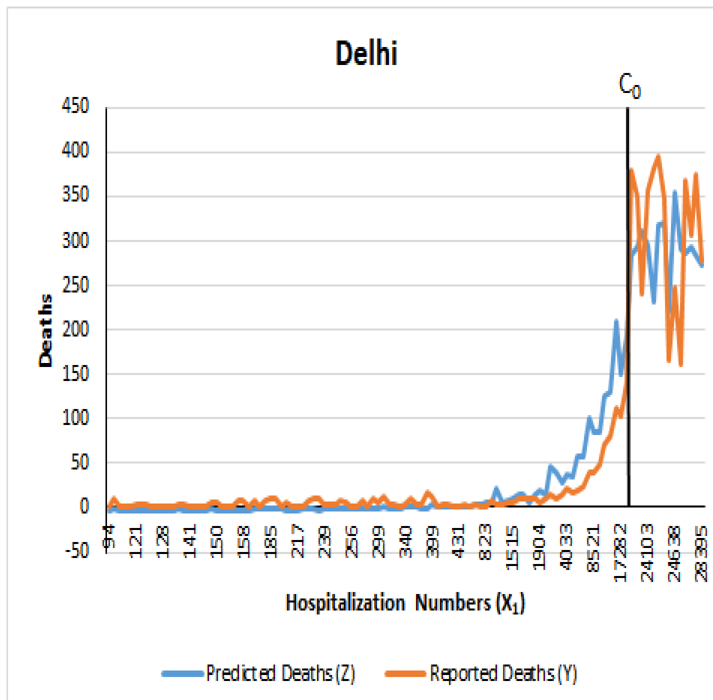


Fig. 1 Time Series, Deaths and D_0	Fig.2 Hospitalizations, Deaths and C_0

5. Limitations

There are three key limitations to index-based allocations.

Under-reporting. There is substantial under-reporting of infections and deaths and this changes from state to state, and within states too.

Informality. There is considerable informal medical care, i.e., care given by non-Covid-19 designated hospitals, and also home-care with private provisioning of medicines, and even oxygen.

Lack of Access. Finally, the medical care available may itself be limited and hence a case, even if recorded, may not translate into a demand. A crucial factor is the extent of urbanization and the availability of formal medical care.

The ICMR index and the other proposed demand indices depend crucially on reported data. This may be of confirmed cases, hospitalizations or deaths. Even in normal times, there is a great spread in registration of deaths and adherence to the standard Medical Certification of Cause of Death protocol while recording deaths. This ranges from about 35% in Maharashtra, to less than 10% in Uttar Pradesh. During the epidemic, there are substantial incentives for individuals, their families as well as state agencies to suppress Covid infection and death reports.

This has resulted in a great divergence in the reported mortality of the epidemic in India. At one end, we have Delhi with 1100 deaths per million (DPM) and Maharashtra with 662 DPM. At the other end, we have Uttar Pradesh with 74 DPM and Gujarat with 135 DPM. It is beyond the scope of this study to address this issue further, except to note that an allocation of critical resources must be based on officially measured quantities.

The second point is that private hospitals have provided much needed medical care where public health facilities were either inaccessible or unavailable. Many such hospitals may not be formally registered as Covid-19 hospitals and thus their demand for medical resources is likely to be missed. Thus, it would be useful to get their demands into official rosters. One solution is recommended below.

An important instruction has been issued in the MHA order of 24th April, where it is required for hospitals to record deaths and undertake an audit of every death. One suggestion is to use the following format of Table VI to collect weekly occupancy and cause of death data for all the critical care beds in all hospitals in a district or a city:

Weekly Data for 26th April-2nd May, 2021 District:XX						
	Hospital Name	Critical Care Beds	Occupancy	Covid Deaths	Non Covid Deaths	Oxygen consumed (MT)
1.	H1	100	650	10	2	20
2.	H2	400	2350	12	0	35
3.	H3	500	3200	35	4	90

Table VI: Hospital Data Format

By MHA orders, part of the above data should be publicly available on the city or district dashboard. Thus, collection of such data and its dissemination will help patients make informed choices and also district and state administration to plan on resources.

Finally, coming to the question of access, it is likely that many patients do not access the formal health care system at all. It is assumed that such consumption of medical resources is small as compared to the total of official and private but unofficial or informal consumption.

Conclusions

1. Hospitalization numbers X(n) and severity profile within this set, are closest to the problem of estimation and allocation of oxygen and other medical resources. These are available in some form on covid19india.org. Better and more refined numbers with better granularity may be available with ICMR or MoHFW. They will provide the best estimates of demand.

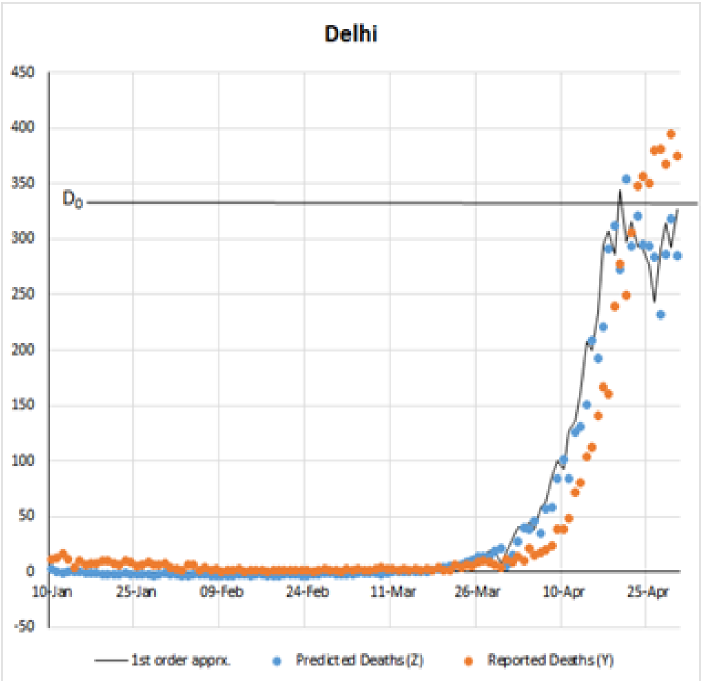
2. There is an inherent limitation to using active cases numbers to estimate the severity mix within hospitalization numbers, and therefore to estimate demand.

3. The Daily Death Rate (DDR) is strongly correlated with the hospitalization number in a linear manner. To be precise, DDR(n)=***a****X(n) + ***b*** where the number M=1/***a*** is the critical care mortality multiplier, a number with clear significance for the public at large. In other words, 1-in-M deaths are observed per day from within hospitals. However, this M depends on the state and varies from 82 for Delhi to 1382 for Kerala. Thus the severity with the hospital varies greatly across states.

4. The quantity DDR(n), the daily death rate, is the most reliable index to determine total resource requirement. For computing oxygen requirement, DDR*2.2 (in MT) is a good estimate of the demand for oxygen.

5. The use of a transparent index may lead to gaming of the index by states. However, the cost of reporting excess new infections, hospitalizations or deaths in terms of public perception is likely to discourage over-reporting. On the other hand, the fact that under-reporting has costs in terms of allocations, may persuade states to report approximately correct numbers. This should be encouraged. This will substantially help planning.

Appendix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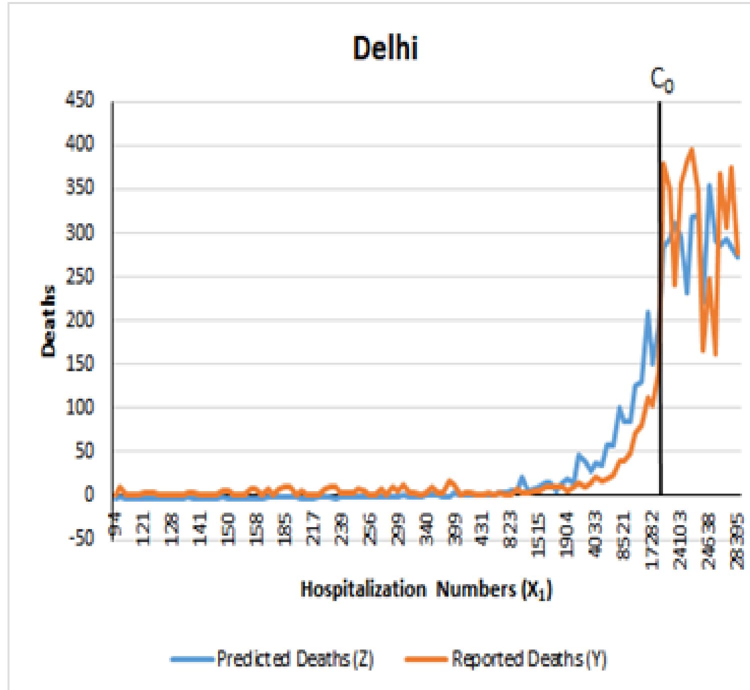
Reported Deaths (Y)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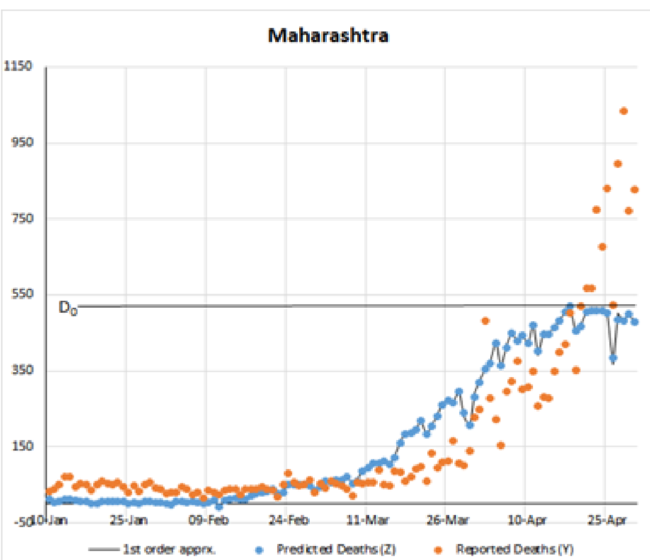
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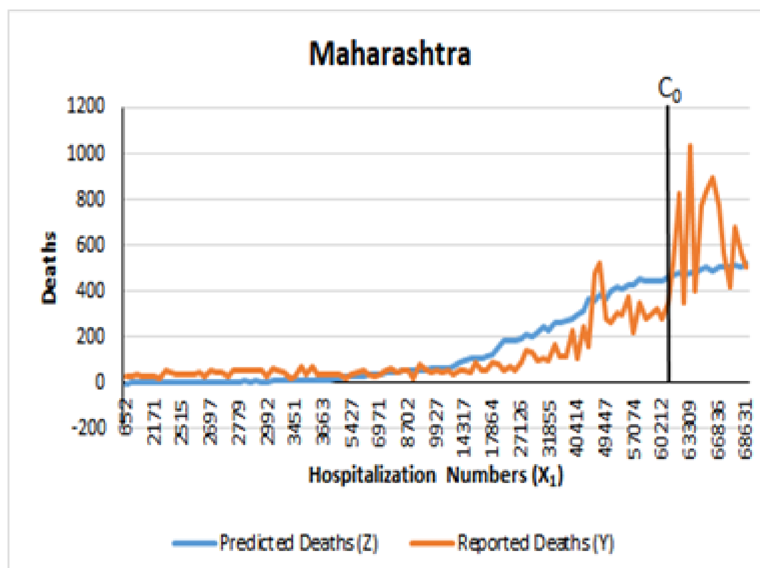
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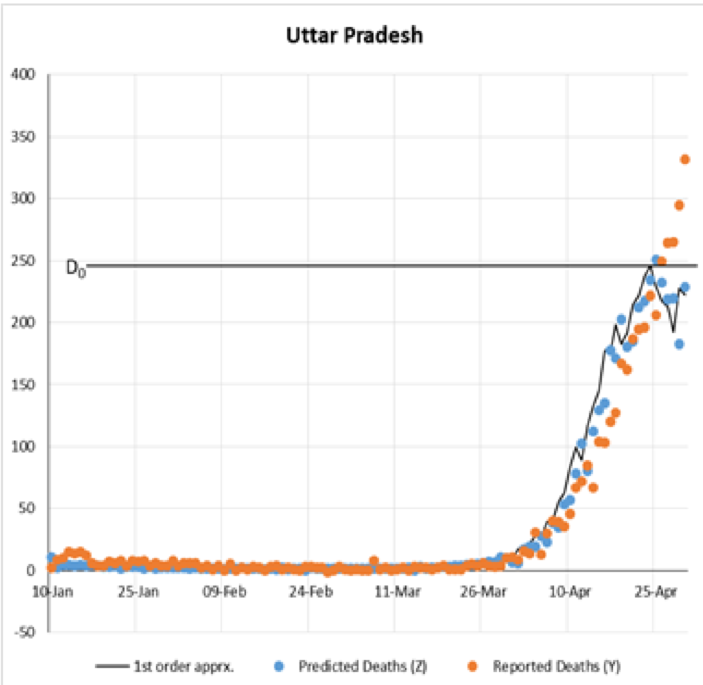
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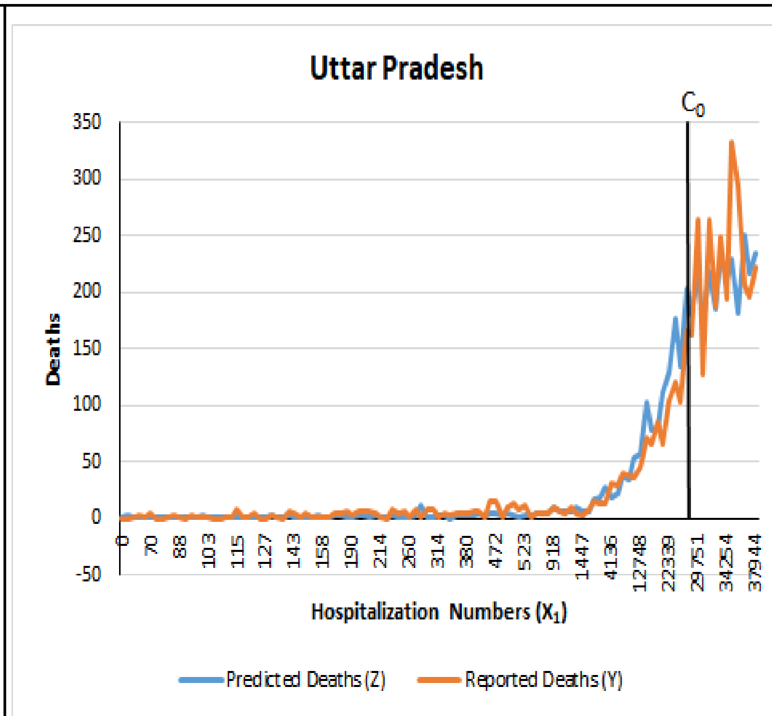
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Hospitalization Numbers (X_1)
Predicted Deaths (Z)
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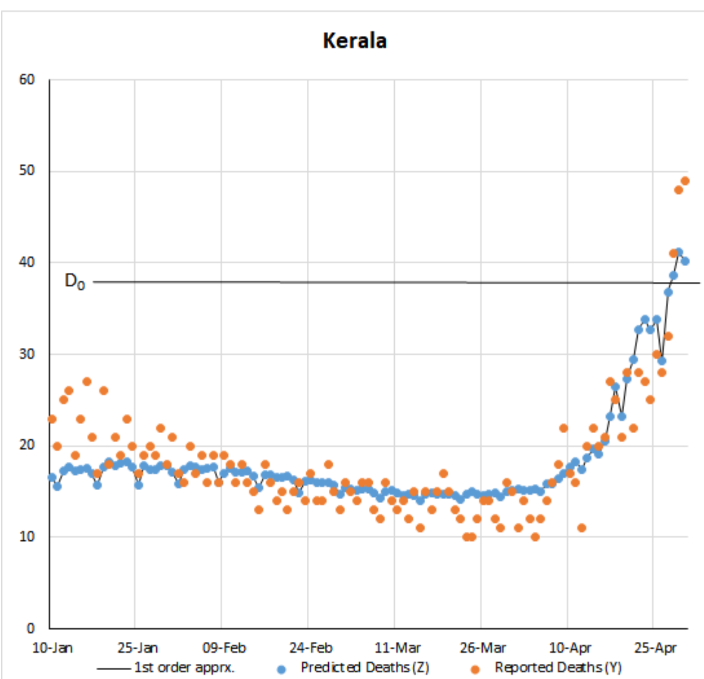
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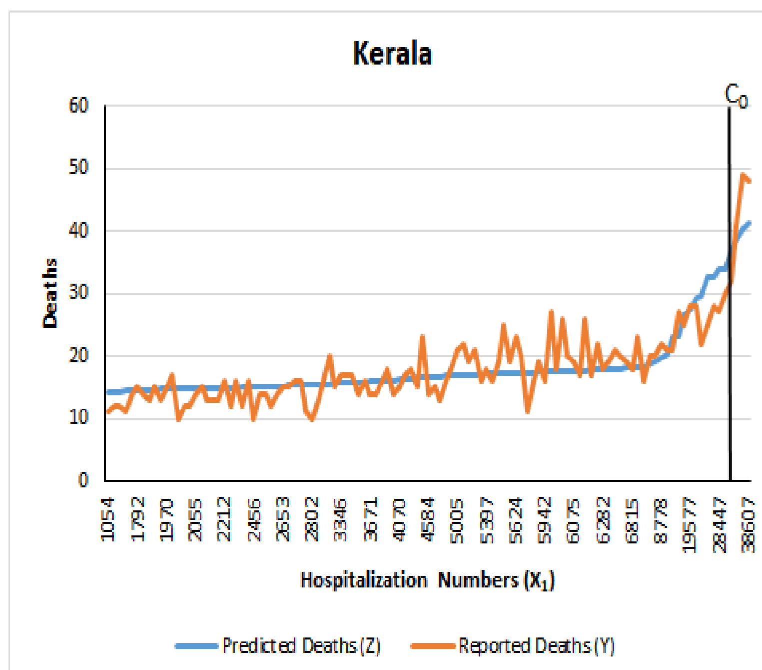
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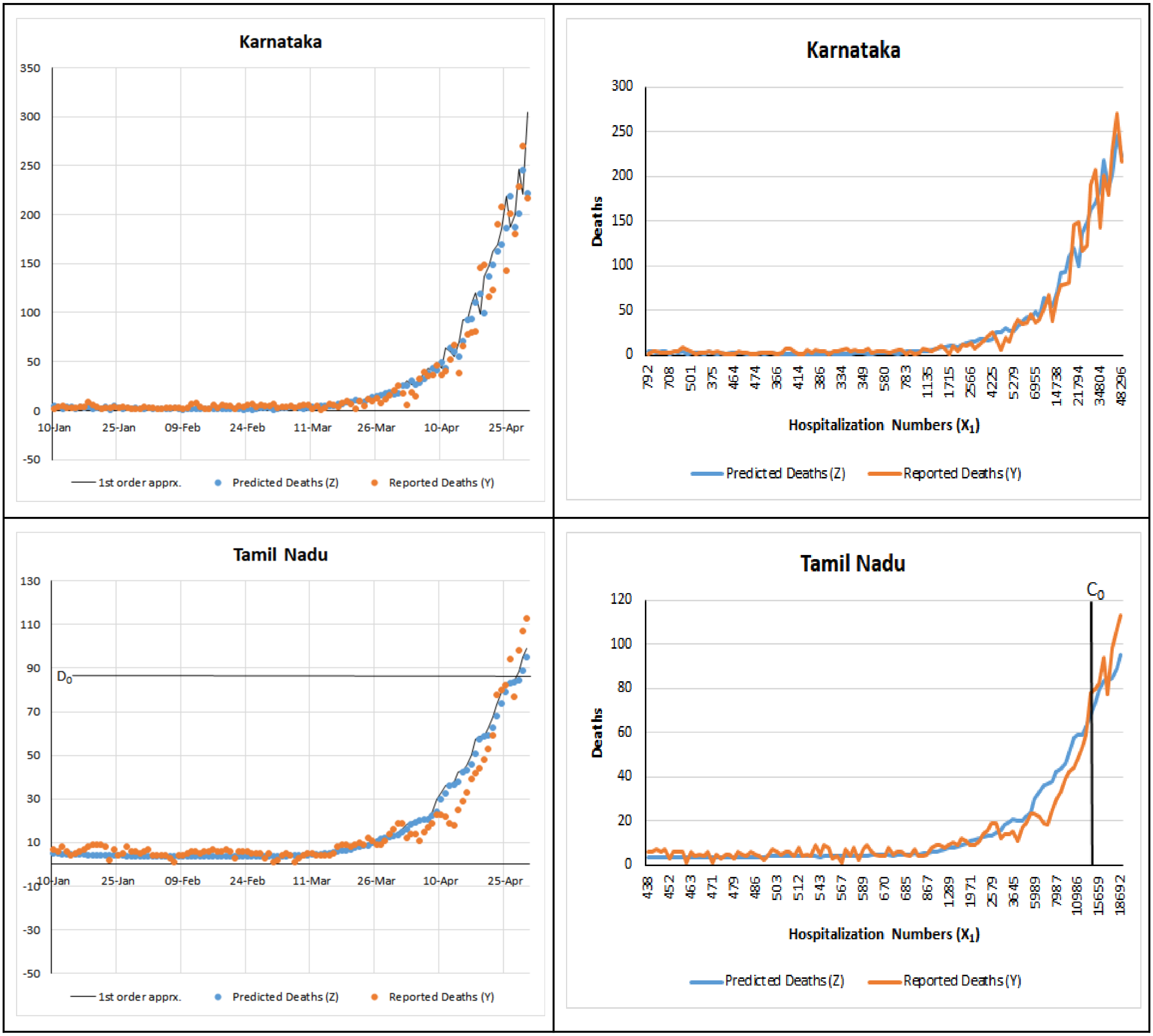
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Karnataka
Deaths
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Predicted Deaths (Z)
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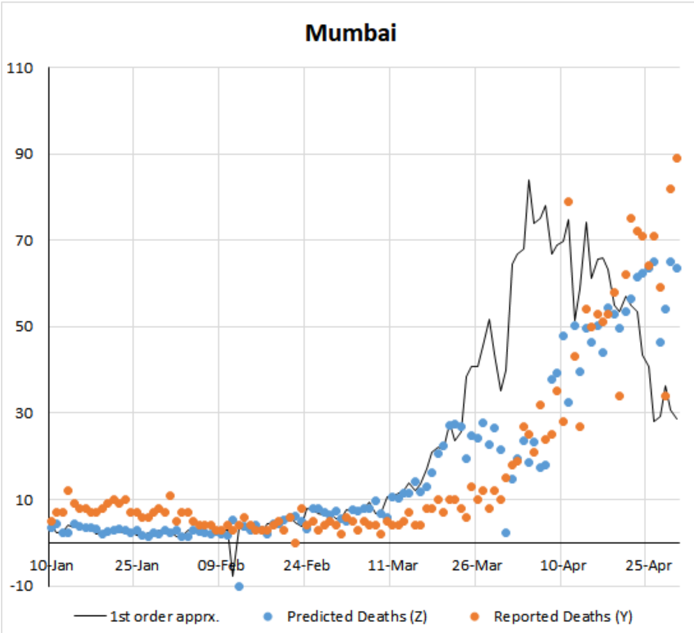
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Predicted Deaths (Z)
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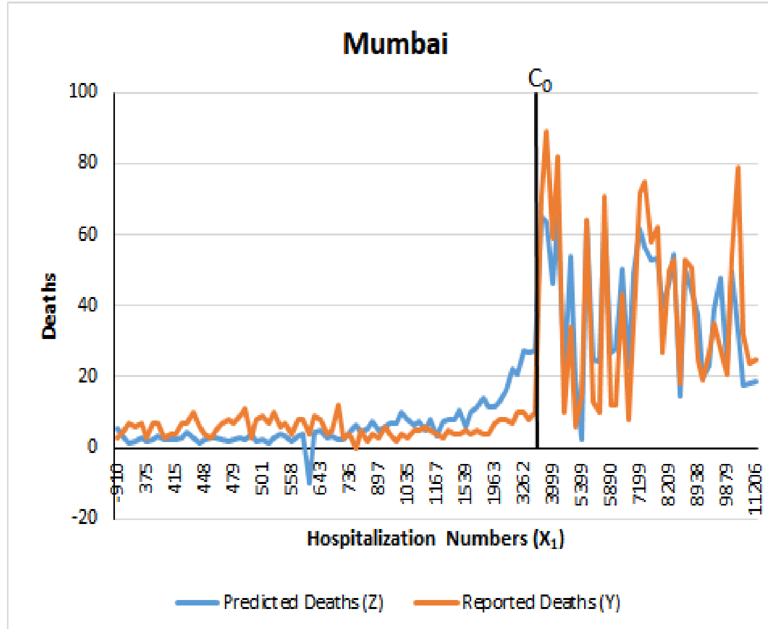
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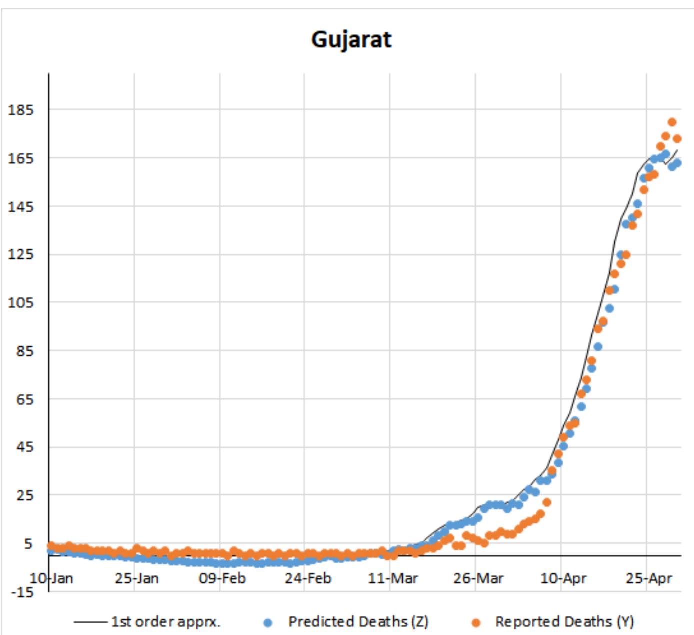
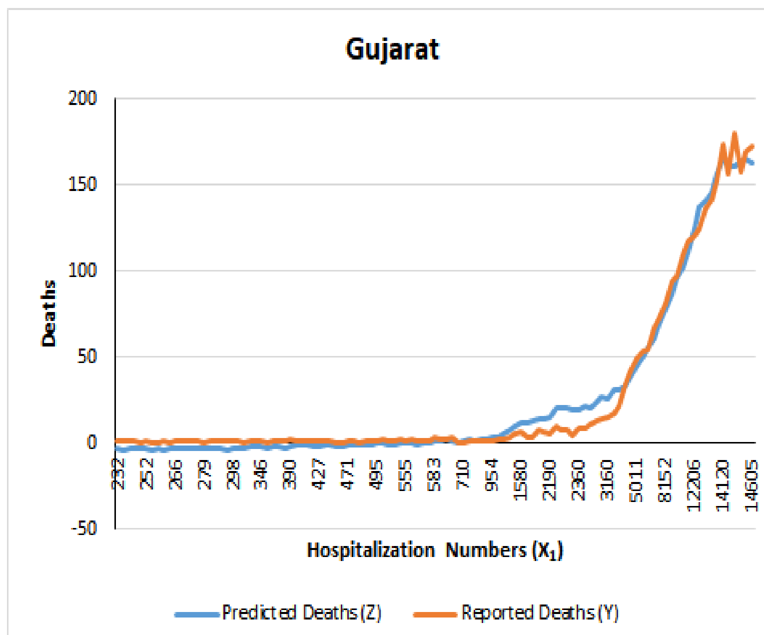
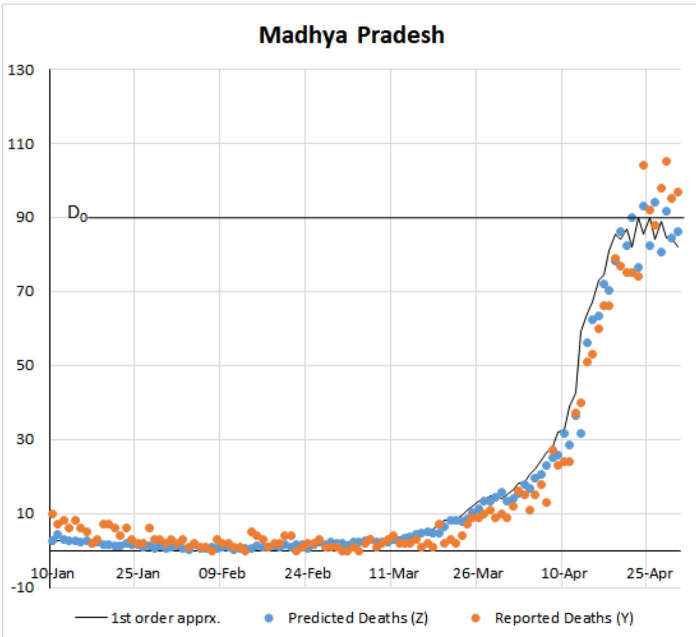
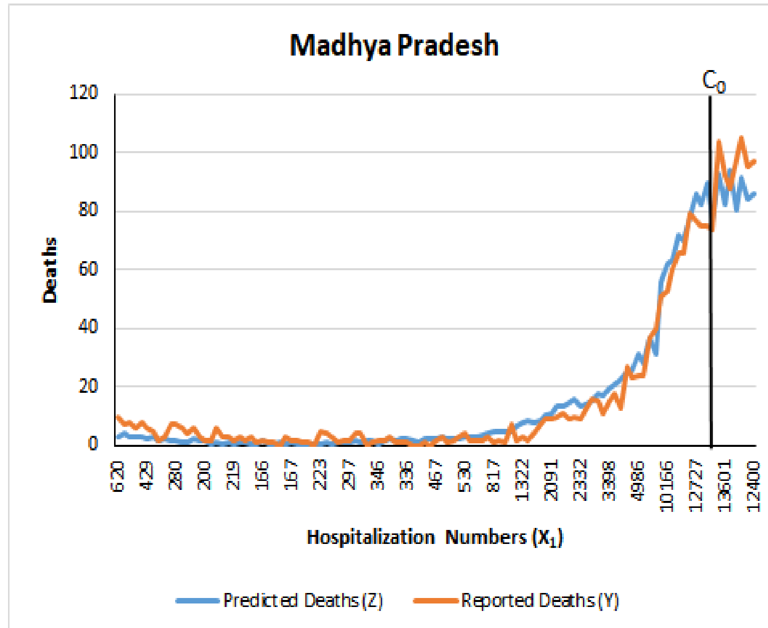
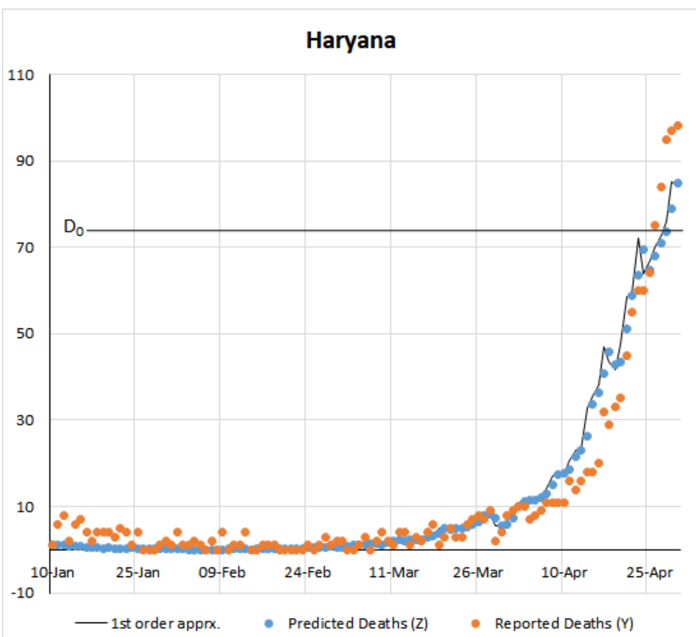
Deaths
Hospitalization Numbers (X_1)
Predicted Deaths (Z)
Reported Deaths (Y)

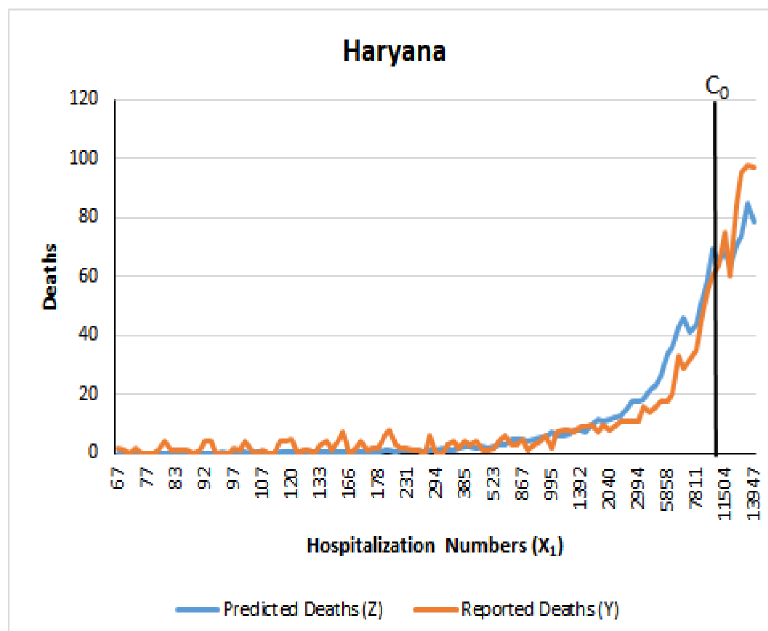

Gujarat
185
165
145
125
105
85
65
45
25
5
-15
10-Jan
25-Jan
09-Feb
24-Feb
11-Mar
26-Mar
10-Apr
25-Apr
1st order apprx.
Predicted Deaths (Z)
Reported Deaths (Y)


Gujarat
200
150
100
50
0
-50
Deaths
Hospitalization Numbers (X_1)
Predicted Deaths (Z)
Reported Deaths (Y)


Madhya Pradesh
D_0
130
110
90
70
50
30
10
-10
10-Jan
25-Jan
09-Feb
24-Feb
11-Mar
26-Mar
10-Apr
25-Apr
1st order apprx.
Predicted Deaths (Z)
Reported Deaths (Y)


Madhya Pradesh
C_0
Deaths
Hospitalization Numbers (X_1)
Predicted Deaths (Z)
Reported Deaths (Y)


Haryana
D_0
110
90
70
50
30
10
-10
10-Jan
25-Jan
09-Feb
24-Feb
11-Mar
26-Mar
10-Apr
25-Apr
1st order apprx.
Predicted Deaths (Z)
Reported Deaths (Y)


Haryana
C_0
Deaths
Hospitalization Numbers (X_1)
Predicted Deaths (Z)
Reported Deaths (Y)