



Cigniti

To Extend or Not to Extend – That is the Question

A Tech Brief



Introduction

With the COVID-19 pandemic raging across India, we have been under lockdown since March 25th, 2020. It is widely welcomed by close to 1.3 billion people, even though this has bought their lives to a standstill. The 800-pound gorilla in the room, of course, are the questions **“When should this lockdown be relaxed and how do we know that we are making progress?”**.

In any epidemic, **Rt** is the measure known as the **effective reproduction number**. It is the average number of people who become infected by an infectious person at a time t . The most well-known version of this number is the basic reproduction number: **R0** when $t = 0$. However, **R0** is a single measure that does not adapt with changes in behavior and restrictions.

As a pandemic evolves, increasing restrictions (or potential relaxing of restrictions) changes **Rt**. Knowing the current **Rt** is essential for policy-based decision-making. When $Rt > 1$, the pandemic will spread through the entire population. The lower **Rt**, the more manageable the situation.

The value of **Rt** helps us in:

- Understanding how effective the non-pharmaceutical interventions have been in controlling the outbreak.
- Giving vital information, regarding whether we should increase or reduce restrictions, based on our competing goals of economic prosperity and saving human lives.[1]

Somehow this particular insight has been mainly missed by the world. Except for Hongkong[2], no one seems to be tracking this, at least on a real-time basis. This number is generally not that useful at the national level. The key aspect is to understand this number at the state or district level, where decisions regarding tightening or relaxing the non-pharmaceutical interventions are implemented.

In this tech brief, let's try and discuss a framework for this solution for the Indian states of Telangana (where I am based), Maharashtra, and Tamil Nadu, where the number of COVID cases seems to be growing at the fastest rate in India.

As part of future work, we will be trying to do the same at the district/city level for a better understanding of **Rt** at the ground level.

This borrows heavily from the work of Betterncourt and Riberio[3] and also from Kevin's GithubRepository[4].

Approach

We have an estimate of the number of new COVID-19 patients daily. We can use this to estimate the current value of R_t . We can also see that the value of R_t will depend on R_{t-1} (yesterday's value) and for every previous value of R_{t-n} .

We can use Bayes Rule to update our belief about R_t , based on the new infection data that we are seeing each day.

$$P(R_t | k) = [P(R_t) \cdot \text{Likelihood}(R_t | k)] / P(k)$$

The above equation can be interpreted as, having seen k cases, the distribution of R_t is equal to:

- The prior belief of the value R_t is assumed to be $P(R_t)$
- Times the likelihood of R_t given that we have seen k cases
- Divided by the probability of seeing k cases under all hypotheses of R_t .

Importantly, since $P(k)$ is a constant, the numerator is proportional to the posterior. As all probabilities sum to 1.0, we can ignore $P(k)$ and normalize the posterior sum to 1.0

$$P(R_t | k) \propto P(R_t) \cdot \text{Likelihood}(R_t | k)$$

Of course, this is for one day. Generalizing this across all the previous days we have measurements for, we can write the same as

$$P(R_t | k) \propto P(R_0) \cdot \text{Likelihood}(R_1 | k_1) \cdot \text{Likelihood}(R_2 | k_2) \cdot \dots \cdot \text{Likelihood}(R_t | k_t)$$

With a uniform prior $P(R_0)$, this reduces to:

$$P(R_t | k_t) \propto \text{Likelihood}(R_t | k_t)$$

One of the potential issues with this Bayesian approach is that the posterior is equally influenced by events in the distant past as much as in the recent past. In our case, this would mean that if $R_t > 1$ for a long period, and has come under control ($R_t < 1$) recently, the posterior will get stuck at values > 1 for a long time.

Of course, this would not work for us, because the entire purpose of this exercise is to see when R_t has dipped below 1.

One way to resolve this would be to just use the previous “ m ” days for calculating the likelihood function, rather than the entire history.

LIKELIHOOD FUNCTION:

We will be using Poisson Distribution as the likelihood function for this analysis, as this is the preferred model for understanding the “number of arrivals” in a given time period. Given an average arrival rate of ‘ λ ’ new cases per day, the probability of seeing k new cases are distributed according to the Poisson distribution:

$$P(k | \lambda) = (\lambda^k e^{-\lambda}) / k!$$

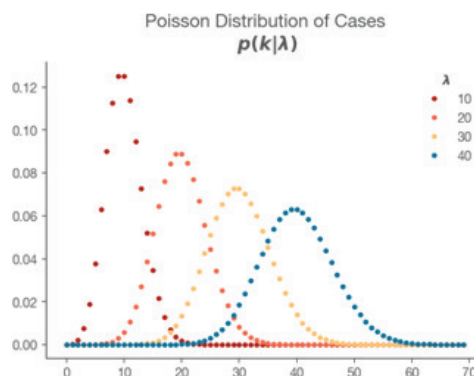


Figure 1: Poisson Distribution

DERIVING R_t FROM λ

The most important feature of this work is to connect R_t to λ . The derivation is itself out of the scope of this blog post, but the derivation can be found here.

$$\text{Derivation} = \lambda = kt \cdot 1eY(R_t - 1)$$

The Y is taken as the reciprocal of the serial interval (5 days for COVID-19).

The problem can now be written as

$$\text{Likelihood}(R_t | k) = (\lambda k e^{-\lambda}) / k!$$

In the next steps, we just have to perform the Bayesian update on the most likelihood function, which in this case we have chosen to be Poisson.

Just to Summarize

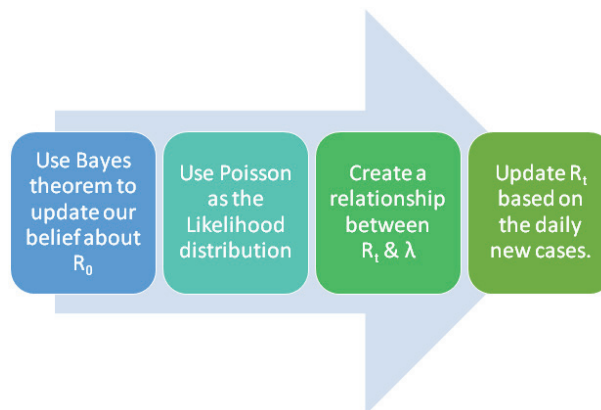


Figure 2: Approach Summary

Data for the Real World

We have used data from the COVID-19 India Tracker website (<https://www.covid19india.org/>). We have extracted the data for the states of Telangana, Maharashtra, and Tamil Nadu for the period 14th March 2020 to 14th April 2020.

We are in the process of collecting more data, but the present analysis is limited to the above-mentioned three states.

Analysis

The analysis has been conducted for each of the three states of Telangana, Maharashtra, and Tamil Nadu.

Telangana

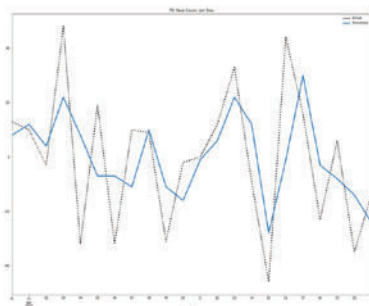


Figure 3: Gaussian Smoothed new cases for Telangana

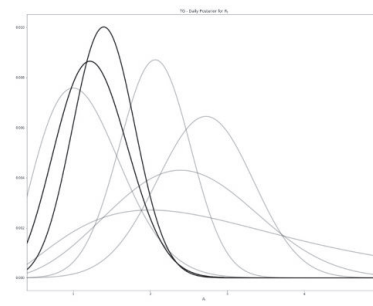


Figure 4: Bayesian Update showing an increase in confidence

Date	Most Likely R_t	Low @ 90% confidence	High @ 90% confidence
2020-03-31	2.00	0.50	5.54
2020-04-05	1.22	0.52	1.99
2020-04-10	1.22	0.52	1.99
2020-04-15	1.4	0.78	2.08
2020-04-21	1.4	0.78	2.08

Table 1: Confidence Intervals for R_t for Telangana

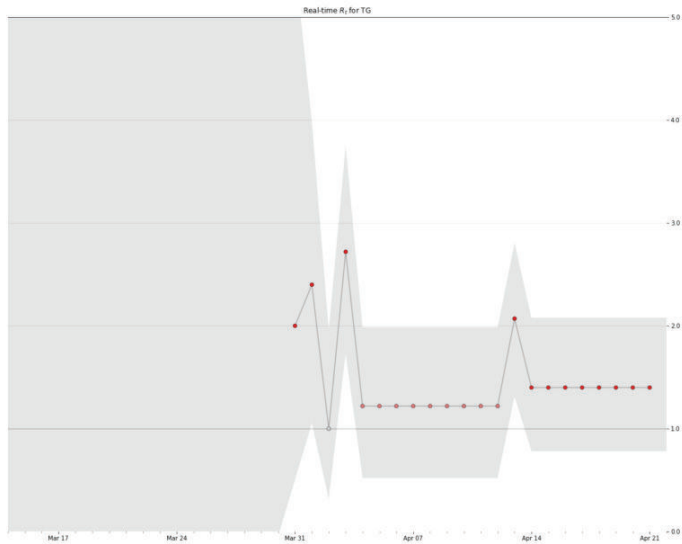


Figure 5: Pictorial Representation of Confidence Intervals

Maharashtra

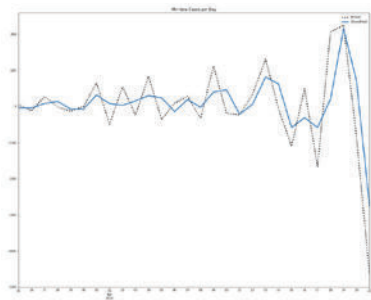


Figure 6: Gaussian Smoothed new cases for Maharashtra

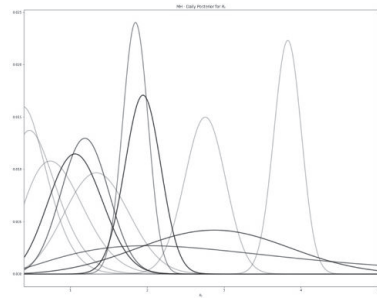


Figure 7: Bayesian Update showing an increase in confidence

Date	Most Likely R_t	Low @ 90% confidence	High @ 90% confidence
2020-03-31	2.87	1.39	4.43
2020-04-05	1.06	0.55	1.68
2020-04-10	1.19	0.72	1.73
2020-04-15	1.95	1.57	2.34
2020-04-21	1.85	1.58	2.13

Table 2: Confidence Intervals for R_t for Maharashtra

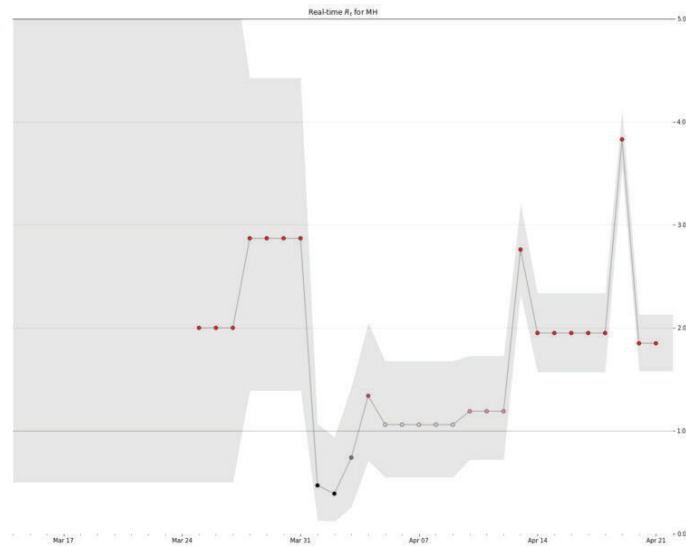


Figure 8: Pictorial Representation of Confidence Intervals

Tamil Nadu

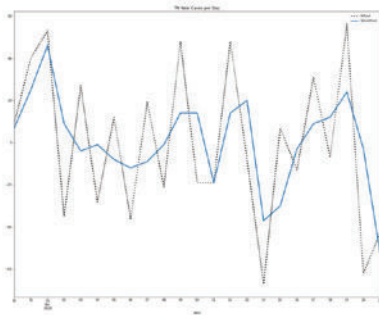


Figure 9: Gaussian Smoothed new cases for Tamil Nadu

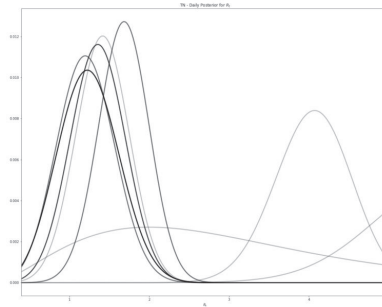


Figure 10: Bayesian Update showing an increase in confidence

Date	Most Likely R_t	Low @ 90% confidence	High @ 90% confidence
2020-03-31	5.66	4.26	6.99
2020-04-05	1.23	0.64	1.89
2020-04-10	1.20	0.63	1.80
2020-04-15	1.36	0.83	1.96
2020-04-21	1.69	1.17	2.20

Table 3: Confidence Intervals for R_t for Tamil Nadu

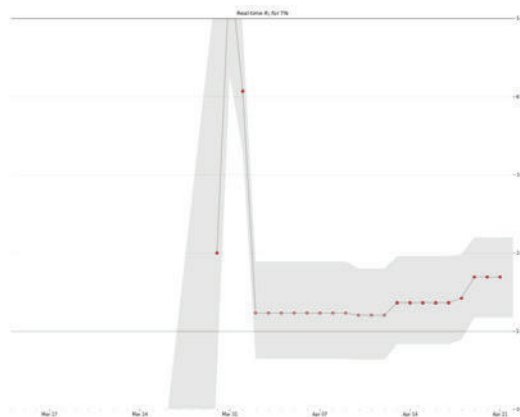


Figure 11: Pictorial Representation of Confidence Intervals

Implications

There is a general decline in R_t among the states and there is relatively a higher confidence level. But we are still not at that level where it is less than 1.

Future Work

We have planned to work on the following in the next few weeks:

- Real-time R_t for all the States and UTs. Given the availability of data, it can be extended to other countries.
- Publish the real R_t for each district in the country.
- An integrated dashboard that is updated automatically to aid decision-making around relaxing/tightening the lockdown.

References

[1] Gabriel Leung (2020) Lockdown Can't Last Forever. Here's How to Lift It. Retrieved from <https://www.nytimes.com/2020/04/06/opinion/coronavirus-end-social-distancing.html>

[2] School of Public Health, The University of Hong Kong (2020). Retrieved from <https://covid19.sph.hku.hk/dashboard>

[3] Luís M. A. Bettencourt, Ruy M. Ribeiro (2008) Real Time Bayesian Estimation of the Epidemic Potential of Emerging Infectious Diseases. Retrieved from <https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0002185>

[4] Kevin Systrom (2020) Estimating COVID-19's R_t in Real-Time. Retrieved from <https://github.com/k-sys/covid-19/blob/master/Realtime%20R0.ipynb>

[5] John K. Kruschke (2015) Highest Density Interval. Retrieved from <https://www.sciencedirect.com/topics/mathematics/highest-density-interval>

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CTO Speak



Data pipeline buildout, Software development, Salesforce development, AWS System admin/DevOps, BI/Dashboard. The execution has been very good.

- Satyadeep "Bobby" Patnaik, CTO



CEO Speak



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- Dr. Ganesh Naidoo, CEO



CTO Speak



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- Graeme Dollar, CTO



COO Speak



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- Mark Mortimer, COO



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