

コロナ感染レポート（2020年8月29日現在）
SEIRRモデルによる分析結果

Covid-19 Developments Report as of 29th August, 2020
SEIRR model analysis

2020年9月2日/ September 2, 2020
Promontory Financial Japan
An IBM company

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分析結果/Analysis results

* English follows Japanese.

(最近の動向)

新規感染者の動きをみると、前回レポート時（7月下旬）とは異なり、一日当りの新規感染者数が再び増加傾向にあった日本、オーストラリア、米国で、7月末（米国）～8月初（日本、オーストラリア）頃から増勢がピークアウトする一方、これまで収束状況にあった欧州において、スペインやフランス、ドイツ、英国、そしてイタリアでも7月末から8月初頃から増勢傾向が際立ち始めた。また同じようにこれまで収束状況にあった韓国でも、ここに来て新規感染者が急増する傾向にある。

なお、これら諸国の一日当り死者数は、日豪米では、前回までの分析で示した致死率低下が足許一服したためかここに来て感染者の動きと連動（2～3週間程度のラグ）するようになっており、足許は減少傾向。一方欧州では、（仮に致死率の低下傾向が続いていなければ）、足許はまだ目立っていないものの、今後緩やかに増加する可能性がある。また韓国では既に急ピッチで増加する傾向。

その他のエマージング諸国の新規感染者の動きをみると、ブラジルが緩やかにピークアウトしつつあるほか、ロシアでは漸減傾向が続く。一方、これまで漸減傾向にあったトルコやチリでは、足許横ばいの動きに転じている。インドでは引き続きオーバーシュートが続く。

(分析結果)

モデルによる分析の結果、日米豪等で新感染者が7月末～8月初を境に減少傾向に向かい始めたのは、再生産数の7月下旬（米国）から8月初頃（日本、豪州）の低下が寄与していることが分かった。特に豪州（1.856⇒0.87）や日本（1.392⇒0.899）の低下幅が大きかった。なお、googleのcommunity mobility reportをみる限り、日本では夏休み要因から職場への移動が、また豪州では公園等への移動が8月初頃から大きく落ちたものの、その後8月下旬には再び元の水準に戻っており、こうした再生産数の減少も一時的なものに過ぎない可能性もある。

同様に欧州においてここに来て新規感染者が増えているのも、バカンスシーズンに当たる6月中旬（独）から7月初（英、スペイン）にかけて再生産数が上昇しているためだと考えられる。

なお前回レポートで指摘したように、6月初頃からの致死率低下を仮定することで、多くの国で、新規感染者数と死者数の推移を整合的に説明することが可能となったわけだが、今回の分析の結果、同様のことがここにきて新規感染者数が増加に傾向にある欧州（ドイツ、イタリア、英国）にも当てはまること分かった。その一方で、豪州の場合は逆に致死率がここに来てやや上昇しているように見える。再生産数のみではなく、致死率も季節性からも影響を受ける可能性が懸念される。

(Recent trend)

In Japan, Australia and the United States, where the number of Covid-19 cases had been on the rise again, this increases have peaked out from around the end of July (United States) to the beginning of August (Japan, Australia). Meanwhile, in Europe including not only Spain and France but also Germany, the U.K. and Italy, where the epidemic had long been under control, the number of Covid-19 cases have started to increase from around the end of July to the beginning of August. The number of new cases is also increasing in Korea.

In Japan, Australia, and the United States, the number of fatalities per day in these countries has recently been linked to the movement of infected persons (with lag of about 2 ~ 3 weeks), probably because the decline in the fatality rate shown in the previous analysis has come to a halt, and hence the number on a downward trend. In Europe, on the other hand, (If the trend of decreasing fatality rates does not continue,) , but it is likely to see some moderate increase in deaths in the near future even though it is not yet noticeable. In Korea, it is already increasing rapidly.

In other emerging countries, the number of Covid-19 cases is gradually peaking out in Brazil and is on a downward trend in Russia. On the other hand, Turkey and Chile, which had been on a gradual decline, have recently leveled off. Overshooting continues in India.

(Analysis result)

Our model analysis indicates that the decline in the reproduction number from the end of July (United States) to the beginning of August (Japan and Australia) contributed to the fact that the number of newly infected persons began to decrease from the end of July to the beginning of August in those countries. In particular, Australia (1.856 ⇒ 0.87) and Japan (1.392 ⇒ 0.899) saw the largest declines in reproduction rates. According to Google's community mobility report, the number of people who moved to work has dropped sharply from around the beginning of August due to summer vacation in Japan, and similarly the number of people moves to parks in Australia dropped around the same period. They might contribute to the decline in reproduction rates in those countries. However, the Google mobility report indicates that those mobility levels returned to the previous level in late August in Japan and Australia, implying that the decline in reproduction numbers could be only temporary.

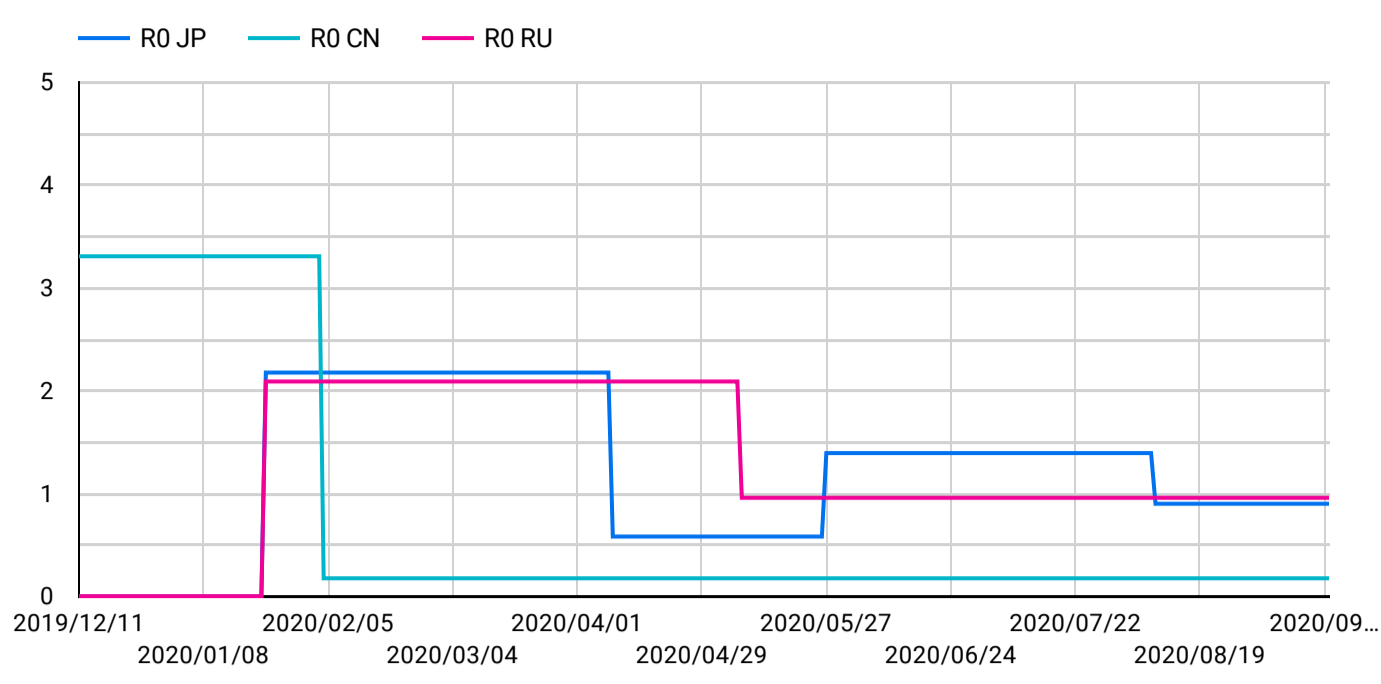
Meanwhile, the increase in the number of new infections in Europe is mainly due to a rise in reproduction numbers from mid-June (Germany) to early July (U.K. and Spain), which might be caused by the starting of vacation seasons.

As pointed out in the previous report, by assuming a decline in the fatality rate from around the beginning of June, it has become possible to explain the developments in the number of new infections and deaths in a consistent manner in many countries. The results of this analysis also show that the same applies to Europe (Germany, Italy, and the United Kingdom), where the number of new infections has recently been increasing. In Australia, on the other hand, the fatality rate appears to have risen slightly since then. This might cause some concerns that not only the number of reproduction rates but also the mortality might assume the seasonality feature.

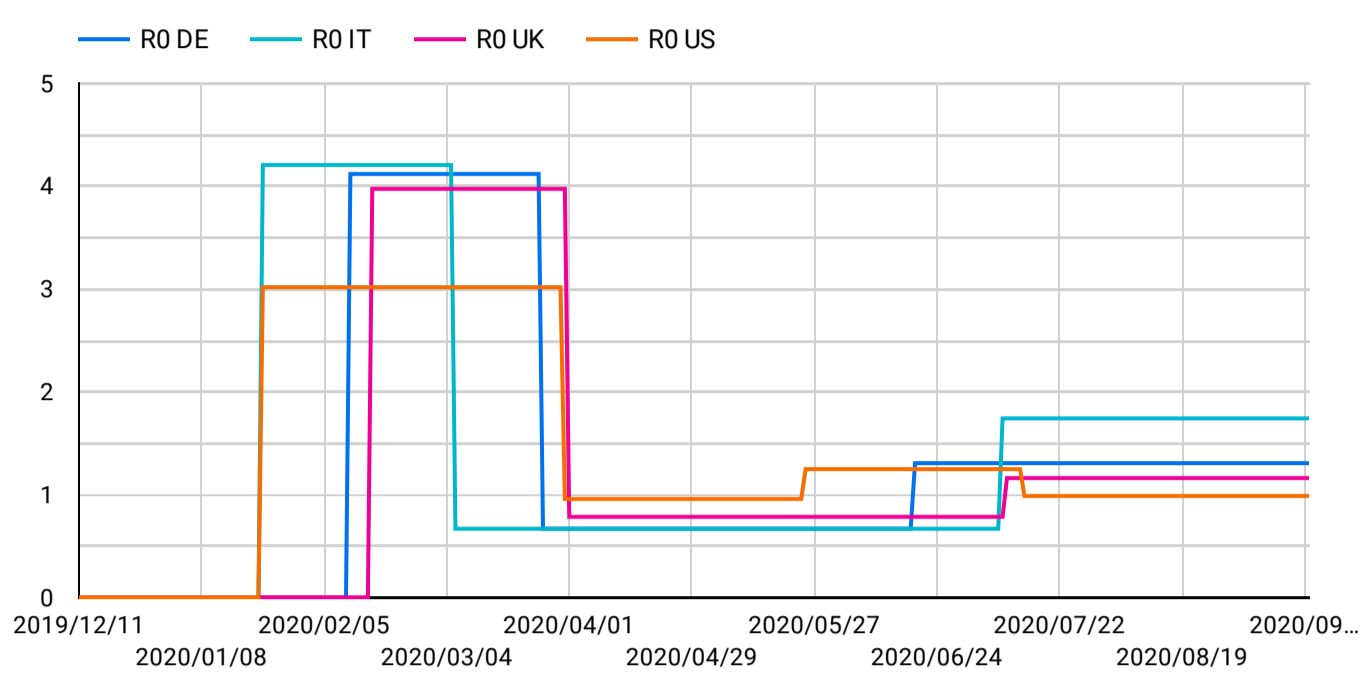
主要パラメータ推計値の各国比較 Cross-country comparison of major parameter estimates

R0（再生産数）推計値 /R0 estimates

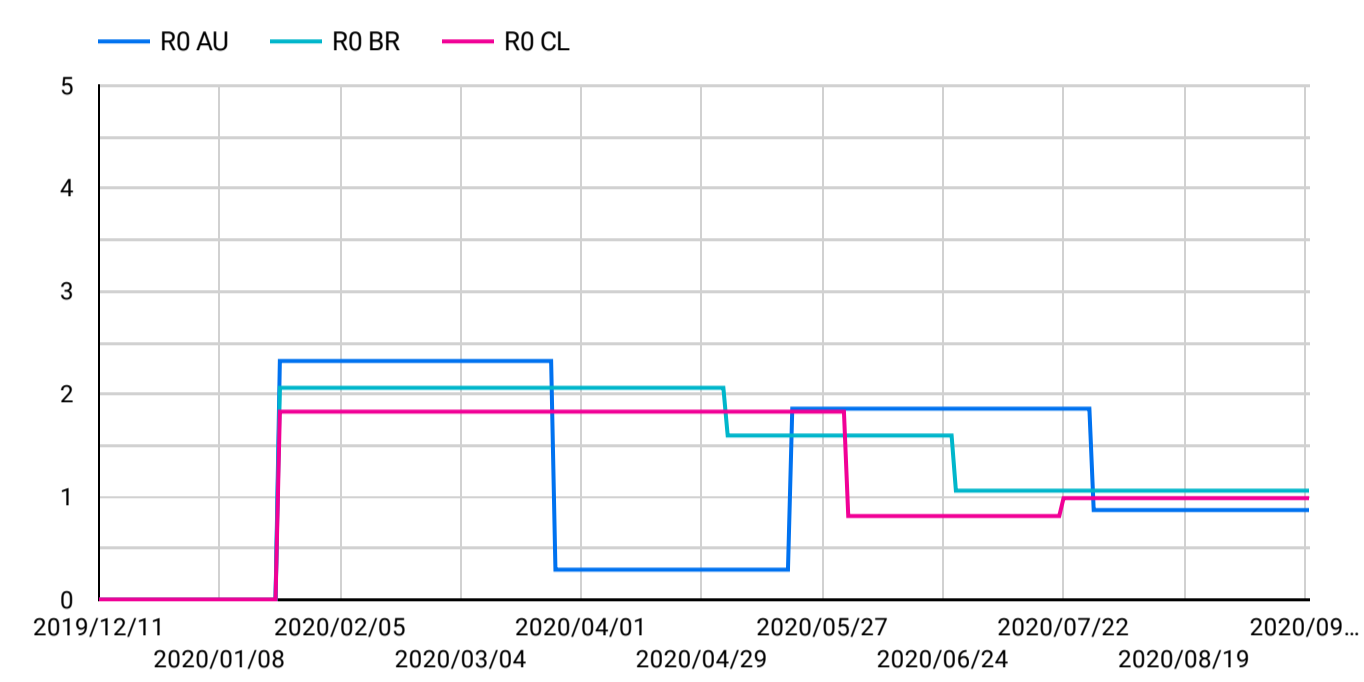
R0（再生産数）推計値（アジア及びロシア）
R0 estimates (Asia and Russia)



R0（再生産数）推計値（欧州及び米国）
R0 estimates (Europe and the U.S.)

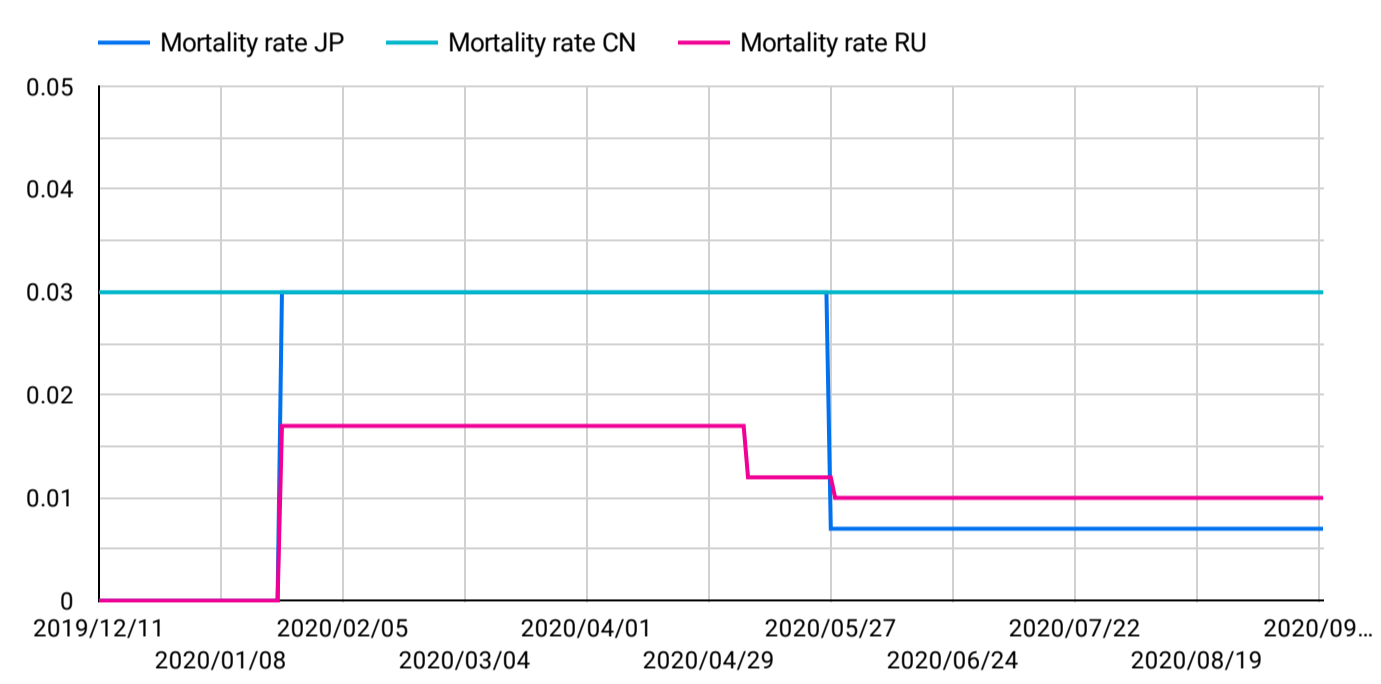


R0（再生産数）推計値（南半球）
R0 estimates (Southern hemisphere)

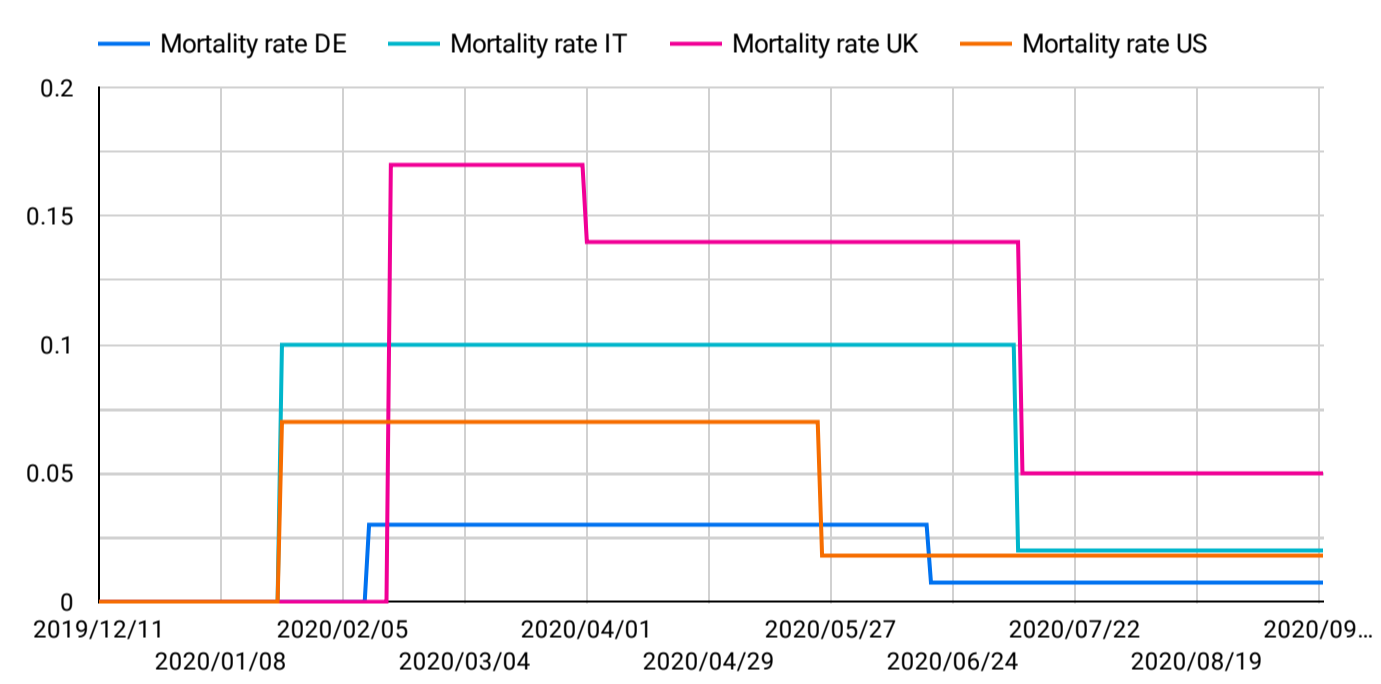


致死率推計値 /Mortality rate estimates

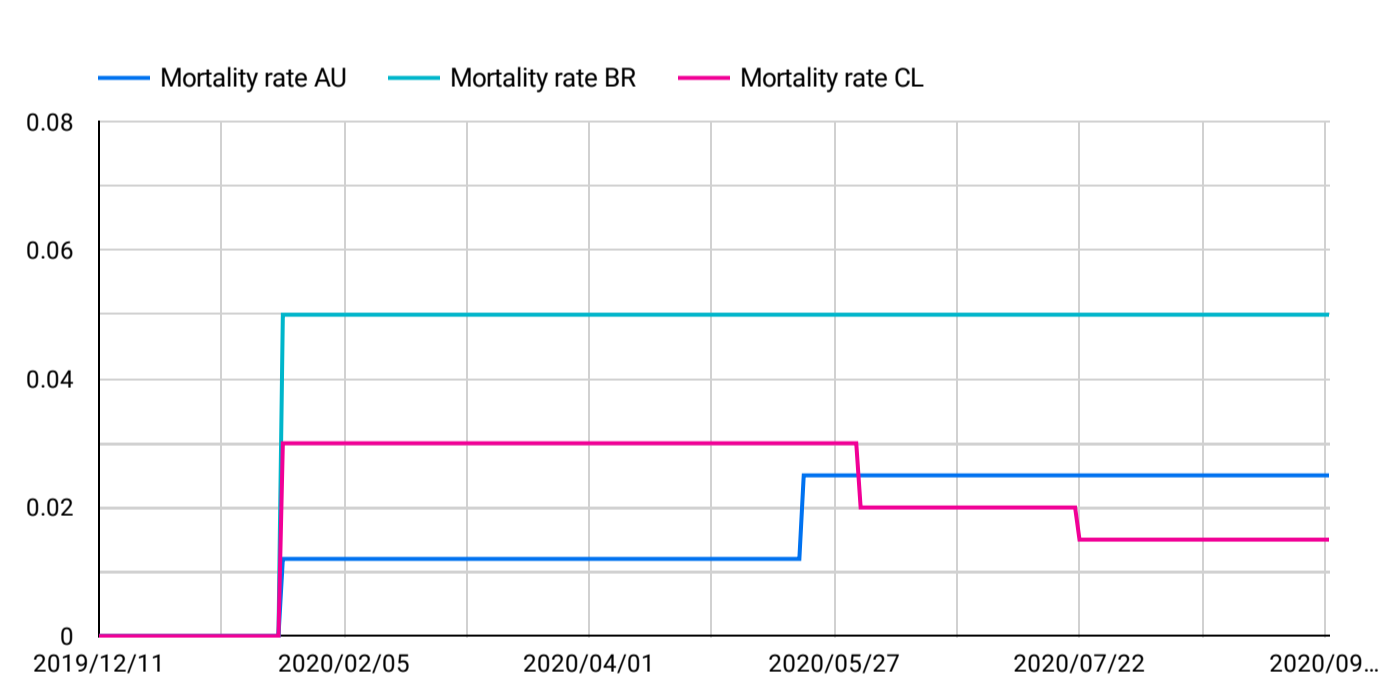
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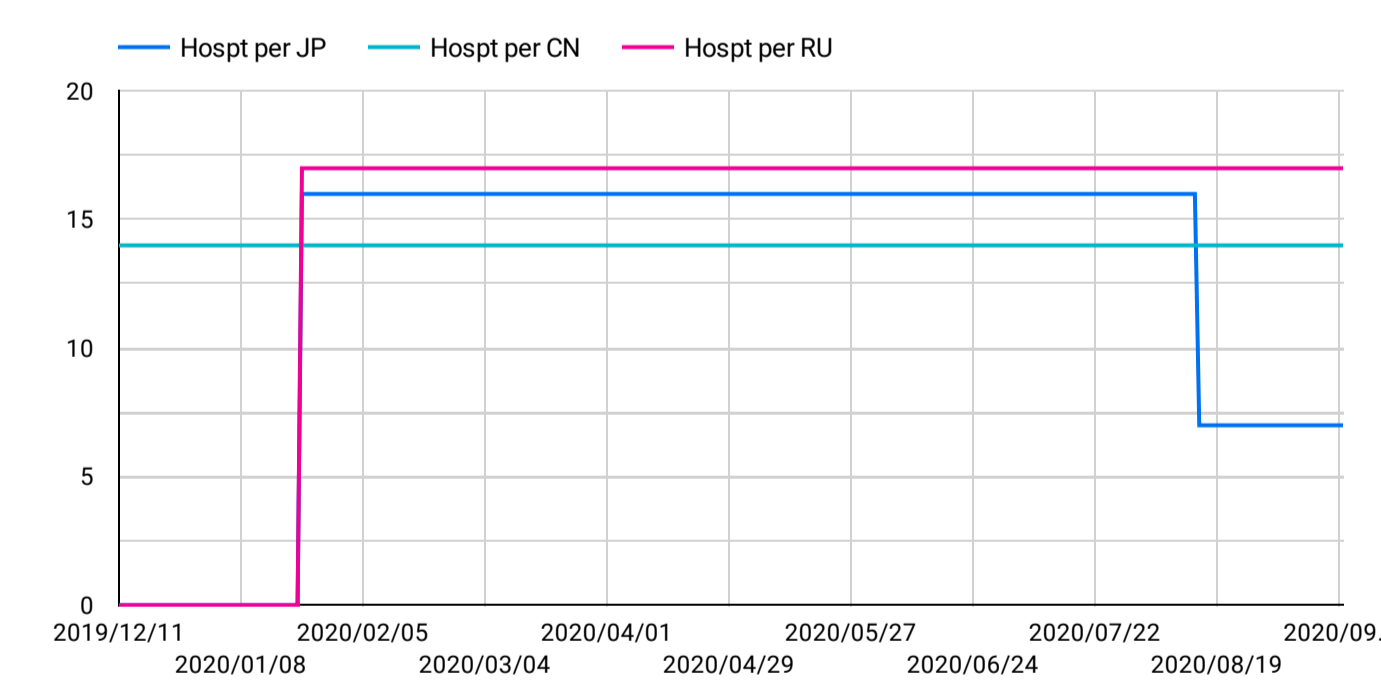


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Mortality rate estimates (Southern hemisphere)

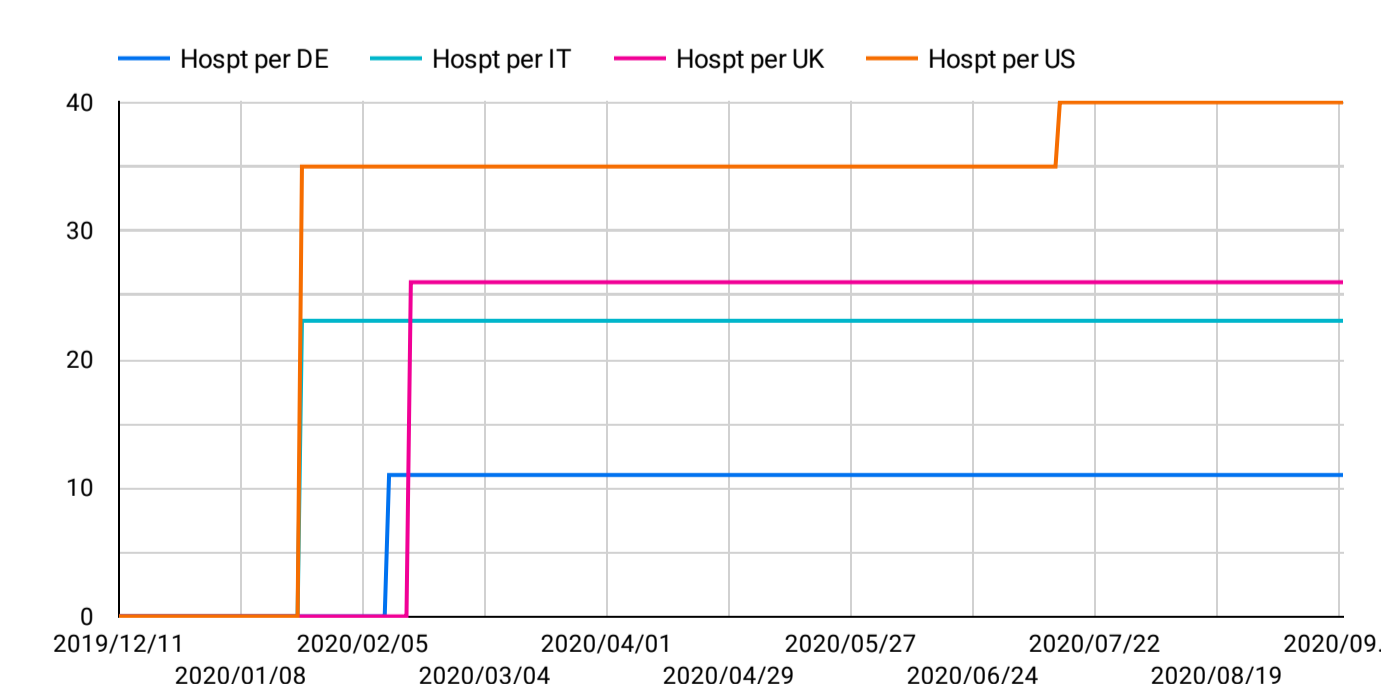


入院期間 /Hospitalization period

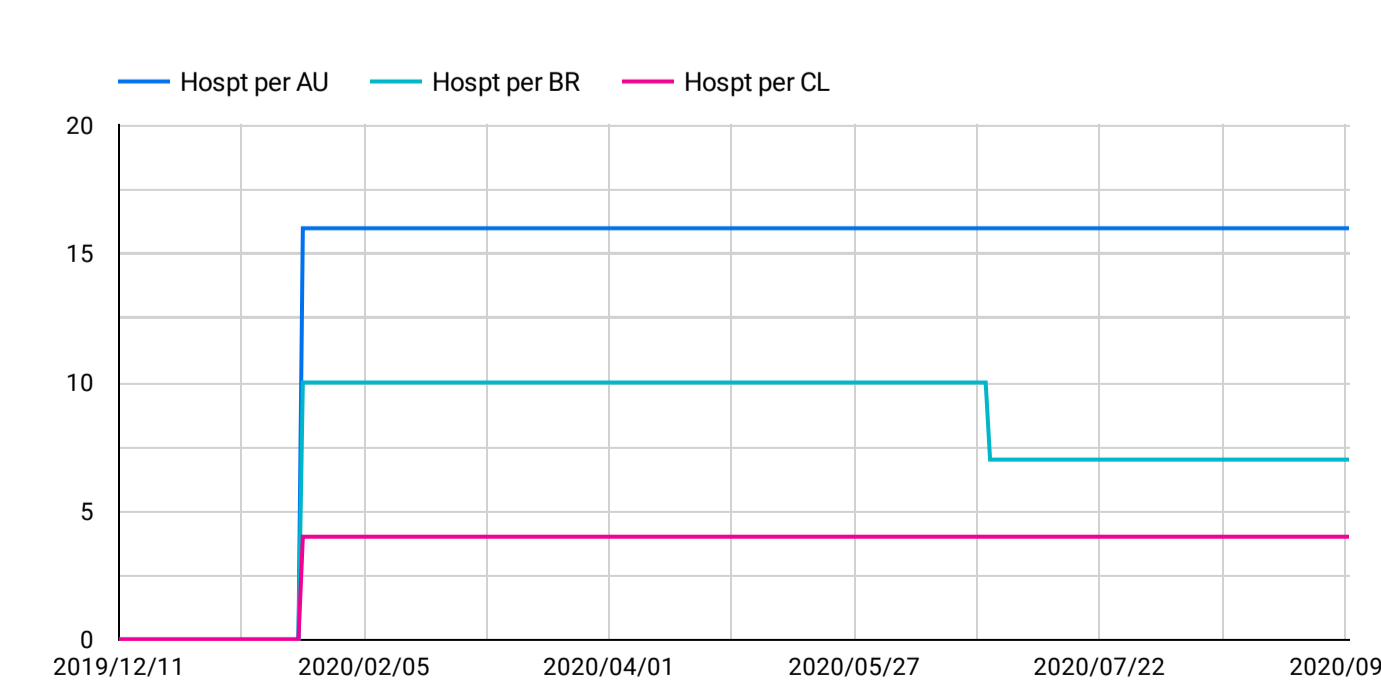
入院期間推計値（アジア及びロシア）
Hospitalization period estimates (Asia and Russia)



入院期間推計値（欧州及び米国）
Hospitalization period (Europe and the U.S.)

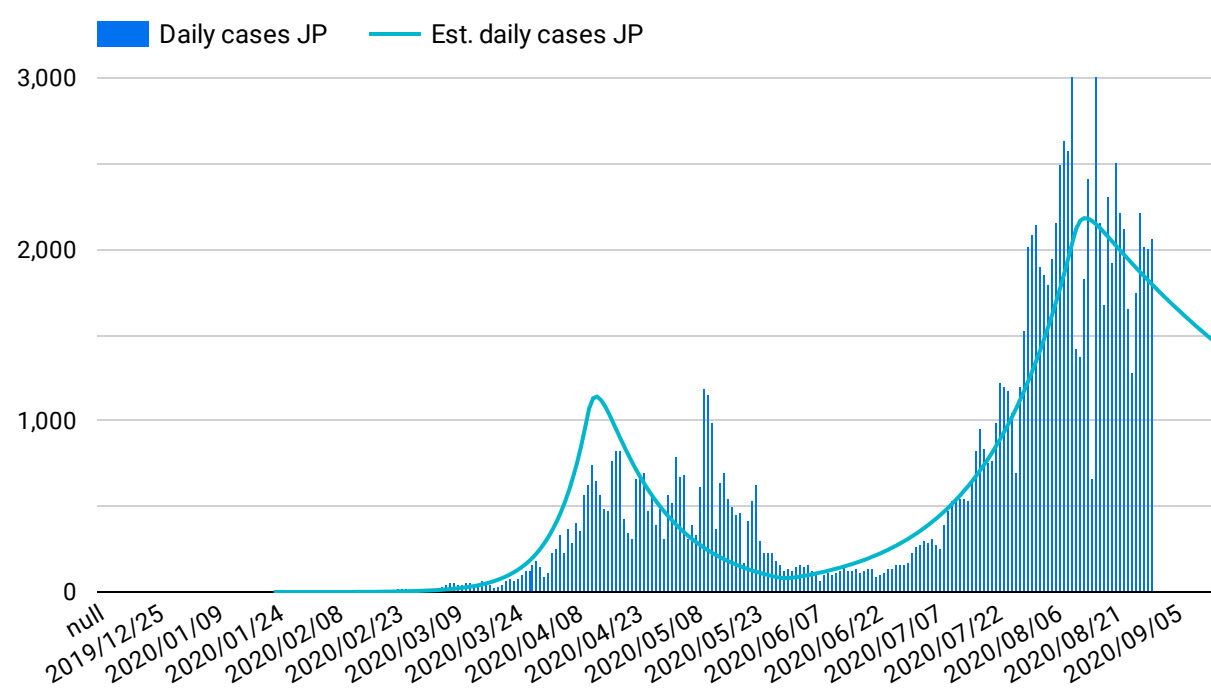


入院期間推計値（南半球）
Hospitalization period estimates (Southern hemisphere)

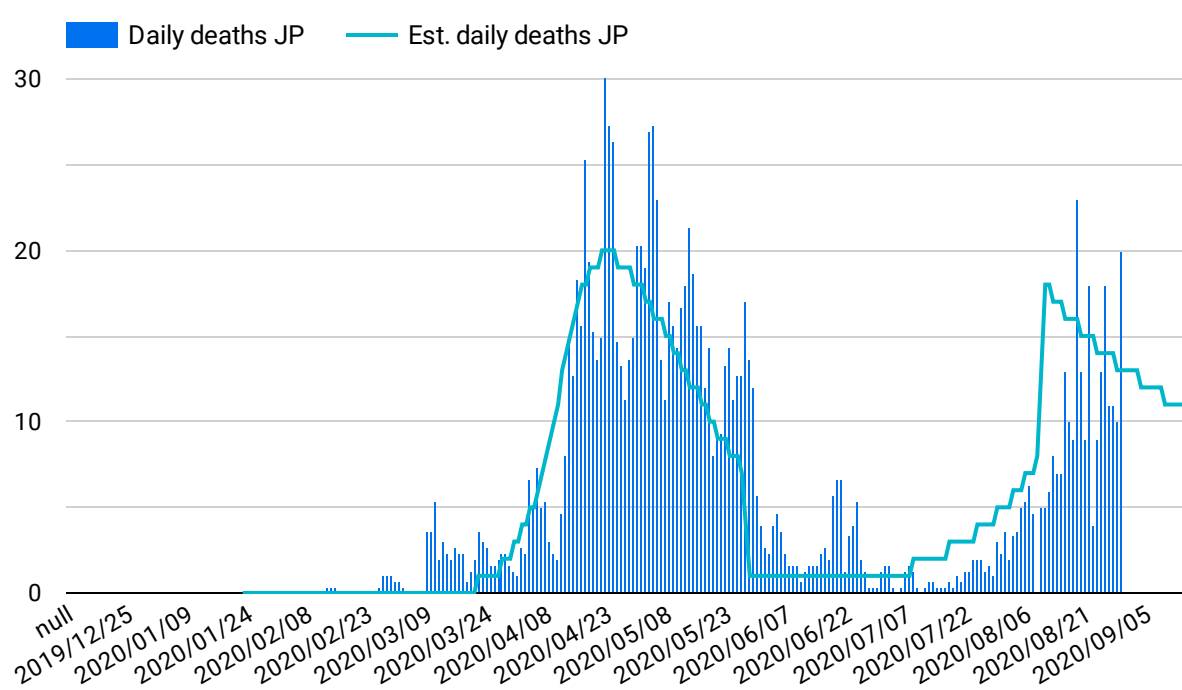


日本/Japan

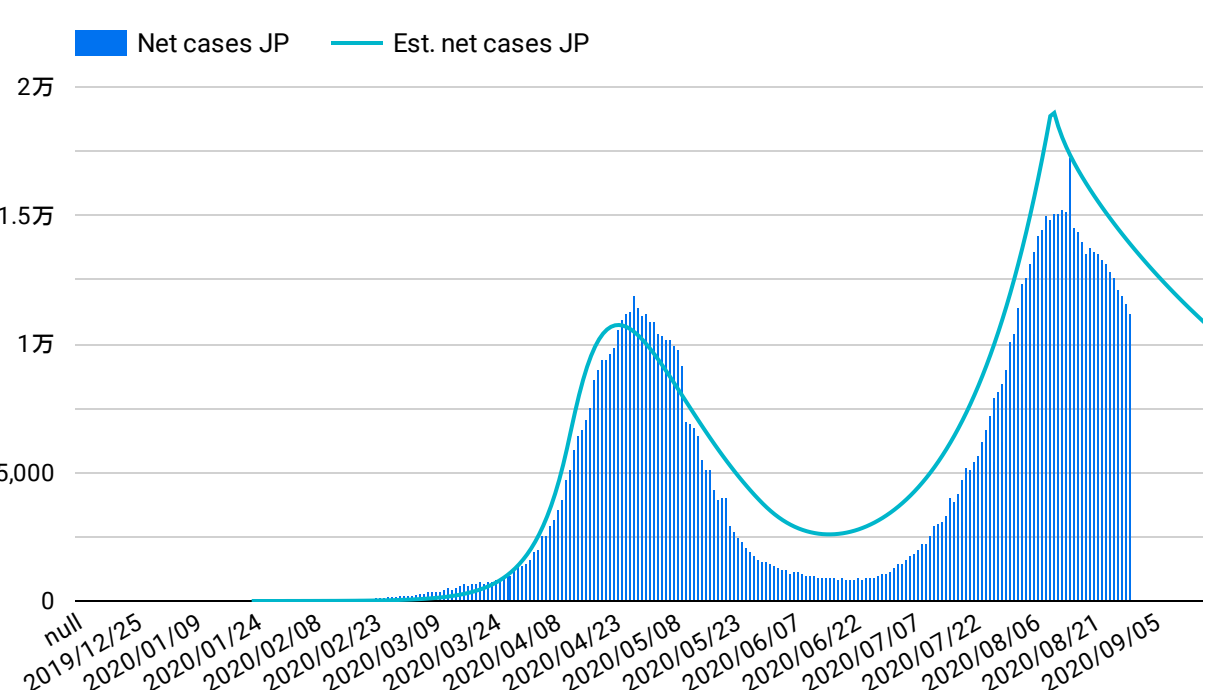
1日当り新規感染者数とモデル推計値 Daily new cases and model estimates



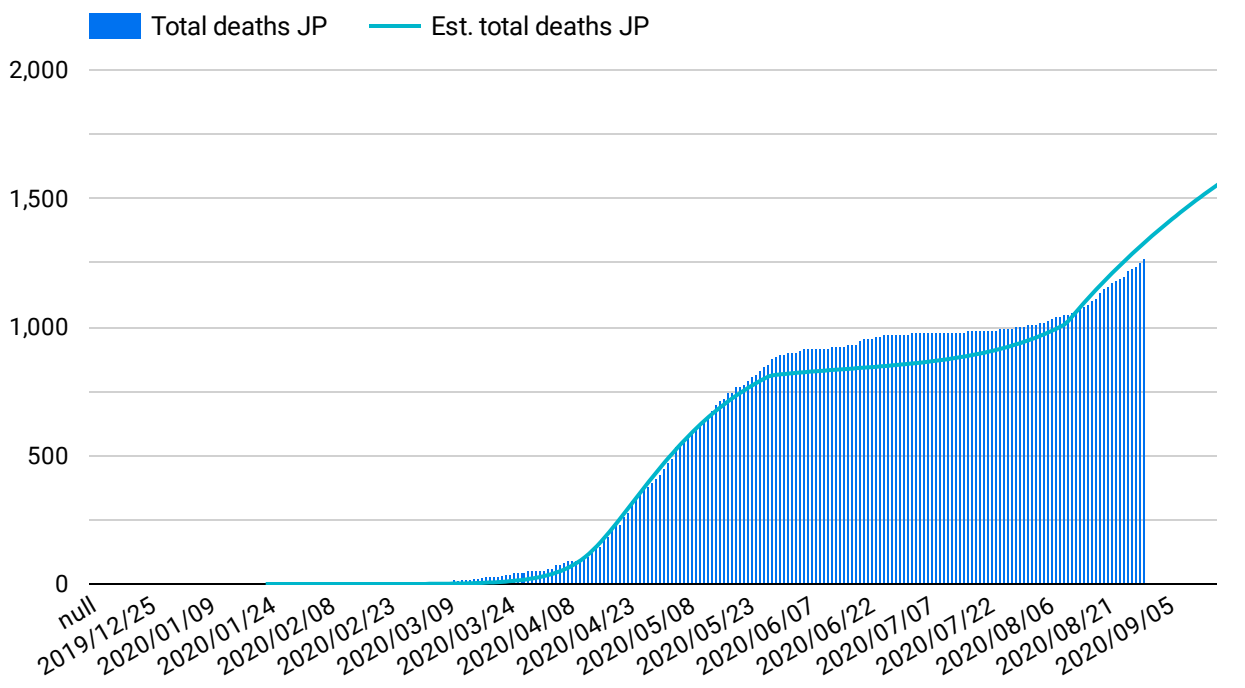
1日当り死者数とモデル推計値 Daily new deaths and model estimates



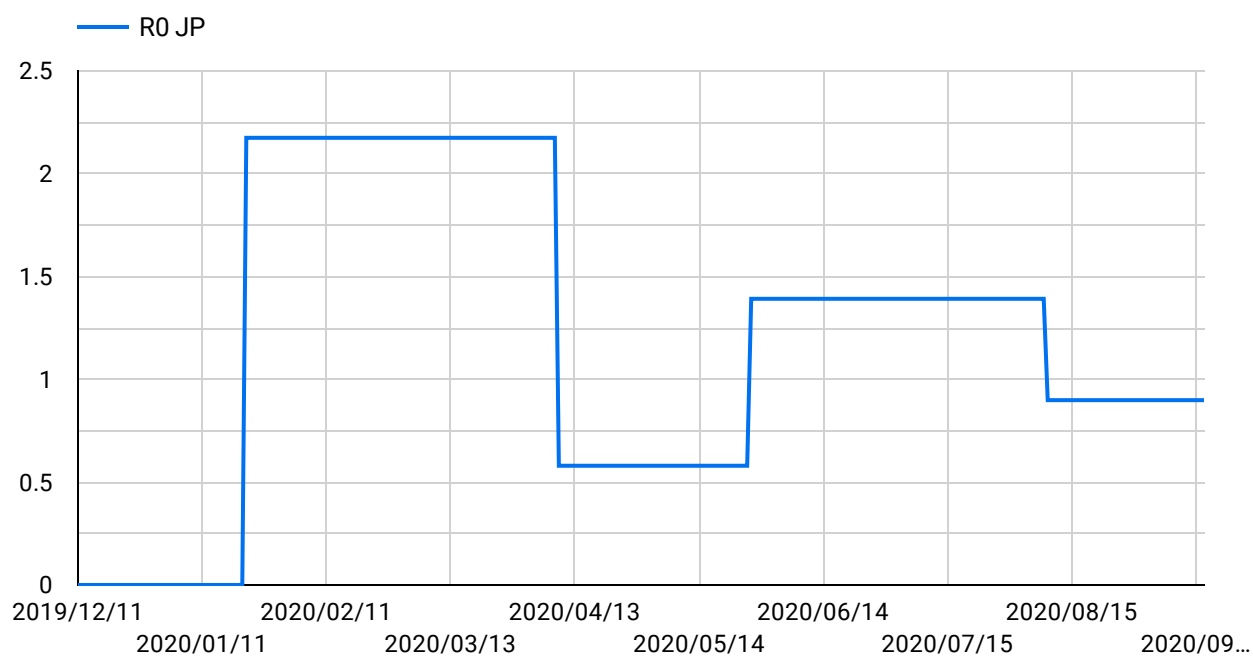
ネット総感染者数とモデル推計値 Net total cases and model estimates



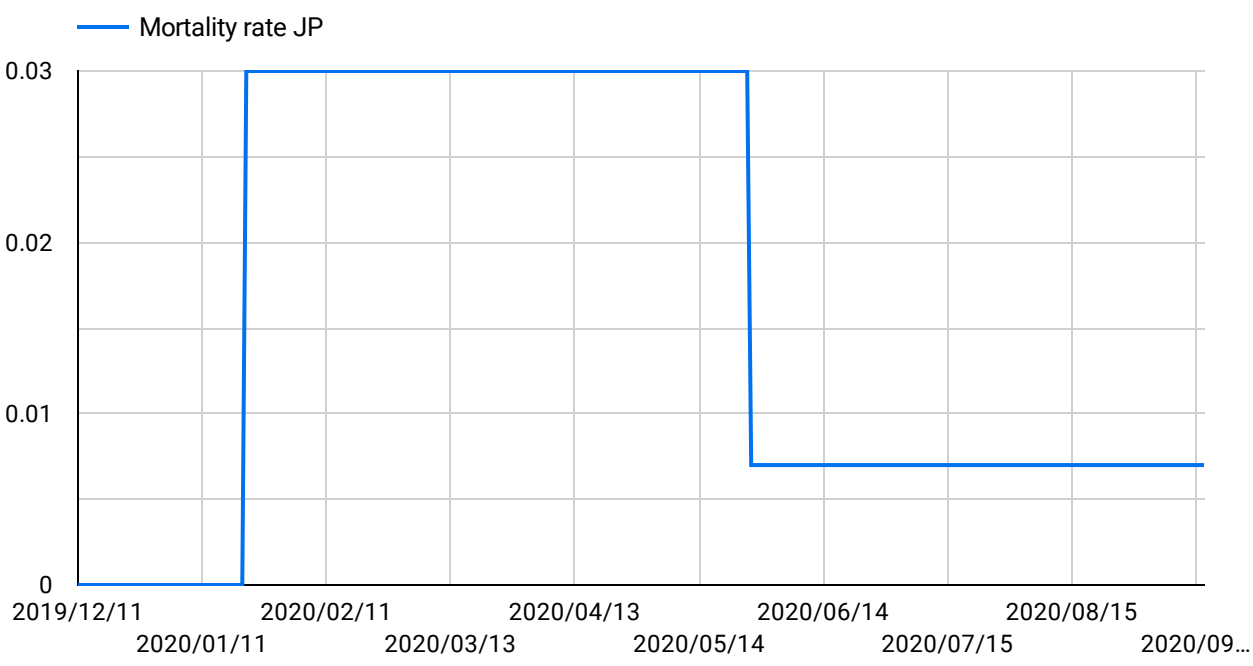
累計死者数とモデル推計値 Total deaths and model estimates



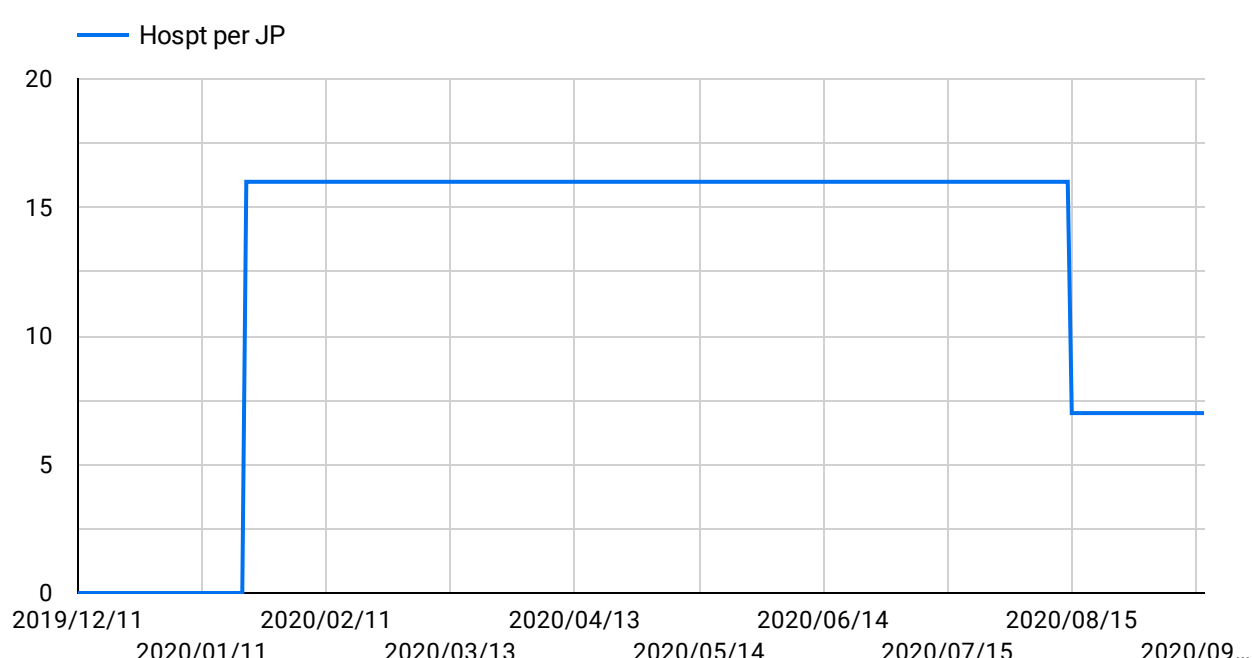
R0 (再生産数) 推計値 R0 estimates



致死率推計値 Mortality rate estimates

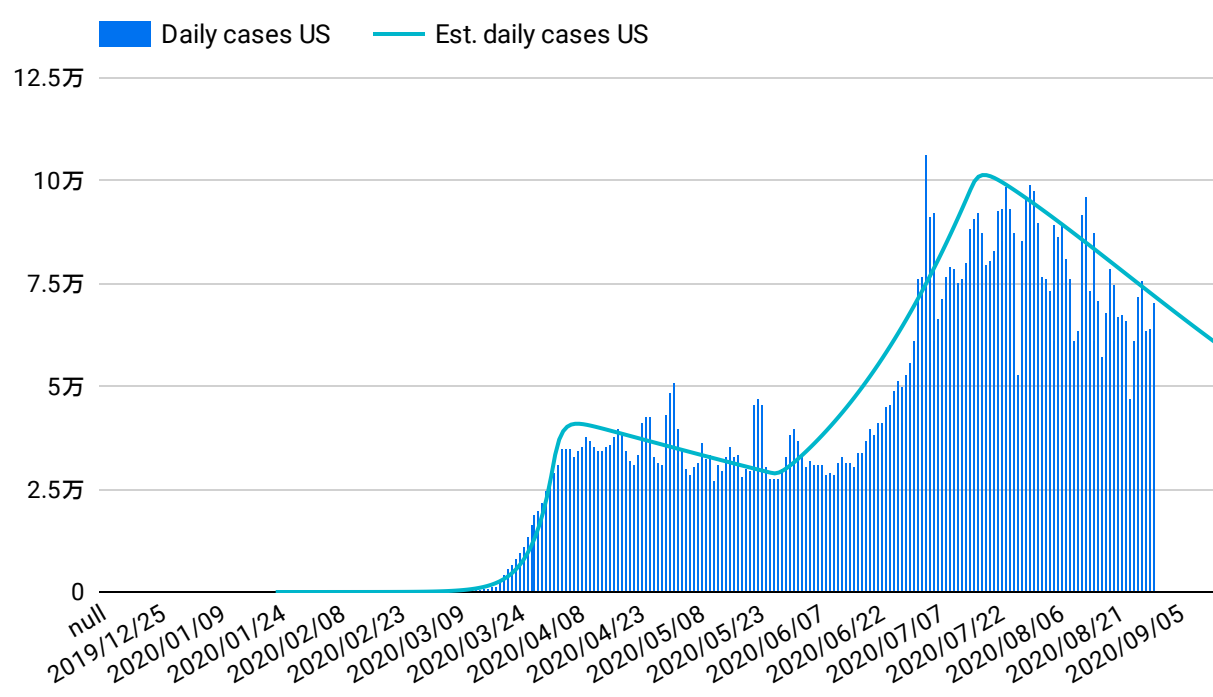


入院期間推計値 Hospitalization period estimates

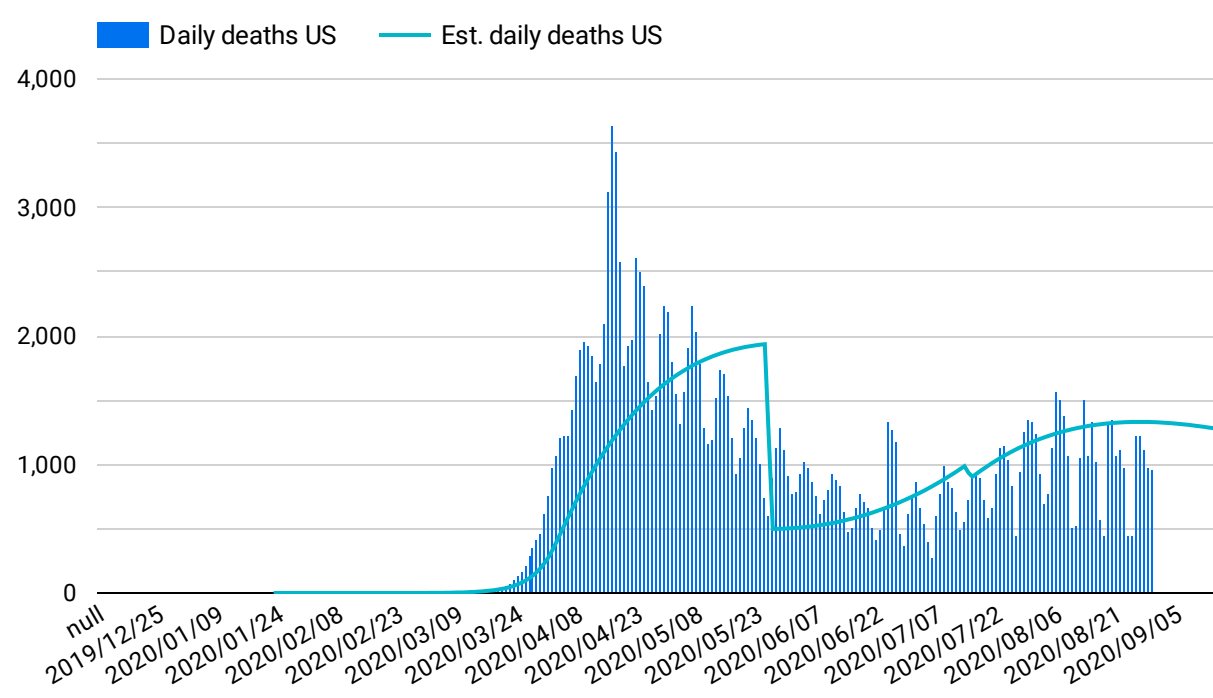


米国/U.S.

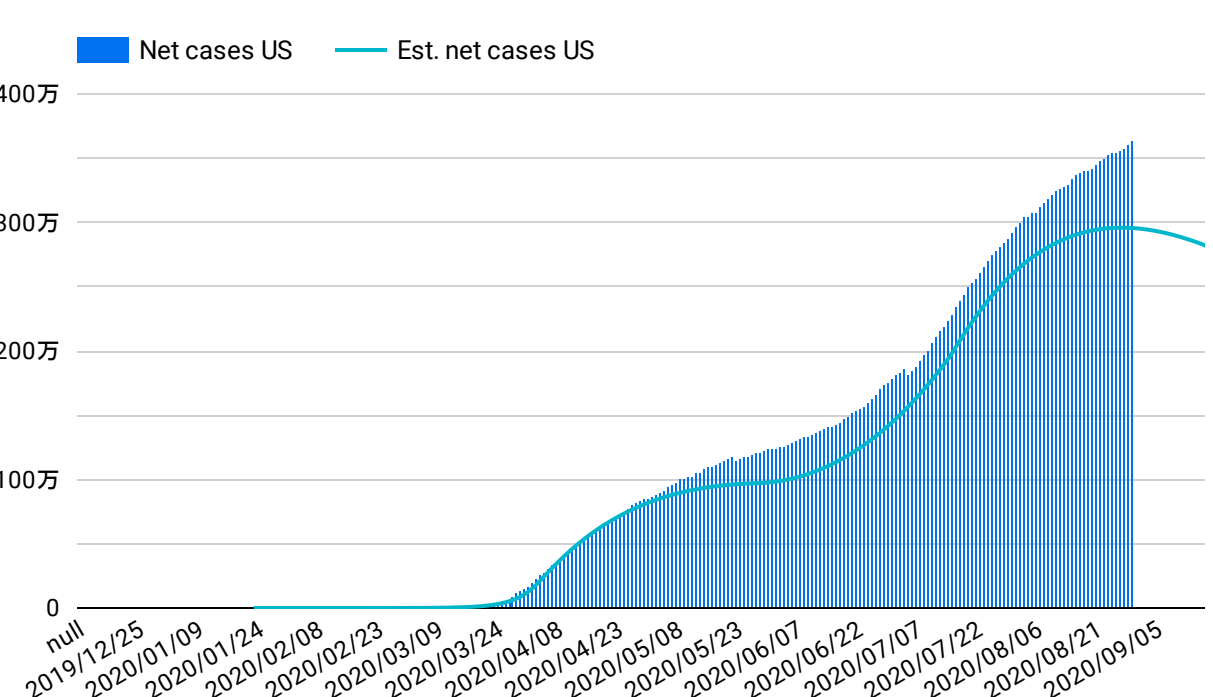
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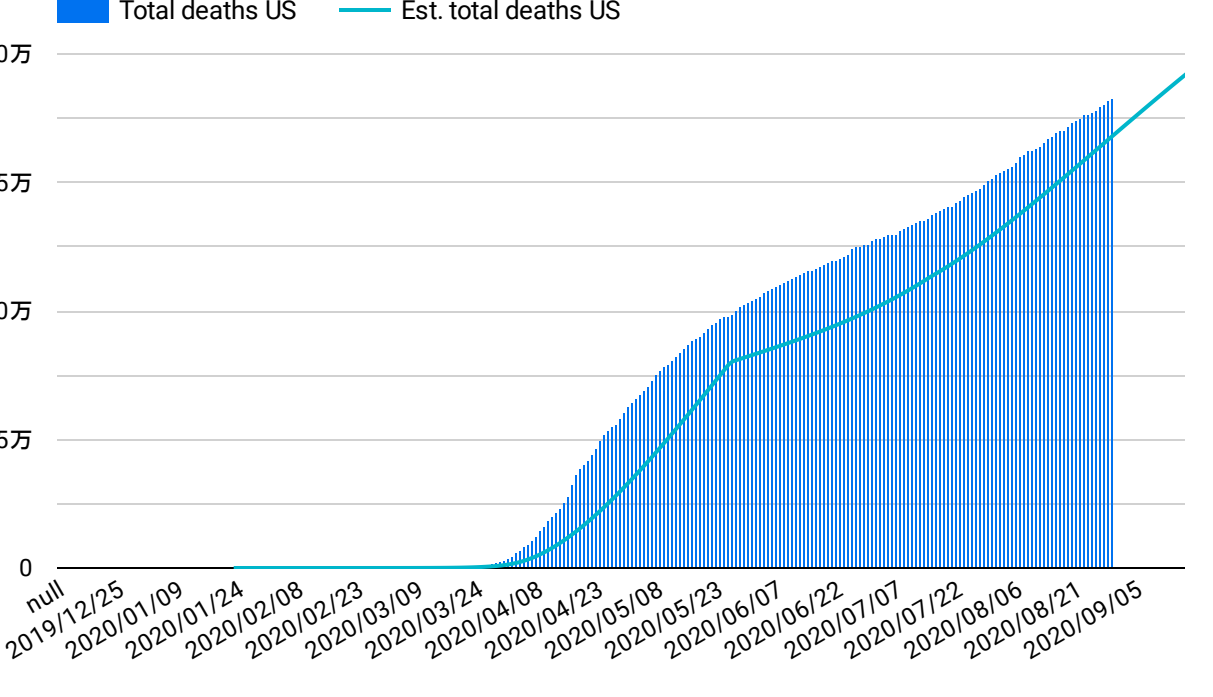
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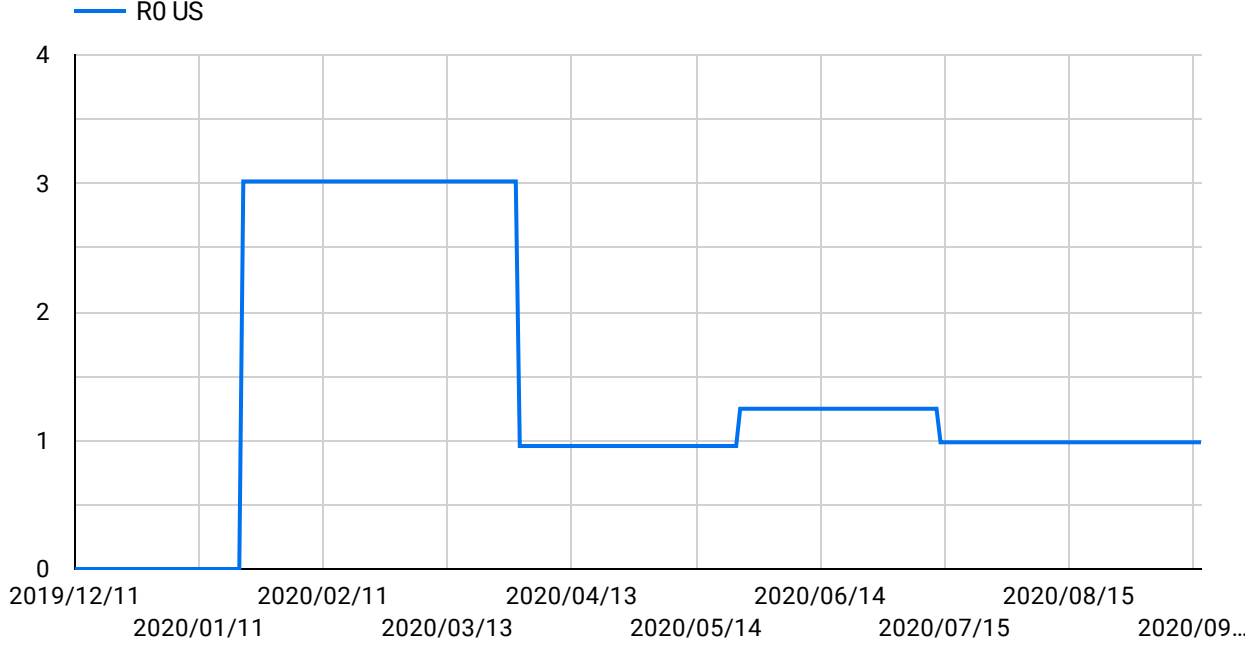
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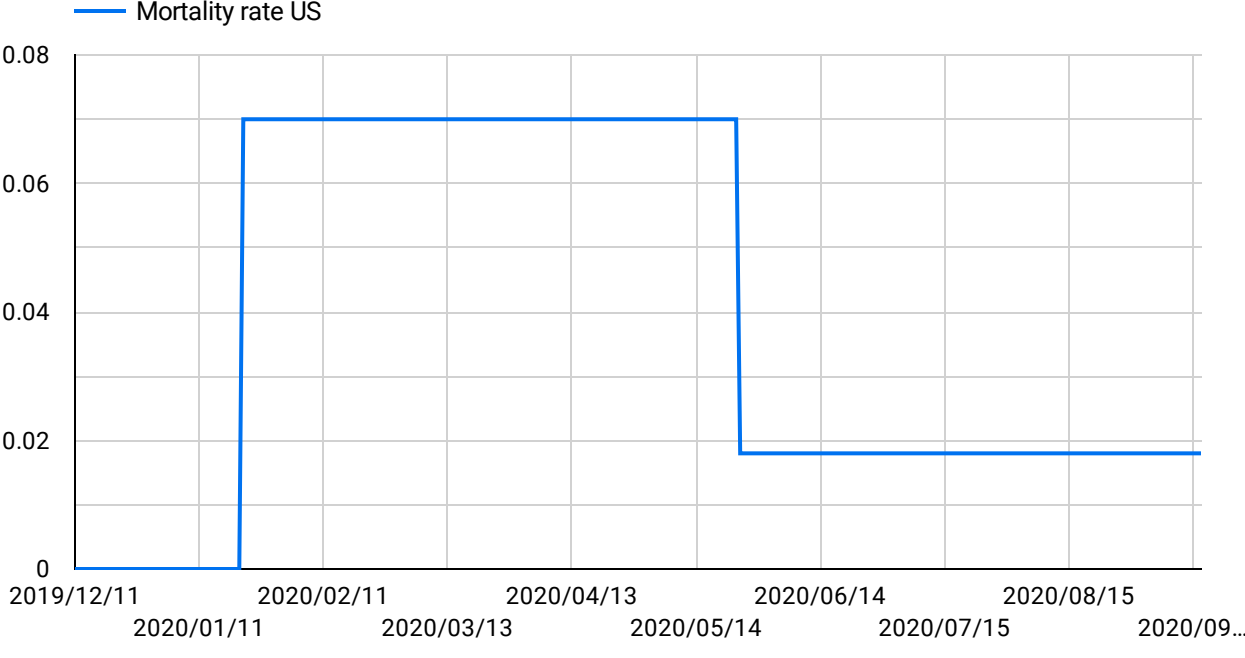
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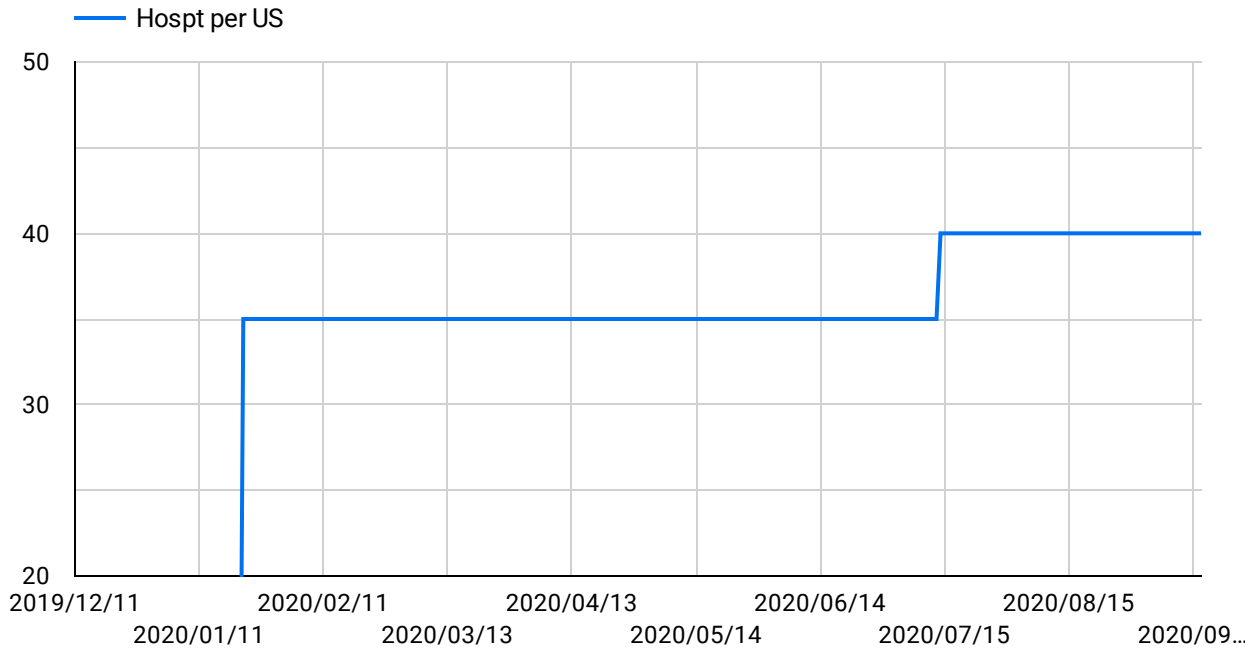
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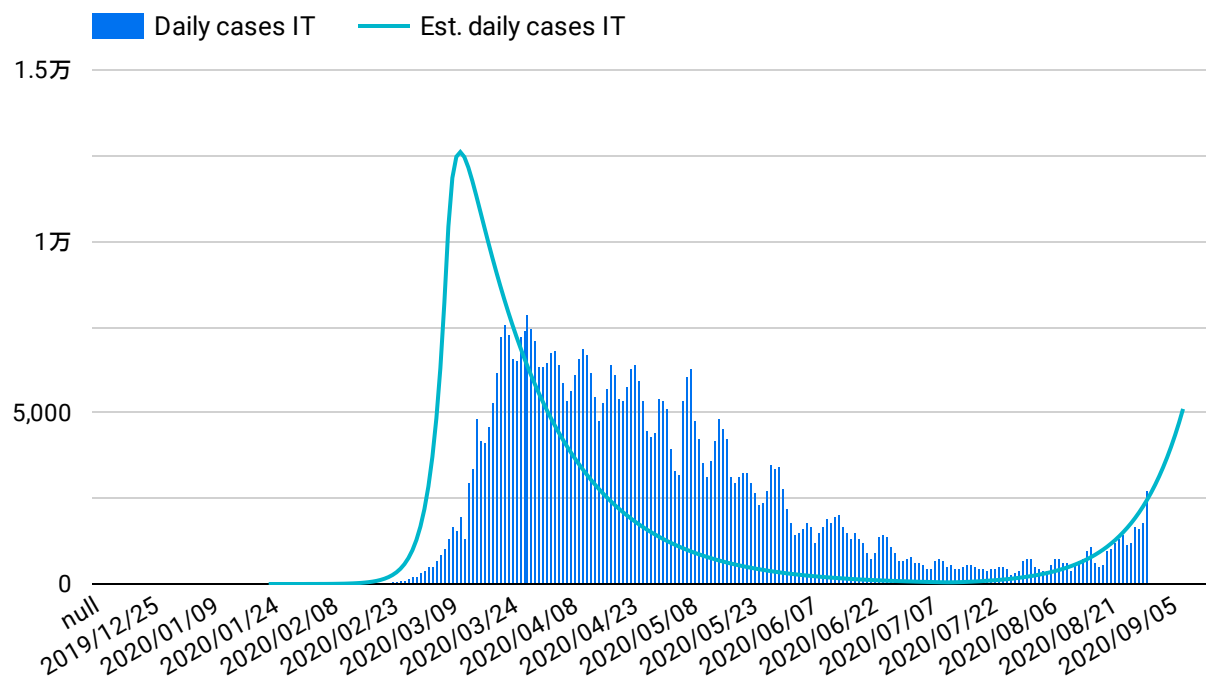


入院期間推計値 Hospitalization period estimates

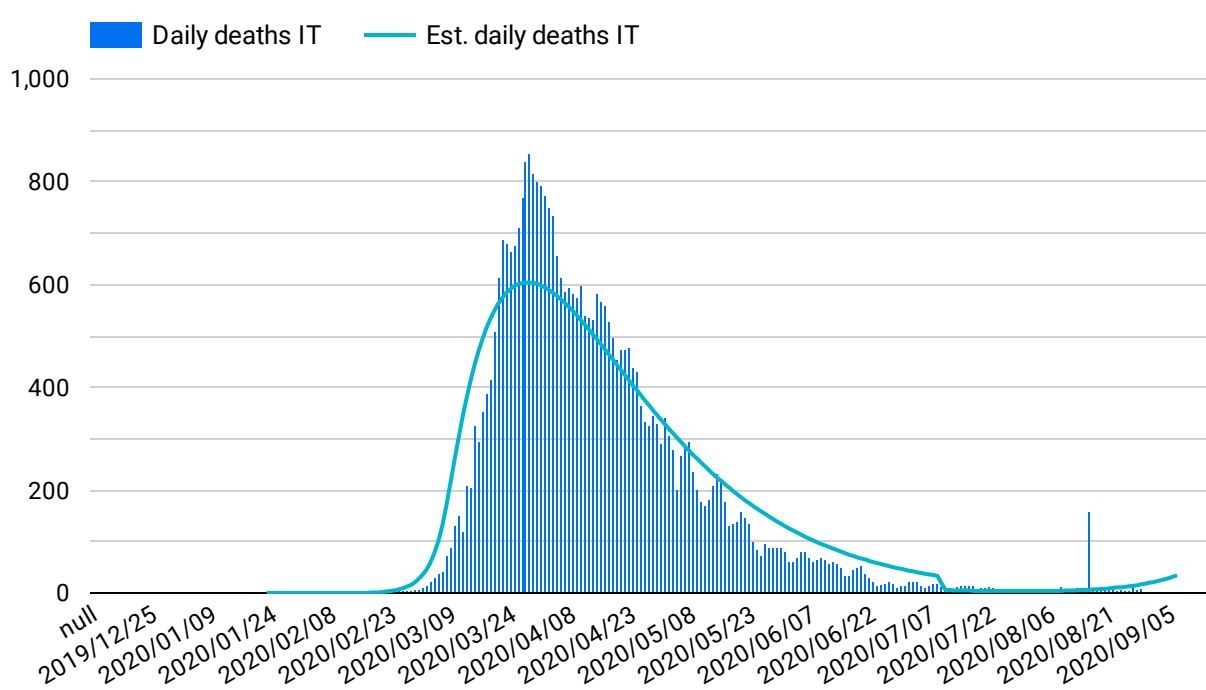


イタリア/Italy

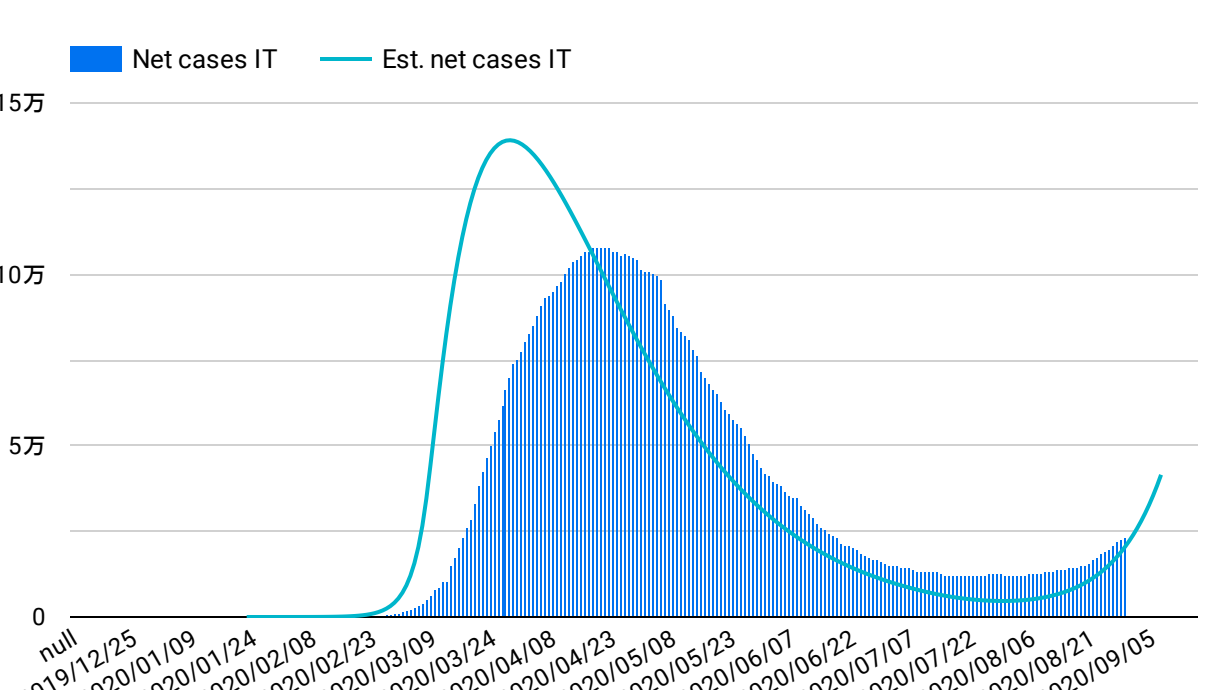
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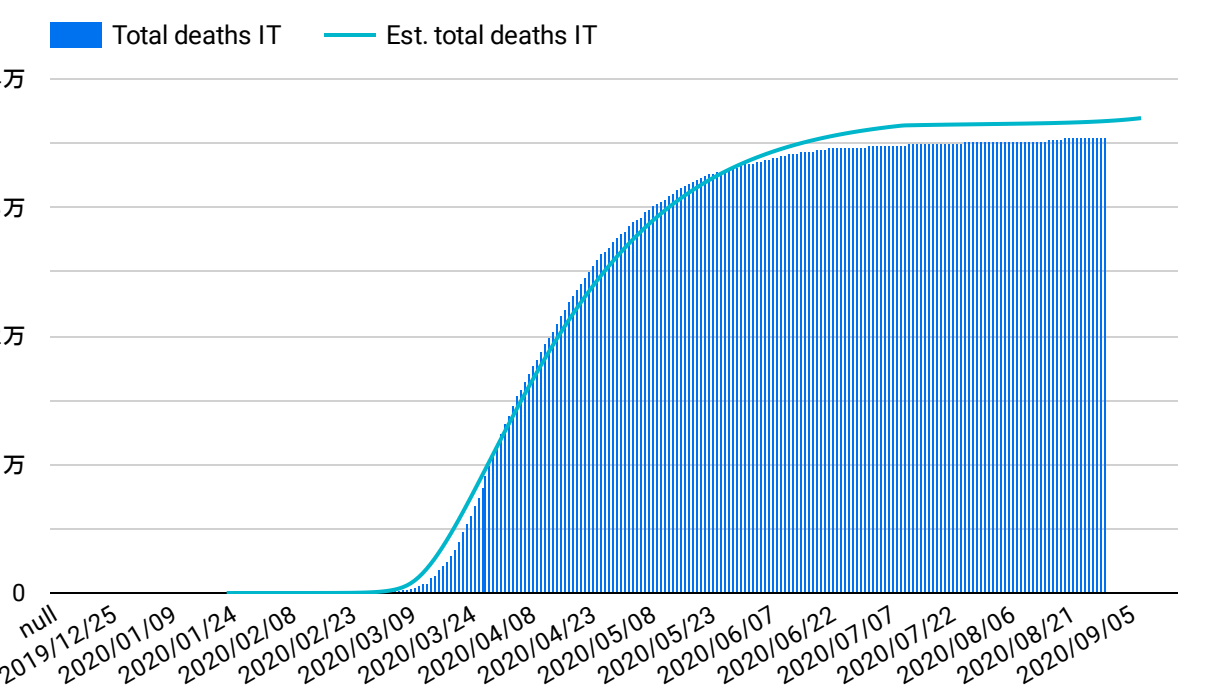
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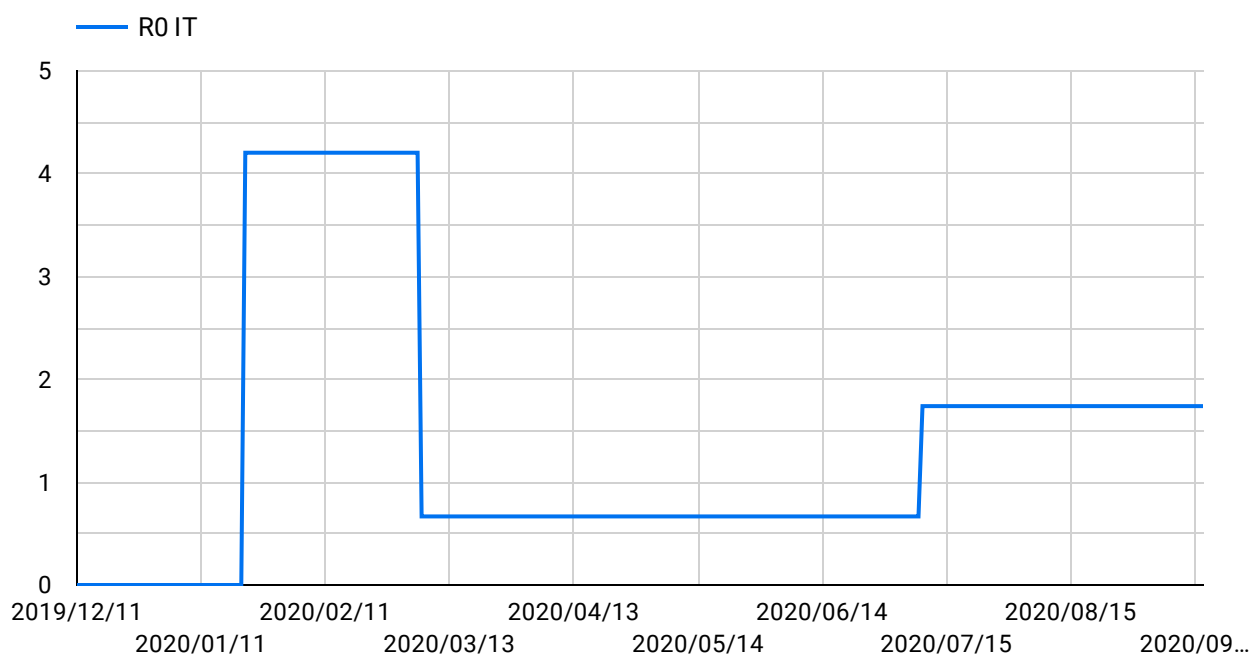
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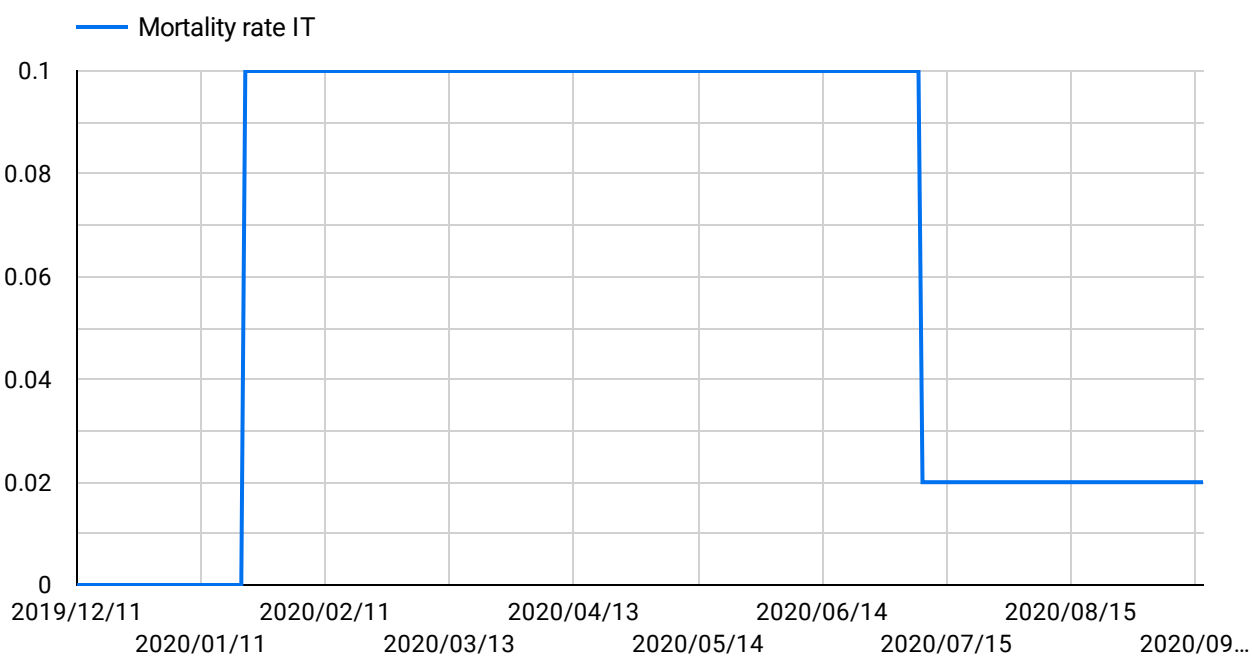
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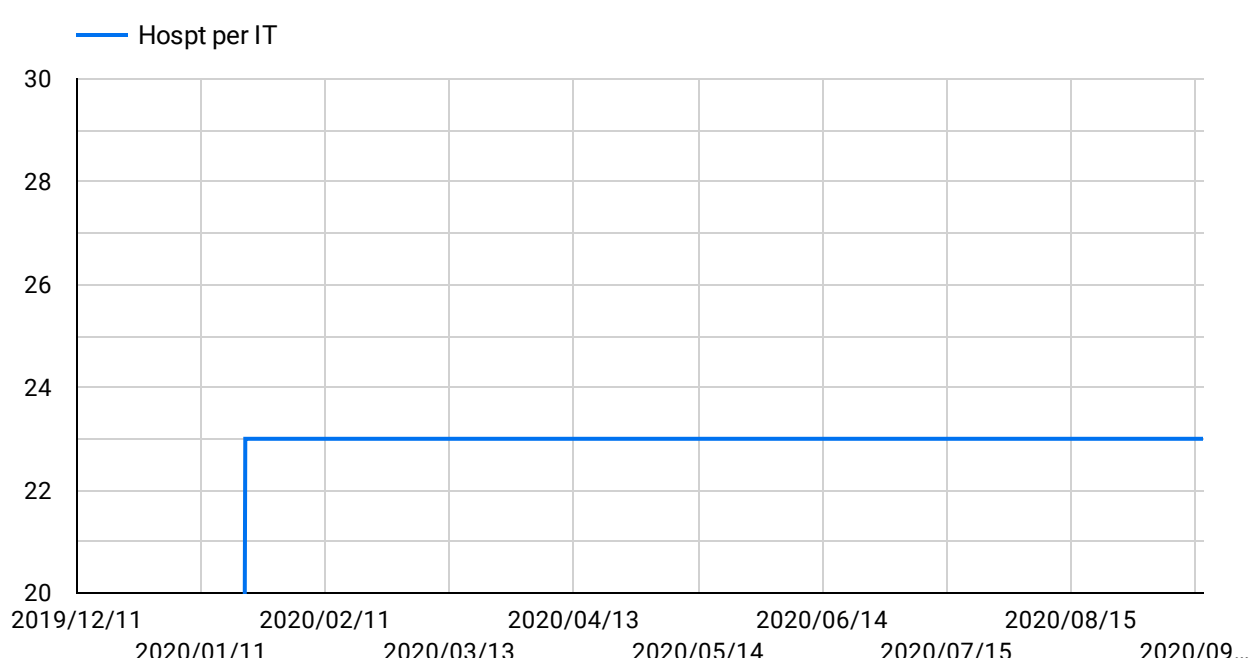
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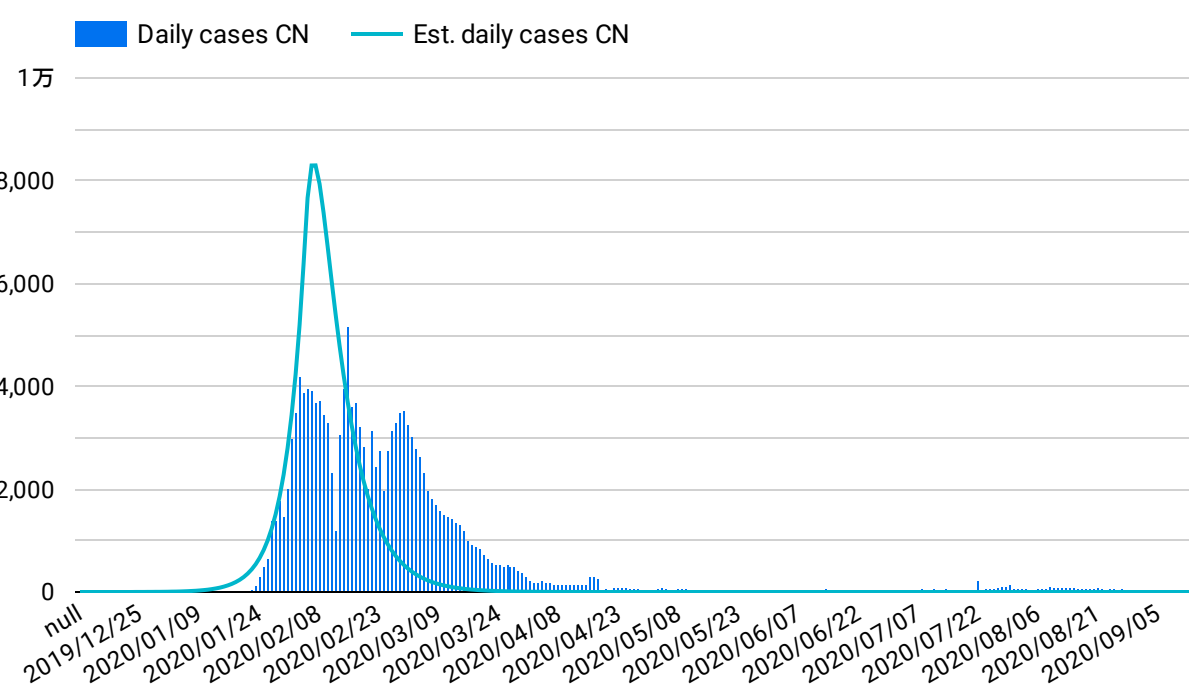


入院期間推計値 Hospitalization period estimates

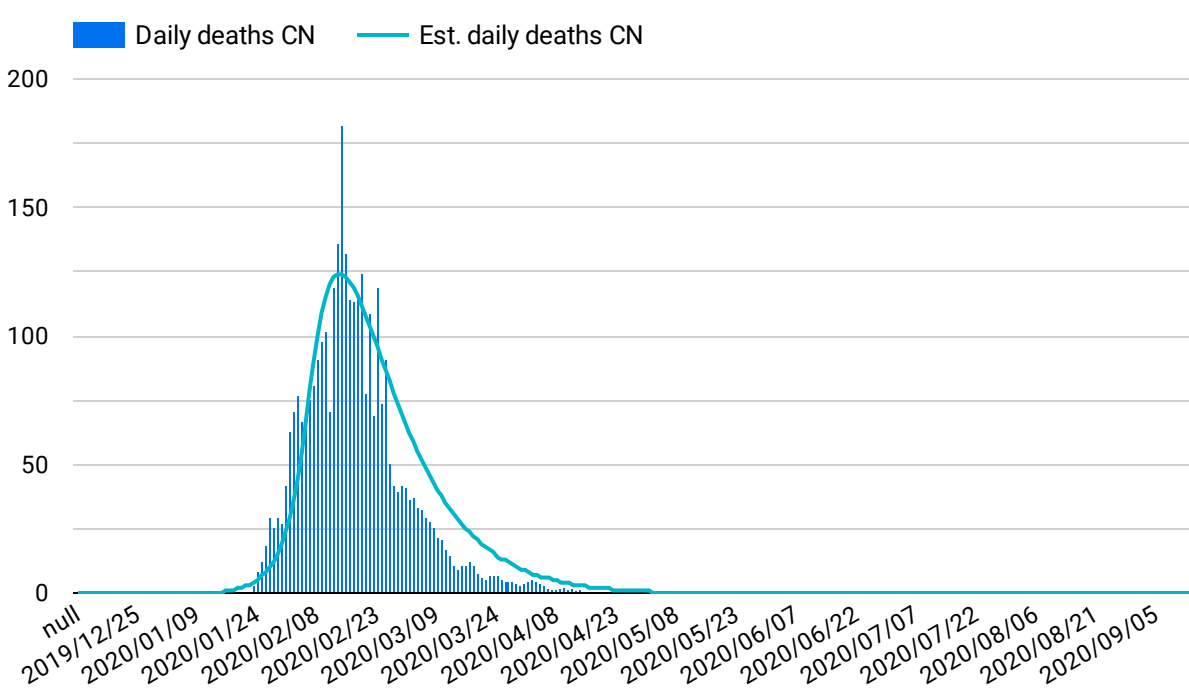


中国/China

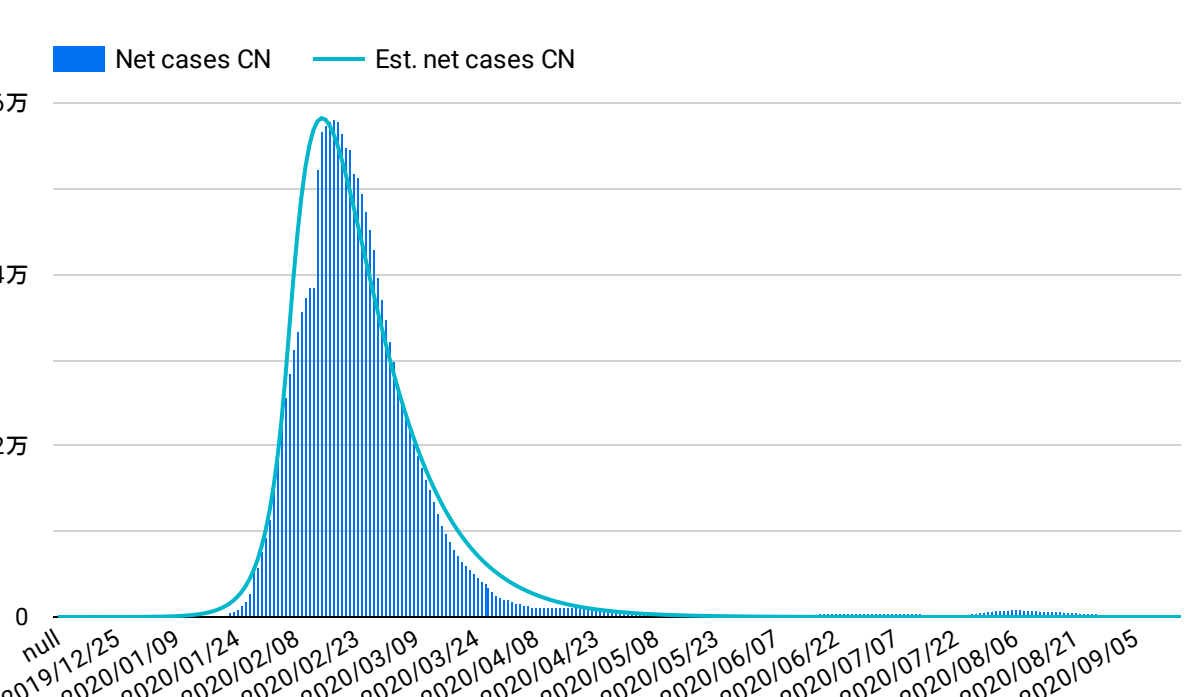
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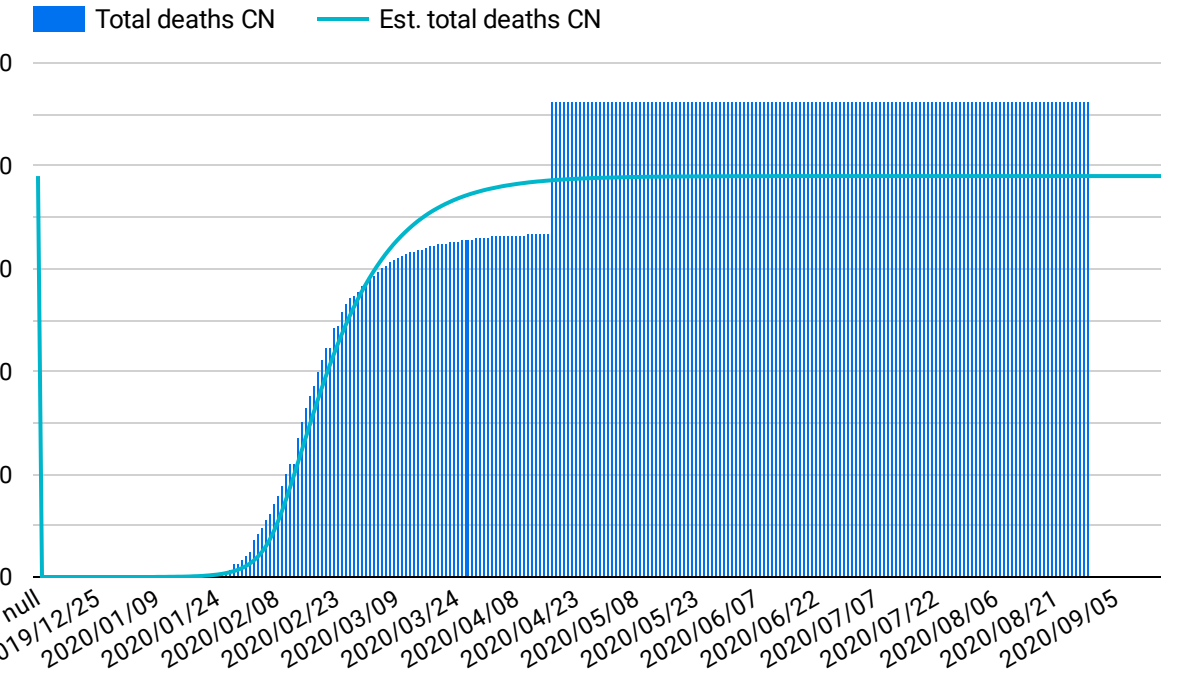
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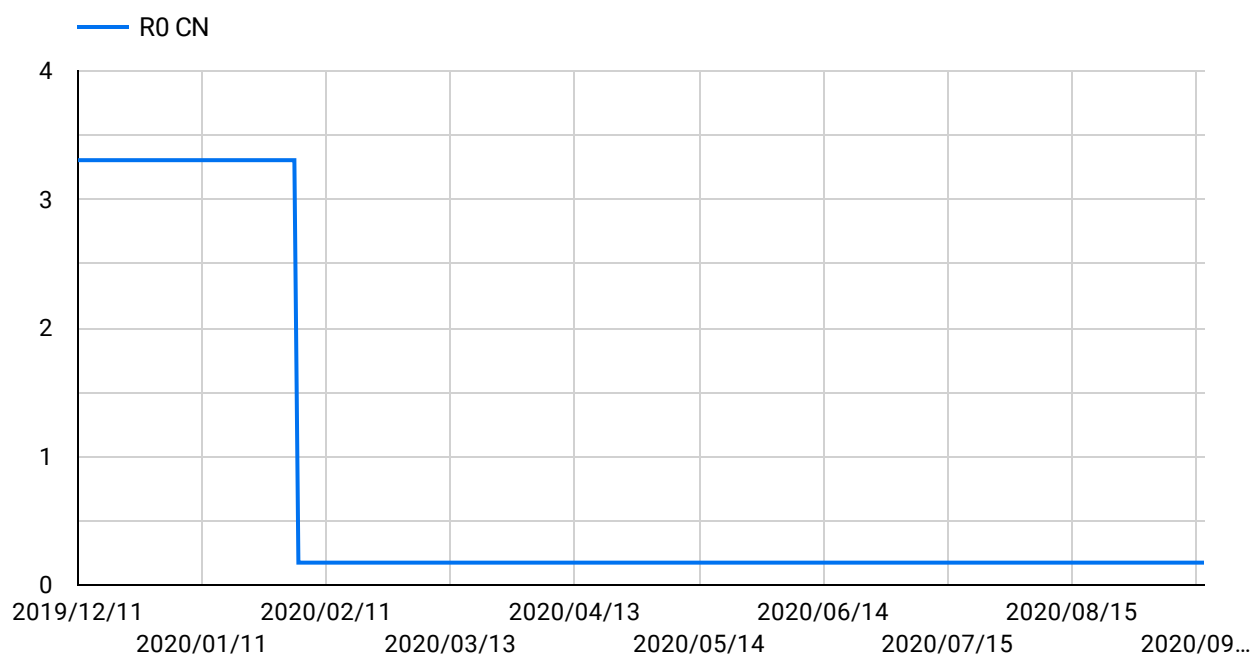
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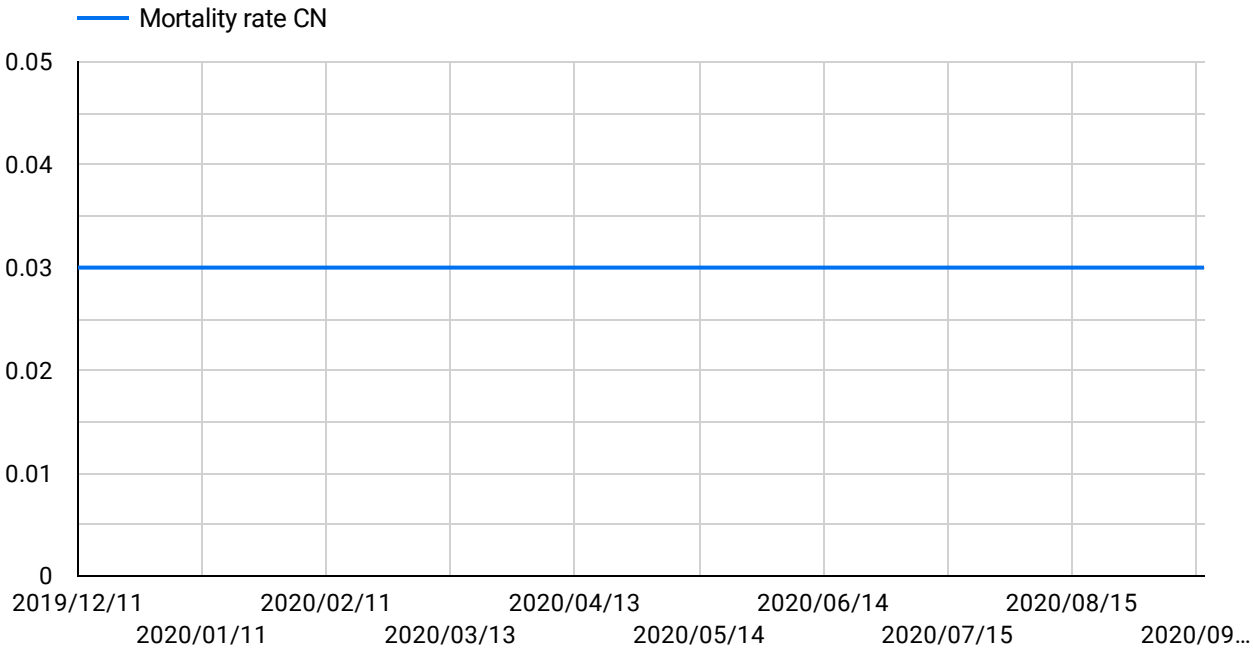
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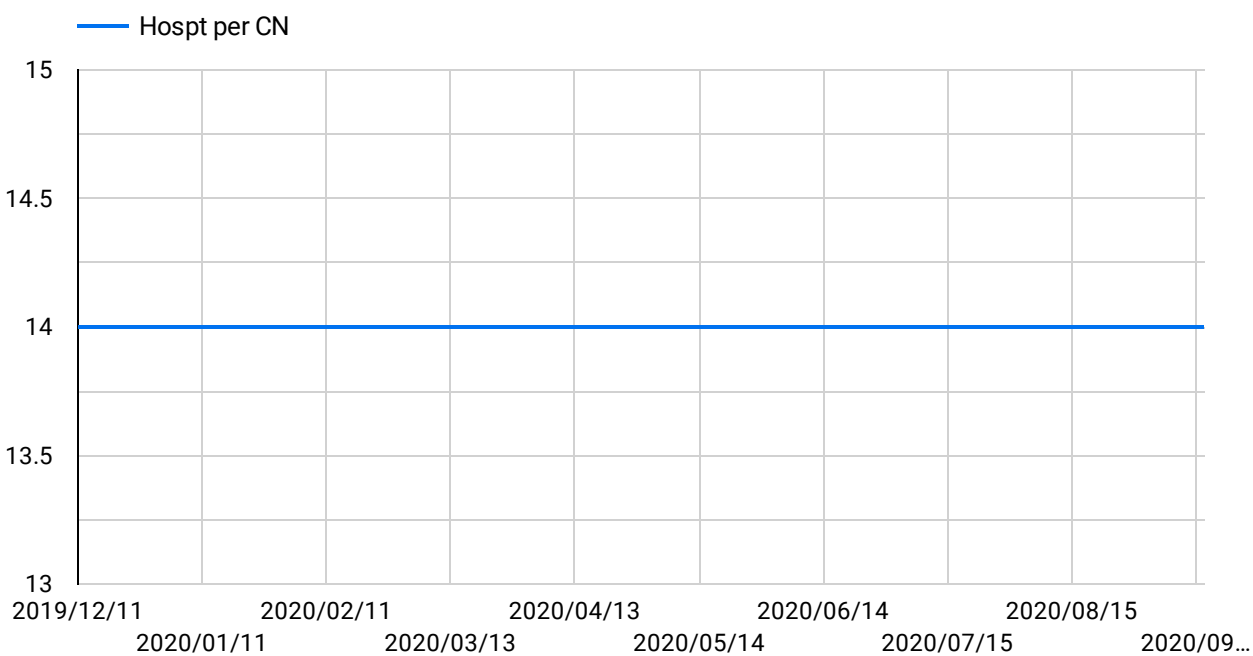
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致死率推計値 Mortality rate estimates

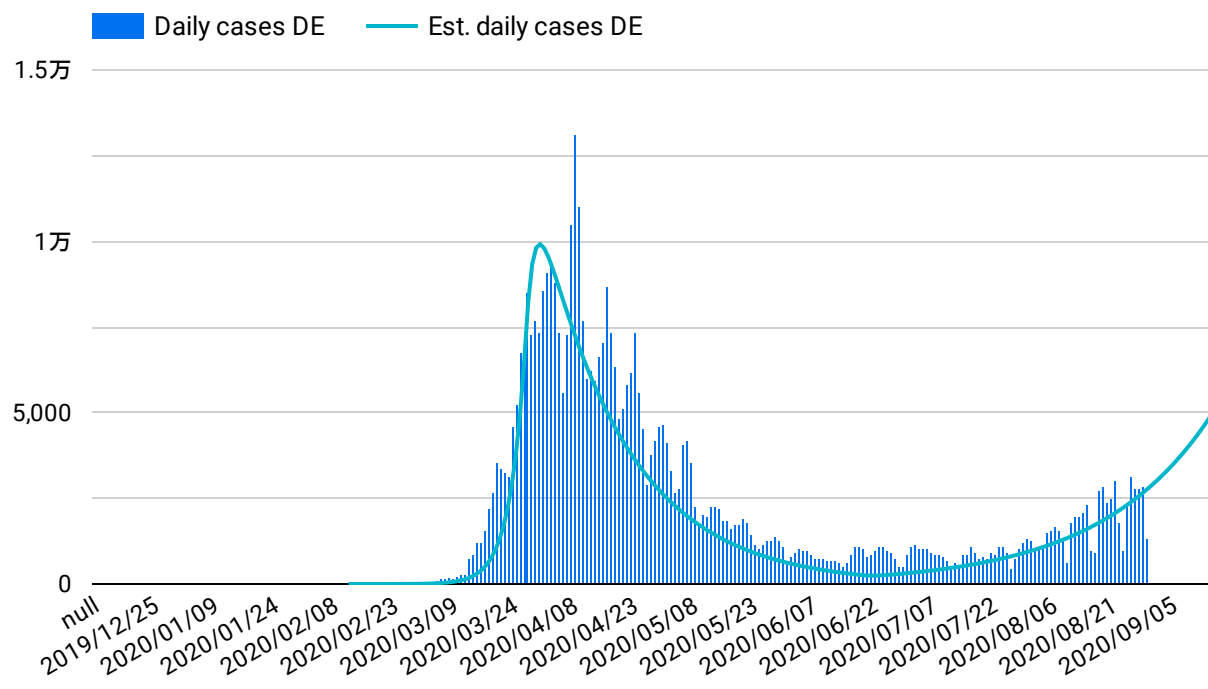


入院期間推計値 Hospitalization period estimates

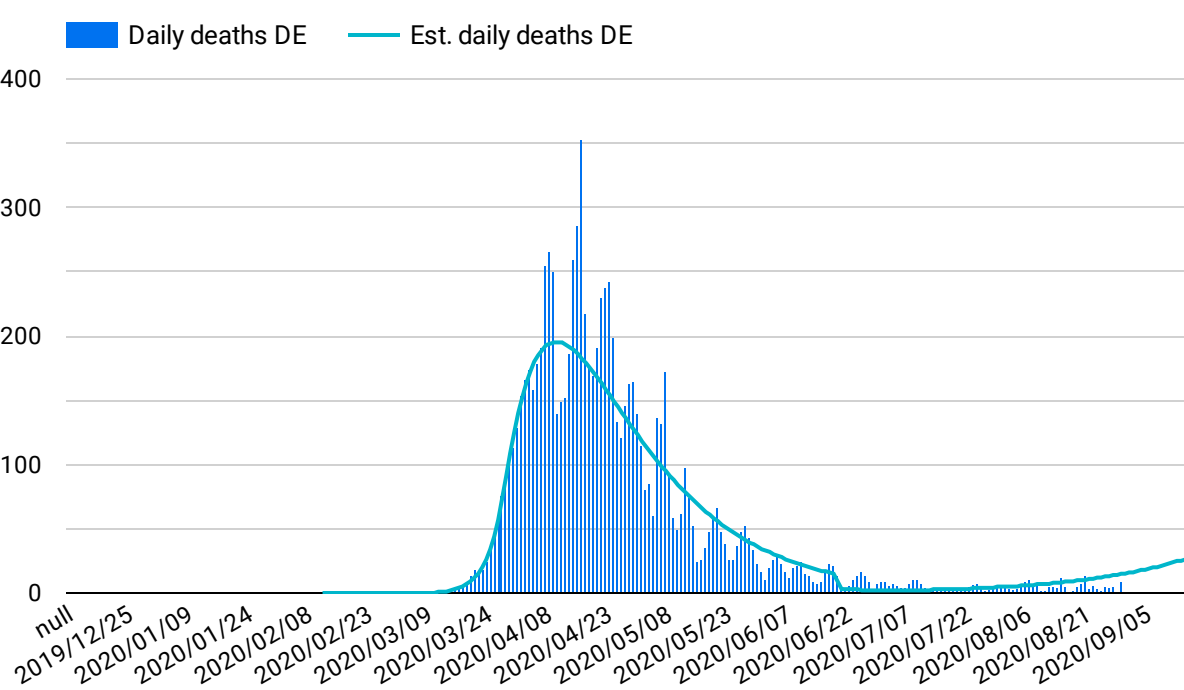


ドイツ/Germany

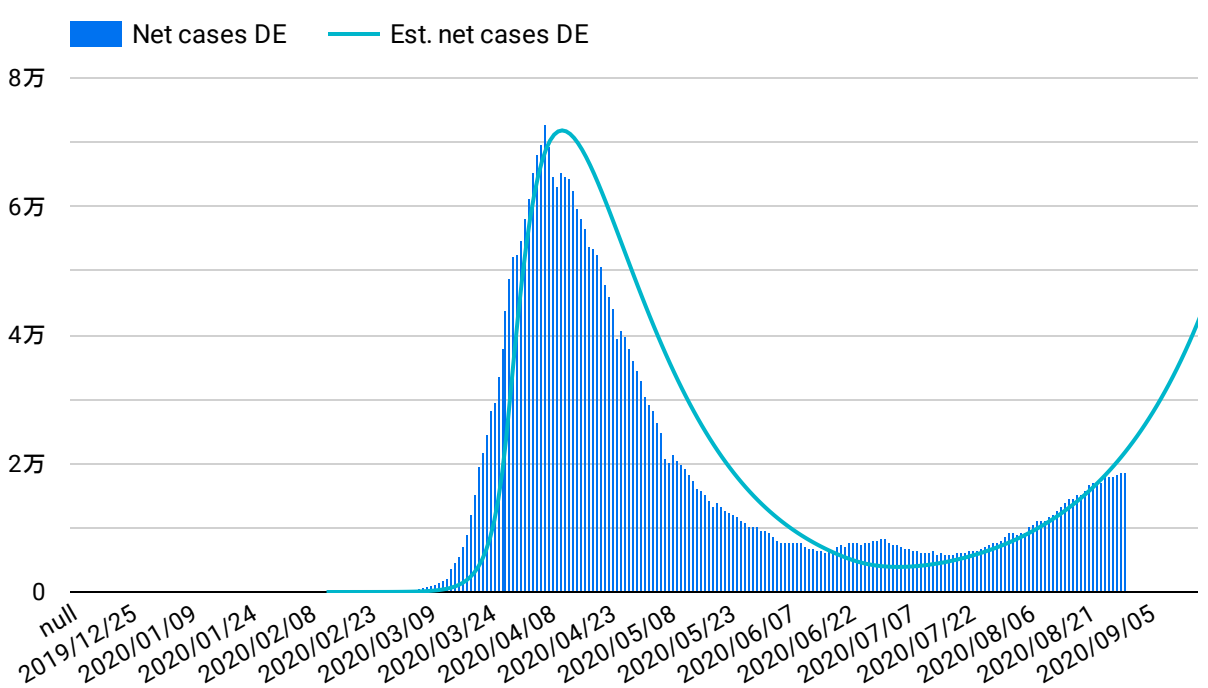
1日当り新規感染者数とモデル推計値 Daily new cases and model estimates



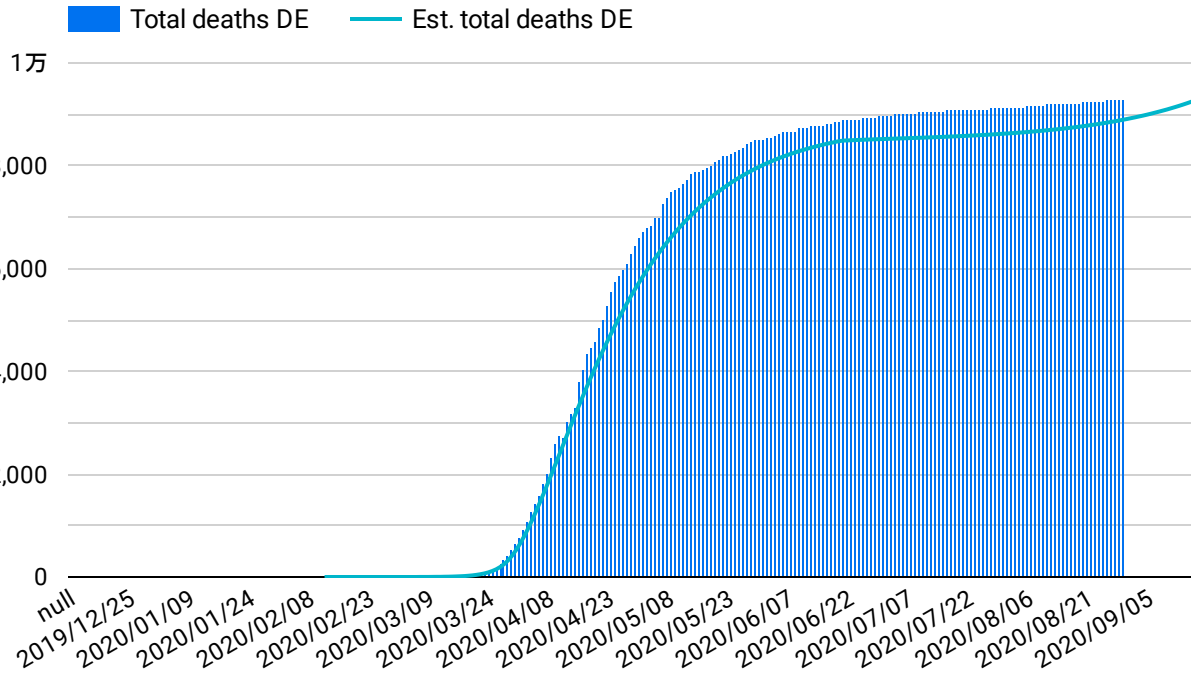
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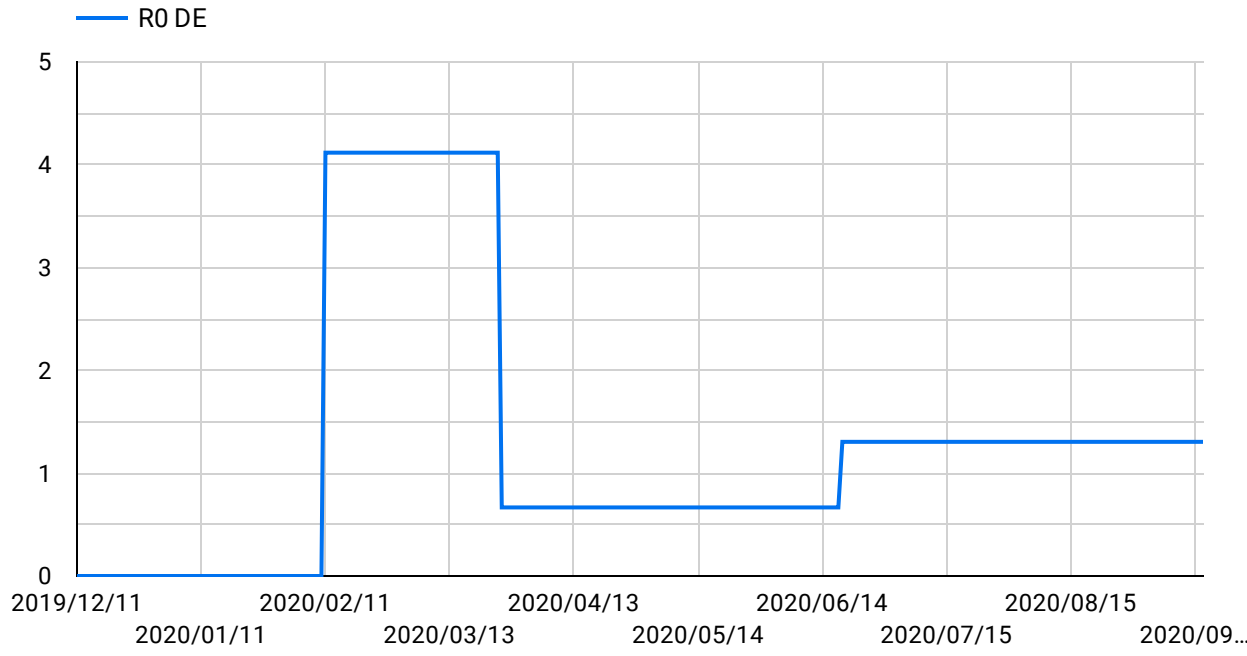
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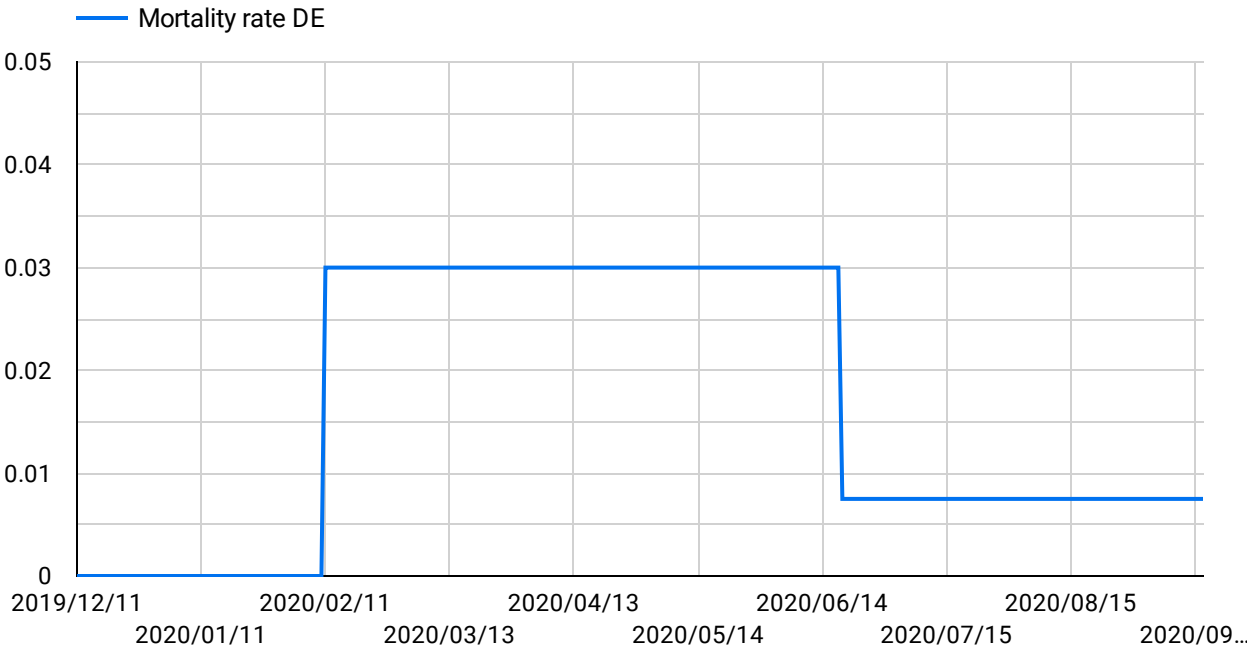
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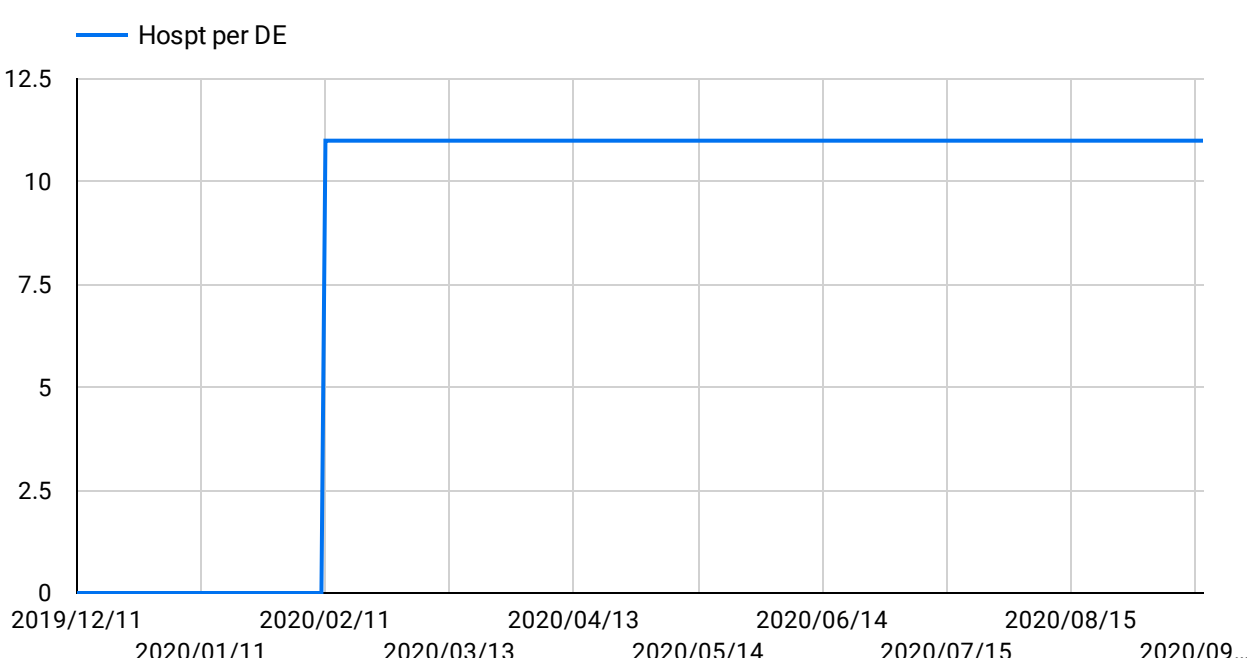
R0 (再生産数) 推計値 R0 estimates



致死率推計値 Mortality rate estimates

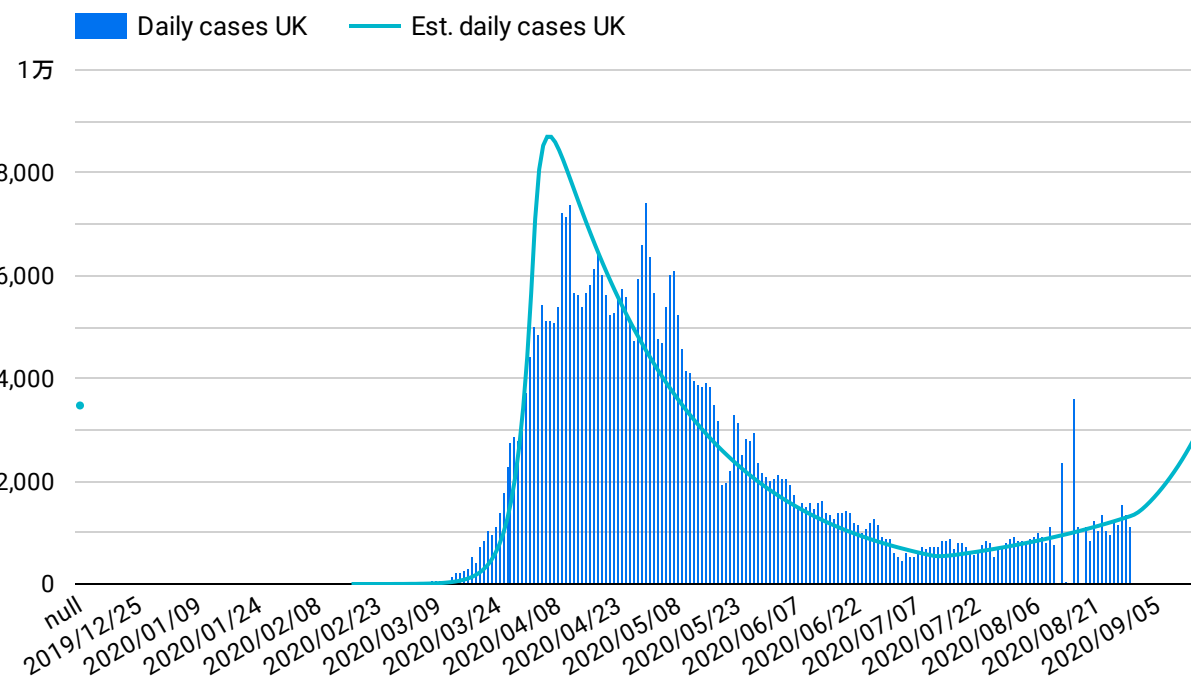


入院期間推計値 Hospitalization period estimates

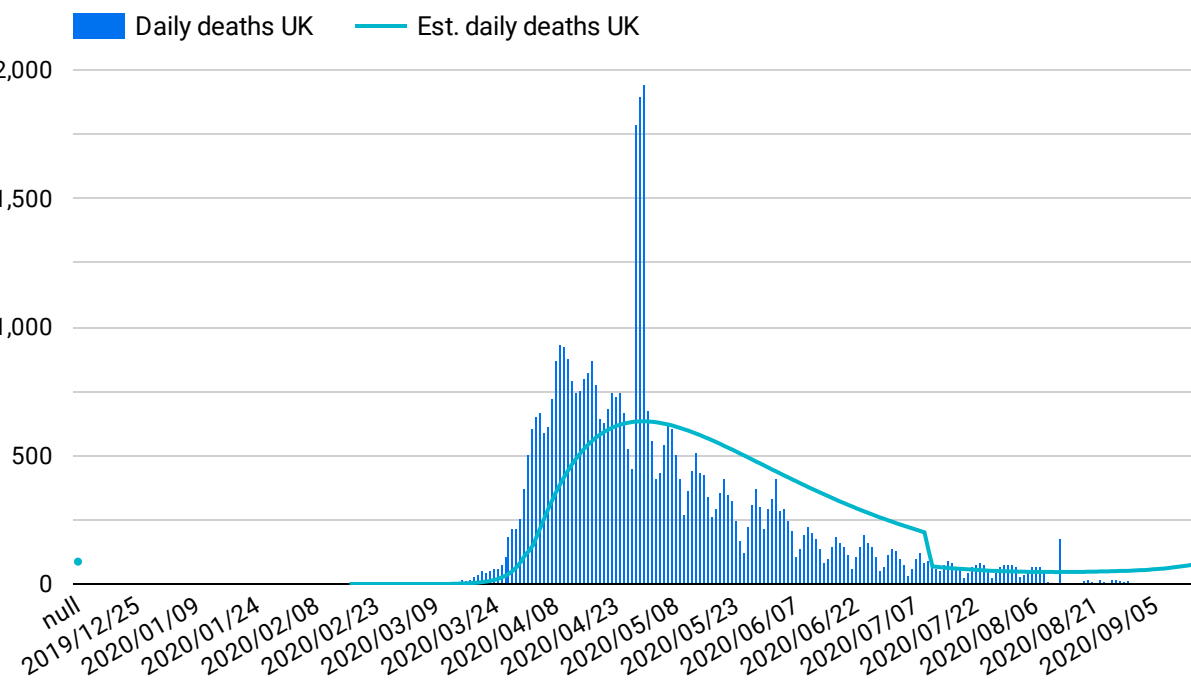


英国/U.K.

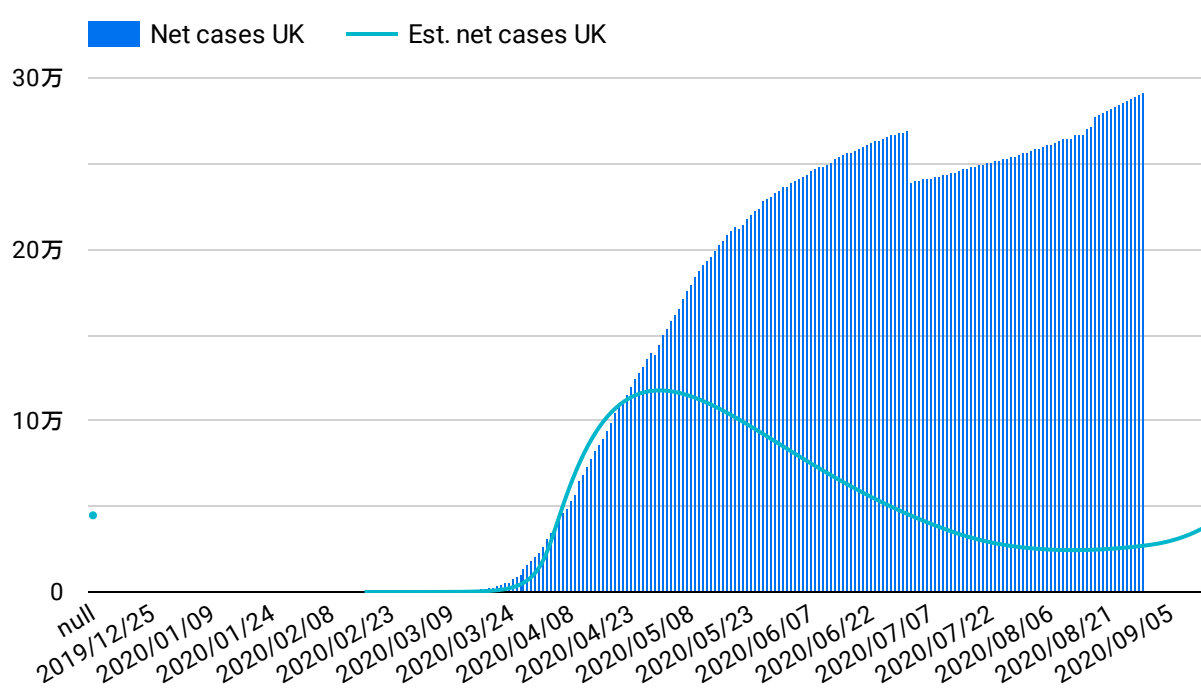
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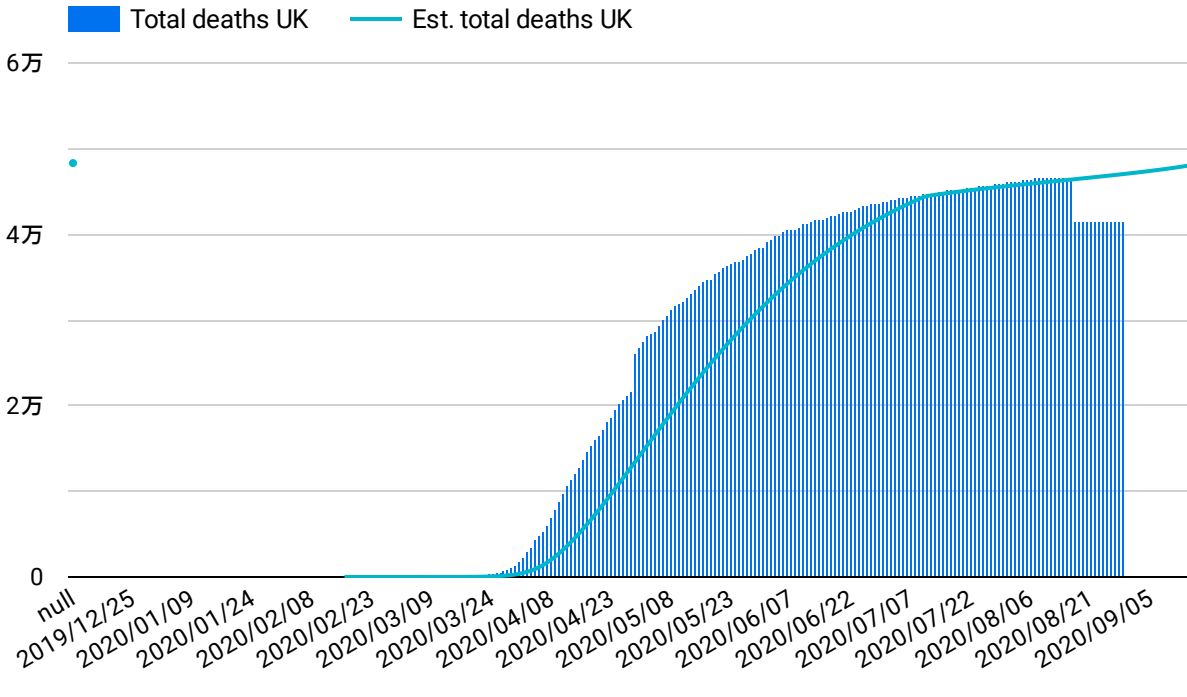
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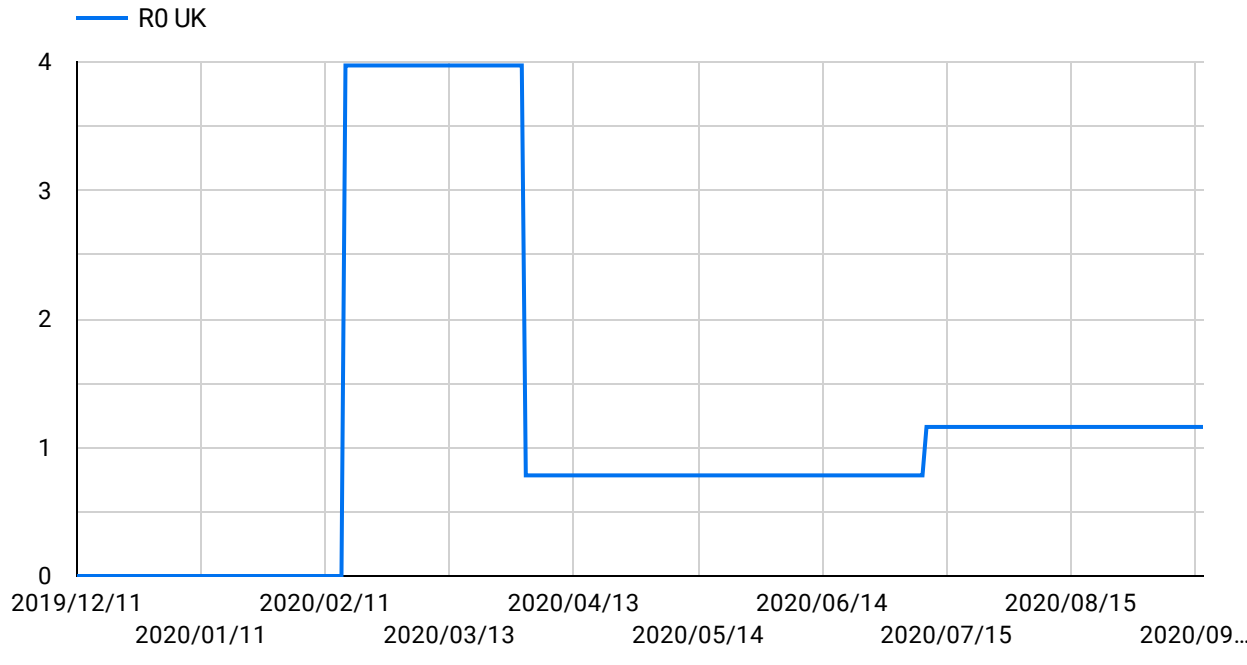
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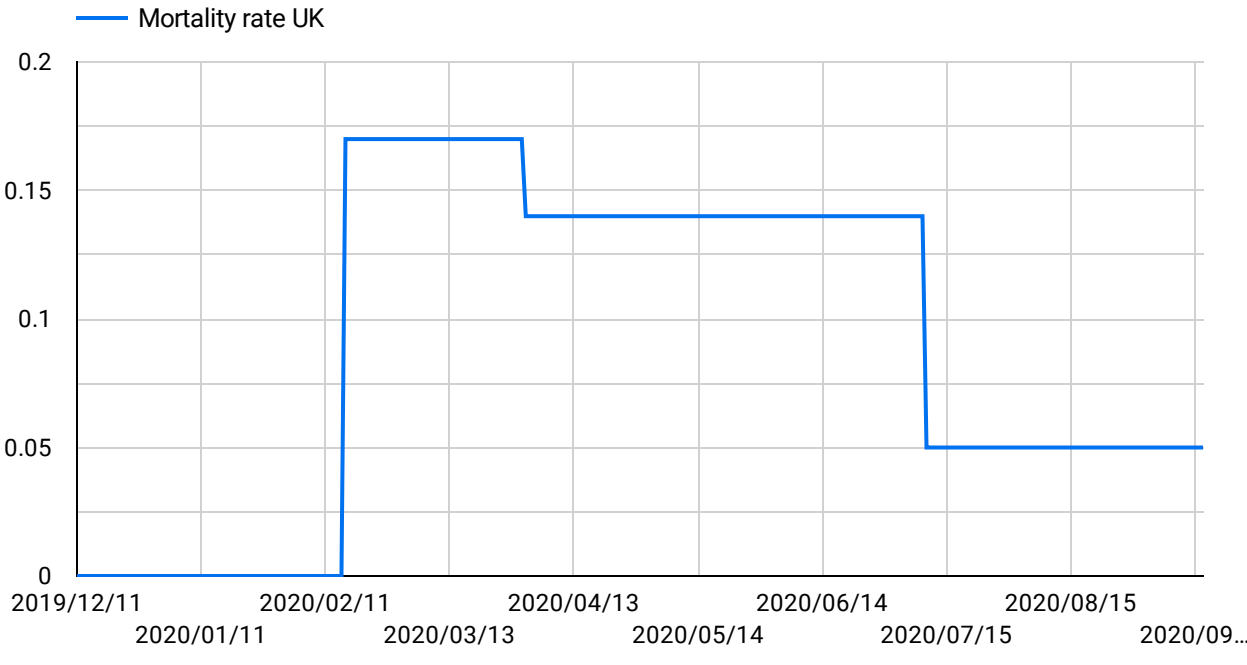
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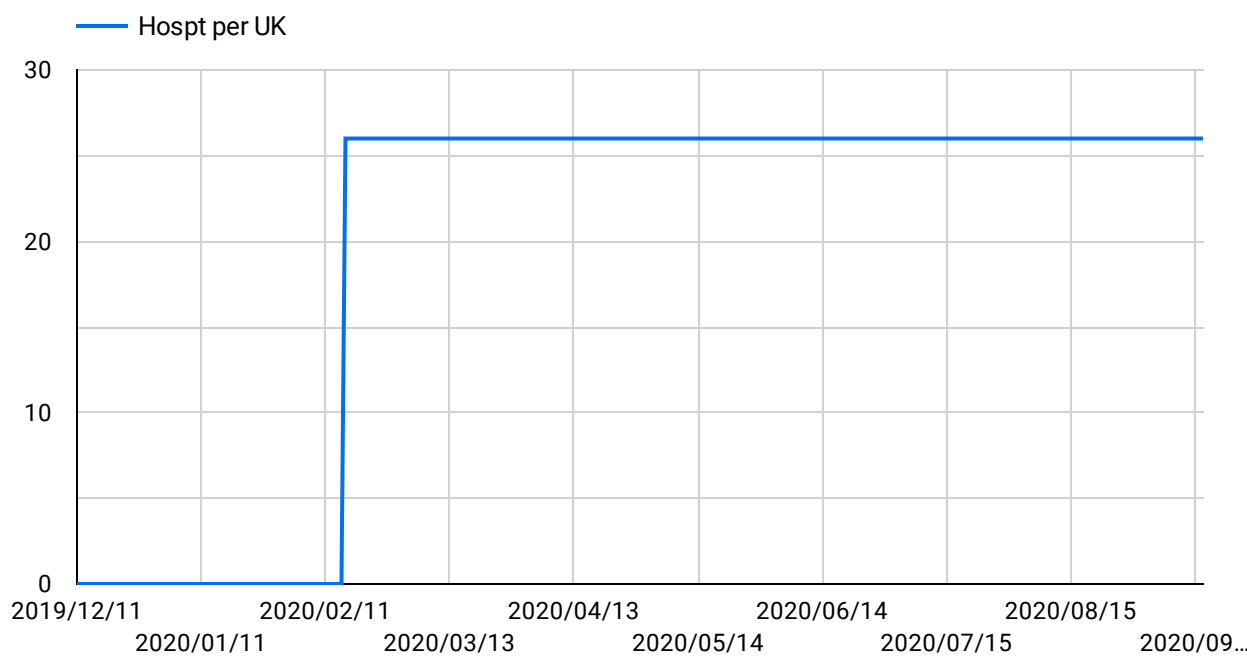
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致死率推計値 Mortality rate estimates

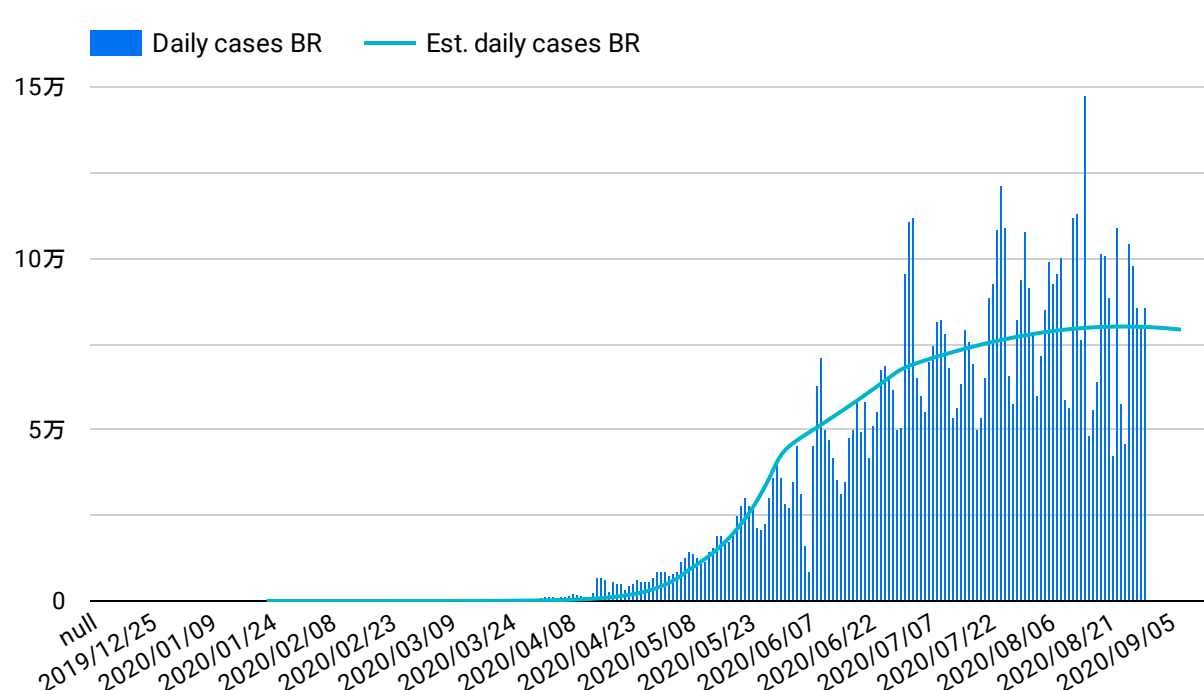


入院期間推計値 Hospitalization period estimates

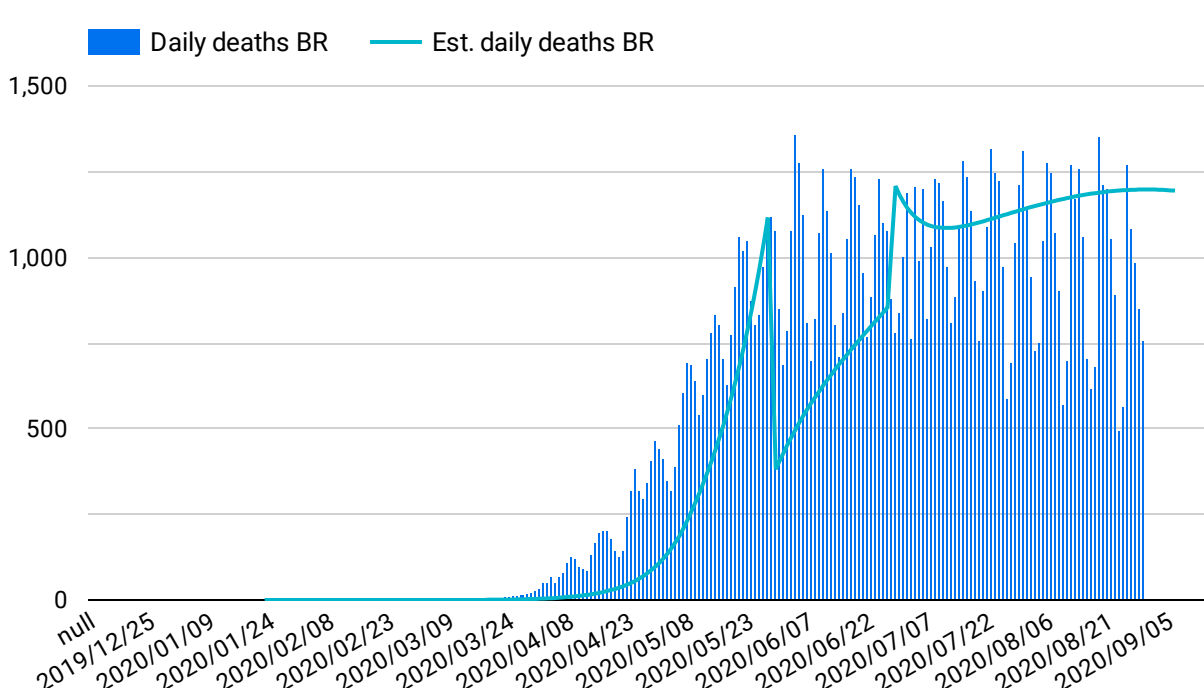


ブラジル/Brazil

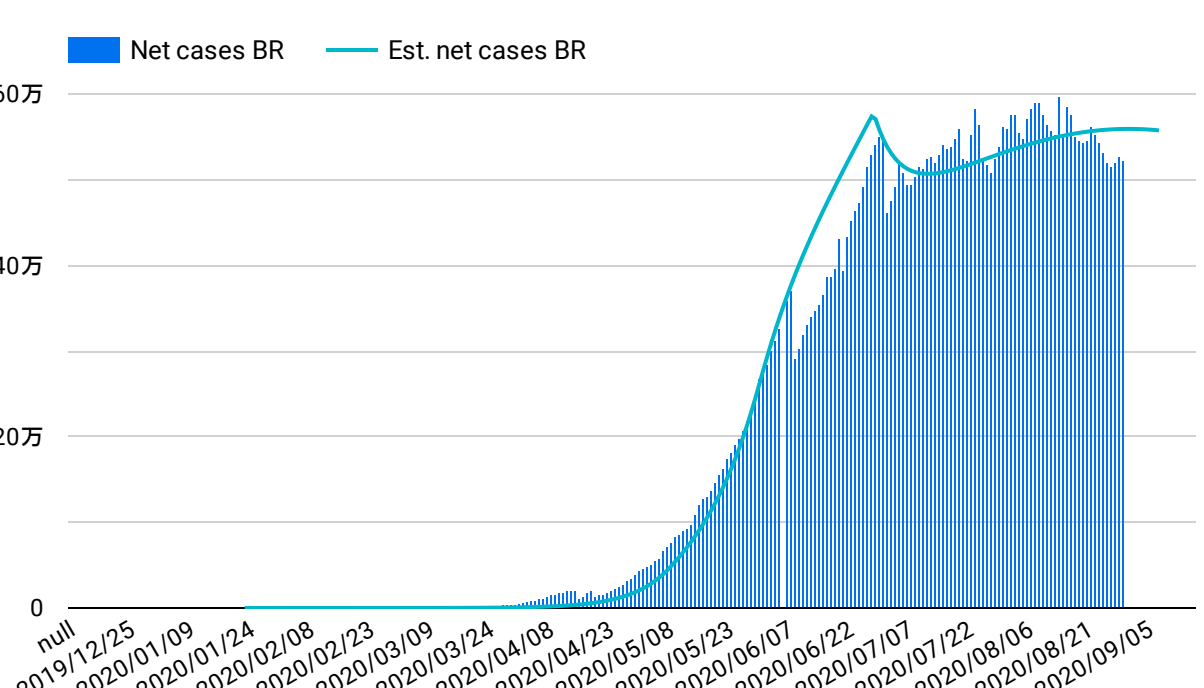
1日当り新規感染者数とモデル推計値 Daily new cases and model estimates



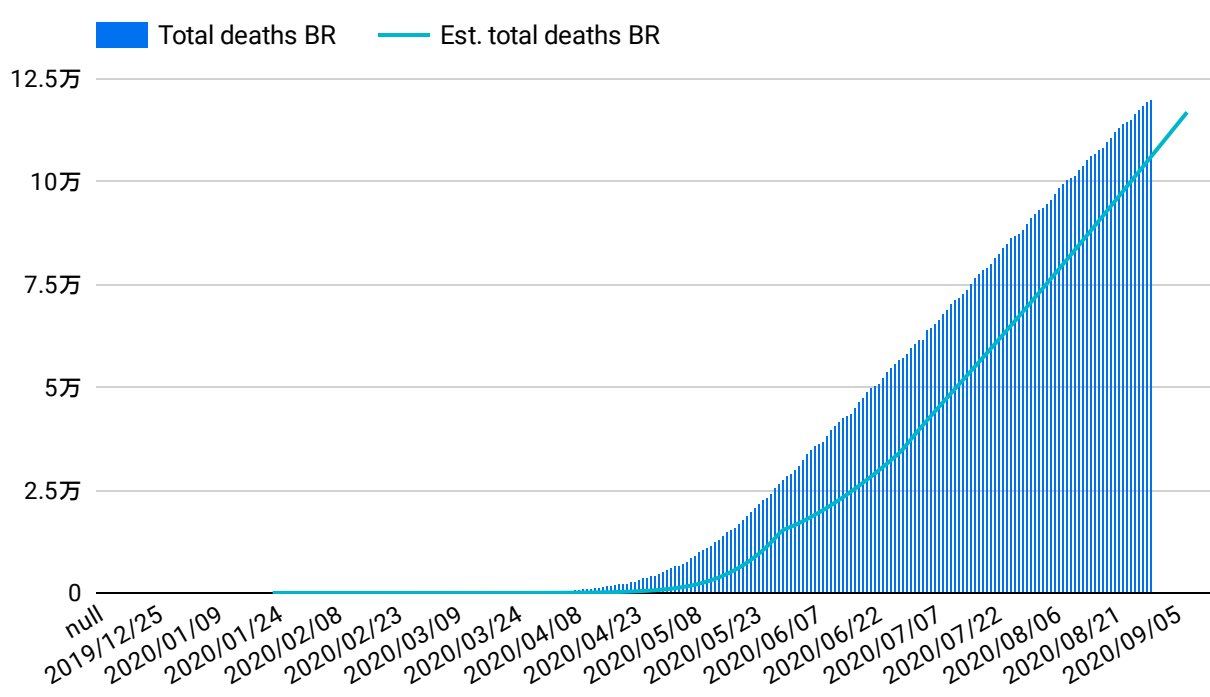
1日当り死者数とモデル推計値 Daily new deaths and model estimates



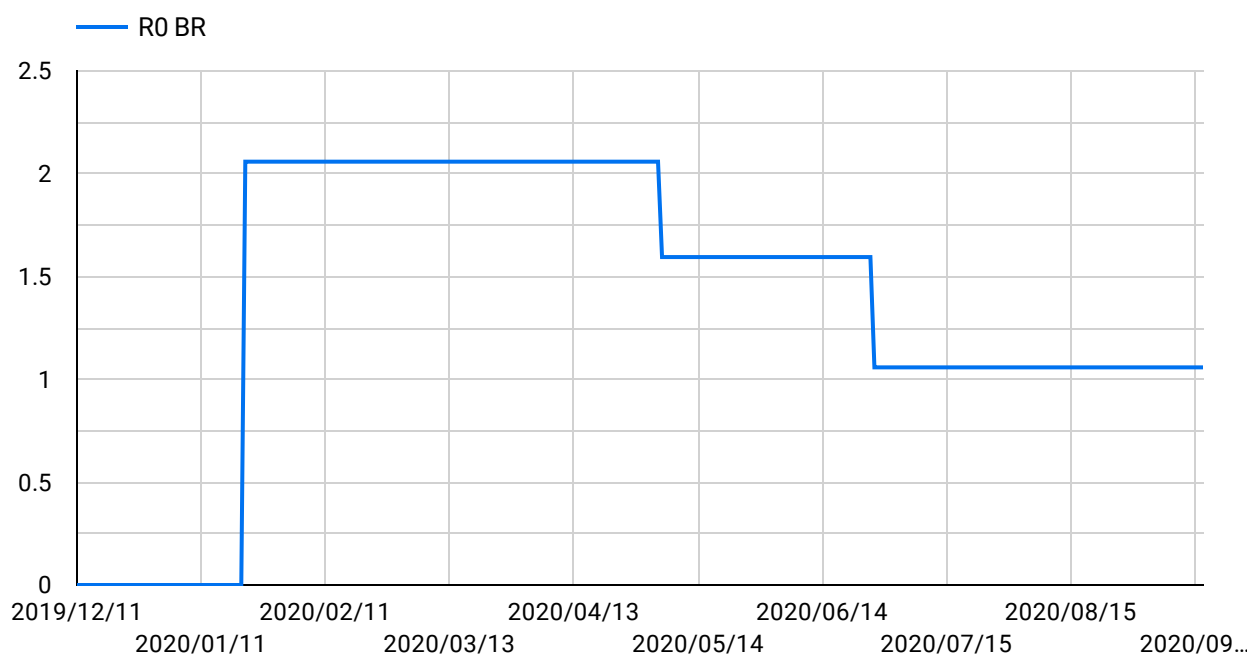
ネット総感染者数とモデル推計値 Net total cases and model estimates



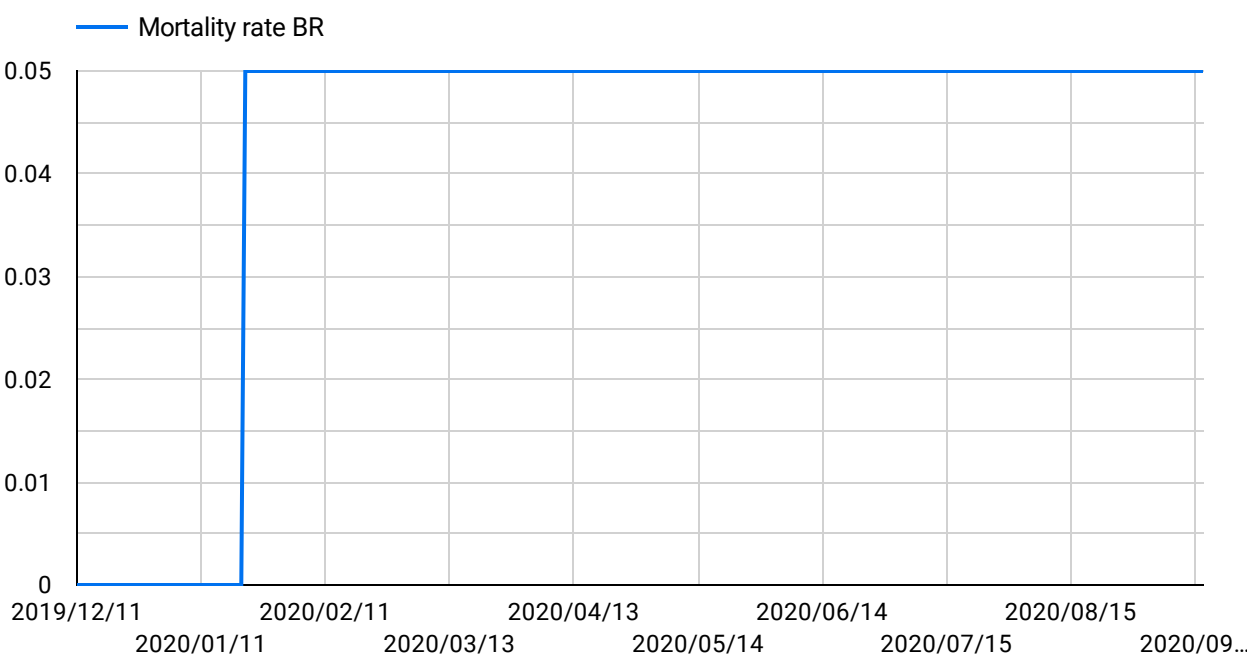
累計死者数とモデル推計値 Total deaths and model estimates



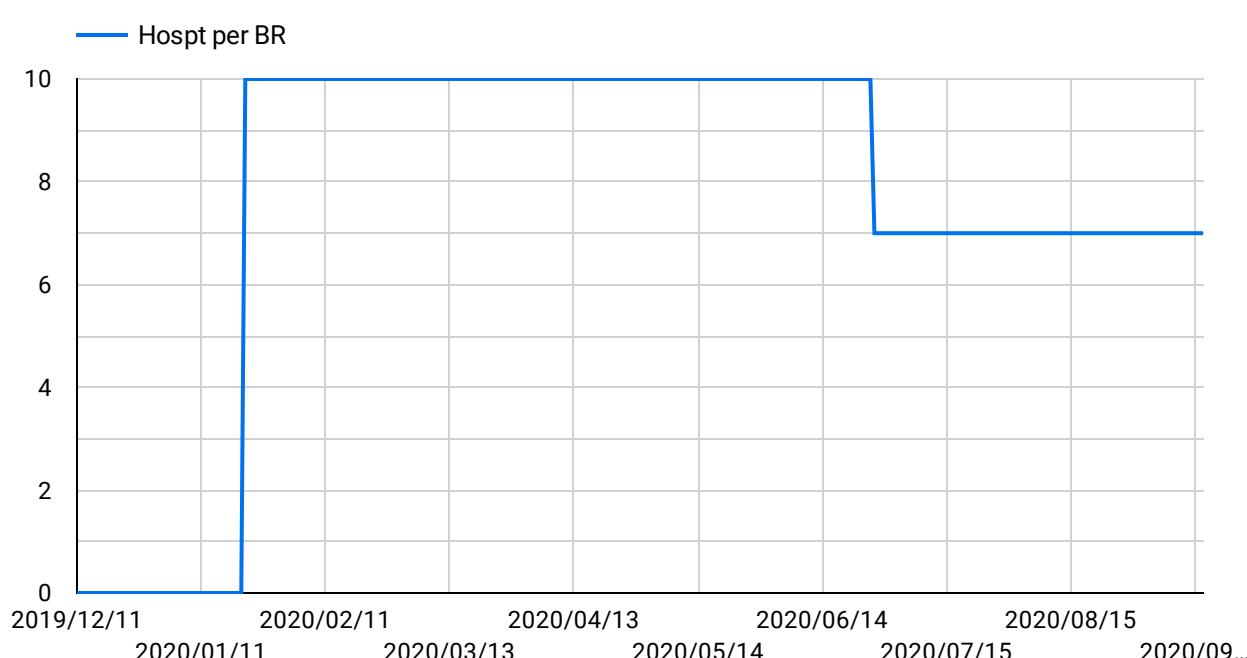
R0 (再生産数) 推計値 R0 estimates



致死率推計値 Mortality rate estimates

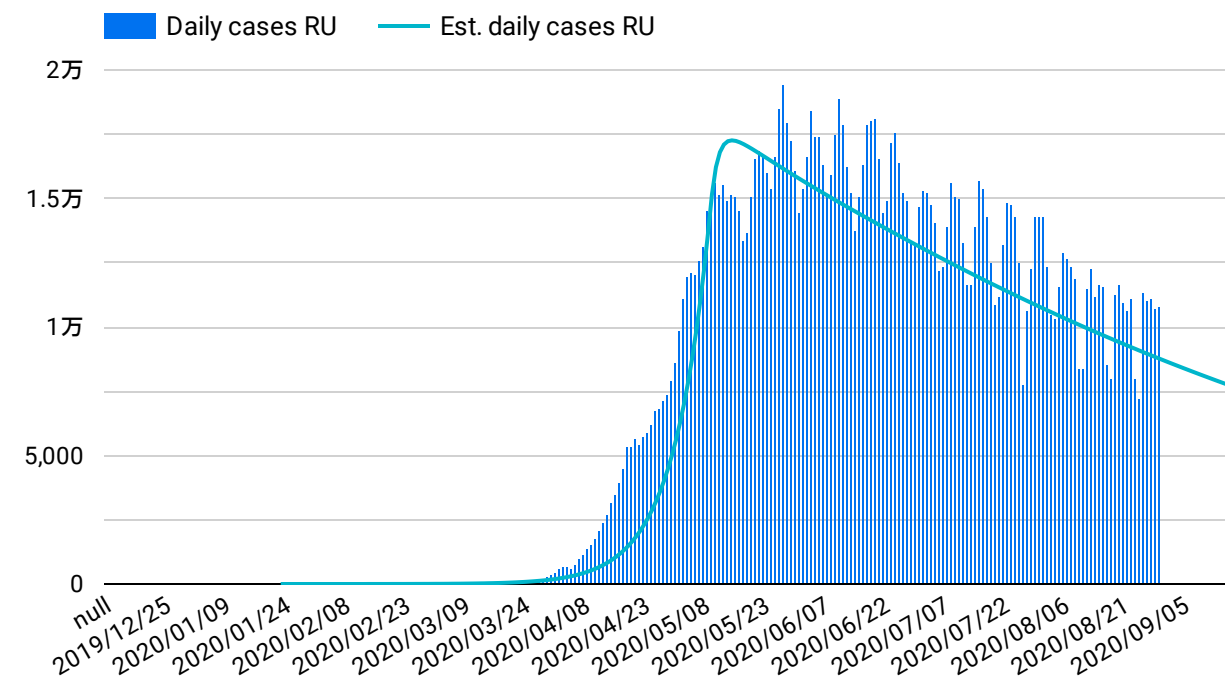


入院期間推計値 Hospitalization period estimates

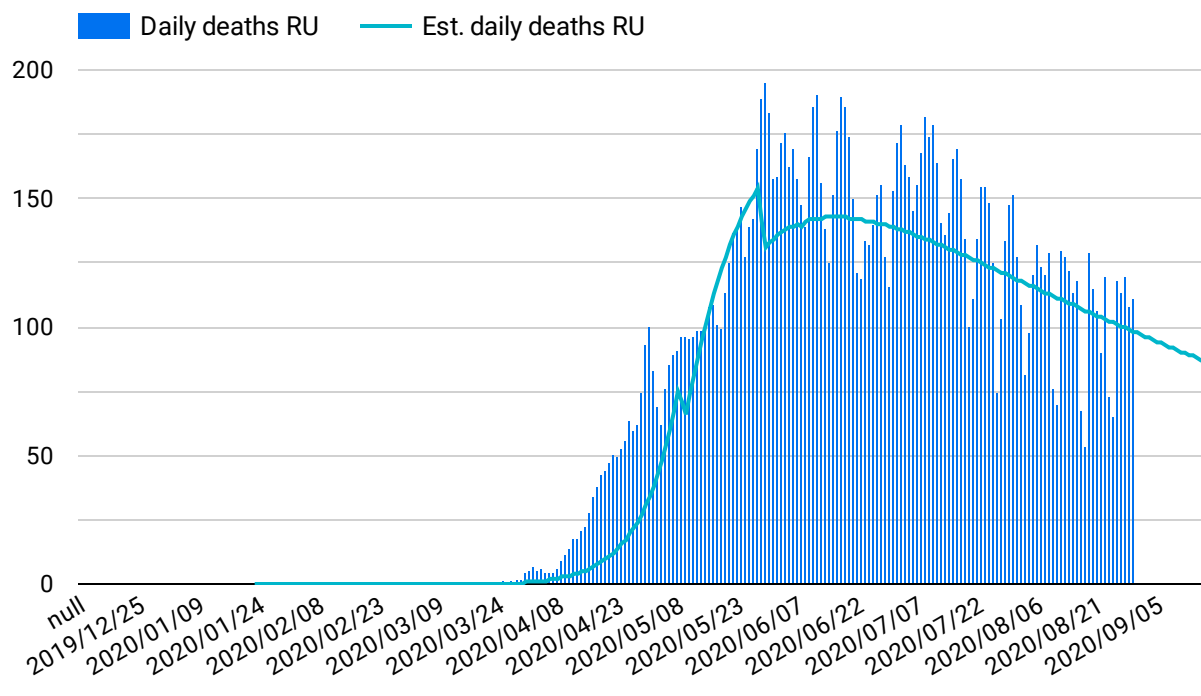


ロシア/Russia

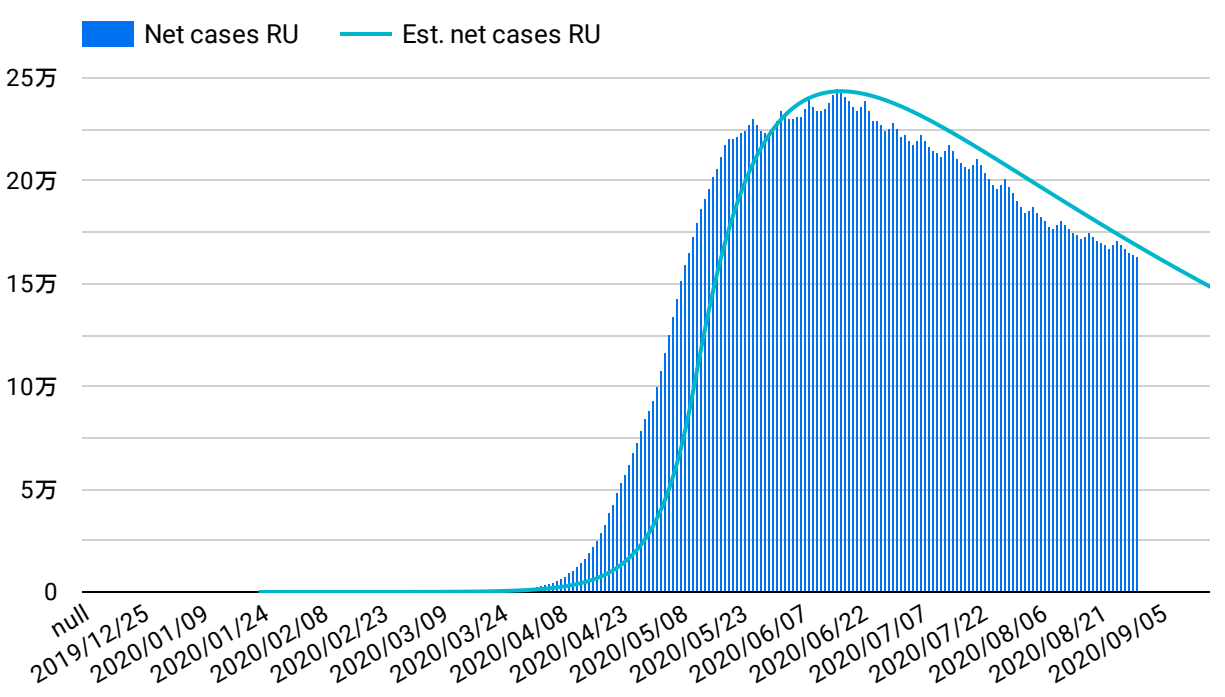
1日当り新規感染者数とモデル推計値 Daily new cases and model estimates



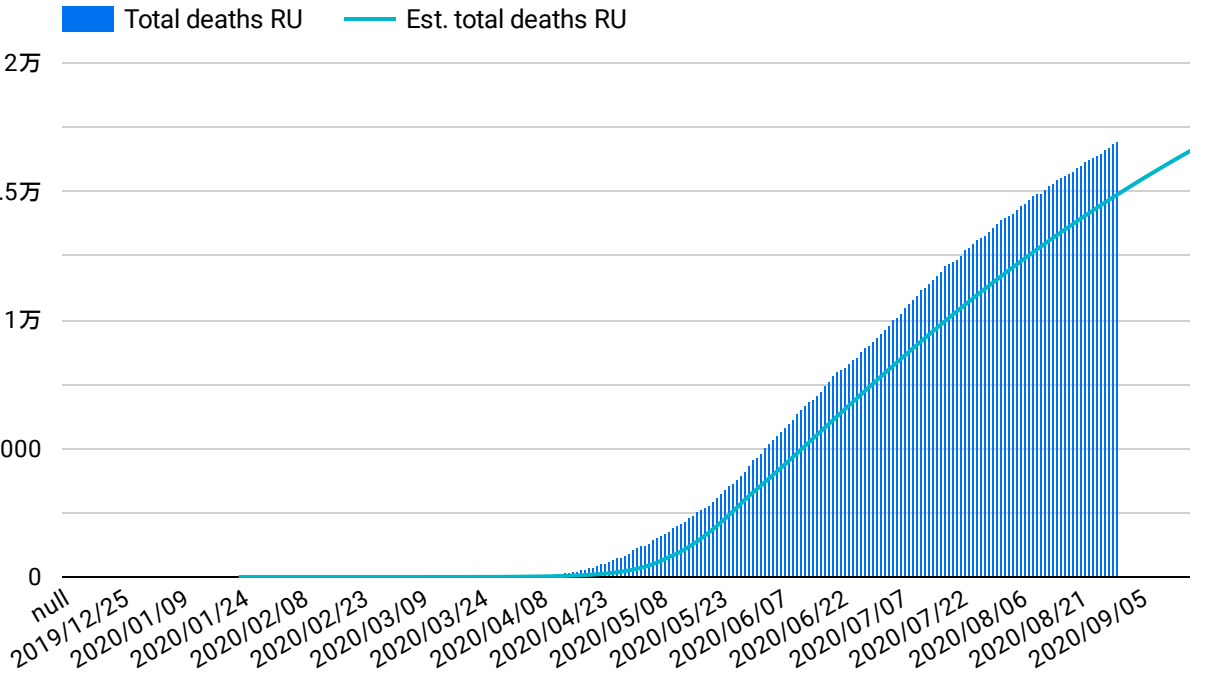
1日当り死者数とモデル推計値 Daily new deaths and model estimates



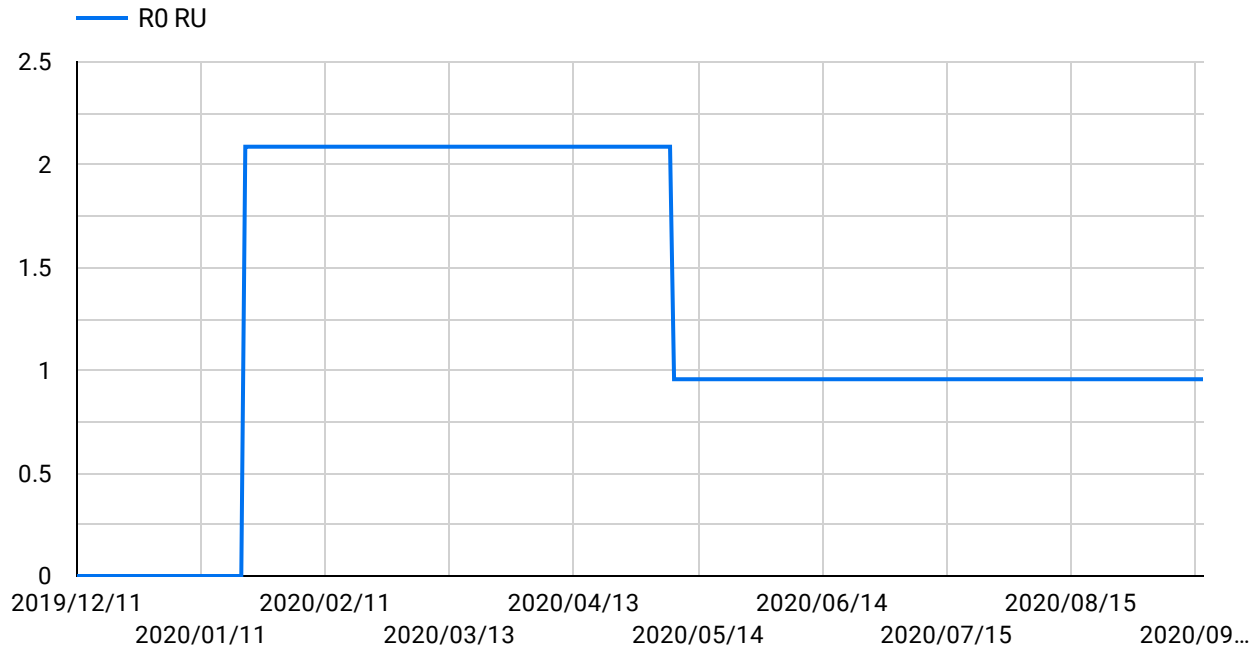
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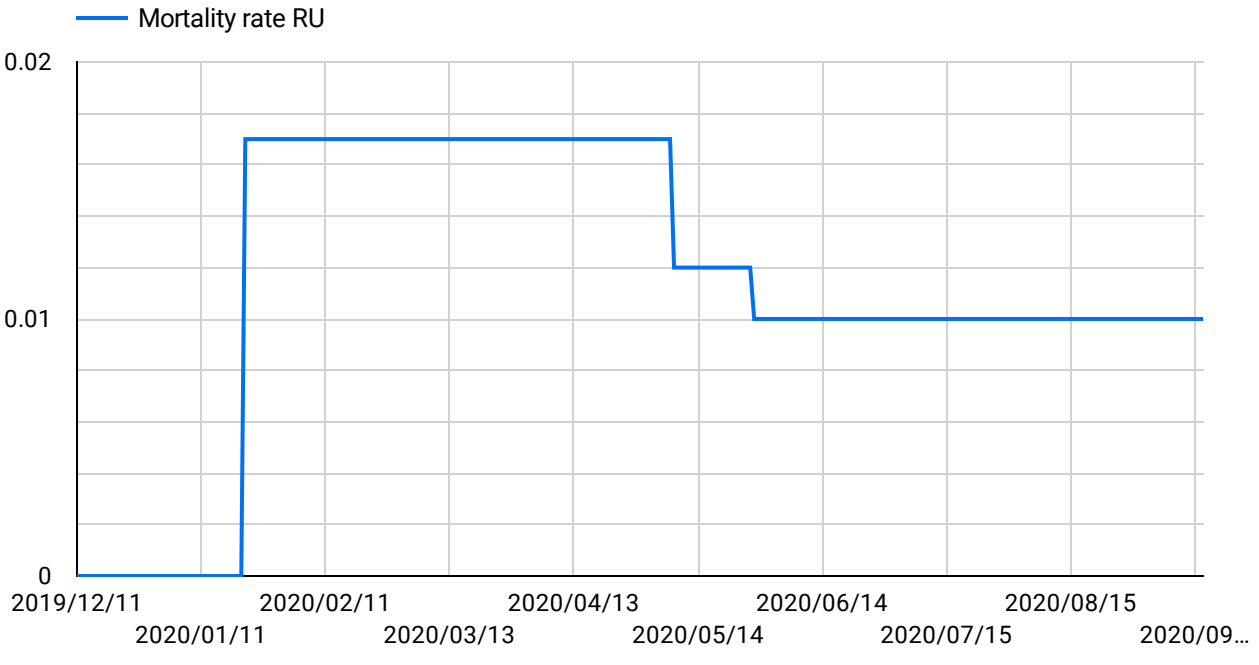
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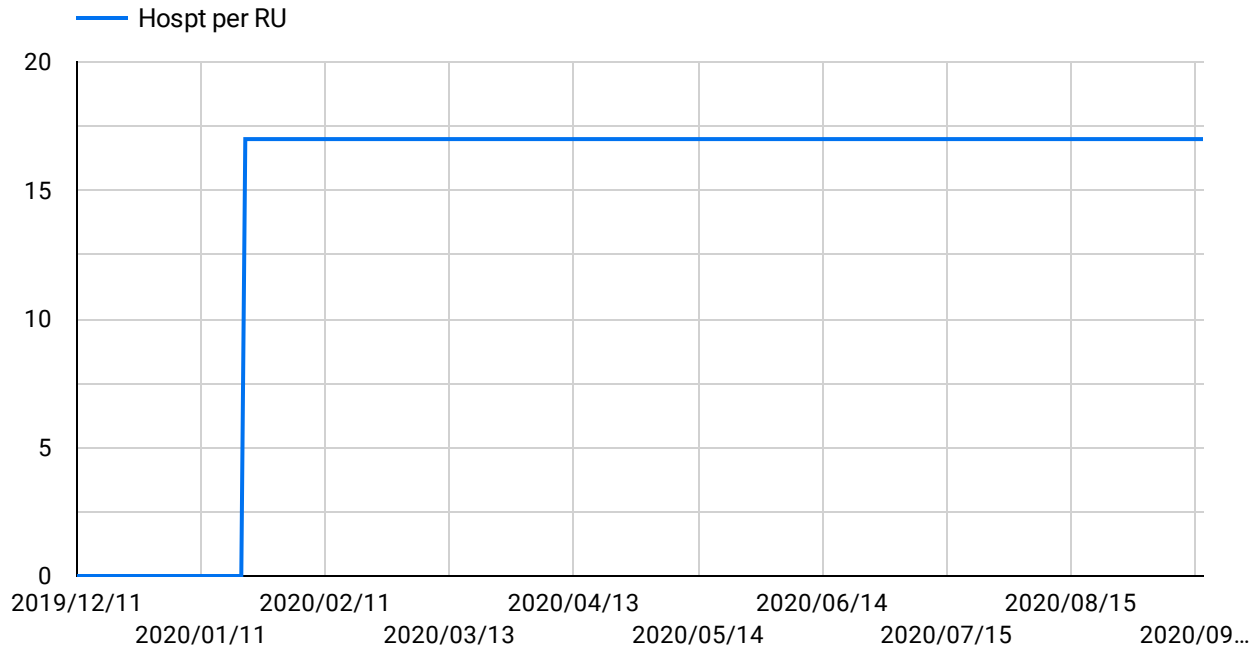
R0 (再生産数) 推計値 R0 estimates



致死率推計値 Mortality rate estimates

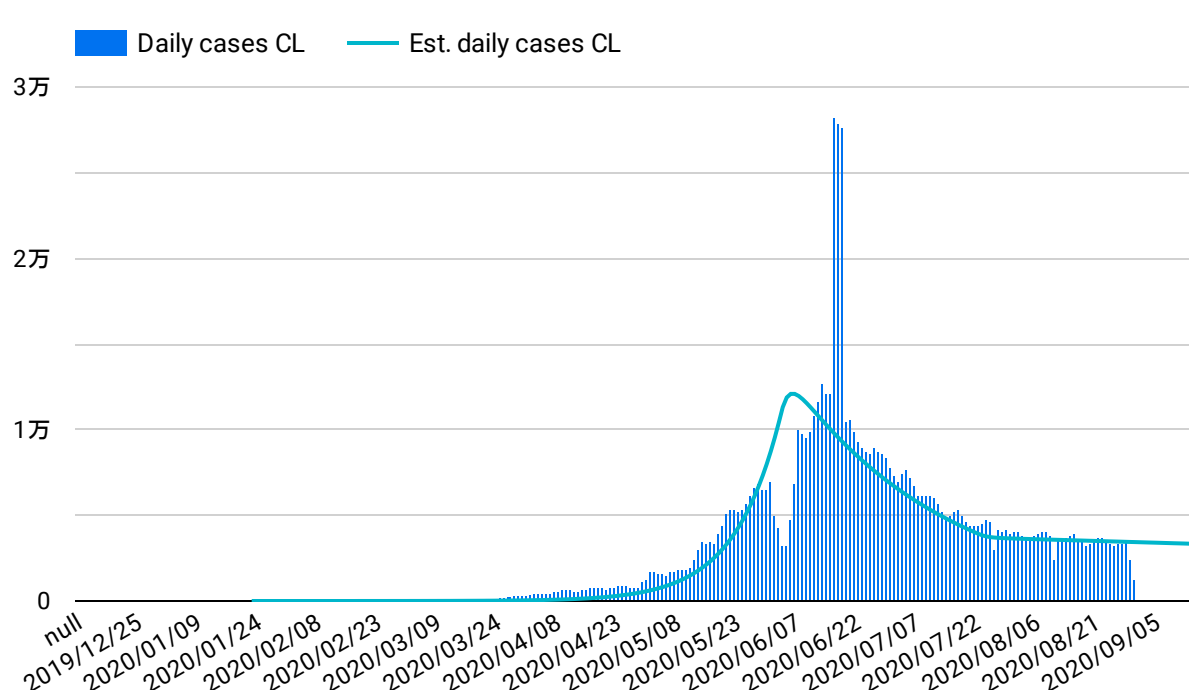


入院期間推計値 Hospitalization period estimates

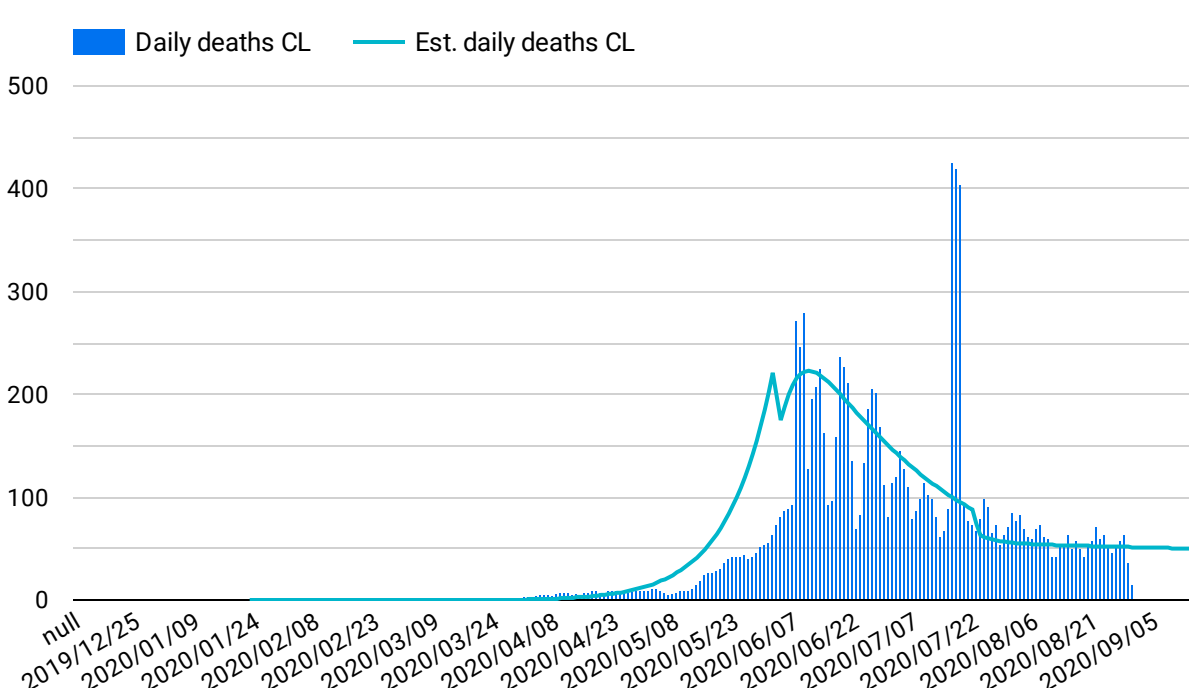


チリ/Chile

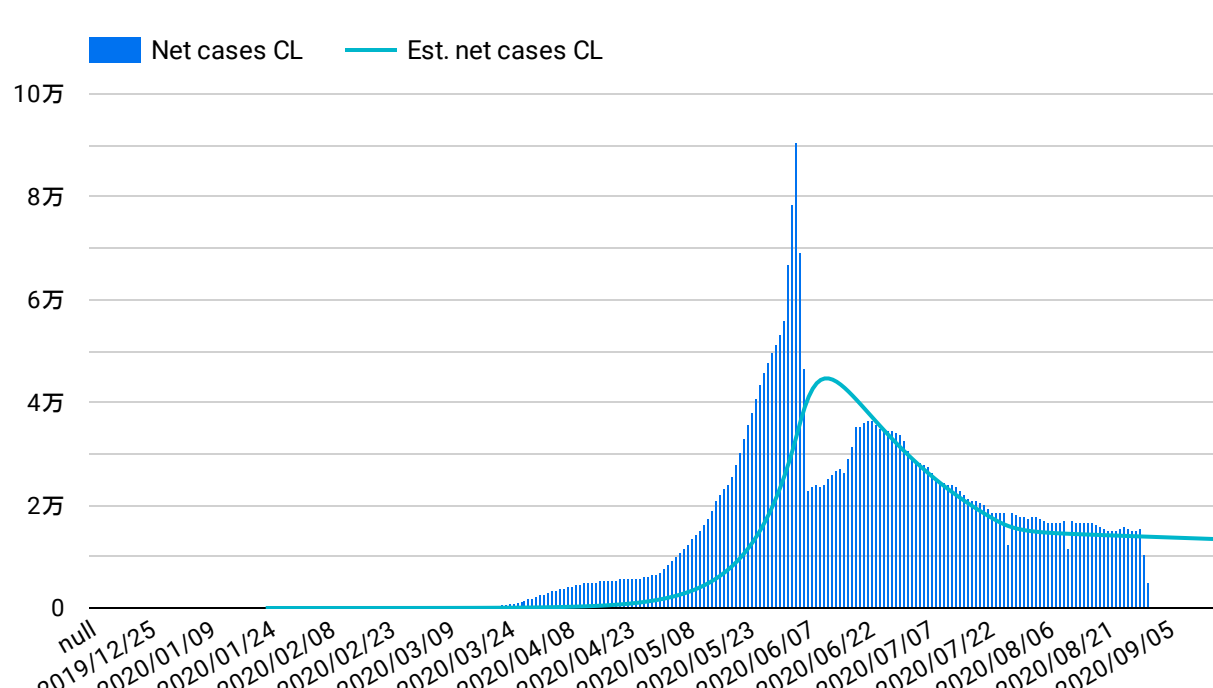
1日当り新規感染者数とモデル推計値 Daily new cases and model estimates



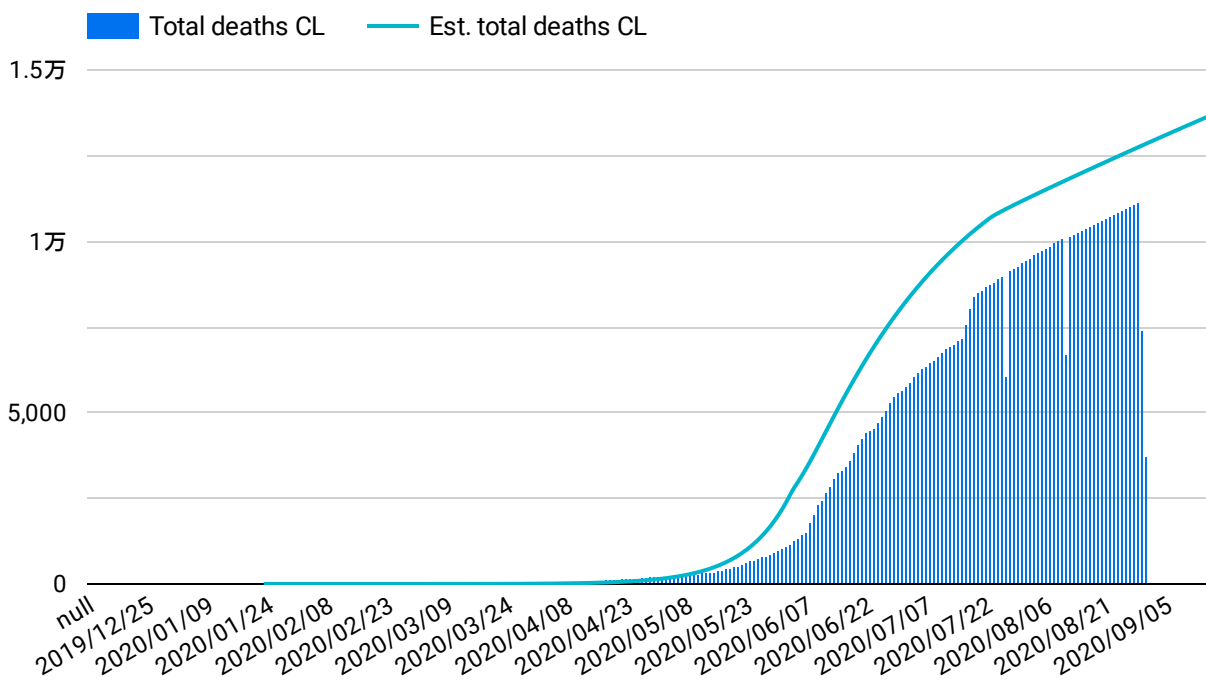
1日当り死者数とモデル推計値 Daily new deaths and model estimates



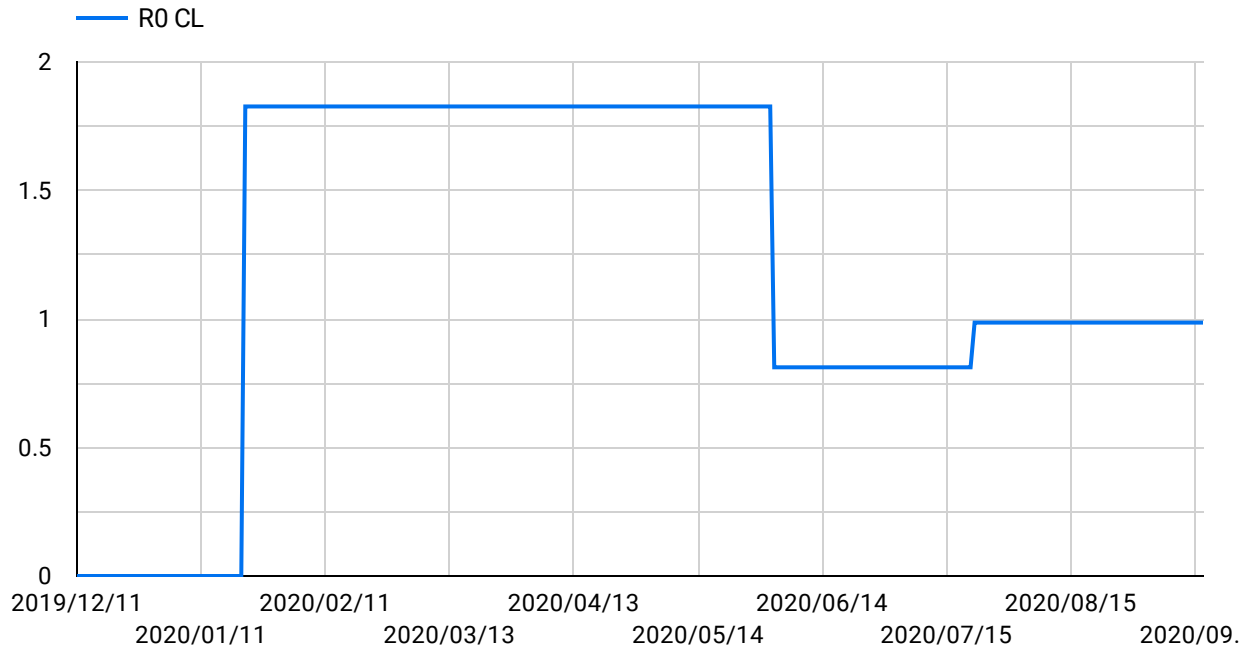
ネット総感染者数とモデル推計値 Net total cases and model estimates



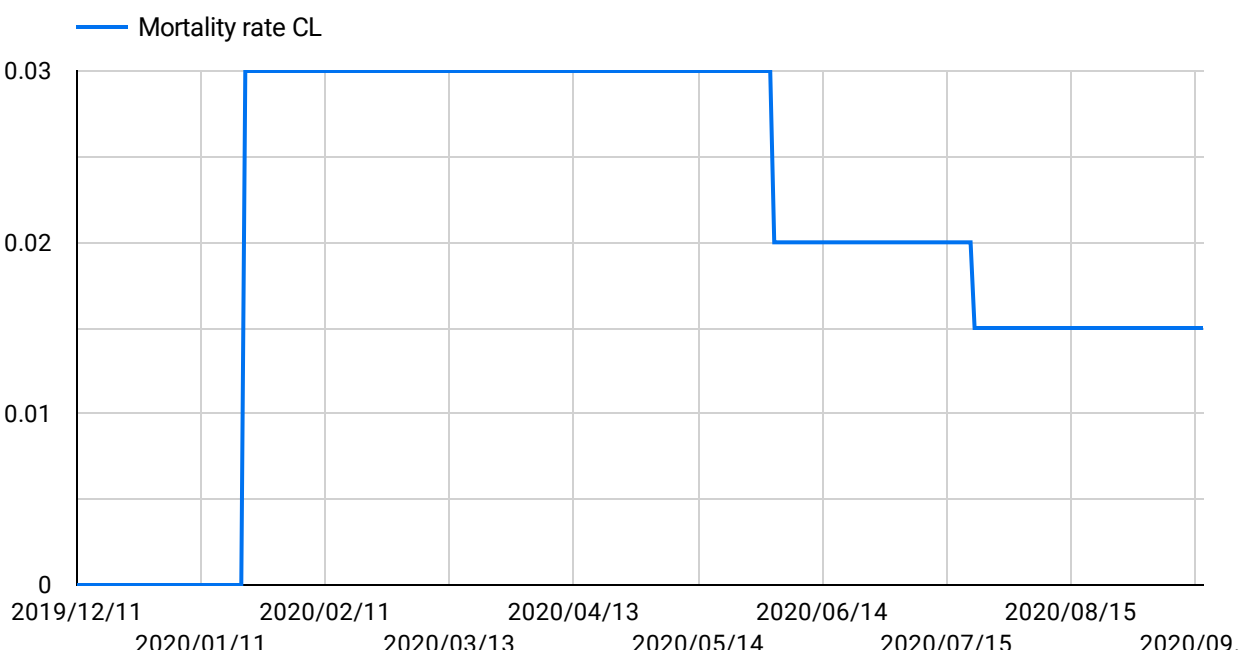
累計死者数とモデル推計値 Total deaths and model estimates



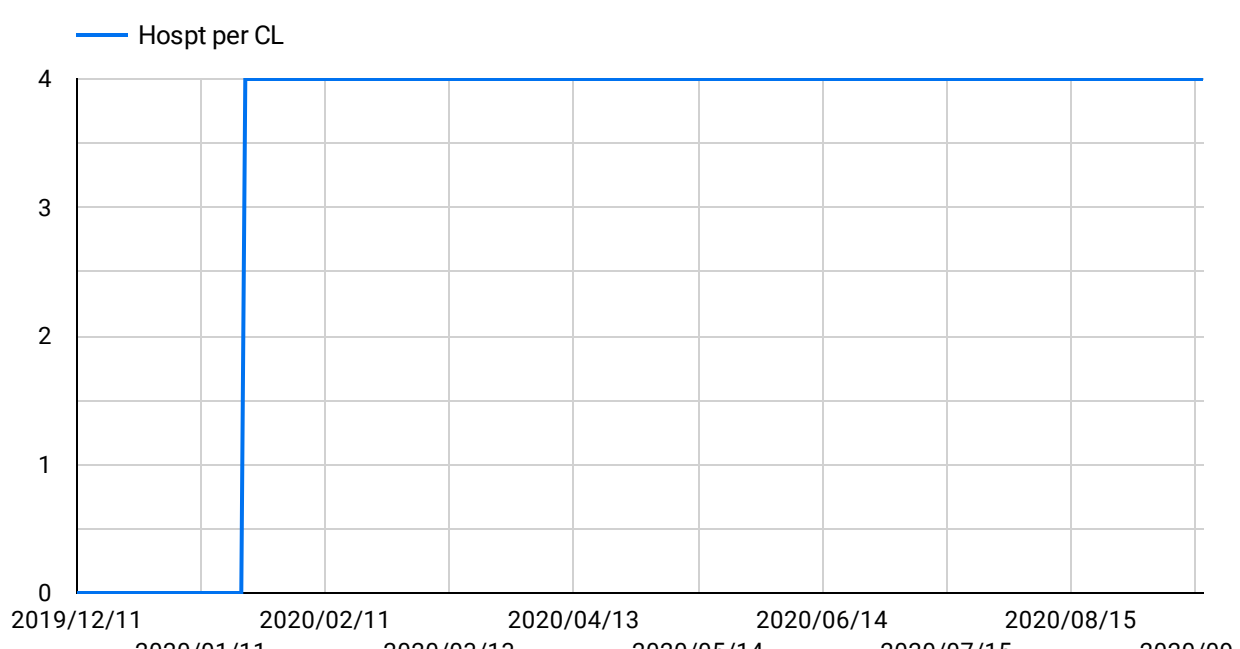
R0 (再生産数) 推計値 R0 estimates



致死率推計値 Mortality rate estimates

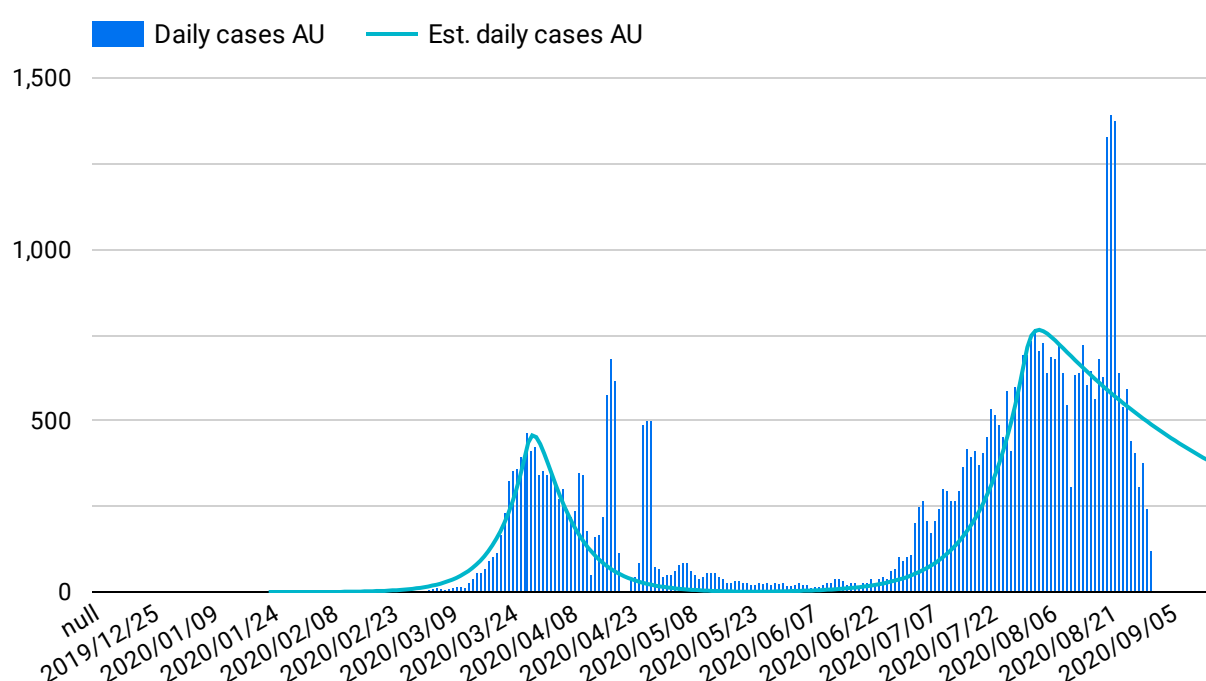


入院期間推計値 Hospitalization period estimates

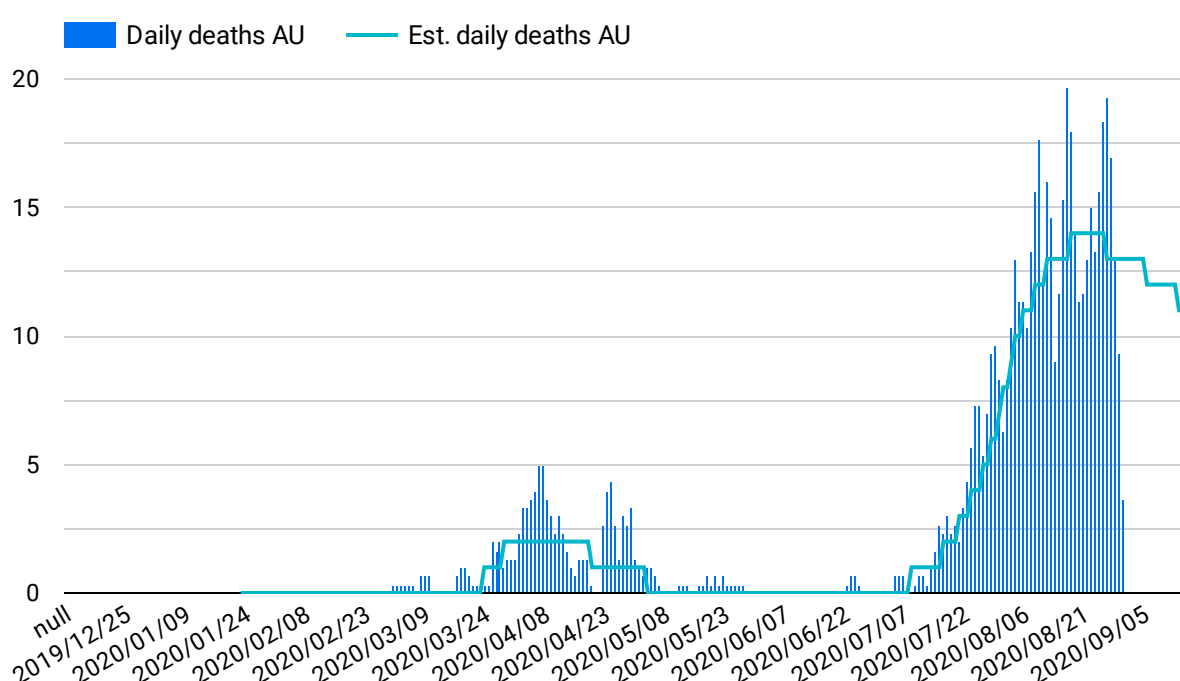


オーストラリア/Australia

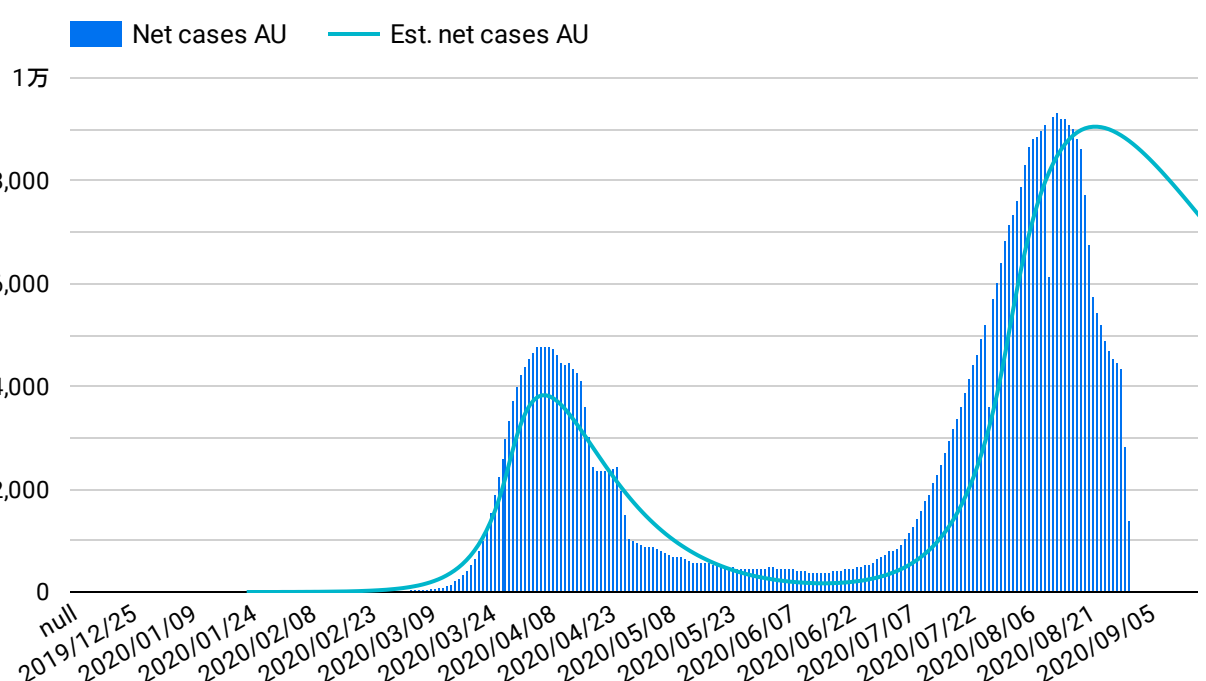
1日当り新規感染者数とモデル推計値 Daily new cases and model estimates



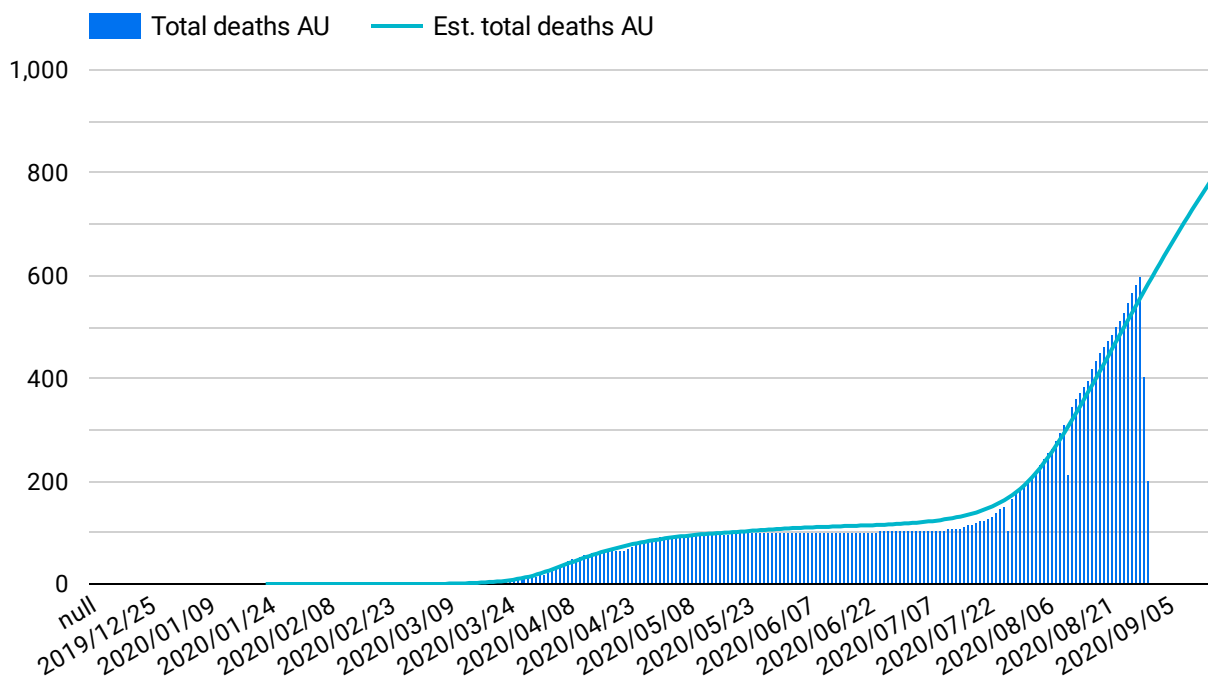
1日当り死者数とモデル推計値 Daily new deaths and model estimates



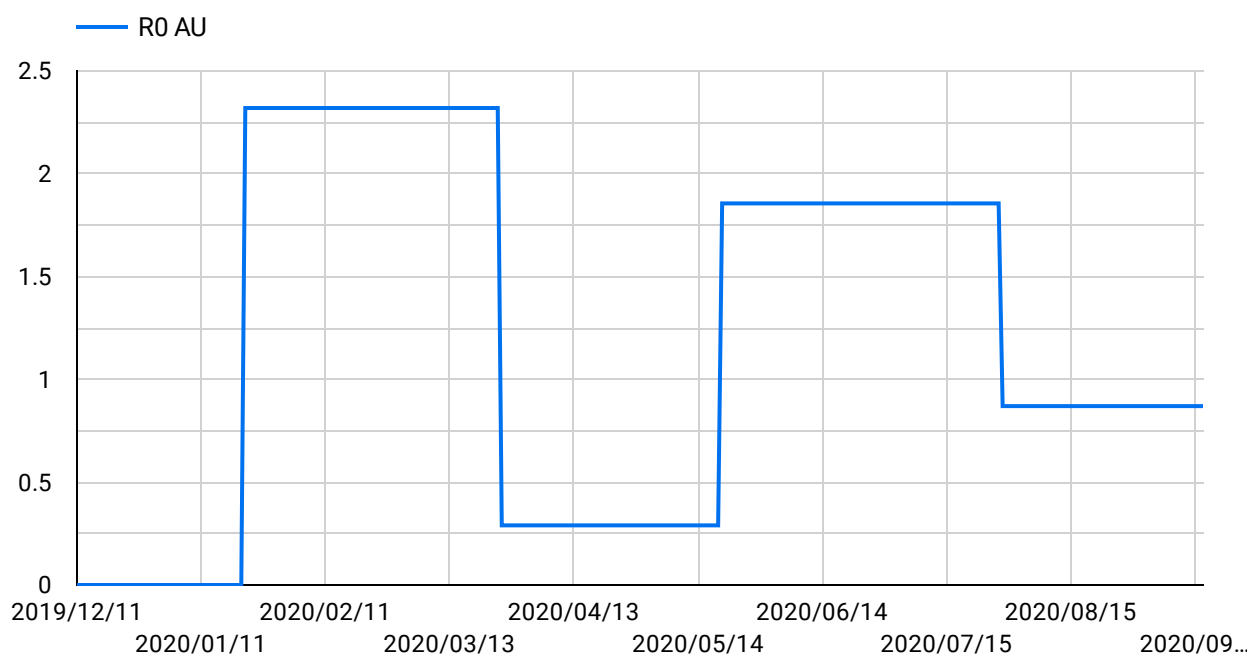
ネット総感染者数とモデル推計値 Net total cases and model estimates



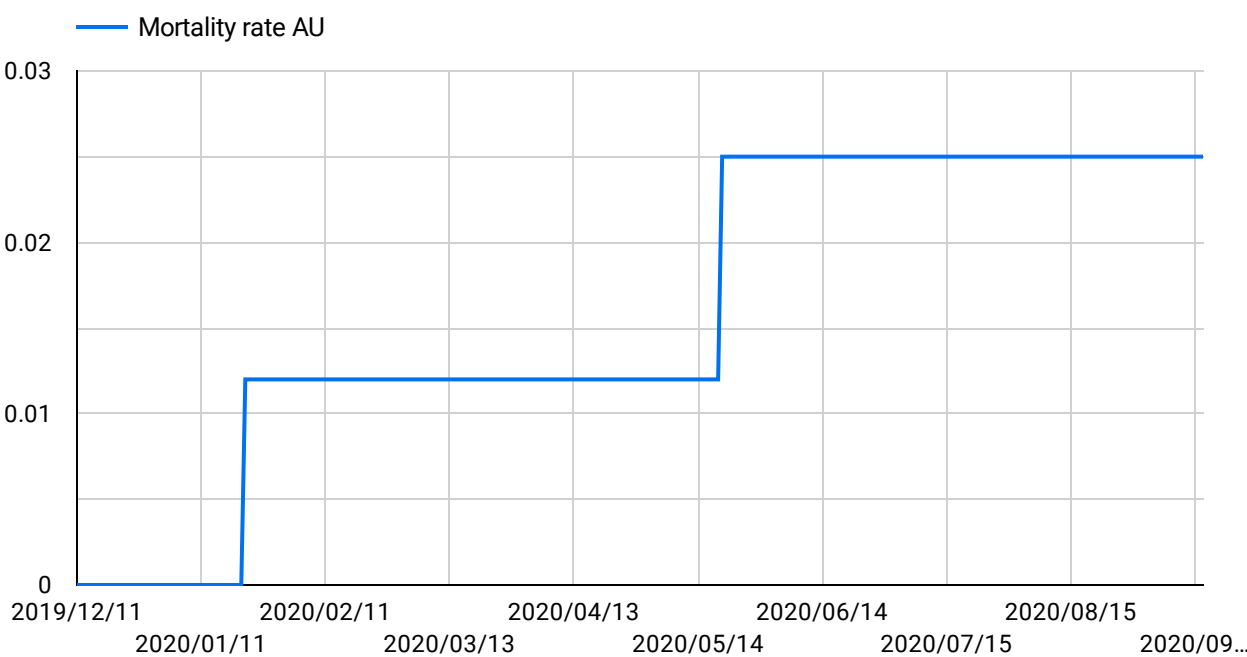
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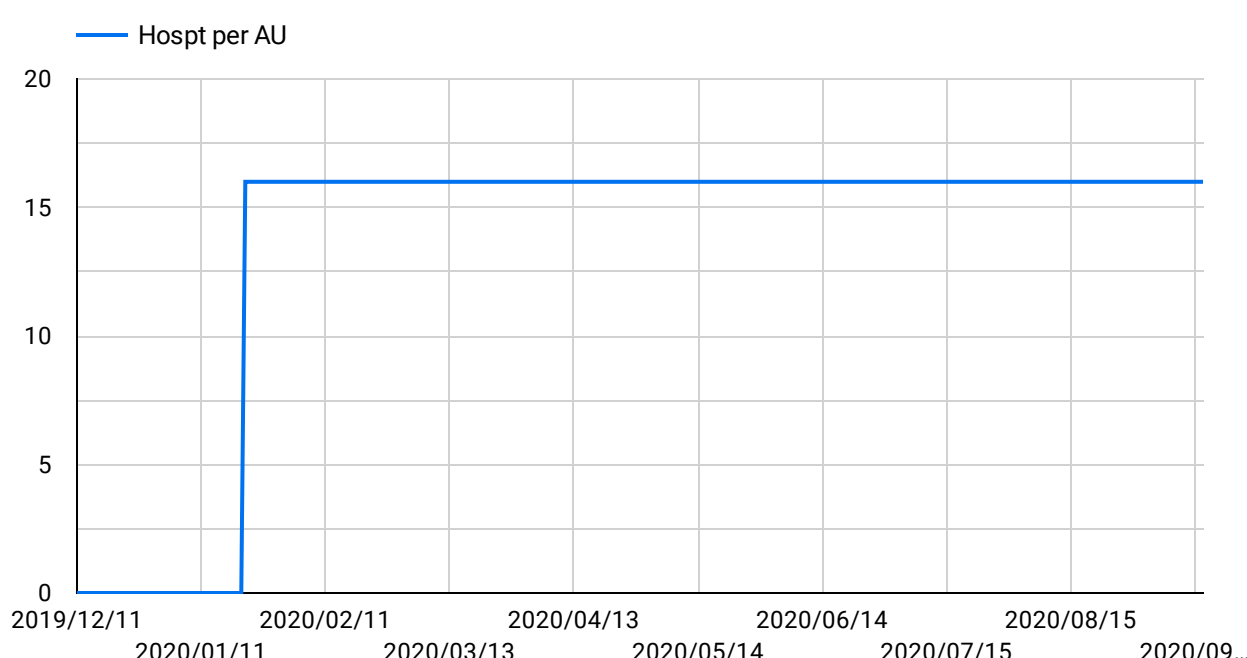
R0 (再生産数) 推計値 R0 estimates



致死率推計値 Mortality rate estimates

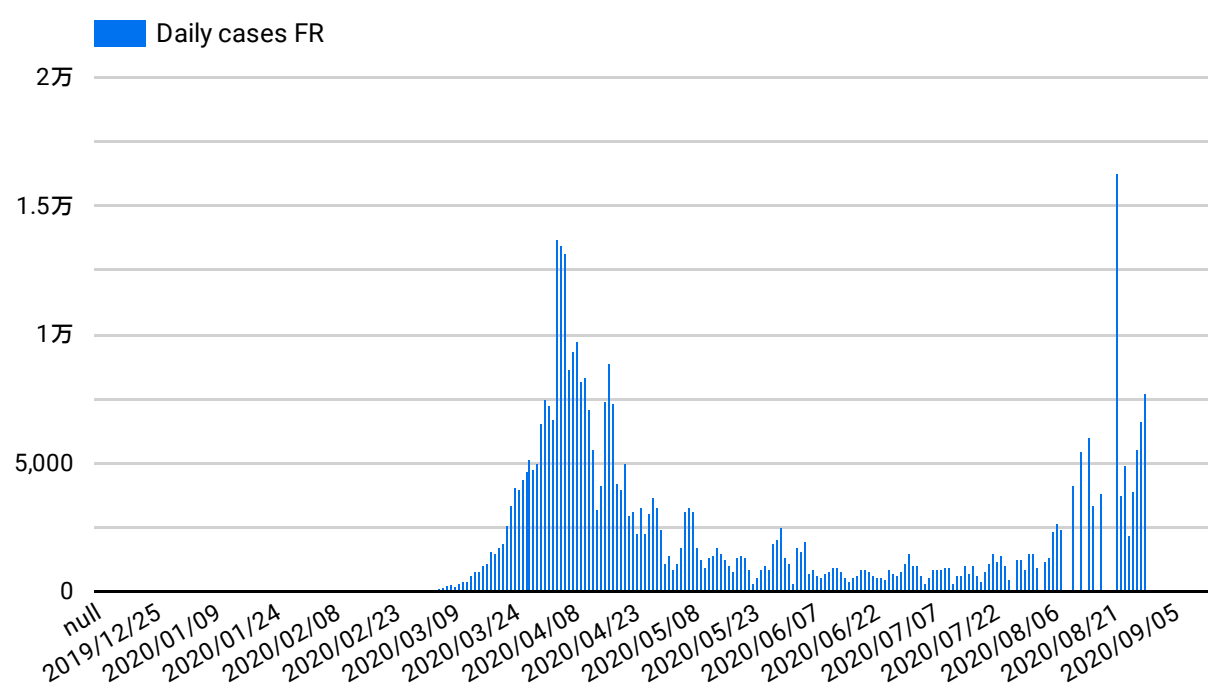


入院期間推計値 Hospitalization period estimates

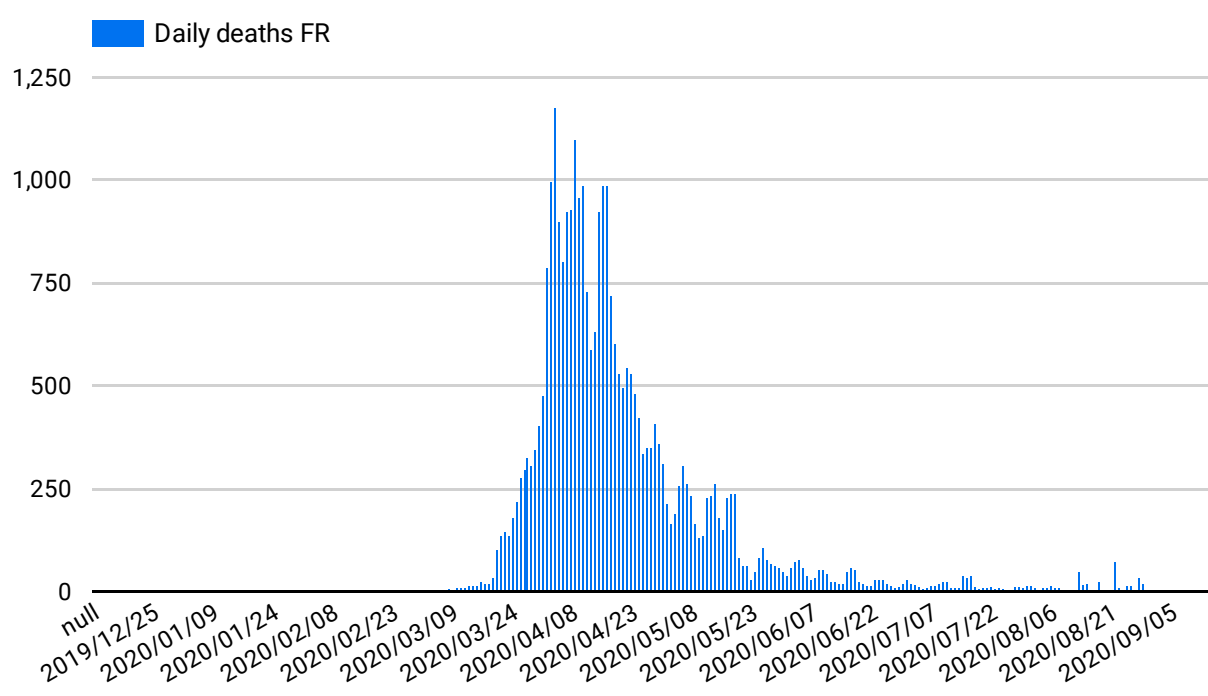


フランス/France

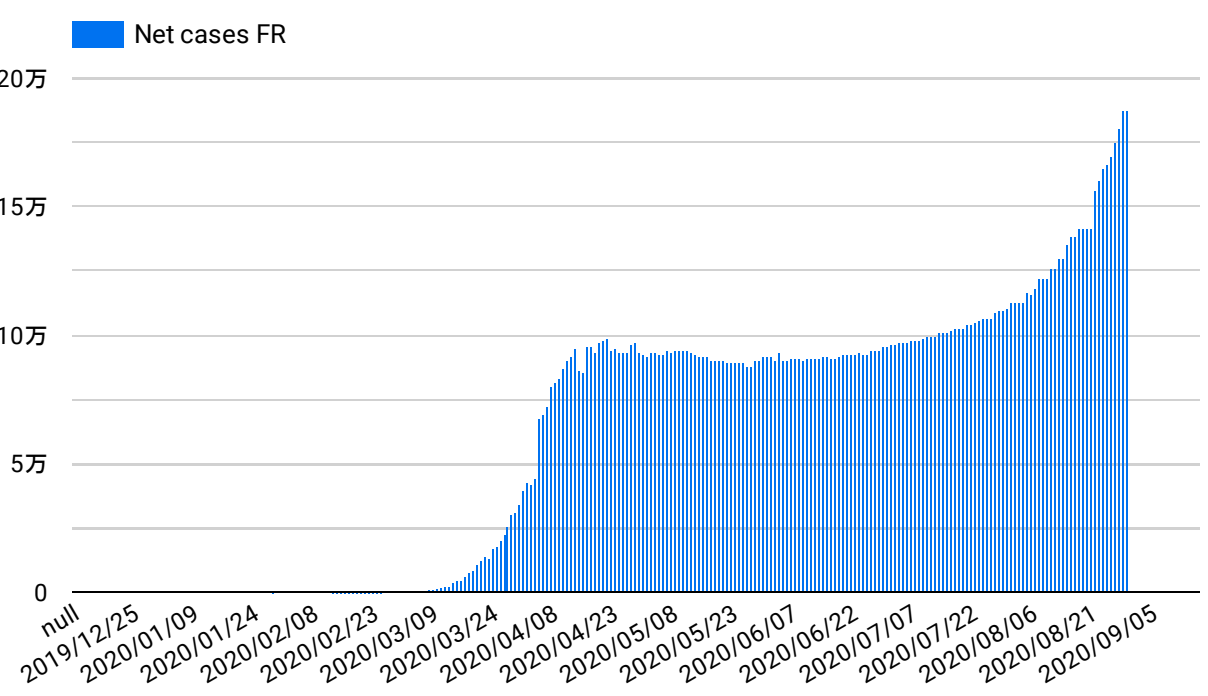
1日当り新規感染者数 Daily new cases



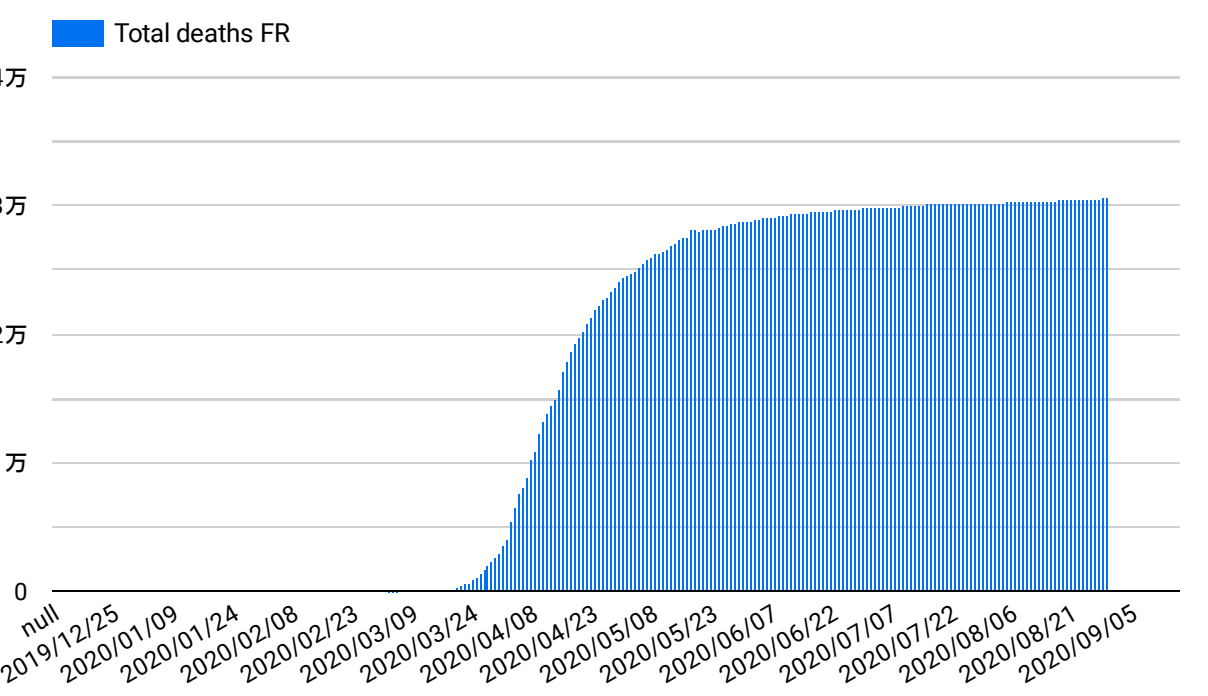
1日当り死者数 Daily new deaths



ネット総感染者数 Net total cases

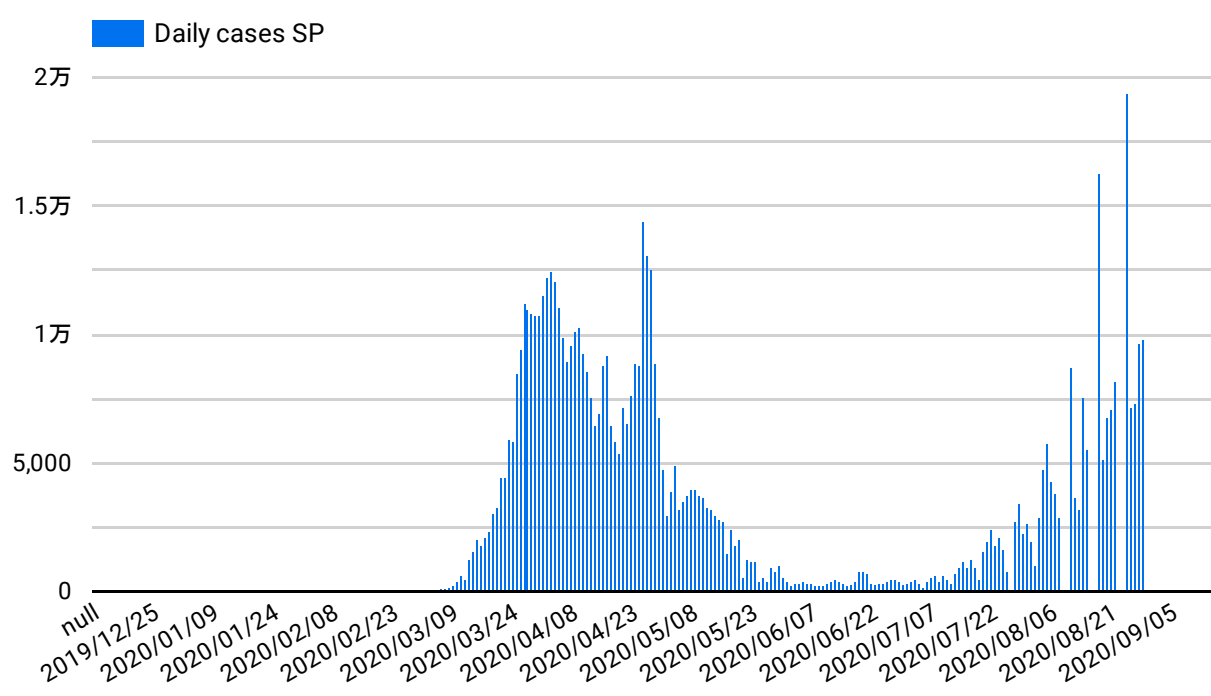


累計死者数 Total deaths

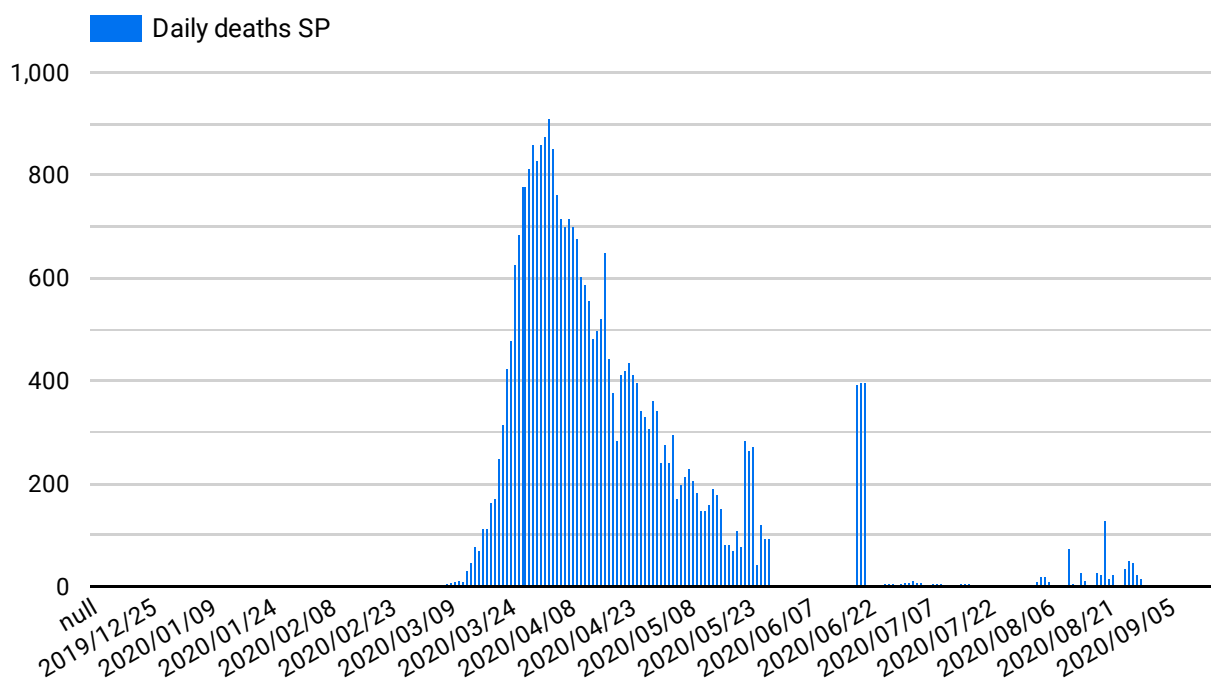


スペイン/Spain

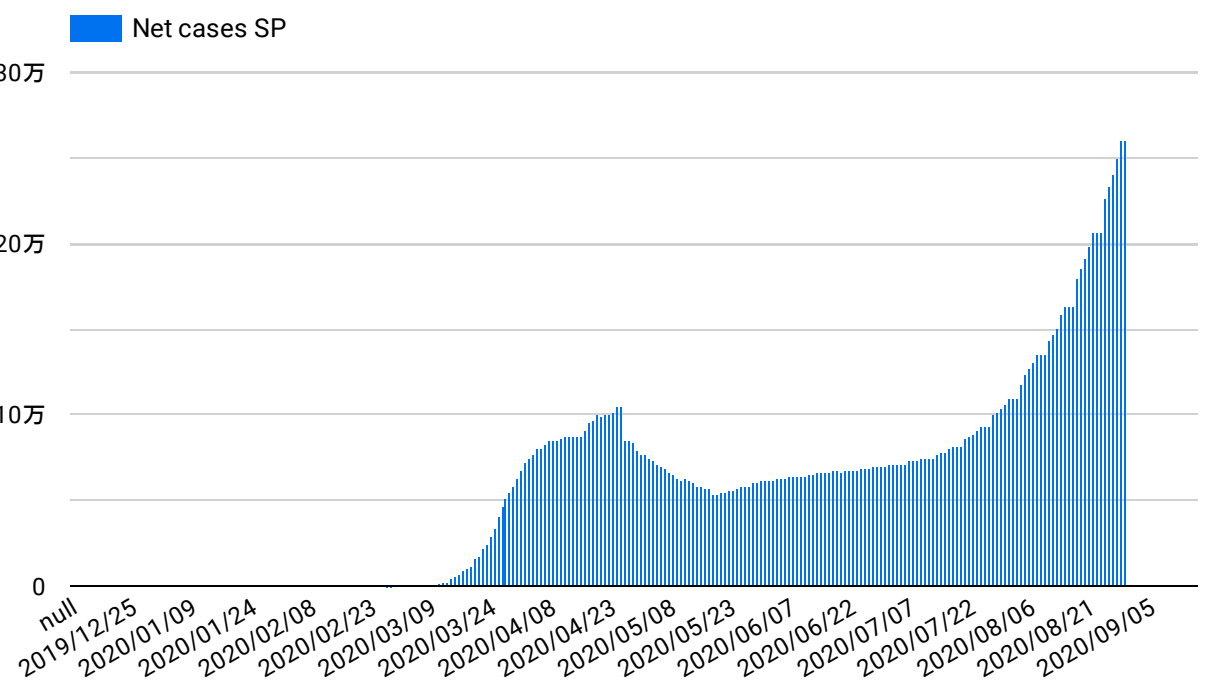
1日当り新規感染者数 Daily new cases



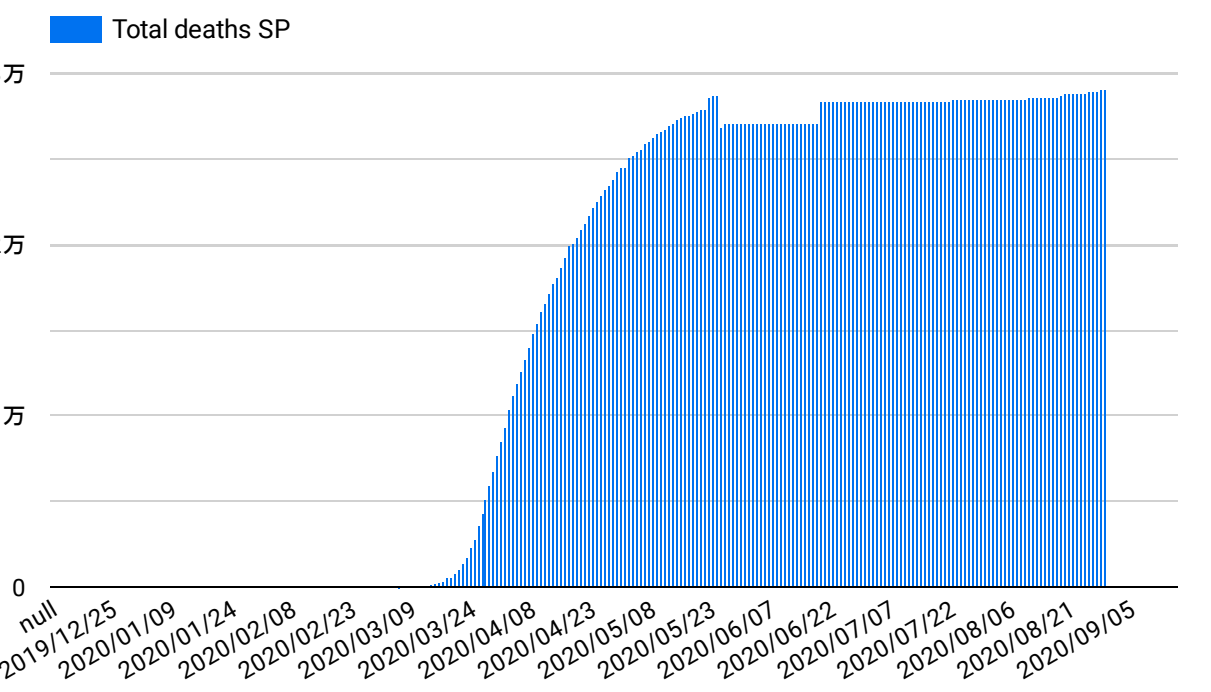
1日当り死者数 Daily new deaths



ネット総感染者数 Net total cases

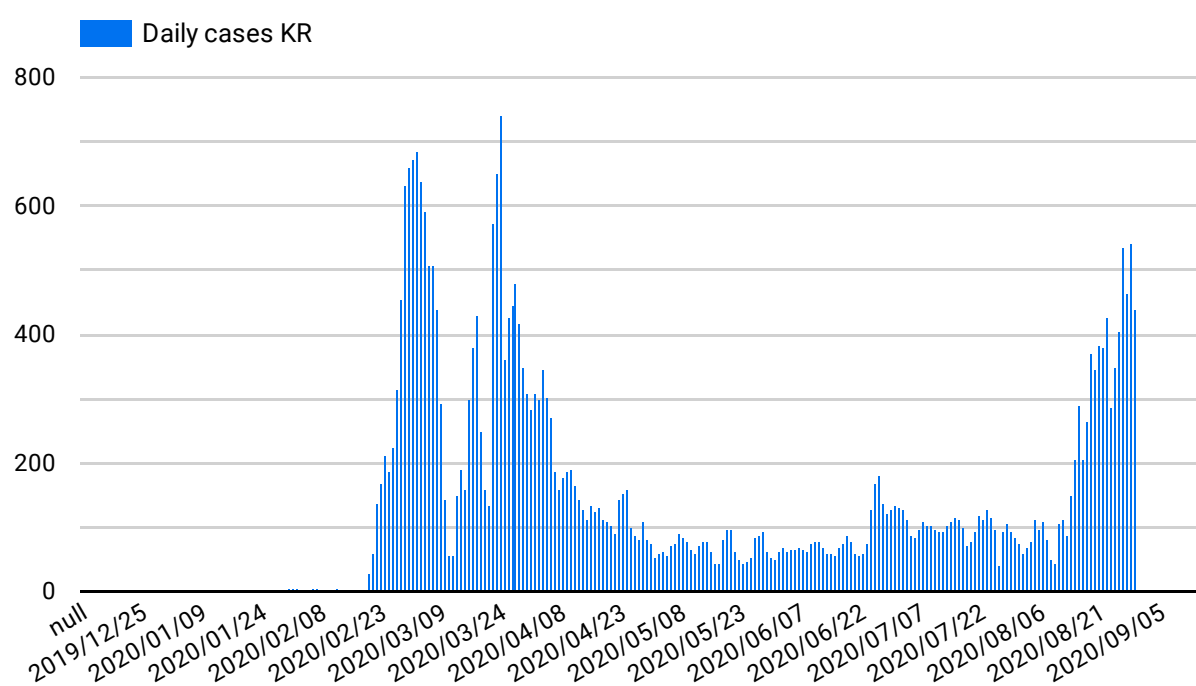


累計死者数 Total deaths

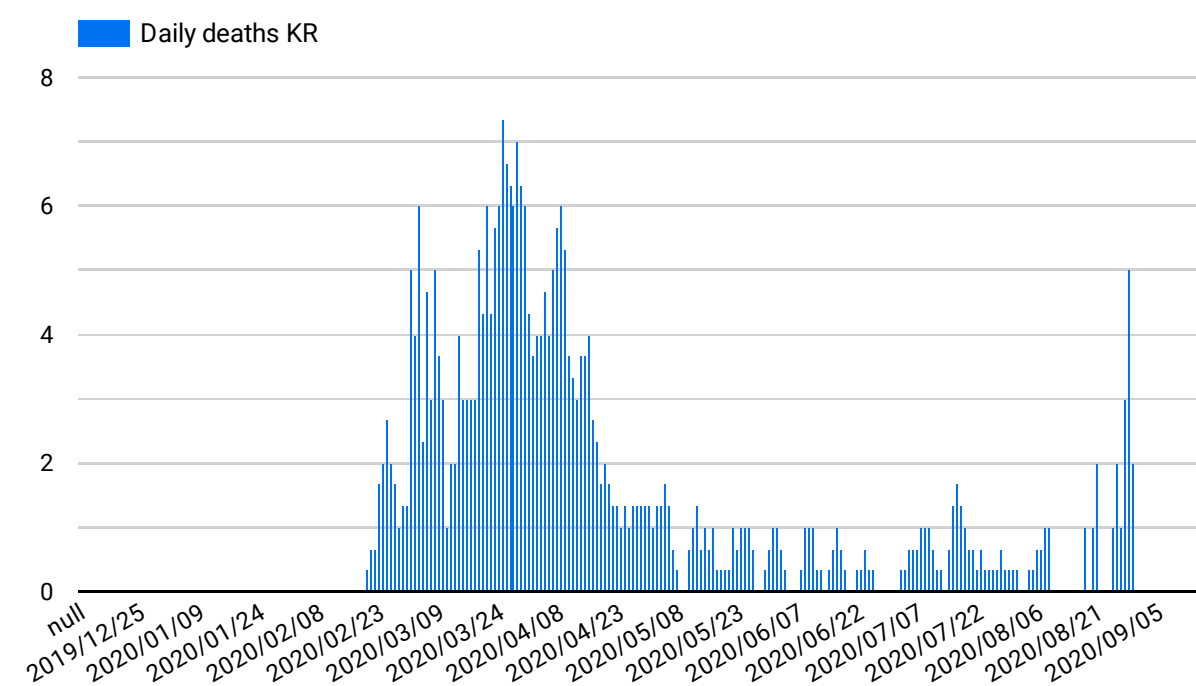


韓国/Korea

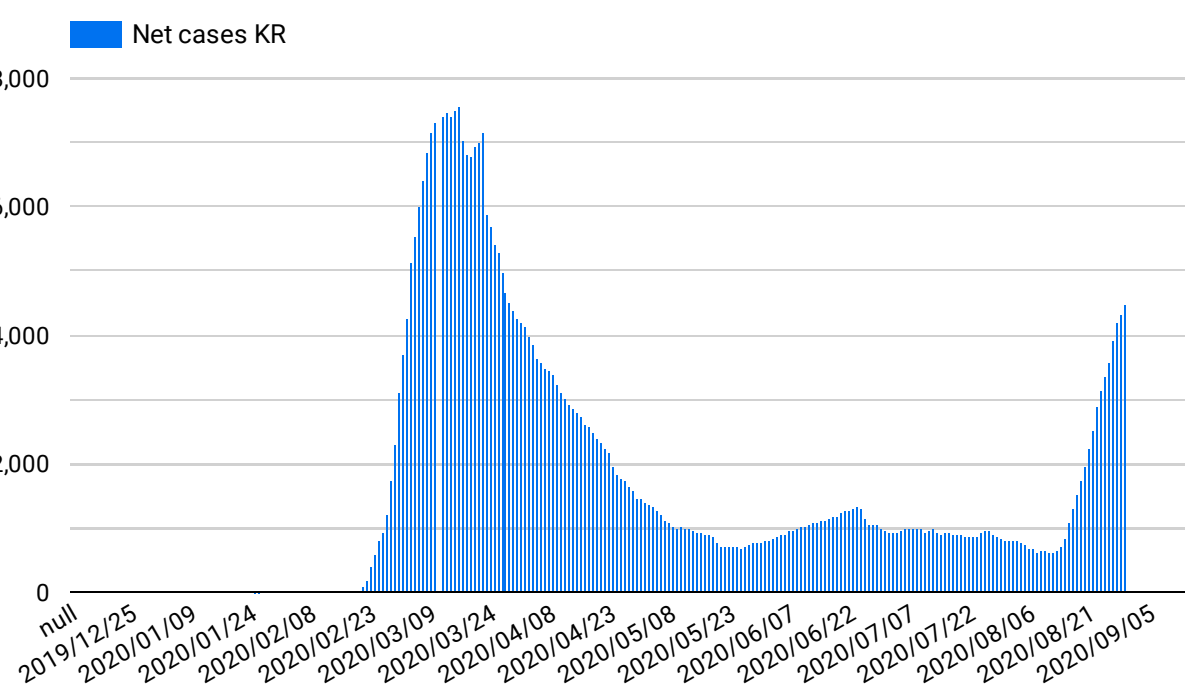
1日当り新規感染者数 Daily new cases



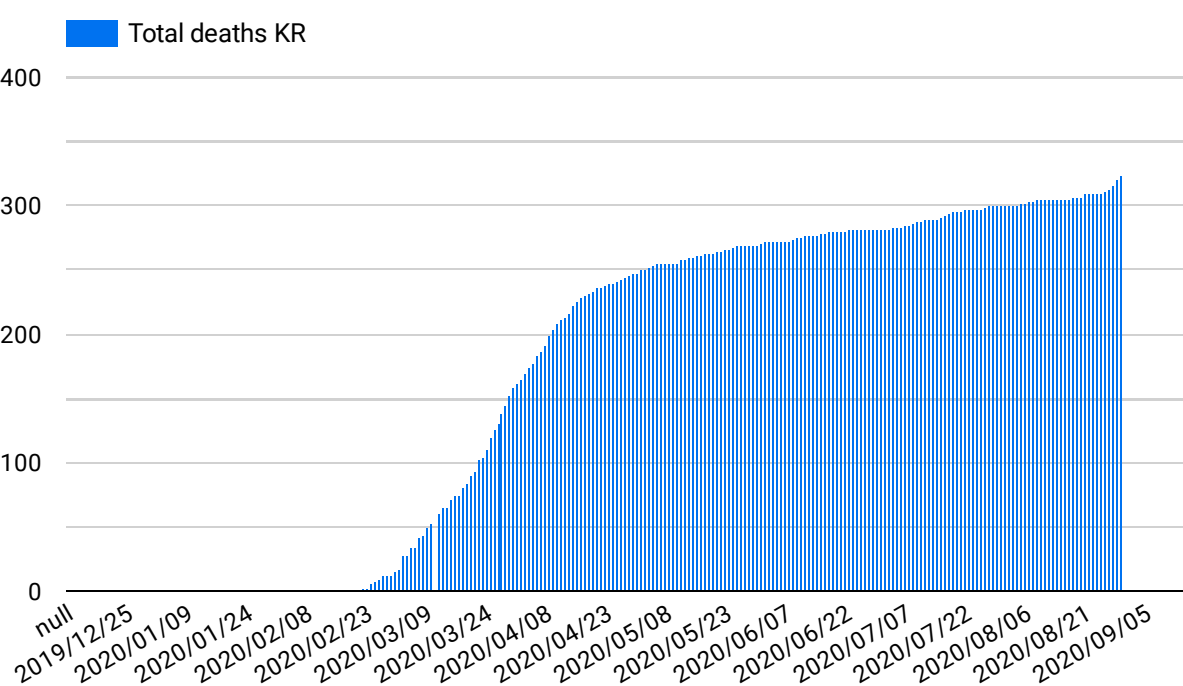
1日当り死者数 Daily new deaths



ネット総感染者数 Net total cases

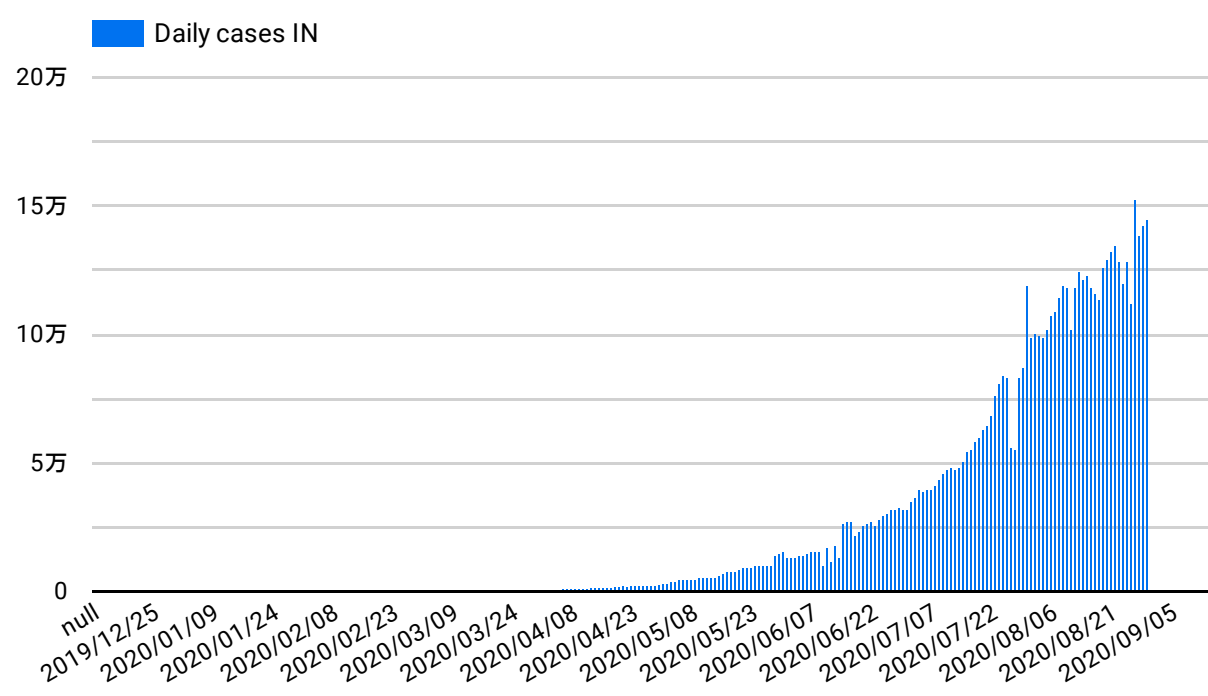


累計死者数 Total deaths

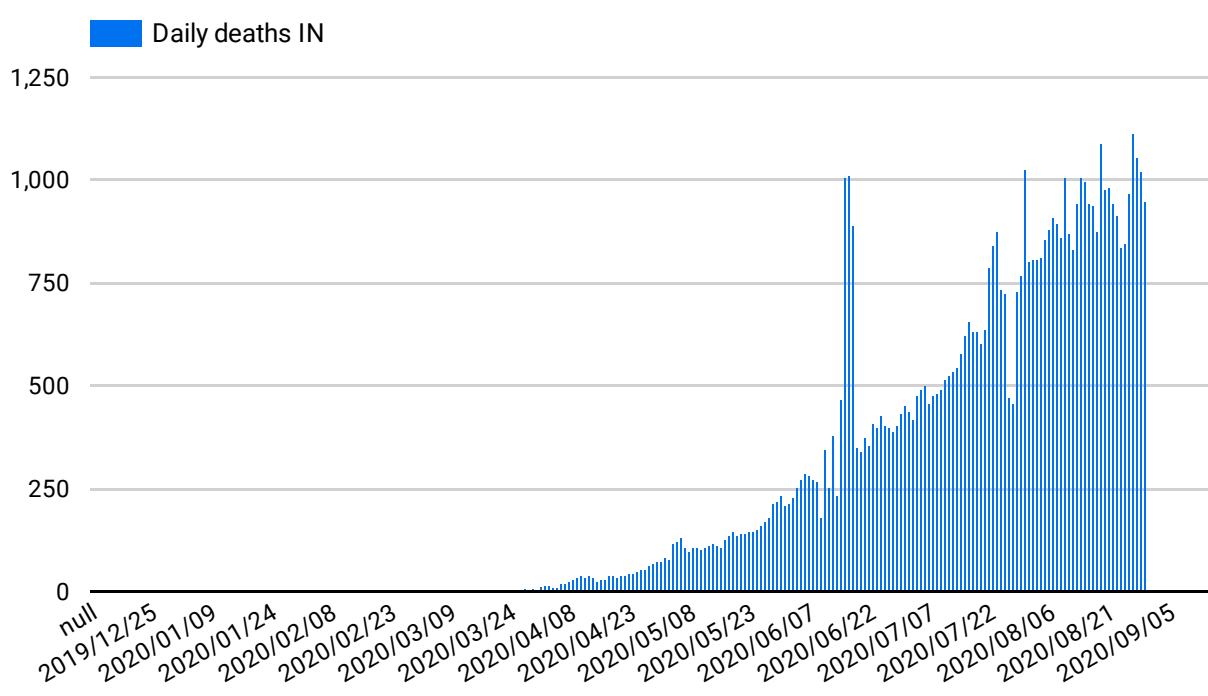


インド/India

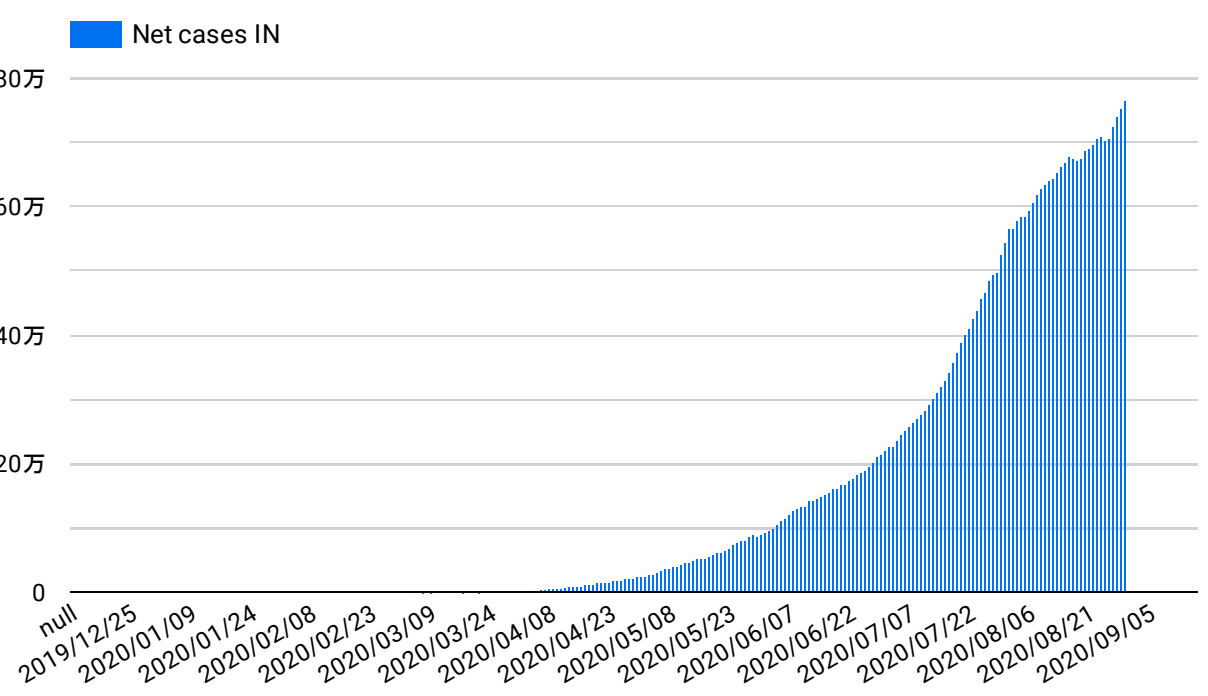
1日当り新規感染者数
Daily new cases



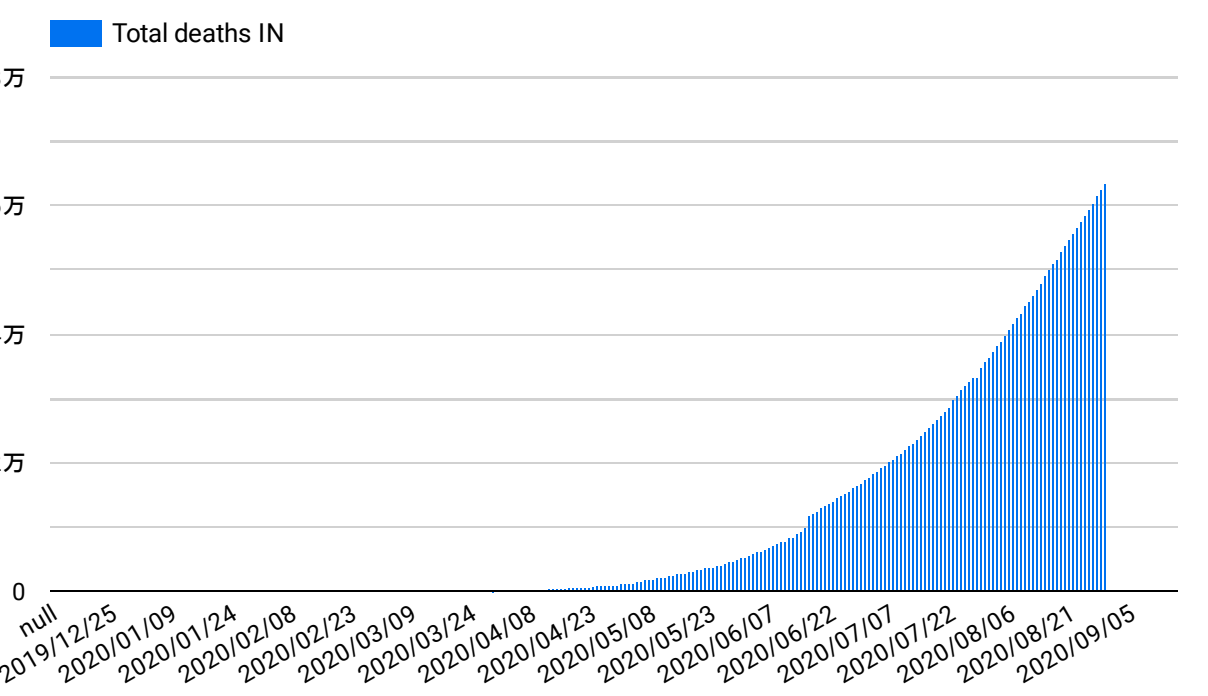
1日当り死者数
Daily new deaths



ネット総感染者数
Net total cases

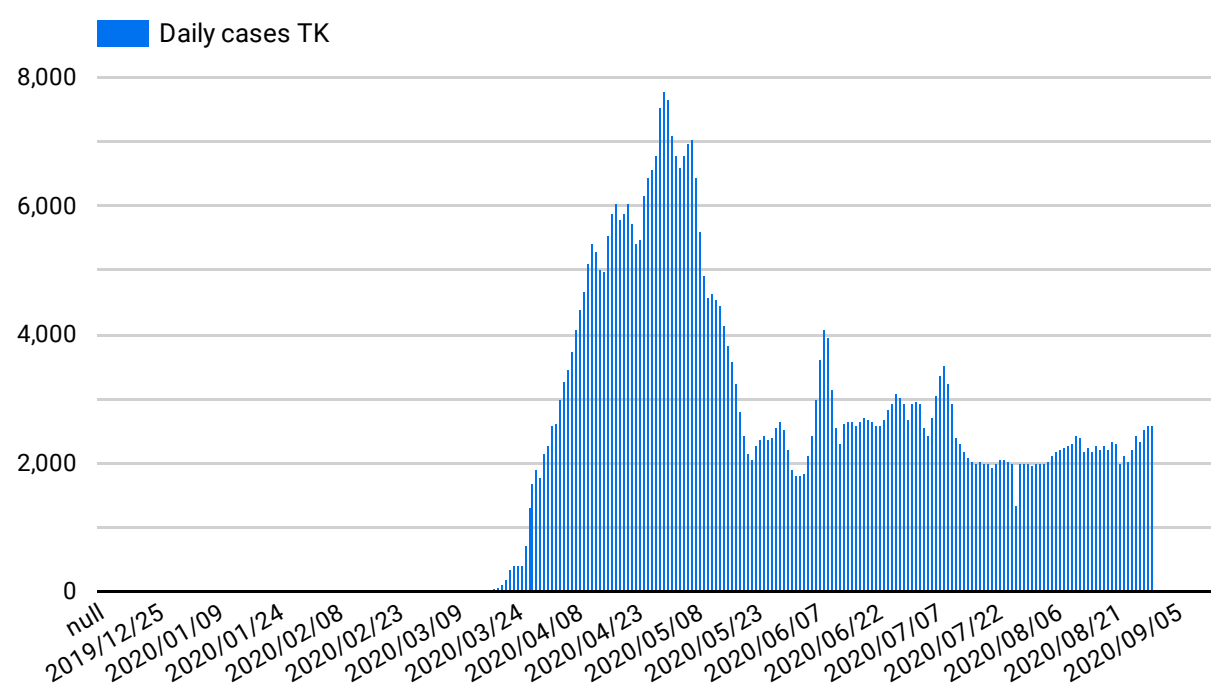


累計死者数
Total deaths

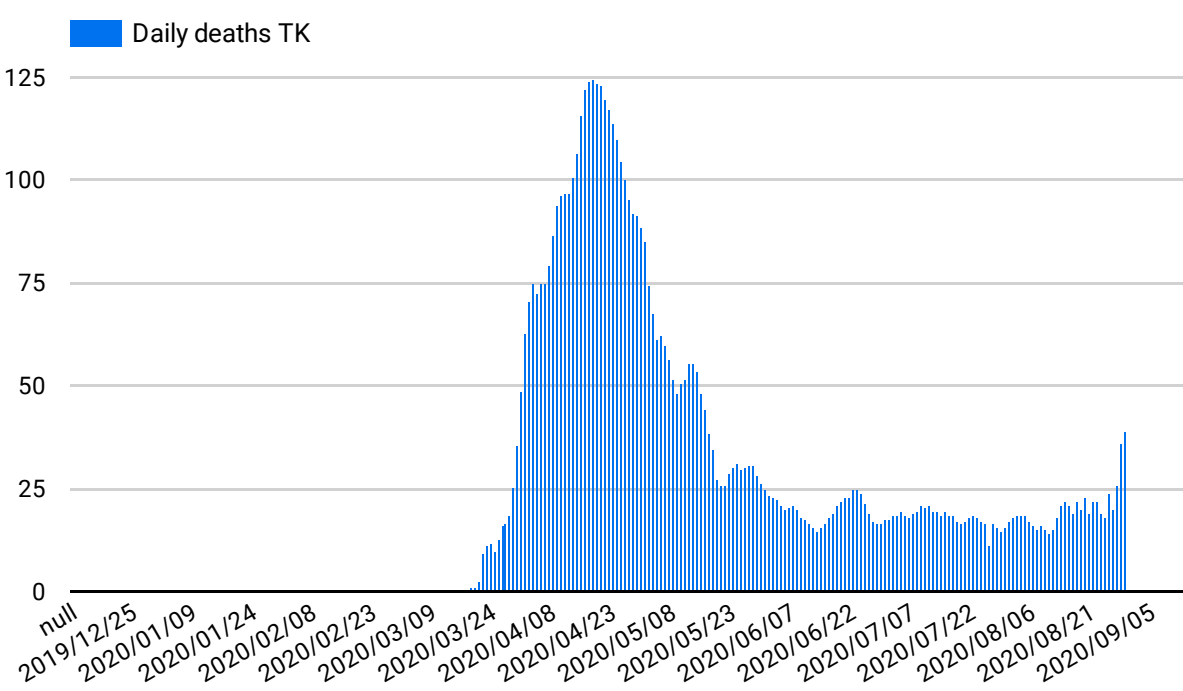


トルコ/Turkey

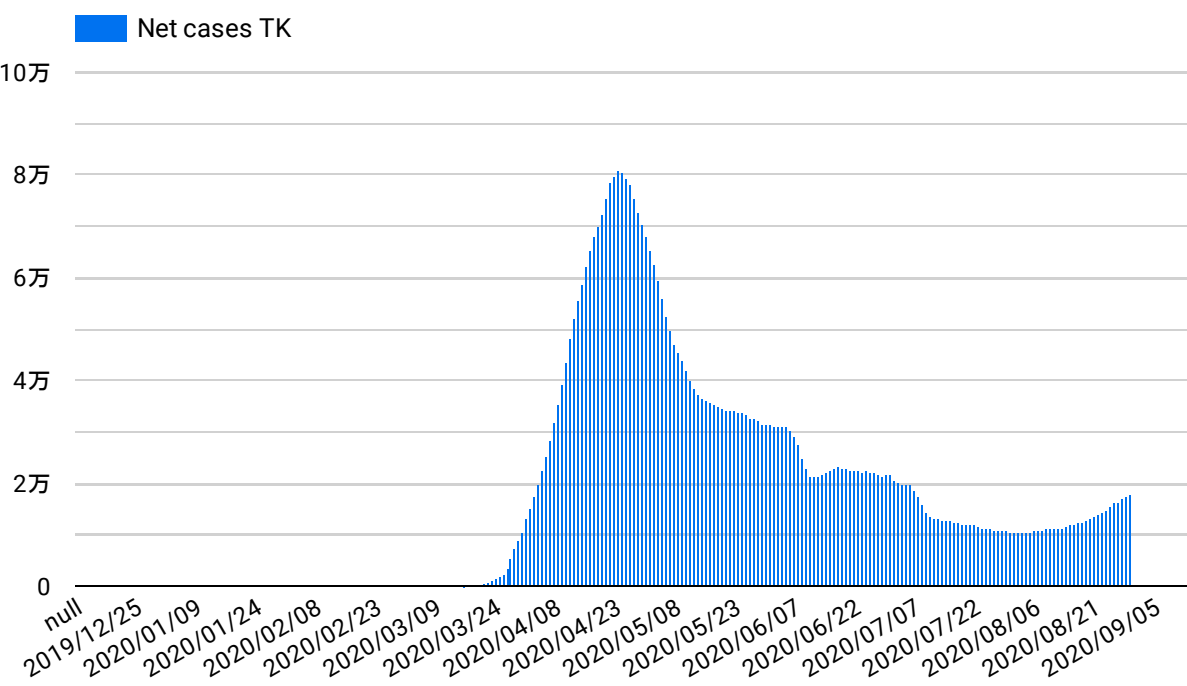
1日当り新規感染者数 Daily new cases



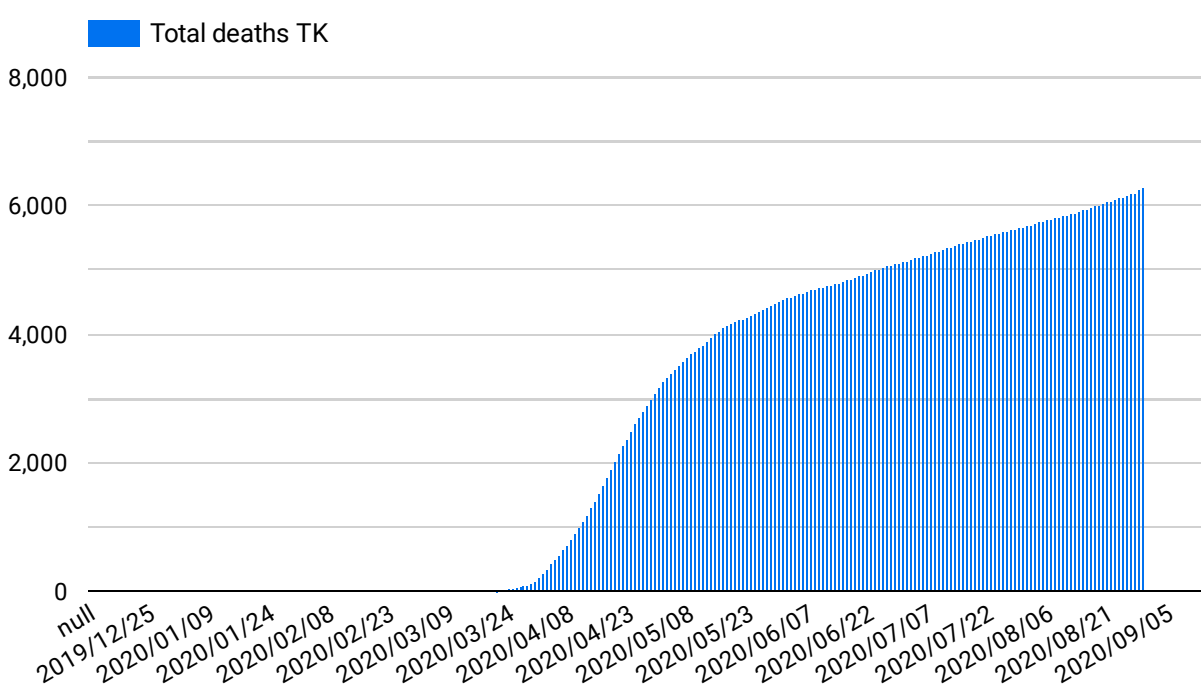
1日当り死者数 Daily new deaths



ネット総感染者数 Net total cases

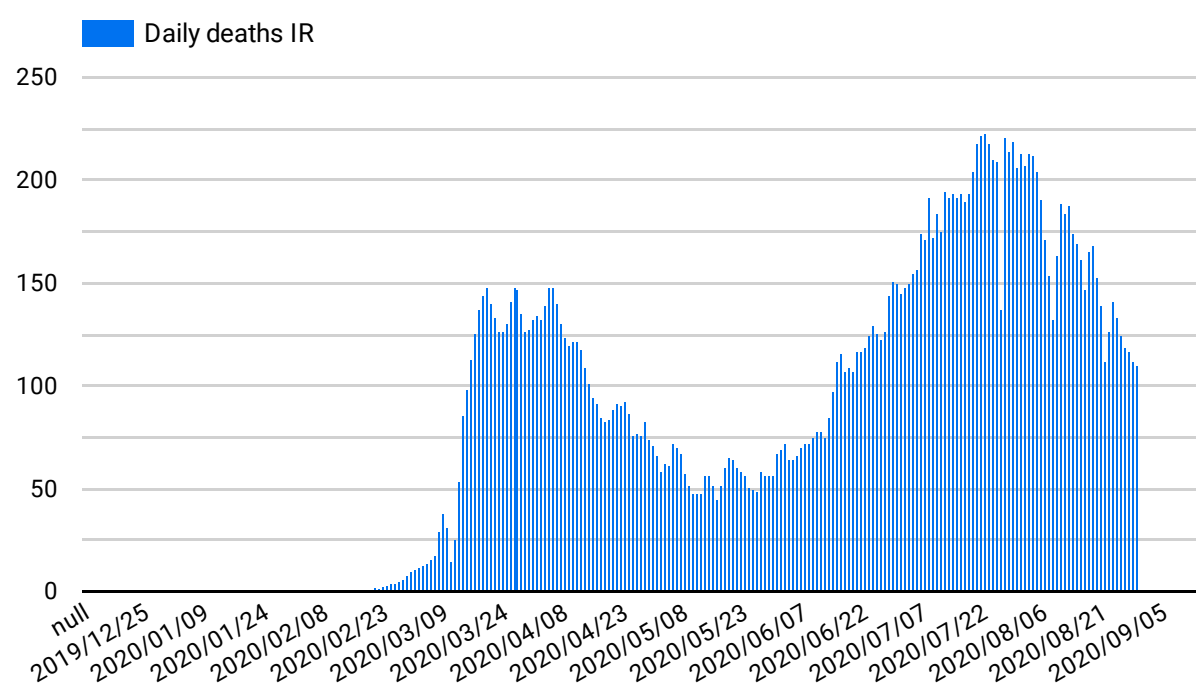


累計死者数 Total deaths

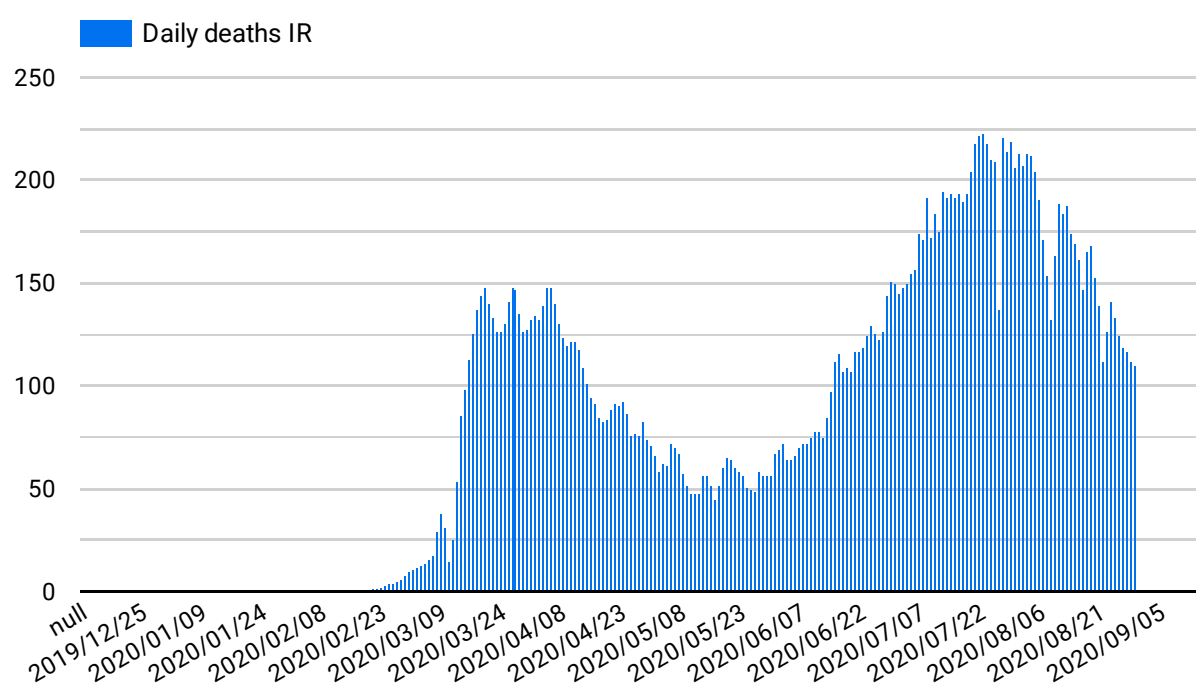


イラン/Iran

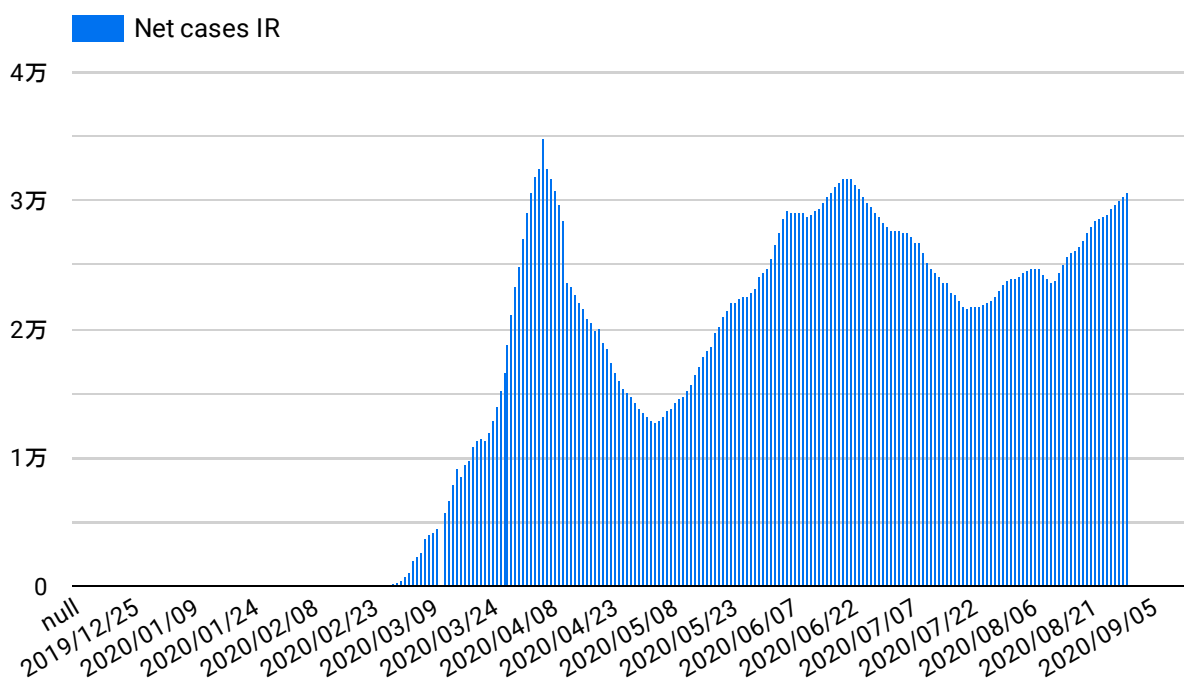
1日当り新規感染者数 Daily new cases



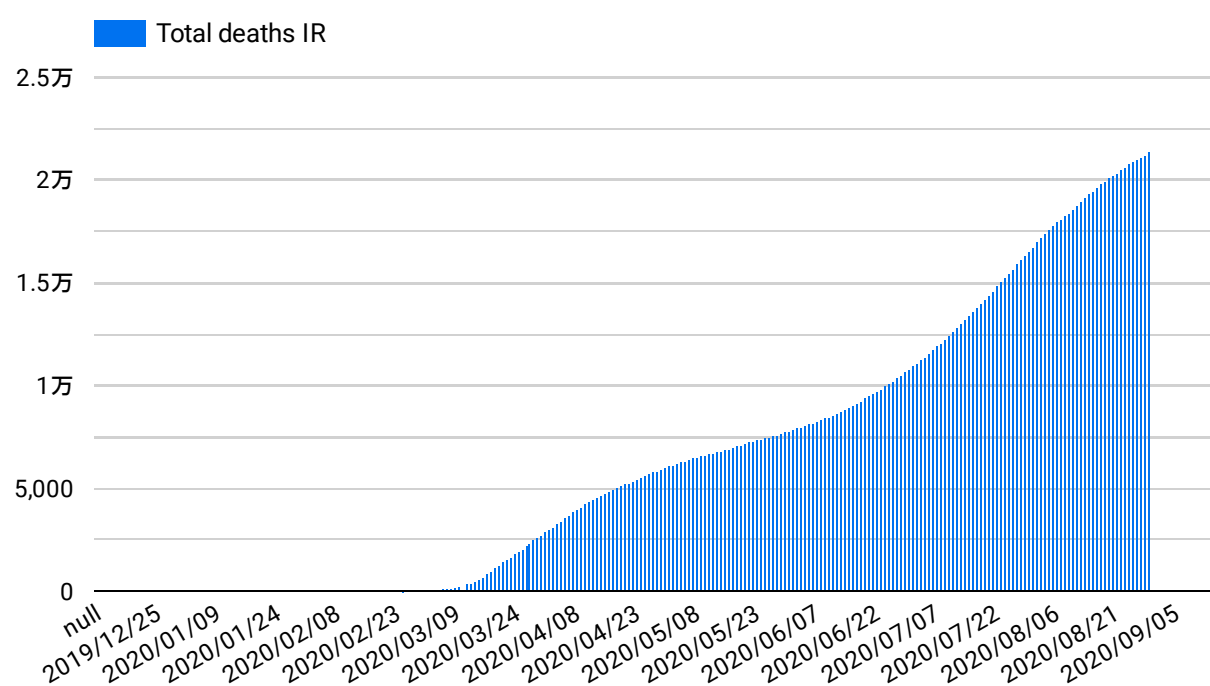
1日当り死者数 Daily new deaths



ネット総感染者数 Net total cases



累計死者数 Total deaths



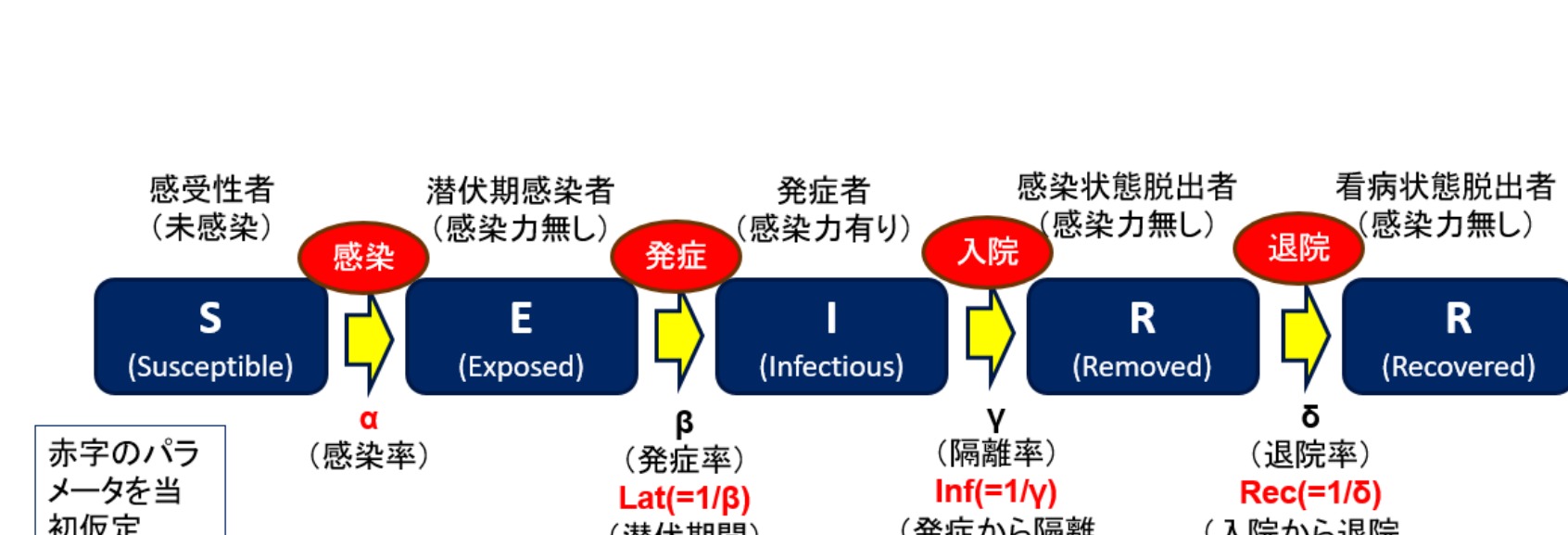
SEIRRモデル概要/SEIRR model overview

* English follows Japanese.

新型コロナウイルスモデル (SEIRR) の概要

(モデルの概要)

SEIRモデルとは、感染症の感染者群が一定の時間を置きながら辿る各状態 (susceptible ⇒ exposed ⇒ infectious ⇒ removed) を遷移するパターンを、一定の感染率や遷移確率等を仮定しながら捉えることで、一定時間経過後の各状態の感染者数が何人いるかを予想するモデル。
今回構築したSEIRRモデルは、SEIRモデルにさらに、最後の状態としてrecoveredを加え (これにより状態の遷移はsusceptible ⇒ exposed ⇒ infectious ⇒ removed ⇒ recovered ⇒ recoveredとなる)、removed (隔離、或いは抗体を持つことで、他者への感染が止まる状態、本モデルでは全ての者が一度入院すると仮定) からrecovered (隔離状態からの回復<退院>、或いは死亡する状態) への遷移状況を特定化することで、感染者数や死者数も併せて予想するもの。



具体的には、以下に示した連立常微分方程式を解くことで、変数 (各S、E、I、R、R2状態にある人口) の推移が得られる。

$$\begin{aligned} dS(t)/dt &= -S(t) \cdot \alpha \cdot I(t) / n \\ dE(t)/dt &= S(t) \cdot \alpha \cdot I(t) / n - \beta \cdot E(t) \\ dI(t)/dt &= \beta \cdot E(t) - \gamma \cdot I(t) \\ dR(t)/dt &= \gamma \cdot I(t) - \delta \cdot R(t) \\ dR2(t)/dt &= \delta \cdot R(t) \end{aligned}$$

(変数)

- S: 感染する可能性がある人口
- E: 感染した者のうち未発症者の人口 (感染力無し)
- I: 発症者のうち隔離されていない人口 (感染力有り)
- R: 発症者のうち病院等に隔離された人口 (感染力無し)
- R2: 病院等に隔離された者のうち回復、或いは死亡した人口
- n: 全人口

(参考文献) Iwata K, Miyakoshi C. (2020) A Simulation on Potential Secondary Spread of Novel Coronavirus in an Exported Country Using a Stochastic Epidemic SEIR Model. J Clin Med <https://www.preprints.org/manuscript/202002.0179/v1>

(パラメータの設定方法)

推計に際し設定したパラメータは以下のとおり。基本的には、以下のサイトで見られた数値等を参考として、初期値を設定した上で、実際の3つの変数 (累計死者数、1日当り新規感染者数、1日当り死者数) の推移に出来るだけフィットするようなパラメータ値を選択。
通常は、以下のような順序でパラメータを推計。

1. 1日当り新規感染者数の推計値が実際に合致するようにR0水準やその変化/変化タイミングを設定
2. その上で、1日当り死者数の推計値が実際に合致するように致死率水準やその変化/変化タイミングを設定
3. 必要に応じて、累計死者数やネット感染者数の推計値が実際にフィットするようにR0水準や致死率を再調整

比較対象の実績値のうち、1日当り新規感染者数、及び1日当り死者数に関しては、異常値 (統計の期中の改訂により発生) を除いた上で、3日間の移動平均とする。
パラメータの初期値設定に際し参考とした情報が取られたサイトは以下のとおり。
<https://gabgoh.github.io/COVID/index.html>
基本的なデータは以下のサイトから入手。
<https://www.kaggle.com/sudalairajkumar/novel-corona-virus-2019-dataset/data#>

(各パラメータ設定の具体的な考え方)

スタート日: 最初の感染者が発生したと想定する日で、デフォルトは1月22日 (WHOからの各国毎の感染者数が入手可能となる日で武漢閉鎖前の武漢からの春節旅行者が各国に拡散した頃の日) ながら、新規感染者数の動きが推計値とフィットしないケースでは、適宜フィットするようにずらす。既存推計国中、1月22日からずらしたケースは、中国 (42日前倒し、12月11日)、ドイツ (20日後倒し、2月11日)、英国 (25日後倒し、2月16日)。ドイツや英国では既に想定スタート日以前に感染者は発生しているが、市中感染が開始したのがこの頃と想定。

感染率 (α): この値と以下のInfを乗じたものがR0 (1人の感染者が発症期間中に何人に感染させるか) となることから、R0の初期値を2.2 (したがってαは0.76) とした上で調整

潜伏期間 (Lat): 5.2日で固定

発症から隔離までの期間 (Inf): 2.9日で固定

入院から退院、死亡までの期間 (Rec): 初期値を30日とした上で調整

致死率: 初期値を2%とした上で調整

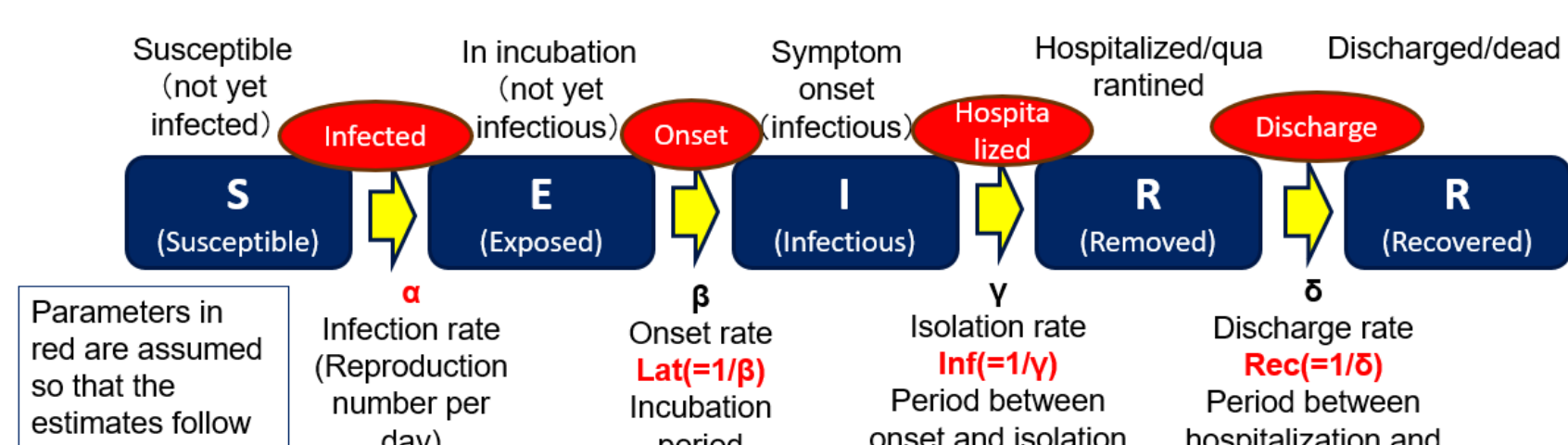
行動規制を導入するまで日数: ロックダウンや非常事態宣言等でαが大きく変化したと考えられる日で、最初の感染者が発生したと想定する日からの経過日で表示

行動規制後の感染率: Infを乗じたR0が0.95となる値 (すなわちα=0.33) を初期値とした上で調整

SEIRR model overview

(Model Overview)

The SEIR model is a widely-used model that predicts the number of people who belongs to the four different transitional states vis-à-vis certain epidemic such as Covid-19, that is 1) susceptible, 2) exposed, 3) infectious and 4) removed, assuming a certain infection rate, transition probability, etc.
The SEIRR model that we developed adds one more state, 5) recovered, as the last one to the SEIR model (this results in a state transition of susceptible ⇒ exposed ⇒ infectious ⇒ removed ⇒ recovered), and thereby identifies the transition from 4) removed to 5) recovered, which enables us to capture the number of current patients (excluding recovered) and deaths as well.



The following simultaneous ordinary differential equations are solved to obtain the transition of variables (Population in each S, E, I, R, R2 state).

$$\begin{aligned} dS(t)/dt &= -S(t) \cdot \alpha \cdot I(t) / n \\ dE(t)/dt &= S(t) \cdot \alpha \cdot I(t) / n - \beta \cdot E(t) \\ dI(t)/dt &= \beta \cdot E(t) - \gamma \cdot I(t) \\ dR(t)/dt &= \gamma \cdot I(t) - \delta \cdot R(t) \\ dR2(t)/dt &= \delta \cdot R(t) \end{aligned}$$

(Variables)

- S: Population susceptible to infection
- E: Population infected but not yet facing onset (not yet infectious)
- I: Population onset but not yet isolated (infectious)
- R: Population isolated (not infectious)
- R2: Population discharged from hospitals (not infectious)
- n: Total population

Reference: Iwata K, Miyakoshi C. (2020) A Simulation on Potential Secondary Spread of Novel Coronavirus in an Exported Country Using a Stochastic Epidemic SEIR Model. J Clin Med <https://www.preprints.org/manuscript/202002.0179/v1>

(The methodology to set parameters for SEIRR model)

The parameters set for the estimation are as follows. Basically, an initial value is set referring to the values shown in the following site, and then a parameter value is adjusted so that the estimates of three variables (Cumulative number of deaths, new cases per day, and deaths per day) fits well with their actuals as much as possible.
Parameters are usually adjusted in the following order:

1. Set R0 level and its change/change timing so that the estimated number of new cases per day matches its actual.
2. We then set the mortality rate level and its change/change timing so that the estimated number of deaths per day matches its actual.
3. R0 levels and mortality rates are readjusted as needed to fit actual estimates of cumulative deaths and net cases.

The actual number of new cases per day and of deaths per day shall be calculated as a 3-day moving average so as to exclude outliers often owing to the revision of statistics.

The following sites contain information that was used as a reference when setting the initial values of the parameters.

<https://gabgoh.github.io/COVID/index.html>
All the data used for this analysis is available from:
<https://www.kaggle.com/sudalairajkumar/novel-corona-virus-2019-dataset/data#>

(The initial values set for parameters)

Start date: The date on which the first patient is assumed to have occurred. The default date is set at January 22 (The date when the number of patients from each country became available from WHO, and the date when the number of new year tourists from Wuhan spread to each country before the closure of Wuhan). If the movement of the number of new cases does not fit the estimated value, the start date should be shifted to the appropriate fit. Of the existing countries, those shifted from January 22 are China (42 days earlier, December 11), Germany (After 20 days, February 11) and the United Kingdom (After 25 days, February 16). In Germany and the United Kingdom, cases had already occurred before the assumed start date, but it was assumed that community acquired infection began around this time.

Infection rate (α): Since R0 (How many people are infected during the period of its onset before isolation) is obtained by multiplying this value by the following (Inf), the initial value of R0 and α are set at 2.2 and 0.76 simultaneously.

Incubation period (Lat): fixed at 5.2 days

Time from onset to isolation (Inf): fixed at 2.9 days

Time from hospitalization to admission to discharge, or to death (Rec): adjusted with an initial value of 30 days

Mortality rate: adjusted with initial value of 2%

Number of days until the government containment measures are introduced: The day on which α is reduced significantly due to lockdown, state of emergency, etc., and is indicated as the elapsed day from the day on which the first patient is assumed to have occurred (start date).

Post-intervention infection rate: adjusted with an initial value of 0.33, or 0.95 of R0 (α x inf-fixed at 2.9 = R0)

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