Dynamic Modelling and Live Prediction of COVID-19 Using SIR-D model.

On quantative prediction of COVID-19 using simple spreadsheets for Pune region.

Rajas Vijay Chavadekar (*Author*), 30th of April, 2020. updated 15th of May, 2020.
Sinhgad College of Engineering, Vadgaon, Pune, Maharashtra, India.
rvchavadekar@gmail.com
linkedin.com/in/rvchavadekar

***Abstract*—This research puts forth an approximate quantitative prediction of COVID-19 (coronavirus) counts i.e. affected, infected and dead population and suggestions on measures to be taken in Pune City in coming months. The effects of premature lifting of lockdown in the city are discussed regarding the above counts, the overall magnitude and time-wise progress of the pandemic. This document also provides some important suggestions to the bodies in execution as well as the individuals in the city. We have coarsely made an attempt as an individual to map the further cases and do the planning accordingly although there are various prestigious organizations working on this issue. We have now updated the observations and made respective prayers considering the latest data.**

Keywords—pandemic, prediction, SIR-D epidemic model, mathematical modelling, COVID-19, Pune City.

I. INTRODUCTION

With the outbreak of Coronavirus in Pune active since 9th of March, 2020, There has been a lot of strain on the health services, law enforcement, and the overall tolerance of people. This report provides a crude prediction and also a spreadsheet [1] which has SIR-D [2] epidemic dynamics implemented. The main motive of this analysis is to alert the bodies in execution to continue the lockdown like restrictions till end of August as of April end, 2019. The magnitude of the peak infected count may rise above lakhs if the lockdown is lifted considering the stabilized recovery, infection and death rate. In lockdown state the peak of infected count is expected around mid of August. In this model we have considered the previous ten stabilized counts for fitting our model to prevent the errors in curve parameters caused by the unstable rates till the havoc recedes and individuals stabilize. **We have given a live spreadsheet that calculates prediction for any other city/locality by just putting in the actual values at respective dates.**

II. MOTIVATION

The main motivation of this research was to exactly study COVID-19 dynamics in order to frame further planning of all kinds of economic and social policies.

It was in August 2019 well before the outbreak, since my father Late Dr. Vijay Chavadekar left this world because of ILD (Interstitial Lung Disease). My father was critical on oxygen machines since 2.5 long years and after which we prepared for a bilateral lung transplant. He faced severe casualty while transporting for a lung transplant in ambulance itself after which he didn't open his eyes ever. It is our experience that the respiratory cases are extremely fragile which the medical teams are handling reluctantly.

I couldn't save my Father being potent in my skills but I earnestly don't want so many people to face similar conditions which is why I am deeply studying this pandemic and is trying to put my honest efforts in order to alert and update all the bodies in execution on how to maximize the recoveries. Because I and my family have handled all the economic and clinical crisis and we know what it is to lose the most precious and we know what is the pain that these thousands of families are facing who have really lost their loved ones in the wave of this virus.

III. ASSUMPTIONS AND DISCLAMERS

A. Source of data

As given in references [3][4][5], the data was taken from official portals of Government of Maharashtra. The infected and death count was taken from [4] and recovered or discharged count was taken from [5]. The collective data was found at [3] with previous records before lockdown since 9th of March 2020, so as to record the rate of infection in pre lockdown state. But it is most important point to consider that how many tests are actually being carried out. Due to lack of testing the predicted data may seem overestimated. But according to the reports of Government of India around 69% [13] cases are asymptomatic i.e. they may not show symptoms but are still infectious and have ability to spread it further. It can happen that such population may not be tested and directly move to the recovered compartment after the incubation period i.e. when they have developed their immunity to do so. Such individuals may not come in actual counting and bypass our model. But this process can occur without hindrance only in lockdown period which is why lockdown is utmost necessary. Hence the predicted values cannot be absolutely ignored or discarded. Developing such herd immunity is an important factor that can safely drive the population through this outbreak safely without any strain on the infrastructure.

B. *Accuracy*

The predictions made in this model are accurate with ±10% errors for next 15 days. The accuracy further cannot be guaranteed as errors build up after differentially aggregating the model with more number of rows. With given data [3][4][5] under consideration, the curve fitting considers that the parameters of the model [2]. The model is gives slightly volatile predictions as minute change in the curve parameters due to recent actions of the individuals or medical response on the active cases to be recovered can cause a huge deviation in predicted values. The prediction can be counter checked on [3][4][5]. Pune's death ratio and reproduction number is very higher compared to other cities. The early lockdown has kept us safe until now. The immunity has very slight or hardly any role here in initial stages. The virus will progress according to following dynamics.

C. *The intervention due to vaccination or immunisation*

According to the news [11], a confirmed vaccine for COVID-19 is expected around September or October, it will change the profile of prediction entirely. Thereafter we need to model the situation using SEIR-D with vaccination [7].

D. *The intervention due to premature lifting of lockdown*

The term premature here refers when the lockdown state is lifted before the peak or maxima of the pandemic. This may lead to sudden (mostly logistically [2]) change of reproduction number [2] which in turn can cause catastrophic spike of active cases in the magnitude of lakhs. In this position, the predictions in lockdown state may not apply. The detail discussion of this factor is discussed in the following section of this document.

E. *Regarding the updates of the spreadsheet*

We have attached a live spreadsheet which gives the prediction accordingly. This spreadsheet can also calculate the predictions of any other city/locality by changing the input data. As said previously that the model is highly volatile, and with incoming data, we may change the prediction model to advanced versions [2][7] which may as well drastically change the magnitude and time of predicted values. The updates of the same spreadsheet will be maintained on the site [1].

IV. The Prediction, Sugested Actions and Prayers

This section describes about the approximate future progress of the virus in the metropolitan and tries to give some suggestions to the bodies in execution and the readers of this document. The total population (N = 31,24,458) was taken from 2011 census reports [9].

TABLE I. PREDICTED COUNTS OF COVID-19 TILL 3RD OF MAY 2020

Date	Predicted COVID-19 Counts in Pune		
	Total Affected	***Recovered***	***Deaths***
29/04/2020	***1250***	***274***	***86***
30/04/2020	***1331***	***306***	***90***
1/5/2020	***1416***	***339***	***95***
2/5/2020	***1505***	***375***	***99***
3/5/2020	***1599***	***411***	***104***

[a.] The previous data was provided by [4][5] and predicted figures can have ±10% error

A. *Lockdown Strategy*

With constantly multiplying number of infected individuals in the metropolitan, we strongly suggest continuation of lockdown state till August start. However, the peak may occur earlier with steep slope and higher magnitude of order of thousands near about first week of June. This prediction is made using the given [3][4] source of data and the parameters calculated considering the recent stable 10 days when lockdown was strictly followed.

From the statistics till now since 10 days the lockdown is appreciably followed in Pune City, a huge thanks to The Pune Police Department, the obedient citizens and their cooperation. But however the dynamics post premature lockdown are not so much in favor.

The population of the city is very high but is currently stabilized under lockdown. Due to sudden ramp up of infected population, the existing medical facilities can get overstrained and probably the situations may get out of control.

We definitely understand the economic crunch and loss of revenue which is very dependent on the mobility of individuals and their transactions, but however if infected count in thousands of magnitude can in turn infect them

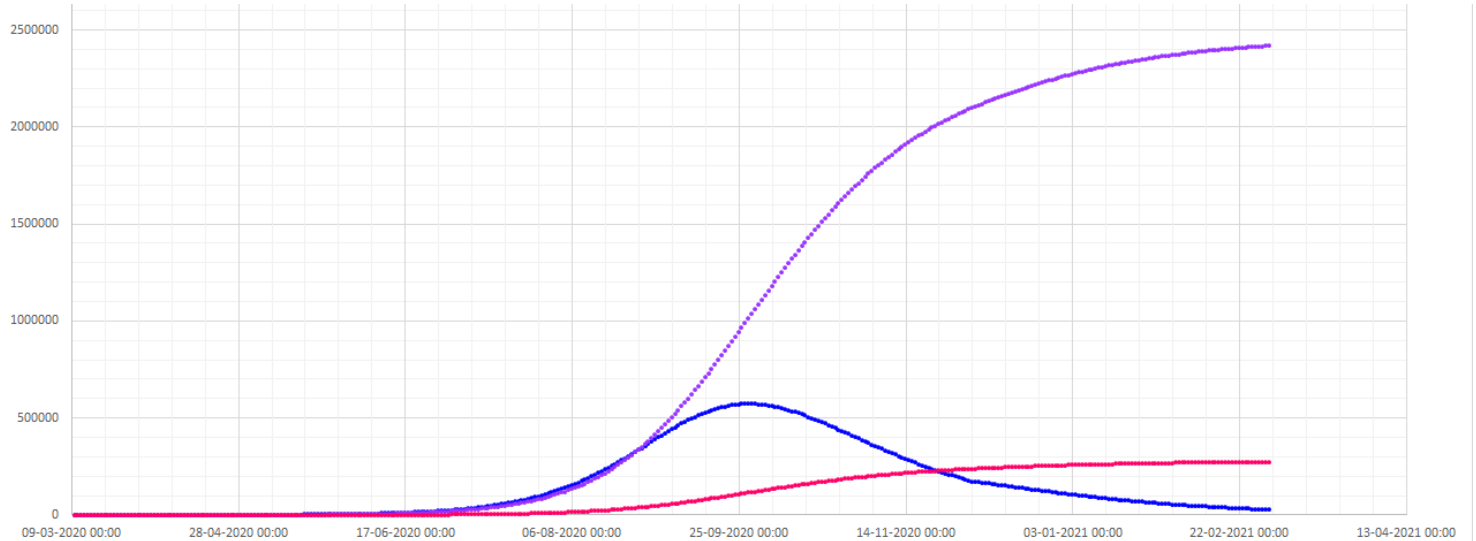


Figure 1: The Progression of COVID counts in lockdown state, blue = infected, purple = recovered, red = deaths.

further and finally again there can be multiple loss of finance and infrastructure.

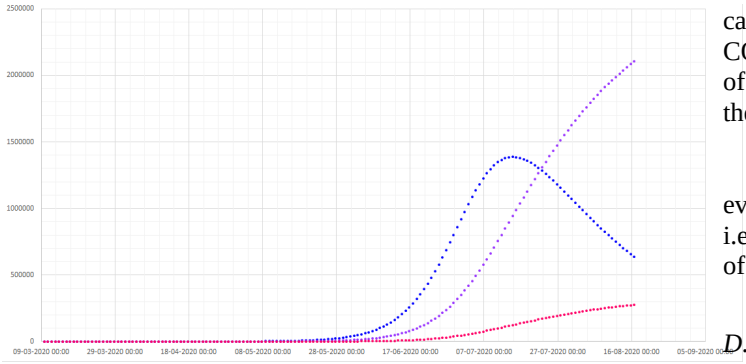


Figure 2: Progression of COVID if lockdown lifted in 3rd of May.

B. Suggested Role of IT and Software Companies or other Industrial policies

It has been observed that the current structures of the IT workplaces have poor ventilation, air conditioning and hygiene practices and external air exchange. This will not only promote the absolute spread of infection but also decrease the overall immunity of the employees. In this scenario, the premature lockdown lifting can infect the employees in mass scale which will dabble the entire predicted dynamics and as well the actual scenario will be pretty vulnerable. Frequent air exchange and better ventilation is highly suggested in these cases and hereafter. It is therefore suggested post lockdown to change the ventilation architecture if possible.

If we have to keep the human resources intact, then we have to actively participate in the planning of further strategies in accordance with the predictions which in turn we will have to make by tedious data analysis and which is why we would encourage such companies to draw certain conclusions and respond to the government and bodies in execution rather than blindly following the instructions. However, for now it is highly suggested not to put the human resources in immediate mobility and patiently wait for the peak to pass. After the situation calms down considerably, and if IT companies in Pune are able to maintain such disciplines, it may as well attract considerable potential investments in near future.

C. Comparative analysis, best and worst case of coronavirus – Thailand and New York, and where Pune lies

Since 8th of April, Thailand has observed a huge drop in COVID-19 active cases from start of outbreak on 15th of February. Till now at peak it had merely 1,451 active cases and only 54 are dead as of April 29 [10]. Due to strict restrictions, it seems that they have won the battle but they still consider the chances of second wave of outbreak. However, they are planning to lift things back to normal.

Since 15th of February, The New York city has 3,05,086 infected count and is now progressing near to peak. Daily around 3000+ cases are added and till now 23,474 are fatal cases as of April 29th [10]. Such may be the progress of COVID in the Pune city if by any chance there is mishandling of individual mobility, lack of medical facilities. In this case the accommodations of nearly 1 lakh beds is suggested.

Currently Pune is in the initial stages of the virus where even a slightest change in the infection and recovery factors i.e. even ±0.1% change deviates the prediction in magnitude of thousands.

D. Measures and Mentality as an Individual

The individuals are firstly requested to stabilize wherever they are and stay safe to prevent any knowing or unknowing transmission of disease. As said earlier that still Pune is in initial stages of outbreak a slight action can engrave entire future of the city. Next big factor is an individual's immunity. It is found that that the people aged 61-70 [12] have maximum mortality rate compared to teenagers or adults. Hence senior citizens have to take extra care while venturing out or rather forbid it.

According to a research [24] in NCBI, it is found that emotions and mental state of an individual play an active role in governing one's immune system. Therefore, it is necessary to slightly change the perspective we are looking at the situation. Instead of a war it has more to tune with nature and maintain a healthy wellbeing, mental and most importantly physical hygiene and physical fitness.

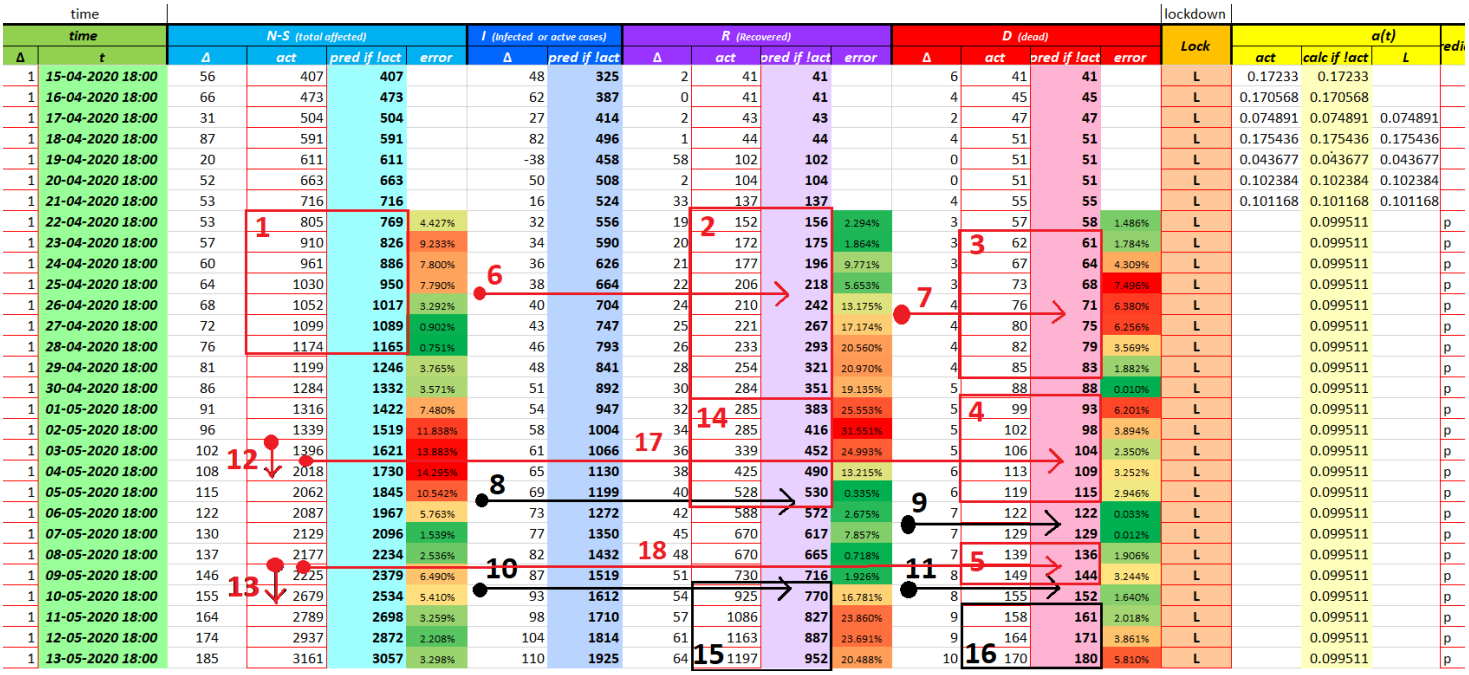
Individuals are also highly requested to follow the guidelines given by the Government and avoid as much physical contacts as possible for example, cash payment which was predominantly found to exchange the infection in a large mob and use online transactions wherever possible.

V. UPDATED ANALYSIS OF PREDICTED DYNAMICS V/S OBSERVED STATISTICS

A. Observations of previous 22 days as of predictions done on 22nd of April.

As said before we had provided the updates and study of the disease dynamics and have updated the suggestions to be given to all the bodies in execution in accordance to the latest progression of COVID-19 in Pune as suggests our title.

The pandemic curve was fitted based on the parameters aggregated from 16th of April to 21st of April, 2020. Due to the discrete nature of data, this range was derived based on trial and error that which date range shows up minimum mean error. It was then evident enough that the model is considerably fitted as it predicts the affected count on 13th of May with merely 4% error.



time		N-S (total affected)				I (Infected or actve cases)		R (Recovered)				D (dead)				lockdown	a(t)			
time		Δ	act	pred if !act	error	Δ	pred if !act	Δ	act	pred if !act	error	Δ	act	pred if !act	error	Lock	act	calc if !act	L	edi
Δ	t																			
1	15-04-2020 18:00	56	407	407		48	325	2	41	41		6	41	41		L	0.17233	0.17233		
1	16-04-2020 18:00	66	473	473		62	387	0	41	41		4	45	45		L	0.170568	0.170568		
1	17-04-2020 18:00	31	504	504		27	414	2	43	43		2	47	47		L	0.074891	0.074891	0.074891	
1	18-04-2020 18:00	87	591	591		82	496	1	44	44		4	51	51		L	0.175436	0.175436	0.175436	
1	19-04-2020 18:00	20	611	611		-38	458	58	102	102		0	51	51		L	0.043677	0.043677	0.043677	
1	20-04-2020 18:00	52	663	663		50	508	2	104	104		0	51	51		L	0.102384	0.102384	0.102384	
1	21-04-2020 18:00	53	716	716		16	524	33	137	137		4	55	55		L	0.101168	0.101168	0.101168	
1	22-04-2020 18:00	53	805	769	4.427%	32	556	19	152	156	2.294%	3	57	58	1.486%	L		0.099511		p
1	23-04-2020 18:00	57	910	826	9.233%	34	590	20	172	175	1.864%	3	62	61	1.784%	L		0.099511		p
1	24-04-2020 18:00	60	961	886	7.800%	36	626	21	177	196	9.771%	3	67	64	4.309%	L		0.099511		p
1	25-04-2020 18:00	64	1030	950	7.790%	38	664	22	206	218	5.653%	3	73	68	7.496%	L		0.099511		p
1	26-04-2020 18:00	68	1052	1017	3.292%	40	704	24	210	242	13.175%	4	76	71	6.380%	L		0.099511		p
1	27-04-2020 18:00	72	1099	1089	0.902%	43	747	25	221	267	17.174%	4	80	75	6.256%	L		0.099511		p
1	28-04-2020 18:00	76	1174	1165	0.751%	46	793	26	233	293	20.560%	4	82	79	3.569%	L		0.099511		p
1	29-04-2020 18:00	81	1199	1246	3.765%	48	841	28	254	321	20.970%	4	85	83	1.882%	L		0.099511		p
1	30-04-2020 18:00	86	1284	1332	3.571%	51	892	30	284	351	19.135%	5	88	88	0.010%	L		0.099511		p
1	01-05-2020 18:00	91	1316	1422	7.480%	54	947	32	285	383	25.553%	5	99	93	6.201%	L		0.099511		p
1	02-05-2020 18:00	96	1339	1519	11.838%	58	1004	34	285	416	31.551%	5	102	98	3.894%	L		0.099511		p
1	03-05-2020 18:00	102	1396	1621	13.883%	61	1066	36	339	452	24.993%	5	106	104	2.350%	L		0.099511		p
1	04-05-2020 18:00	108	2018	1730	14.295%	65	1130	38	425	490	13.215%	6	113	109	3.252%	L		0.099511		p
1	05-05-2020 18:00	115	2062	1845	10.542%	69	1199	40	528	530	0.335%	6	119	115	2.946%	L		0.099511		p
1	06-05-2020 18:00	122	2087	1967	5.763%	73	1272	42	588	572	2.675%	7	122	122	0.033%	L		0.099511		p
1	07-05-2020 18:00	130	2129	2096	1.539%	77	1350	45	670	617	7.857%	7	129	129	0.012%	L		0.099511		p
1	08-05-2020 18:00	137	2177	2234	2.536%	82	1432	48	670	665	0.718%	7	139	136	1.906%	L		0.099511		p
1	09-05-2020 18:00	146	2225	2379	6.490%	87	1519	51	730	716	1.926%	8	149	144	3.244%	L		0.099511		p
1	10-05-2020 18:00	155	2679	2534	5.410%	93	1612	54	925	770	16.781%	8	155	152	1.640%	L		0.099511		p
1	11-05-2020 18:00	164	2789	2698	3.259%	98	1710	57	1086	827	23.860%	9	158	161	2.018%	L		0.099511		p
1	12-05-2020 18:00	174	2937	2872	2.208%	104	1814	61	1163	887	23.691%	9	164	171	3.861%	L		0.099511		p
1	13-05-2020 18:00	185	3161	3057	3.298%	110	1925	64	1197	952	20.488%	10	170	180	5.810%	L		0.099511		p

Figure 3: Observations v/s Predictions on previous 22 days with labelled annotations.

Within these 22 days we have observed very interesting deviations of the observed values with the model. We have made 18 significant observations which are annotated on Figure 4 above. The first we observe that people who are having considerable symptoms only are voluntarily carrying out the tests. The fact that the population with mild or no symptoms but yet are potent to spread infection further exist in very large numbers in the given [9] population. As stated before that 69% cases [13] are asymptomatic for the people of Indian origin due high immune response due to the significant presence of the HLA genes [14]. However, Indians having this natural advantage above a certain threshold of infection can fight no more against the virus.

Now coming to what had been the situations since 22 days as of today (15th of May, 2020), it is a general observation that after every 4 to 7 days the observed count of the affected individuals very accurately matches with the model or predicted values with error < 1%. Here this was observed on 28th of April, 7th of May, and 12th of May, 2020. There was a considerable havoc till 26th of April where the observed number of affected people of was higher by 30 to 50 than the model values as you can see in **(annotation 1 in Figure 4)**.

During this period as a result **(annotation 6)** the medical facilities got overstrained as we observe that the recoveries were lesser **(annotation 2)** than 5 to 20 than the model and as a result **(annotation 7)** there were more deaths than expected i.e. 2-5 more than model **(annotation 3)**. After that the actual affected values started matching closely with the model after 26th of April thereby reducing excess number of deaths and the recoveries and death count started matching the model with <1% error after 27th of April. But after 29th of April the actual count of affected individuals kept dropping by 50-100 till 3rd of May. This may be due to lesser testing conducted, the nature of virus of having infection pulses every 7 days. It is obvious that people will hardly voluntarily test for COVID-19 having no/mild symptoms in spite of being infectious, but after a period of 5-7 days when they suddenly face some symptoms, such individuals immediately conducted voluntary tests. Suddenly on 3rd of May when government loosened the lockdown strategies and permitted opening of liquor shops, till 4th of May, 622 new active COVID-19 cases raised **(annotation 12)**.

On 3rd of May when the affected patients were 225 less than the model value and immediately a day later became 288 more than the model value. There may be two possible reasons for this pretty discontinuous rise. 1) the immediate mobility of asymptomatic infected and untested individuals in the susceptible population and 2) these individuals immediately took the voluntary test for COVID-19 which they were supposed to take 3 to 4 days before. Hence it is evident enough that whatever data we are provided are of those who had voluntarily came up for the test or those who were tested positive explicitly for COVID-19. It is clear that during this period there was lesser testing than expected. This also resulted in lesser recoveries and deaths than expected **(annotation 14 and 4)** because if individuals don't come up how will they get recovered. From **(annotation 17)** we understand that who were untested but critical cases of COVID-19 faced immediate fatalities without treatment which led to higher death count than the model by 3 to 5 **(annotation 4)** also lesser number of recoveries during this period **(annotation 14)**.

However, after 5th of May ,2020, the medical setup showed quite improvement **(annotation 8)** in the treatment where the observed number of recoveries has closely matched the model with < 1% error and after which higher recoveries than

expected were observed then after. After which the death count exactly matched the model with 0% error i.e. 122 total deaths till 6th of May and 129 deaths till 7th of May **(annotation 9)**.

But as the havoc increased, the similar history of 3rd to 4th May repeated from 9th to 10th May **(annotation 13)**. Within this period 454 new cases were reported also the death count as 2 to 5 greater than model **(annotation 5)**. It is a similar scenario as of previous where the asymptomatic infected and untested individuals remained quarantined and after facing considerable symptoms carried out voluntary tests. But again during this period those who were at critical stages yet untested faced fatalities without treatment **(annotation 18)**. As a result, the death count became 2 to 4 higher than the model values.

But after 10th of May hospitals seem to have higher recoveries with fitted model **(annotation 15)** and lesser deaths than model **(annotation 16).** Here again many individuals seem to come for voluntary testing and get recovered quickly **(annotation 10)** which is why the death count was quite lesser than the model **(annotation 11)**. However, if we update the curve parameters for these days, the situations might get reversed as well. Which is why we can accurately predict till next 15 days and get the overall dynamics to be estimated in order rather than magnitude due to building up of errors.

testing. It may so happen that after 4 to 5 days next pulse of affected individuals may rise like that of 4th to 5th and 9th to 10th of May, 2020.

These observations are based on the lesser observed count i.e. lesser tests due to which lesser recovery count and deaths **(annotations 1 and 2 in Figure 5)**. **Till 31st of May, 2020 the model predicts total 8344 affected, with 4182 total recoveries, and 385 deaths. We request the bodies in execution to prepare in accordance with these figures.**

C. The Observed Psychology and Tendency of individuals towards voluntary testing, immunity and fatality factors.

By keenly observing the progression in COVID-19, people are appreciably following the rules of social distancing and hygiene, the reproduction number of coronavirus in Pune is higher relative to Maharashtra except Mumbai.

Most of the people are following the homemade recovery methods such as natural kitchen medicines and steaming, and most of the population yet and maybe already infected in very large numbers compared to the records whatever we are getting from portals. As mentioned above, according to the reports of Government of India around 69% [13] cases are asymptomatic i.e. they may not show symptoms, as the people of Indian origin have high immune response due to the

time			N-S (total affected)			I (infected or actve cases)		R (Recovered)				D (dead)				lockdown	curves			
time		Δ	act	pred if !act	error	Δ	pred if !act	Δ	act	pred if !act	error	Δ	act	pred if !act	error	Lock	a(t)			edi
Δ	t																act	calc if !act	L	
1	03-05-2020 18:00	57	1396	1396		-1	951	54	339	339		4	106	106		L	0.059964	0.059964		
1	04-05-2020 18:00	622	2018	2018		529	1480	86	425	425		7	113	113		L	0.420542	0.420542	0.420542	
1	05-05-2020 18:00	44	2062	2062		-65	1415	103	528	528		6	119	119		L	0.031116	0.031116	0.031116	
1	06-05-2020 18:00	25	2087	2087		-38	1377	60	588	588		3	122	122		L	0.018168	0.018168	0.018168	
1	07-05-2020 18:00	42	2129	2129		-47	1330	82	670	670		7	129	129		L	0.0316	0.0316	0.0316	
1	08-05-2020 18:00	48	2177	2177		38	1368	0	670	670		10	139	139		L	0.035112	0.035112	0.035112	
1	09-05-2020 18:00	48	2225	2225		-22	1346	60	730	730		10	149	149		L	0.035687	0.035687	0.035687	
1	10-05-2020 18:00	454	2679	2679		253	1599	195	925	925		6	155	155		L	0.284171	0.284171	0.284171	
1	11-05-2020 18:00	110	2789	2789		-54	1545	161	1086	1086		3	158	158		L	0.071261	0.071261	0.071261	
1	12-05-2020 18:00	184	2937	2973	1.212%	74	1619	103	1163	1189	2.152%	7	164	165	0.880%	L		0.115957		p
1	13-05-2020 18:00	193	3161	3166	0.153%	78	1697	107	1197	1296	7.643%	8	170	173	1.887%	L		0.115957		p
1	14-05-2020 18:00	202	3314	3368	1.600%	81	1778	113	1377	1409	2.250%	8	175	181	3.559%	L		0.115957		p
1	15-05-2020 18:00	212		3580		85	1863	118		1527		9		190		L		0.115957		
1	16-05-2020 18:00	222		3801		89	1952	124		1650		9		199		L		0.115957		
1	17-05-2020 18:00	232		4034		93	2045	130		1780		9		208		L		0.115957		
1	18-05-2020 18:00	244		4277		98	2143	136		1916		10		218		L		0.115957		
1	19-05-2020 18:00	255		4533		103	2246	142		2058		10		229		L		0.115957		

Figure 4: Predictions for previous 3 days with updated curve parameters.

B. Observations of previous 3 days as of predictions done on 11th of May.

After updating the parameters, considering the statistics from 4th of May to 11th of May, 2020, the pandemic curve has been refitted, which has evidently given correct predictions for 14th of May, 2020, with reasonably error < 4%. But here we have to be extra cautious and minutely observe this error wherein the observed number of affected individuals is less than the model value. The recoveries have still become lesser than expected. In contrast to statement made in previous subsection which was indeed based on previous statistics, a month before. The model now suggests improvement in significant presence of the HLA genes [14]. but are still infectious and have ability to spread it further. These records are only updated when the medical teams come across relatively severe active or critical cases which are voluntarily reported.

It is true that the people might not come up for official testing due to the fear or havoc that may be induced due to the very scenario of the pandemic. But if they don't do any testing on the other side such individuals may not even get to know that they are having COVID-19 and unknowingly simply treat it as a normal viral fever and most of the population may be becoming immune to various mutations of COVID-19. This may be a natural advantage of genes in Indian origin as stated

before [14]. In this case a large population gets susceptible and infected many number of times which is where SISR, SIRS or SEIRS model is more applicable, but due to the lack of data for the exposed (E) compartment we are neither able to synthesize it due to inconsistent linear system nor extract any of its parameters due to absence of data.

This tendency is observed here on community basis where near about every 3 to 5 days there is steep rise of active cases, the progress of which is discussed in previous sections. But such inconstancies can cause load on medical teams **(annotation 6 of Figure 4)**.

VI. Further Suggestions on Actions to be Taken and Prayers

A. Nature of further lockdowns or restrictions in the race of economy v/s health.

With no public vaccine available on COVID-19 till date, lockdown has been a temporary measure to restrict infection of the virus. It is definitely true that as a consequence the economy has drastically reduced and cash flows, stocks and the government revenue have dropped down considerably.

But after 3rd of May it was loosened to some extent where small mobility of individuals was permitted, like the restrictions on refueling their vehicles were removed, some commodities and allied businesses in the orange and green zone were permitted to operate with certain restrictions and etc. This had created some small flow in the economy of the state. The immune individuals can be permitted to get back to their routines which are working only under essential services by which most of the market and economy resumes.

The mid to end of August is suggested as peak infection of the virus. However, we will provide the updates after next 15 days and eventually the peak will be foreseeable, provided that we get precise testing data on [4] and [5]. Hence the testing should be carried before putting any individual at work. Basically we would rather suggest two tests to be taken mandatorily taken before putting any human resource at work i.e. immune-profile (multiple tests consisting of CBC, Random Sugar, IgA, IgG, and IgM tests) or ANA (antibody) test and COVID-19 test. The immuno-profile test should show up with considerable count of antibodies required to resist this infection and secondly that individual oneself should not be infectious which is given by COVID-19 test.

With these precautions especially industries in Pune can put their skeletal staff to work physically onsite only after their employees are having their testing done. The industries should deploy their separate testing facility specially for their employees. In this way to some extent lockdown can be loosened up but with acute rise of infection the restrictions have to be imposed immediately by respective Government bodies in execution. With acute increase of infections, the restrictions and strict lockdown in the complete city must be immediately introduced, and to resume the activities observing lesser rate of infections further once again in such a way that the medical facilities aren't overstrained and the death count remains lesser than or equal to the model values. Hence we would rather suggest step by step resumption process rather than immediate which will definitely require precise and consistent data of the active COVID-19 cases, its keen observation and analysis, and quick planning.

To conclude this prayer, it is evidently true every time that 'Health is Wealth'. I.e. if the working class is healthy then and then only the economy can run smoothly and keep growing.

B. The development of COVID-19 isolation bed facilities and ICU units.

It is very appreciable that the multinational IT and automobile companies in Pune like Tech Mahindra [16] has developed reasonable ventilators, Wipro [17], and Mercedes Benz [18] have developed their facilities with full-fledged COVID-19 isolation units that can accommodate the critical patients in thousands. Also the SKN hospital at Narhe, Pune [19] has a capacity of accommodating 500 patients. The Pune Civic hospital has made considerable installations for handling COVID-19 patients [20].

But whenever we setup a facility or isolation beds for COVID-19 patients, we have to setup all other facilities like their timely and hygienic food, sanitation, their medicine, one must not be in proximity of other patient's infection, and a trained, immune and dedicated staff to handle any kind of emergency one has. The testing speed should be made higher and serious cases should get immediate accommodation without disturbing other patients' space and enough and handy oxygen supply to handle any kind of respiratory emergencies faced.

Till 31st of May, 2020 the model predicts total 8344 affected, with 4182 total recoveries, and 385 deaths. We request the bodies in execution to prepare in accordance with these figures. With this progression Pune may need at least 50,000 isolation beds with at least 6,000 to 7,000 ICU facilities to handle the infection peak of pandemic in coming 3 to 5 months.

C. Distribution of Ayurvedic and Homeopathic immuno-modulator packages or kits.

According to the advisory of Ministry of AYUSH [21]. As well as it is evident from many instances that Ayurveda is effective in prevention. Many people are taking homemade medicines and remedies such as basil – pepper – ginger tea, medicinal steaming and supplementary vitamins at their own pace.

The immunity promoting packages should be made commonly and readily (if possible door to door delivery) available to all citizens, doctors, hospital staff and importantly to the patients in isolation. Either paid or if possible free of

cost. It is therefore our request to the Ministry of AYUSH and volunteering organisations to come into action in this regard which might reduce critical COVID-19 cases in initial stages itself.

D. Rectifying the problem of sanitation disposal in drinkable water bodies: Khadakwasla Dam backwaters in Pune

It is observed that some of the villages and settlements near the catchment area of Khadakwasla Dam backwaters in Pune are disposing their sanitation in the backwaters itself, which is supposed to be classified as drinking water [22]. Rather it is in general observed, not only in Maharashtra but in nearly all of the nation where sewage is disposed in drinking water bodies.

It is evident that even in Paris, France, their sanitation being entirely disconnected found traces of virus in their drinking water. The considerable count of COVID-19 in their sewage water pointed to their early warning system [23].

There has been considerable amount of active COVID-19 cases in the nearby villages who have been found to dispose their wastes in the water body itself [23]. These villages themselves fetch the same contaminated backwater thus causing a contaminated feedback to amplify not only COVID-19 but any kind of infection further. The same water is supplied to the entire Pune City. Strict corrective measures are suggested in order to curb and terminate any kind of contaminations, by the Government and local bodies in execution.

E. Making the actual data consistently available on the government portals.

The data available on portals [4][5] being timely updated was only of the present counts of COVID-19. We would highly suggest to maintain a graphical record like worldometers portal [10] for each city of previous counts so that epidemiologists can voluntarily carry out similar analysis and which in turn may assist the Government. We can provide the analysis for Mumbai, Nashik and other hotspot cities as well if data is given.

VII. Basis of Prediction - The SIR model with Fatalities

SIR, standing for Susceptible, Infected and Removed, modeling infectious diseases is as important as it has been in 1760, when Daniel Bernoulli presented a solution to his mathematical model on smallpox. It was however not until 20th century that mathematical models became a recognized tool to study the causes and effects of epidemics. In 1927, Kermack and McKendrick introduced their SIR-model based on the idea of grouping the population into susceptible, infected, and removed. The model assumes a constant total population and an interaction between the groups determined by the disease transmission and removal rates. Although the removed represent in some models the vaccinated individuals, it can also be used to transform a time dependent population size into a constant population. In the latter case, the total number of contacts that a susceptible individual could get in contact with, is not the individuals of all three groups but S + I [6]. However, the Removed compartment contains both the recovered and death cases. We will derive these compartments as suggested in [2]. We will not actually solve this model analytically as their solutions are relatively complex and deriving the solution may require the reader to be proficient in solving the system of differential equations. But still if the reader is curious enough, one can refer [6]. We will try to fit an approximate curve formally known as state space fitting. In our case we will be using simple spreadsheet calculations to numerically solve by a variant of Euclid's method so that every reader can actually work with this model in their computers without installing any special software or programs like JRE, Python or other simulation runtimes.

A. The Model

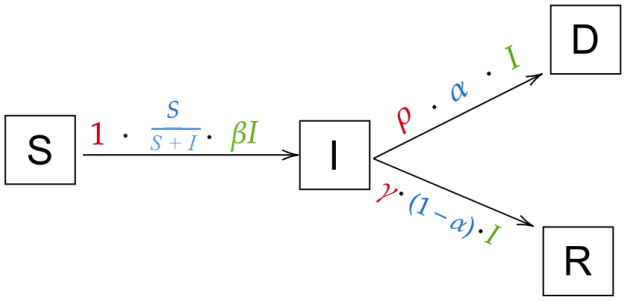


Figure 5: The SIR transitions with dead compartment. [2]

Every transition of the state is represented by three factors - The *rate(red)* describes how long the transition takes, *population(green)* is the group of individuals that this transition applies to, and *probability(blue)* is the probability of the transition taking place for an individual [2]. Where **β** is expected amount of people an infected person infects per day, **γ** is the proportion of infected recovering per day, **ρ** is rate at which people die (= 1/days from infected until death) and **α** is the fatality rate.

We investigate a susceptible-infected-removed (SIR) model proposed by Norman Bailey in of the form. The differential system [6] for our model with dead compartment becomes,

$$\frac{dS}{dt} = -\beta \frac{IS}{I+S} \tag{1}$$

$$\frac{dI}{dt} = \beta \frac{IS}{I+S} - (1-\alpha)\gamma I - \alpha\rho I \tag{2}$$

$$\frac{dR}{dt} = (1-\alpha)\gamma I \tag{3}$$

$$\frac{dD}{dt} = \alpha\rho I \tag{4}$$

For our computation purposes, resolution of parameters α, β, γ and ρ is pretty tedious in the above forms and may as well

lead to larger error in prediction. We need to derive simpler parameters of this ODE system to enable easy calculations. Let us define a, b and c as,

$$a = \beta \tag{5}$$

$$b = (1-\alpha)\gamma \tag{6}$$

$$c = \alpha\rho \tag{7}$$

Also, it must be noted that,

$$S + I + R + D = N \tag{8}$$

is constant, where N is constant. Furthermore, we do not have the Susceptible count, instead we have affected count A with us as sum of Infected, Recovered and Death population so,

$$A = I + R + D = N - S \tag{9}$$

Then our differential system becomes,

$$A = I + R + D \tag{10}$$

$$\frac{dI}{dt} = \left(a\frac{N-A}{I+N-A} - b - c \right) I \tag{11}$$

$$\frac{dR}{dt} = bI \tag{12}$$

$$\frac{dD}{dt} = cI \tag{13}$$

The parameters a, b, and c can be the functions of time like a(t), b(t) and c(t) as the clinical responses and other factors like mobility and reproduction number can vary with time. Considering this, the curious readers can see the solution to this system of linear differential system with recovered and dead called as removed compartment R. the recovered and the dead both are proportional to the removed population R (here only), with this we have the solution from [6],

$$A = N - (N - A_0)\exp\left\{ -\frac{I_0}{N-A_0}\int_{t_0}^{t}\left[\frac{a(s)}{\frac{I_0}{N-A_0} + e^{\int_{t_0}^{s}(b-a)(\tau)d\tau}} \right] ds \right\} \tag{14}$$

$$I = I_0 \exp\left\{ \int_{t_0}^{t}\left[\frac{a(s)}{1 + \frac{I_0}{N-A_0} e^{\int_{t_0}^{s}(a-b)(\tau)d\tau}} - b(s) \right] ds \right\} \tag{15}$$

$$R = N - \left(N - A_0 + I_0 e^{\int_{t_0}^{t}(a-b)(s)ds} \right) \exp\left\{ -\frac{I_0}{N-A_0}\int_{t_0}^{t}\left[\frac{a(s)}{1 + \frac{I_0}{N-A_0} e^{\int_{t_0}^{s}(b-a)(\tau)d\tau}} \right] ds \right\} . \tag{16}$$

Where I_0 and A_0 are initial (at $t = t_0$) number of affected and infected number of individuals. Being very impractical for their application we have to numerically solve this system.

B. *Parameters Estimation and Tuning*

To resolve our newly derived parameters a, b and c,

$$b = \frac{1}{I}\frac{dR}{dt} \tag{17}$$

$$c = \frac{1}{I}\frac{dD}{dt} \tag{18}$$

Now plugging in (17) and (18) in (11), we have,

$$\frac{dI}{dt} + \frac{dR}{dt} + \frac{dD}{dt} = a\frac{I(N-A)}{I+N-A} \quad .$$

$$\frac{dA}{dt} = a\frac{I(N-A)}{I+N-A} \quad \text{… from (9)}$$

$$a = \left(\frac{1}{I} + \frac{1}{N-A} \right)\frac{dA}{dt} \tag{19}$$

However, it is to be noted that as reproduction number R_0 which is a measure of virus multiplication, clearly the number of infections an infected individual produces is given [2] by,

$$R_0 = \frac{\beta}{\gamma} \tag{20}$$

Depends on time with the lockdown measures, the properties of virus and its mutation, etc. factors. These all factors are the functions of time. Considering that γ is constant with time, (17) clearly implies that β is the function of time. And in turn a is the function of time. However, for our calculations in the predictions, we will consider its mean value constant over further period of time in constant conditions of lockdown and without lockdown. Let a_l be the mean value of a calculated from previous records using (16) and a_{nl} is the mean value of a since outbreak till lockdown start. We assume that after lockdown the mobility of individuals is same as that was before lockdown. Let t_l be the time at which there is lockdown. With this our parameter 'a' becomes as,

$$a = \begin{cases} a_l ; lockdown \\ a_{nl} ; nolockdown \end{cases} \tag{18}$$

It is true the fact that the parameters b and c are as well are the functions of time as the recovery rate or death rate may be influenced by the immunity response of individuals or the herd immunity concept. However, the recoveries and death count in the initial stages of outbreak are relatively small and may not give enough characteristic or deviation to fit their curves, especially after lockdown state. It is assumed that lockdown was taken immediately until the death and recovery count has not shown reasonable deviations. Hence we calculate the parameters b and c where they show a near constant trend and utilize their mean values for predicting the recoveries and

deaths during and after lockdown. We will keep their values constant w.r.t time henceforth.

C. *The Nature of Solution curves and brief explanation to pandemic dynamics*

The infected count curve is a distorted bell shaped graph as shown in Figure 1 in blue, the maxima of curve gives the peak magnitude and the time at which it may occur. The inflection point of this curve has maximum rate of infection. Both the death and recovery curve has a logistic nature.

This follows, as the susceptible population is infected, simply stated will either live or die. If they show resistance or higher immunity, the recovered compartment gets filled with a rate proportional to the infected count and who cannot sustain the disease will go in dead compartment with the rate proportional to infected count. As these to compartments get filled with time, there is decrease in active cases or the infected population. But at the same time the virus keeps on infecting the new individuals. At some time when the rate of infection is in the dynamic equilibrium with the recovery and death rate, the count of infections is at maximum which we here refer to as the peak of outbreak. After which all the rates come to a static equilibrium with infection and death rate reducing to zero asymptotically.

However, if we are having less initial data points, we cannot fit the curve with reasonable accuracy. This is because there is no characteristic deviation in parameters in initial stage. At this position it becomes very critical that even 0.1% change in curve parameters drastically affect the prediction.

D. *Sensitivity of parameters*

It is observed that even 0.1 % change in these parameters especially a causes around 30% change in predicted values. It implies that even 10% improvement in recovery or decrease in infection rate can cause volatile change in predictions.

Also the data available to us is on daily basis so the minimum time step '*dt'* we can take is of 1 day or 24 hours. It might be so that if the data is updated every 3 to 4 hours in a day there might be greater accuracy with $1/8^{th}$ day or $1/6^{th}$ day step as this model is a differential system and lesser amount of '*dt'* is preferable for accurate parameter estimation.

CONCLUSION

From this report we have tried to put forward some quantitative prediction, given some suggestions to various bodies of the society and execution and as well given a live tool in the form of spreadsheet which will enable any individual or authority to analyze and predict the COVID-19 outbreak in their areas.

ACKNOWLEDGMENTS

In the first position I would like to thank my mother, Smt. Shilpa Vijay Chavadekar for encouraging me for this study and my grandfather Dr. Shivaji Karad, who has a major in 'The Preventive and Social Medicine' for guiding me through the course. I would also like to thank the team behind Arogya Maharashtra [4][5] portals and Pune corona tracker [12] developers for providing me with the live data. Also a huge thanks to Henri Froese [2] to provide a simple explanation on the dead compartment of SIR-D epidemic model.

REFERENCES

[1] Rajas Vijay Chavadekar "Rvc Pandemic Predictor v1.1" spreadsheet. Available on https://unipune.academia.edu/RajasChavadekar

[2] Henri Froese "Infectious Disease Modelling: Beyond the Basic SIR Model" https://towardsdatascience.com/infectious-disease-modelling-beyond-the-basic-sir-model-216369c584c4

[3] https://en.wikipedia.org/wiki/2020_coronavirus_pandemic_in_Pune

[4] https://arogya.maharashtra.gov.in/1175/Novel--Corona-Virus

[5] https://phdmah.maps.arcgis.com/apps/opsdashboard/index.html#/2cc0055832264c5296890745e9ea415c

[6] Bohner, Martin & Streipert, Sabrina & Torres, Delfim F. M.. (2018). Exact Solution to a Dynamic SIR Model. Nonlinear Analysis: Hybrid Systems. 32. 10.1016/j.nahs.2018.12.005.

[7] Biswas, Md. Haider Ali & Paiva, Luís & De Pinho, Maria do Rosario. (2014). A SEIR Model for Control of Infectious Diseases with Constraints. Mathematical biosciences and engineering: MBE. 11. 10.3934/mbe.2014.11.761.

[8] https://news.abplive.com/videos/news/india-know-all-about-the-most-dangerous-avatar-of-coronavirus-1208605

[9] https://www.census2011.co.in/census/city/375-pune.html

[10] https://www.worldometers.info/coronavirus/

[11] https://www.fortuneindia.com/technology/covid-19-vaccine-possible-by-q2-of-2022-adar-poonawalla/104401

[12] https://punecoronatracker.in/

[13] https://timesofindia.indiatimes.com/india/69-of-cases-found-positive-were-asymptomatic-icmr/articleshow/75282825.cms

[14] https://theprint.in/india/indians-seem-to-have-genetic-and-regional-advantages-in-fight-against-coronavirus/393939/

[15] https://www.timesnownews.com/international/article/coronavirus-could-become-endemic-like-hiv-and-may-never-go-away-warns-who/591592

[16] https://economictimes.indiatimes.com/industry/healthcare/biotech/healthcare/mm-along-with-two-psus-helping-ventilator-manufacturer-to-scale-up/articleshow/74822747.cms

[17] https://www.thehindu.com/news/national/other-states/wipro-to-turn-pune-campus-into-covid-19-hospital/article31511376.ece

[18] https://m.economictimes.com/industry/auto/auto-news/mercedes-benz-to-set-up-1500-bed-temporary-hospital-in-pune-for-covid-19-patients/amp_articleshow/74931208.cms#aoh=15895625070679&referrer=https%3A%2F%2Fwww.google.com&amp_tf=From%20%251%24s

[19] http://www.punekarnews.in/500-bed-isolation-ward-and-icu-for-50-ready-at-skn-hospital-pune-to-combat-covid-19/

[20] https://www.hindustantimes.com/cities/pmc-to-acquire-beds-at-private-hospitals-to-treat-covid-19-patients/story-7IW0t0lt40I3tkVqXDpeFM.html

[21] https://www.mohfw.gov.in/pdf/ImmunityBoostingAYUSHAdvisory.pdf

[22] https://www.hindustantimes.com/pune-news/khadakwasla-dam-catchment-back-to-back-notices-to-zp-by-mpcb-fail-to-curb-pollution/story-nPVqh431t3rIHM5A7vrX7J.html

[23] https://www.sciencemag.org/news/2020/04/coronavirus-found-paris-sewage-points-early-warning-system#

[24] D'Acquisto F. Affective immunology: where emotions and the immune response converge. Dialogues Clin Neurosci. 2017 Mar;19(1):9-19. PMID: 28566943; PMCID: PMC5442367.