# World Health Organization COVID-19 Essential Supplies Forecasting Tool (COVID-19 ESFT)

## An overview of the structure, methodology, and assumptions used

Interim guidance
7 April 2021

## Summary

**This document provides technical details and methodological explanations on the structure of the COVID-19 Essential Supplies Forecasting Tool (ESFT). It is intended to provide information that will allow users to a) trace and understand the calculations, assumptions, and limitations of ESFT; and b) modify these assumptions for different contexts or use cases.**

## Inputs Tab

### Structure

- All user entry is in column C, blue cells
- All reference values are in column E
- All values that feed the calculations in the model pull from the corresponding row, but in column I (which is locked and has white text so is not visible to users)
- This formula allows for a) the use of the toggle button to switch between manual vs. default inputs; and b) overriding errors/gaps if a user accidentally leaves an input in column C empty (in which case it will pull the default)
- Inputs are bucketed by area to allow for easier navigation

### Methodology

Parameters entered constrain the demand forecast by:

- HCW constraints limit the number of HCWs forecast per week, capped by the maximum available, and thus constrains a) the PPE forecast and b) the HCW forecast
- Bed constraints limit the number of patients forecast as admitted per week, capped by beds available for patients by severity, and thus constrains a) the biomedical equipment forecast and b) the severe/critical inpatient forecast
- Diagnostic test absorption capacity constrains the number of diagnostic tests forecast per week, capped by the absorption capacity, and thus constrains a) the diagnostic consumables forecast, and b) the mild/moderate outpatient diagnosis (of note is that ‘presumptive diagnosis’ is used for severe/critical patients so equipment is forecasted for these patients independent of whether they were able to be tested for COVID-19 or not, provided there is bed space)

### Assumptions

#### Patients and case severity

The model assumes a breakdown of case severity[1] among four patient types: mild, moderate, severe, and critical. Of note, is that we assume patients remain in the same case severity category throughout; we do not model the transition of patients between different levels of severity, e.g., being mild for two weeks, then severe for one week, then critical for one week, then recovered.

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[1] WHO, Interim Guidance, Operational Considerations for Case Management of COVID-19 in health facility and the community, 19 March 2020. Last accessed: https://apps.who.int/iris/bitstream/handle/10665/331492/WHO-2019-nCoV-HCF_operations-2020.1-eng.pdf

| **Case Severity** | **%** |
|---|---|
| % Mild (isolation) | 40% |
| % Moderate (isolation) | 40% |
| % Severe (inpatient, needs O2) | 15% |
| % Critical (inpatient, ventilation) | 5% |

Due to the structure of the model, we model length of stay[2] in whole numbers of weeks, rather than the number of days, and assume an average number of weeks.

| **Length of Stay** | **# Weeks** |
|---|---|
| Mild case (isolation) | 2 |
| Moderate case (isolation) | 2 |
| Severe case (hospitalized duration) | 1 |
| Critical case (hospitalized duration) | 2 |

The case fatality rate is used in the calculation of the number of tests needed for discharge of severe and critical patients. We assumed the same severe fatality rate as was observed in Wuhan, China.[3] The case fatality rate for critical patients has varied between 50-81%[4] in different settings; we aligned with Imperial College modelling[5] for the critical fatality rate.

| **Case Fatality Rates** | **%** |
|---|---|
| Severe fatality rate (%) | 13.4% |
| Critical fatality rate (%) | 50% |

## Health care workers (HCW) and staff

The model provides a prompt to the user of the number of HCWs available in the country based on the reported number of doctors in the nurses in the WHO Global Health Observatory (GHO) dataset[6]. We adopted the following process for cleaning data to produce a reference value for each country:

- WHO GHO data is reported as the absolute number of nurses and doctors in a country in a given year. We calculated the five-year average population growth rate, using UNDP population growth from 2015 to 2020 for each country to give an 'average year-on-year growth rate' for each country (five-year average used to minimize effects of anomalous years). We multiplied the reported absolute number of nurses and doctors by the compound growth rate calculated by the delta between reporting year and 2020, using the calculated average year-on-year growth rate. This approach was used to scale nurse numbers to reflect changes in populations and potential corresponding growth in nurse numbers.
- If no value was reported in the relevant dataset, the average value per 1000 population for the income group was taken (as below for manual populations) and multiplied by the population in 2020.

If a user is modelling a manual population size, the model applies the global average for doctors and nurses per capita to the manually entered population size. These averages are based on the same datasets and are as follows:

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[2] WHO Health Emergencies Program

[3] WHO China Joint Mission Report

[4] Clinical course and outcomes of critical ill patients with SARS-CoV-2 pneumonia in Wuhan, China: a single-centered, retrospective observational study (Yang et al., 2020)

[5] Imperial College, Report 9: Impact of non-pharmaceutical interventions (NPIs) to reduce COVID-19 mortality and healthcare demand

[6] https://apps.who.int/gho/data/node.main.HWFGRP_0040?lang=en

| **Income category** | **Average of doctors per 1000 population, for territories with missing data** | **Average of nurses per 1000 population, for territories with missing data** |
|---|---|---|
| Low income | 0.379 | 0.874 |
| Lower middle income | 0.747 | 1.976 |
| Upper middle income | 2.108 | 3.859 |
| High income | 3.339 | 8.452 |
| Manual | 3.788 | 1.639 |

Note that we recognize that a broader range of HCWs than just nurses and doctors will be involved in the COVID-19 response. However, due to a) variation in health workforce response activities to COVID-19 globally, b) limitations in availability and quality of broader datasets (e.g., community health workers are poorly reported), and c) the focus of the ESFT being inpatient and screening/triage essential supply forecasting, we used nurses and doctors for estimating HCW numbers. These can be overridden if the user has more accurate information available.

Users are prompted to enter the % of HCWs not activated for COVID-19 response, with a prompt that this could be around 40%. Once again, due to high-levels of uncertainty and likely strong variation in this number, we advise users to refer to more accurate in-country numbers. The 40% figure was determined through consultation with medical professionals in a few countries (e.g., Nigeria, United Kingdom, Ethiopia, and United States).

Estimated HCW and cleaner staff ratios per bed were calculated using adapted assumptions from the WHO Health Workforce Estimator tool (HWFE)[7] for the LMIC context based on consultant with expert clinicians in LMICs. The HWFE documents the patient time required per 24-hours by patient severity type for a broad range of medical professionals and cleaning/helping staff. To simplify, we grouped all medical professionals as HCWs and all non-medical professionals as cleaners before summing the total time required per patient. This approach was taken and reviewed for LMICs specifically, to give 18.2 hours for severe patients and 32.7 hours for critical patients. We assumed 8-hour shifts per staff members to calculate the number of HCWs and cleaners per bed. We then take the weighted average for critical and severe beds (which is fed by the input patient severity split, as above) in order to arrive at a single proposed value for HCW and cleaners required per bed in an inpatient ward.

Estimated Ambulance Personnel and Biomedical Engineer assumptions were calculated based on assumptions provided by WHO (Operations, Supply & Logistics [OSL] and biomedical team) for the number of each type of staff per 100 beds on average; again assuming 8-hour shifts.

## Hospital infrastructure

The model uses the World Bank dataset for absolute number of beds[8] and Imperial College estimates by income group for the % of beds that are ICU/critical[9]. Where there was no recorded data in the World Bank dataset for a territory, we use Imperial College reported averages per income group, as follows:

| **Income category** | **Proxy of total beds/1000 people, if not reported** | **Estimated % of total beds that are ICU/Critical (%)** |
|---|---|---|
| Low income | 1.24 | 1.63 |
| Lower middle income | 2.08 | 2.38 |
| Upper middle income | 3.41 | 3.32 |
| High income | 4.82 | 3.57 |

The model uses the same assumption on split of non-COVID-19 to COVID-19 beds as used for HCWs, namely 40% not allocated to COVID-19 and the remaining 60% allocated to COVID-19 response. Once again there is likely strong variation in this figure per country, and users are advised to adapt the inputs for their given setting based on known information.

## Labs and Testing

The ESFT contains an embedded laboratory module, which estimates the maximum daily number of COVID-19 tests able to be conducted in each country based on available information on diagnostic absorption capacity. The output of this module ("max number of tests per day") automatically flows into the ESFT as a "cap" on the total number of tests needed for a given scenario. If this value is not overridden by the user, the ESFT will not quantify for more tests than a country can absorb based on current capacity. The reference values for the module were taken from an assessment of available equipment and are based on a number

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[7] http://www.euro.who.int/en/health-topics/Health-systems/pages/strengthening-the-health-system-response-to-covid-19/surge-planning-tools/health-workforce-estimator-hwfe

[8] https://data.worldbank.org/indicator/SH.MED.BEDS.ZS

[9] Imperial College, Report 12: The Global Impact of COVID-19 and Strategies for Mitigation and Suppression

of factors including population size, HIV burden (many machines were initially purchased for HIV testing), and testing platforms known to the WHO. Please note that the reference values are estimates and may not exactly match the number of platforms in each country.

Users enter existing lab capacity metrics such as number of machines available for COVID-19 testing (high-throughput, near-patient, manual, and an "other category"), the number of shifts per day, the number of days the machines are run each week, and what percent of the total machine capacity could be utilized for COVID-19. Based on these inputs, the module calculates the estimated maximum number of COVID-19 tests that can be conducted per day. Please note that programs offering antigen testing have the ability to quantify for these commodities on the "Testing Strategy" section of the 'User Dashboard' tab.

If users would like to model *additional* capacity because of purchasing new (near-patient and/or manual) platforms, users enter in the estimated number of new machines in the "Additional Capacity per Day" module. These machines will be included in the ESFT commodity quantification, and the increase in capacity will be displayed under the module on the Input tab. This increase in capacity can then be fed back into to ESFT via the "User Input Maximum # Tests per Day" cell.

Lab staff availability is referenced through data from the WHO GHO dataset (referring to Medical and Pathology Laboratory Technicians, ILO ISCO 3212). Once again, where data was lacking for a given country, it is estimated by taking the average for the country's income group, as follows:

| **Income category** | **Number of Lab staff/1000 population for unreported countries** |
|---|---|
| Low income | 0.095 |
| Lower middle income | 0.258 |
| Upper middle income | 0.213 |
| High income | 0.533 |
| Manual | 0.275 |

The reference value for the number of labs conducting COVID-19 testing (used to calculate the number of lab staff and cleaners and associated PPE and equipment needs) uses the assumption that there is one lab for every three manual, high-throughput, and/or "other" platforms, and one lab for every four GeneXpert modules.

Assumptions on lab operations (staff per lab, equipment per hospital unit, and wastage) were all provided by the WHO Emergency Response team.

## Oxygen use

The model proposes default O2 flow rates per bed for severe and two different rates for critical beds, with inputs from the WHO Clinical and Biomedical pillar leads. Initially, critical patients were assumed to require different flow rates: 50% on 30 LPM and 50% on a higher rate of 48 LPM. However, due to feedback from countries on reasonable flow rates, these were both switched to the lower rate of 30 LPM in the default assumptions. Users can also adjust the percent of critical patients receiving invasive mechanical ventilation (currently set to two-thirds of critical patients) and those receiving non-invasive ventilation (currently set to one-third of critical patients), and the subsequent flow rate for each type of critical patient.

We do not include the ability to constrain biomedical equipment forecast or critical patient forecast through entering in a) power, b) oxygen supply, or c) health workforce intubation/other critical care activity capacity. This results in an overestimation in the forecast, and may be addressed either in future iterations, or through use of complementary tools and models developed elsewhere.

## Pharmaceuticals

The model includes anticoagulants[10] and corticosteroids[11] for the management of COVID-19 cases in all patient cohorts and forecasts them based on the case severity. The model also includes additional pharmaceuticals to be considered for procurement for the treatment of symptoms and additional infections for patients seeking care for COVID-19, as included on the Essential Medicines List[12].

There are currently two anticoagulants and three corticosteroids approved for the management of COVID-19, and the specifics of use case based on patient type can be found in the "Pharmaceuticals" sheet of the ESFT. Additionally, the user can input price values for each medicine, but there are no default prices included in the pharmaceutical module.

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[10] COVID-19 Clinical Management: living guidance: https://www.who.int/publications/i/item/WHO-2019-nCoV-clinical-2021-1

[11] Corticosteroids for COVID-19: https://apps.who.int/iris/bitstream/handle/10665/334125/WHO-2019-nCoV-Corticosteroids-2020.1-eng.pdf?sequence=1&isAllowed=y

[12] Model List of Essential Medicines: https://list.essentialmeds.org/

# Equipment List & Usage Tab

## Structure

**Equipment groupings:** Equipment items are grouped into the following categories:

- Hygiene
- PPE
- Diagnostics
- Biomedical equipment, consumables & accessories

These categories are listed vertically in column C, with each item within each category broken down, in column D

**Settings of care:** Equipment items are modelled by the following settings of care:

- Inpatient care
- Isolation
- Screening/triage
- Laboratories

These settings of care are listed horizontally in row 13, with each setting of care broken down into different users of equipment in row 14

**Usage assumptions:** Usage assumptions should be interpreted as follows for each individual user:

- *HCW*: usage of an item per **shift** per HCW
- *Cleaner*: usage of an item per **shift** per cleaner
- *Informal caregiver*: usage of an item per **day** per informal caregiver (in days vs. shifts since informal caregivers do not rotate over time)
- *Ambulance personnel:* usage of an item per **shift** per ambulance personnel
- *Biomedical engineer:* usage of an item per **shift** per engineer
- *Severe patient:* usage of an item per **stay** per severe patient, i.e., each severe patient uses a certain amount of these items, and they cannot be reused between patients
- *Critical patient:* usage of an item per **stay** per critical patient, i.e., each critical patient uses a certain amount of these items, and they cannot be reused between patients
- *Both patients:* usage of an item per **stay** per severe and critical patient i.e., each inpatient uses a certain amount of these items per day, and they cannot be reused between patients
- *Severe bed:* placement/availability of an item per **severe bed**, i.e., each severe bed has a certain number of items allocated for it for occasional/periodic use with any number of severe patients lying in that bed over time
- *Critical bed:* placement/availability of an item per **critical bed**, i.e., each critical bed has a certain number of items allocated for it for occasional/periodic use with any number of critical patients lying in that bed over time
- *Both beds:* placement/availability of an item per **severe and critical bed**, i.e., each inpatient bed has a certain number of items allocated for it for occasional/periodic use with any number of patients lying in that bed over time
- *Patient:* usage of an item per **day** per mild/moderate patients
- *Laboratory technician:* usage of an item per **shift** per technician

Default assumptions on usage of equipment are entered in the appropriate grid in the matrix.

Some examples to explain how to read this information:

- *Cell K16*: Cleaners require 0.03 L of alcohol-based hand rub per shift (based on the assumption that 1 liter will last 30 days)
- *Cell R54*: 0.25, i.e., 1/4 of all severe beds have a patient monitor without ECG
- *Cell O74*: 0.67, i.e., 2/3 of all severe patients require a nasal oxygen cannula

## Methodology

Usage assumptions (per shift, per bed, per day – as above) are multiplied through by the appropriate number of shifts/beds/people then multiplied by the length of the forecasting period to give the total. In detail:

- *For Inpatient HCW, Cleaner, Informal caregiver, Ambulance Personnel and Biomedical engineers*: through MMULT (matrix multiplication) of the values in columns J:N in the ‘Equipment List & Usage’ tab with the values in BF110:114 in the ‘Weekly summary’ numbers. This is then multiplied by 7 to get the total, since usage is in shifts/day and HCW & Staff numbers are in weeks.

- *For severe, critical and both patients; and severe, critical and both beds*: values in column O:T are multiplied by the relevant counterpart taken from the 'Weekly summary' tab, namely:
    - *Severe patient* usages are multiplied by the total number of severe patients admitted to beds over the forecast period (capped by bed availability over time) from BF50
    - *Critical patient* usages are multiplied by the total number of critical patients admitted to beds over the forecast period (capped by bed availability over time) from BF51
    - *Both patient* usages are multiplied by the total number of patients occupying beds summed over the forecast period (capped by bed availability over time) from BF64
    - *Severe beds* usages are multiplied by the maximum number of severe beds occupied at any one time (capped by parameters in the inputs) from BH62
    - *Critical beds* usages are multiplied by the maximum number of critical beds occupied at any one time (capped by parameters in the inputs) from BH63
    - *Both beds* usages are multiplied by the maximum number of beds occupied at any one time (capped by parameters in the inputs) from BH64
- The totals per item are summed together in columns BE and BF in the 'Equipment List & Usage' tab and these flow through to the outputs in the 'User Dashboard' tab.

### Assumptions

**Hygiene usage assumptions** were all provided by WHO OSL, based on rational use of items on the COVID-19 Disease Commodity Package.[13]

**PPE usage assumptions** were initially provided by WHO OSL, based on rational use of items on the COVID-19 Disease Commodity Package for v1 of the ESFT. These were subsequently reviewed and updated by the Infection Control and Prevention (IPC) experts at WHO.

**Diagnostic usage assumptions** were all provided by WHO OSL and reviewed by diagnostics technical experts at WHO.

**Biomedical equipment, consumables and accessories assumptions** were all provided by the WHO biomedical and clinical teams and their supporting partners through close discussion and consultation. A few nuances to highlight:

- The items detailed match those in the WHO Priority Medical Device list at time of publication
- The order of items matches the WHO Priority Medical Device list, and this ordering is important
- The prices match the WHO Catalogue price, where available; and if not detailed in the catalogue were estimated by through getting three quotes (each with a low-high range) and taking the average
- Since critical patients can be treated with a range of non-invasive and invasive ventilation machines, modelling is based on an assumption of how this is split by equipment with: 2/3 of critical patients forecast to require mechanical invasive ventilation; and 1/3 of critical patients forecast to require non-invasive ventilation, with the 50% of these using a CPAP device and the other 50% using a High Flow Nasal Cannula. Consumables and accessories assumptions related to these types of patient care are then based on these splits

**Drugs usage assumptions** are calculated by patient type and the assumptions are found under the "Pharmaceuticals" tab

## Pharmaceuticals Tab

### Structure

The pharmaceuticals tab includes a list of medications both for the treatment of COVID-19 and for the treatment of symptoms and additional infections experienced by COVID-19 patients.

- Patient breakdown:
    - Critical patients
    - Severe patients
    - Moderate patients
- Nomenclature:
    - Drug product
    - Classification – drug family to which the drug product belongs
    - Concentration/formulation – dosage and drug form
    - Formulation – just the dosage, used for calculations
    - Units – unit in which the dosage is measured
    - Drug form – formulation in which the drug is packaged (i.e. tablet)
- Outputs
    - Total Drug Forms – this represents the total amount of drug forms (i.e. 28 ampoules of product x) that will be needed
    - Total volume – this represents the total amount of units (i.e. 280 ml of product x) that will be needed

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[13] https://www.who.int/publications-detail/disease-commodity-package---novel-coronavirus-(ncov)

### Methodology

The total drug forms are produced by taking the amount needed per patient type per day, multiplying it by the percentage of the patient type that will require that medication, and then multiplying that by the treatment duration. The totals form each patient cohort are added together for the grand total needed during the forecasted period.

## User Dashboard Tab

### Structure

The User Dashboard is structured in four sections from top-to-bottom:

- **Scenario inputs section:** This section includes inputs for a user to model –
    - Infections and Growth rate, i.e., select the case estimation method and scenario for modelling case load over time
    - Forecast period, i.e., select the window – within the advised constraints – for including in the total forecast
    - Testing strategy, i.e., select who is tested (suspected, mild, moderate, severe, and critical cases) and how many times for diagnosis and release

  These inputs were kept separate from the Inputs tab to reflect the fact they are not country or context parameters and are instead determining the scenario to run.
- **Output figures:** This section visualizes key outputs for users, including cases over time, tests over time, admitted patients and bed occupancy over time, and procurement costs by category.
- **Summary tabular information:** This section details high-level outputs related to HCWs and other staff required per week and patient numbers and beds used per week. Users must note that this should not be used in place of specific HRH forecasting tools (e.g., HWFE[14]) and that this information is displayed in order to explain bottom-up how the totals on PPE and biomedical equipment have been calculated.
- **Summary supply forecast:** This details the total number of each item forecast for the selected period and the corresponding cost for each line item.

### Methodology and assumptions

#### Scenario inputs

**Define infections & Growth rate:**

Users can toggle between multiple methodologies for forecasting infections over time. Depending on user selection, different input cells or links to other input cells will appear to model infection growth using the selected methodology.

- **Imperial SEIR Model:** The Imperial SEIR Model is a model developed by infectious disease epidemiologists at the Imperial College London. It is a compartmental model, built on a Susceptible-Exposed-Infectious-Removed (SEIR) framework, that takes into account country-specific population age structures, population interventions, mobility data, and is calibrated on currently reported death data. Due to the complexity of the model and need for ongoing model revision and calibration, the model is separate from the ESFT as it was developed and is managed by epidemiologists at Imperial College. Output forecast data for each country from this model are uploaded routinely to an online repository. The COVID-19-ESFT model has built-in links to retrieve the most recent forecast data for the user-selected country, and automatically load in this data into the model. While ESFT users are encouraged to review and understand the SEIR model, users do not need to specify any model parameters or inputs. Users can select between three forecast scenarios for each country. The model methodology is described in detail, and summary reports providing more context and detail on specific country forecasts are available from Imperial College at https://mrc-ide.github.io/global-lmic-reports/.
    - *Importing SEIR Model Forecast Data:* Instructions for importing SEIR forecast data are provided in the FAQ document. In brief, there are two options for importing forecast data – either through 1) using the automated data import tool, which requires Excel to have external connections enabled and privacy levels set to allow external data import, or 2) through manually copying the forecast data from the online repository and pasting it into the ESFT. When the SEIR Model is selected as a case estimation method, the user will be prompted to use one of these two methods if data has not already been imported for the country selected on the Inputs tab.
    - *Imperial SEIR Model Scenario:* After data are imported, the user will be prompted to select an Imperial SEIR Model Scenario. For each country, forecasts are provided under three scenarios, roughly corresponding to low, medium, and high estimated transmission dynamics. The transmission parameter specified in each scenario is shown in a table just below the scenario selection drop-down. To compare infections, cases, and deaths under each scenario, side-by-side graphs of each can be found by following the link immediately beneath the scenario selection drop-down. For countries that have reported Covid-19 deaths to-date, the most recent effective reproduction number R(t) estimate under current conditions from the SEIR model is displayed as 'Maintain

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[14] http://www.euro.who.int/en/health-topics/Health-systems/pages/strengthening-the-health-system-response-to-covid-19/surge-planning-tools/health-workforce-estimator-hwfe

current transmission'. Low transmission corresponds to a scenario reducing current transmission by 50%, and high transmission corresponds to a scenario increasing transmission by 50%. For countries that haven't yet reported Covid-19 deaths, hypothetical basic reproduction number R(0) scenarios are provided that forecast what would happen if 5 imported cases occurred today. See the Imperial College model documentation linked above for more information on the scenarios and associated transmission parameters.

- **SIR Model:** The Susceptible-Infectious-Removed (SIR) model is a basic compartmental model commonly used in infectious disease epidemiology. The population is divided into three compartments, Susceptible, Infectious, and Removed, and transmission parameters are specified to define the rate at which persons move between compartments. The SIR model here has a simple deterministic structure, with transmission parameters specified either by the reference values provided or those entered by the user. It is not fitted to reported COVID-19 case or death data. The model structure and system of equations is as follows:

$$S(t) = Number\ of\ susceptible\ persons\ at\ time\ t$$

$$I(t) = Number\ of\ infectious\ persons\ at\ time\ t$$

$$R(t) = Number\ of\ removed\ persons\ at\ time\ t$$

$$N = Total\ number\ of\ persons\ in\ population = (Population * Clinical\ Attack\ Rate)$$

$$s(t) = \frac{S(t)}{N} = Proportion\ of\ population\ susceptible\ at\ time\ t$$

$$i(t) = \frac{I(t)}{N} = Proportion\ of\ population\ infectious\ at\ time\ t$$

$$r(t) = \frac{R(t)}{N} = Proportion\ of\ population\ removed\ at\ time\ t$$

$$\frac{d(s)}{d(t)} = -\big(b * s(t) * i(t)\big)$$

$$\frac{d(r)}{d(t)} = k * i(t)$$

$$\frac{d(i)}{d(t)} = \big(b * s(t) * i(t)\big) - \big(k * i(t)\big)$$

Where:

$$b = (contacts\ per\ person\ per\ day) * (probability\ of\ infection\ per\ contact)$$

$$k = \frac{1}{infectious\ period}$$

- Key parameter inputs include the following:
  - *Infectious period:* the average number of days during which an infected person is likely to transmit the virus to susceptible persons. Modifications to this parameter may have a large impact on the forecasted epidemiologic curve. It is advisable to consult an infectious disease epidemiologist to appropriately set this parameter. The reference value provided is seven days.[15]
  - *Current cumulative cases no longer infectious (Recovered or Dead Cases):* the total number of cases no longer infectious is used to estimate the current number of active infectious cases in the SIR model by subtracting those no longer infectious from the total cumulative cases. If unknown, the cumulative case count one infectious period prior to today can be used. The reference value is an estimate of the number of cumulative cases one infectious period prior to the date of the forecast derived from the specified infectious period (X) and cumulative cases on the date of the forecast (Y), as well as assumed exponential growth in the days leading up to the date of the forecast with a doubling time of four days (Z):

$$Cumulative\ cases\ no\ longer\ infectious = 2^{\frac{\left(\left(\frac{\ln(Y)}{\ln(2)}\right)*Z\right)-X}{Z}}$$

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[15] Prem K, et al. The effect of control strategies to reduce social mixing on outcomes of the COVID-19 epidemic in Wuhan, China: a modelling study. Lancet Public Health. 2020 Mar 25. pii: S2468-2667(20)30073-6. doi: 10.1016/S2468-2667(20)30073-6. [Epub ahead of print]; and Woelfel R, et al. Clinical presentation and virological assessment of hospitalized cases of coronavirus disease 2019 in a travel-associated transmission cluster. medRxiv. 2020; (published online March 5.) (preprint). DOI: 10.1101/2020.03.05.20030502.

  - *Current contacts per person per day:* the average number of other people that one person encounters per day. Country-specific reference values are provided based on extrapolation from an international social mixing study. The original data was collected in the POLYMOD study conducted in eight countries, where a contact was operationally defined as either physical or nonphysical contact.[16] Extrapolation to 152 countries was done through a study that modelled country-specific age-stratified contact matrices based on the POLYMOD data and country demographics, such as age structures.[17] The reference value is specific to the country input based on collapsing the age-stratified contact matrices to a single average number of contacts per person per day for 152 countries. For other countries, the average for the income group is provided as the reference value. If a user is modelling a manual population size, the global average is provided.
  - *Probability of infection per contact:* the average likelihood or risk that a susceptible person becomes infected when contacting an infectious person. The reference value is calculated based on using 2.35 as the basic reproduction number[18] as well as the infectious period (X) and contacts per person per day (Y) specified:

$$\boxed{Probabilty\ of\ infection\ per\ contact = \frac{2.35}{X * Y}}$$

  - *Reproduction number:* the average number of secondary cases generated from a single infected case. For the initial stage of the SIR, the basic reproduction number is estimated to be 2.35. [17] To use a different reproduction number, the transmission parameters can either be modified directly in the SIR Model Step 1 or a different reproduction number can be specified in the SIR Model Step 2 and 3.
  - The transmission parameters are related via the following formula. Thus, specifying any three of the parameters will allow the fourth to be calculated.

$$\begin{aligned} &(Infectious\ period)\\ &* (Contacts\ per\ person\ per\ day)\\ &\underline{* (Probability\ of\ infection\ per\ contact)}\\ &= Reproduction\ Number \end{aligned}$$

  - Users can choose to alter SIR parameters over time for up to five different time-dependent periods or ‘stages’. Each stage is defined by its start date and either anticipated reproduction number or contacts per person per day. These are specified in the SIR Model Steps 2 and 3.
  - After selecting input values for the transmission parameters, the SIR model details can be viewed in the ‘SIR Model Patient Calcs’ tab, although no additional input is needed here.
- **Manual entry:**
  - Users can model the infection growth rate entirely manually through selecting this option. If selected, they are guided to toggle to a specific tab for entering cumulative case load over time via a link.
  - Data validation on the input area ensures that users enter cumulative case load, rather than new cases per week.

### Determine forecast period

Users are prompted, and constrained, to enter a maximum forecast period based on the total length of time until the COVID-19 has infected all members of the population that it is forecast to affect, as determined by the population size and clinical attack rate.

Users can enter a lag time of up to one week (for the time for shipments to arrive) to push the forecast period out one week. We recognize that the delay between ordering and item arrival is likely over one week, nevertheless this constraint was applied in order to mitigate the risk of forecasting very far out in the future, when there are so many unknowns regarding how infections will grow over time due to mitigation and suppression activities.

### Testing strategy

There are two available testing strategy options including “All Suspected Cases” and “Targeted”. These are based on guidance from the WHO Laboratory testing strategy recommendations[19].

- *All Suspected Cases*: this testing strategy assumes that tests will be administered to all presenting suspected cases. Based on guidance, the default assumption is that for every positive COVID-19 case detected there will be 10 negative tests, but this is an editable assumption.

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[16] Mossong J, Hens N, Jit M, et al. Social contacts and mixing patterns relevant to the spread of infectious diseases. PLoS Med. 2008;5(3):e74. doi:10.1371/journal.pmed.0050074 (POLYMOD)

[17] Prem K, Cook AR, Jit M. Projecting social contact matrices in 152 countries using contact surveys and demographic data. PLoS Comput Biol. 2017;13(9):e1005697. Published 2017 Sep 12. doi:10.1371/journal.pcbi.1005697

[18] Kucharski AJ, Russell TW, Diamond C, et al. Early dynamics of transmission and control of COVID-19: a mathematical modelling study. Lancet Infect Dis 2020; published online March 11. https://doi.org/10.1016/S1473-3099(20)30144-4)

[19] https://apps.who.int/iris/bitstream/handle/10665/331509/WHO-COVID-19-lab_testing-2020.1-eng.pdf

- *Targeted*: Tests are only provided for the proportion of cases classified as severe and critical plus an additional user-defined percentage of moderate and mild cases to allow testing of vulnerable populations at-risk. This user-defined percentage is also applied to the assumption about the number of negative tests for every positive COVID-19 test as described above.

Users can then decide how many tests to conduct for each patient type (by severity) for diagnosis and release in the Testing Algorithm section.

**Testing algorithm**

Users can modify the testing algorithm implemented within their region or country by changing the number of tests per case for patients with varying case severities and across different testing time points.

Test parameters are editable by changing the number of tests administered by disease severity type and testing point. The tool automatically sums these to show the total tests per case.

- *For diagnosis:* refers to use of laboratory tests to diagnose patients
- *For release*: refers to use of laboratory tests to confirm a negative result

**Additional testing options**

This allows users to quantify for tests beyond those needed for COVID-19 patients or suspects, or to incorporate antigen testing.

- *Healthcare Workers*: Users can enter the number of tests per week (can be a whole number, 0, or a fraction such as 0.5 to represent a test every other week) required for healthcare workers and other staff. Staff included are inpatient HCW, screening/triage HCW, ambulance personnel, cleaners, lab technicians, and biomedical engineers.
- *Contact Tracing:* Users can decide to quantify for tests needed as part of contact tracing efforts. Users select the average number of contacts per positive case, as well as the estimated percent of contacts who are reached who ultimately get a test
- *Antigen Testing:* Users select if antigen testing is used in their particular context. If yes, users then enter a percent of all COVID-19 testing that will be run via antigen testing. A reference cell has been set up next to this input to show the current *total* estimated testing need for the particular scenario for use as a reference for the percent that will be done via antigen testing. Once users enter the percent for antigen testing, another reference cell will show the estimated *number* of antigen tests for the scenario.

### Output figures

All output figures draw from the summary tabular information and summary supply forecast to display information in visual form for easier digestion.

### Summary tabular information

This information pulls from the ‘Weekly Summary’ tab. See below for more information on how these values are calculated.

### Summary supply forecast

This information pulls from the “Equipment List & Usage” tab and is calculated as explained above.

## Non-COVID Essential Services Tab

### Structure and Methodology

This tab allows for the quantification of PPE for essential medical services that are not related to the COVID-19 response (e.g., midwives, dentists, clinicians and nurses not involved in COVID-19, etc.). Users decide which cadres they want included by selecting Yes or No from the “Included in Forecast” dropdown menu. Then users estimate the number of workers in each cadre (reference values will pre-populate based on publicly available datasets), and then enter the number of working days per week per cadre. The tool then calculates how much PPE is needed for each cadre across the forecast period as specified on the “User Dashboard’ tab.

**Please note: the outputs from this tab are not included in the master outputs on the “Equipment List & Usage” or “User Dashboard” tabs.**

### Assumptions

Existing daily PPE assumptions have been provided for each cadre based on consultation with experts at WHO, but these can be adjusted by the user to fit the PPE use within a particular context.

## Summary Tabs – Commodities by Week

The 'Commodities by Week' tab breaks out the total commodity need (as calculated and displayed on the 'Equipment List & Usage' tab) on a weekly basis for the duration of the forecast. This will enable more granular supply planning. The methodology for calculation is the same as the 'Equipment List & Usage' tab, it is simply a different way of displaying the tool outputs.

## Summary Tabs – Weekly summary

### Structure

The 'Weekly summary' tab calculates the number of patients by severity (mild, moderate, severe, and critical) that are ill/in care each week in both a capped and uncapped scenario. The uncapped scenario calculates cases by severity based on the infection growth. It also calculates the number of HCWs (for inpatients and screening/triage), Cleaners, Informal caregivers, Ambulance Personnel, Biomedical Engineers, and Lab Staff who are in operation each week and who would be required if availability were uncapped. The appropriate values (dependent on the forecast period entered) in 'User Dashboard' are selected from columns BF and BH to flow through to the 'Equipment List & Usage' tab for supply quantification. The tab is locked to users and are intermediate calculation tabs.

### Methodology

#### Cases

Total uncapped new cases presenting each week are pulled from the 'Patient calcs' tab. Sick patients per week are calculated based on the delta between the new cases and those that recover in that week. Recovered (or dead) patients are calculated by shifting the new cases by the number of weeks of illness as per inputs, differentiated by patient severity.

Total capped cases that are admitted and in care each week are calculated using the following logic:

- For each week, the number of sick patients in care is calculated as up to the cap based on the 'Inputs', e.g., the maximum number of severe patients in care is calculated as the maximum number of severe beds as per the 'Inputs' tab.
- For each week, the number of admitted patients is either a) the number of new cases presenting that week (if caps have not been reached) or b) back-calculated based on subtracting the number of patients that were removed (due to recovery or dying) from care from the total number of sick patients in care that week.

#### Diagnostics

Diagnostic tests are calculated based on the inputs on testing strategy from the 'User Dashboard' tab multiplied by the relevant case/patient numbers.

#### Health workforce and staff

Health care worker and other staff numbers are calculated by multiplying the staff ratios by the patient numbers as per above. Unconstrained HCW numbers are also calculated to provide insight into how many HCWs would be required to maintain ideal HCW/patient ratios.

#### Outputs

The two key columns for feeding the rest of the model are column BF and BH. Column BF calculates, using a SUMIFS formula, the total number of each line item over the forecasting period, i.e., from the current time point (plus 1 week if allowing a lag for delivery) to the end forecasting week. These values are used to calculate equipment needs where equipment is based on occupancy of beds or presence of staff overtime (e.g., consumables). Column BH calculates, using an array MAX formula, the maximum volume for each row within the forecasting period (as before). For exponential growth case scenarios, this max will usually occur at the end of the period since cases double over time until the CAR is reached. However, for SIR or manual entry case growth, the maximum bed occupancy and staff presence could occur in any given week, which is why an array formula is used. These values are used to calculate equipment needs where equipment is based on maximum needs required (e.g., biomedical equipment positioned at the ends of beds).

## Patient Calculations Section

### Structure and methodology

The top of this tab calculates in vertical columns the breakdown of cases, by severity, for unconstrained cases (i.e., not factoring in bed capping). Details on information from left to right columns:

- Cumulative total cases column is fed by the selected case estimation method (e.g., exponential growth, SIR model, or manual) and specified transmission parameters (e.g. growth rate, infectious period, etc.). This is then broken down into case severity based on the inputs on severity breakdown
- Removed cases are calculated by shifting the total cases down for the number of weeks corresponding to the duration of illness by case severity

- Quarantines and admissions (no capping) calculates the number of new cases per week by subtracting the cumulative cases week by week to get the new cases
- Suspected cases that test negative are calculated based on the input of suspected cases to positive cases and the cumulative
- These values then feed into the 'Weekly summary' tab to all the uncapped rows, where additional calculations (described above) are completed to calculate the capped scenario

Further down, the tab has a section for manual patient calc inputs, which is hyperlinked from the 'User Dashboard' tab if being used.

Below this are automated calculations that feed in from the relevant other calculations tab to populate values for the SIR model and Exponential growth based on what is being used.

### SIR Model Patient calcs

This sheet provides the daily SIR-model calculations of Susceptible, Infectious, and Removed populations based on the specified population size, current cases, and transmission parameters. The calculations are described above.

### Manual Imperial Model Import

This sheet provides instructions for users who have selected the Imperial SEIR model case estimation method but are unable to use the automated data import feature on how to manually access, download, and import the necessary forecast data for this method.

### Country Imperial Manual Import

This sheet provides a table shell where users who have selected the Imperial SEIR model case estimation and are using a manual import process will paste the forecast data.

## Reference Data

### Country Imperial Model Output

This sheet contains forecast data from the Imperial SEIR model when the data is imported via the automated data import feature.

### HCW, Staff, Beds Summary

This tab consolidates information from the 'WHO GHO Data' and 'WB Beds' and 'UNDP Population data' to give tabular information showing country name, code, WHO region, income group, and total numbers of doctors, nurses and lab staff.

### WHO GHO Data

This tab consolidates cleaned data sets from the WHO Global Health Observatory for nurses, midwives, lab staff and doctors[20]. WHO GHO data is reported in absolute values of cadres for the latest reported year. We applied the five-year average growth rate for each country to manipulate the reported values to a 2020 figure.
As described above, we plugged any gaps where values were not reported by taking the income group average for each non-reported country to reduce the risk of underestimating in the demand forecast.

### WB Beds

This tab details the raw data downloaded from the World Bank[21] for the number hospital beds per 1000 people by country per year.
As described above, we plugged any gaps where values were not reported by taking the income group average for each non-reported country to reduce the risk of underestimating in the demand forecast.

### UNDP Population data

This tab details raw data from the World Bank[22] on country population totals for 2015, 2020 and population growth between these two timepoints.

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[20] https://apps.who.int/gho/data/node.main.HWFGRP?lang=en

[21] https://databank.worldbank.org/home.aspx

[22] https://databank.worldbank.org/home.aspx

# Back calculations

***This tab is a large compilation of all the back calculations used as intermediate calculations in the tool.***

## Staff & Infrastructure Assumptions

### Bed Capping Calculations

- This section simply pulls through the World Bank data from the 'WB Beds tab' for the country that is selected in the 'Inputs' tab and the population data from the 'UNDP Population Data' tab and multiplies together to give the reference value for total number of beds in county.
- If the user is running a manual scenario, the global average beds per capita is applied to the manually entered population size.

### Country health worker calculations

- *Input prompts from datasets:* This section pulls through the number of doctors, nurses, and laboratory staff from the 'HCW + Staff Summary' tab for the user selected country.
- *Output proposed caps based on user inputs:* It then calculates the reference absolute values of HCW/staff across settings of care based on the user inputs for the % split across settings.
- *Calculating weight average HCW per inpatient bed:* This calculates the % of all severe plus critical cases and critical vs. severe to feed into calculations on HCW ratios per bed.
- *Calculating split of HCWs for inpatients vs. outpatient for HCWs working on COVID-19*: On the 'Inputs' tab, users are required to enter a % estimate to split out HCWs into a) non-COVID-19 work, b) COVID-19 inpatient care, and c) COVID-19 screening/triage in order to feed into PPE calculations as caps on HCW availability. The prompts and reference values for users are calculated here by comparing the HCWs required per inpatient vs. for screening/triage, which depends on:
    - Case severity breakdown – i.e., what is the probability that each new case requires inpatient care vs. just screening and triage
    - HCW ratios per bed – i.e., for inpatients, how many HCWs are required per day and thus what is the inpatient: HCW ratio
    - HCW screening rate – i.e., for screening/triage, how many patients can a single HCW see per day and thus what is the "outpatient" (refers to screening/triage): HCW ratio
    - The inpatient vs. "outpatient" HCW ratios are compared to give the % of total HCWs required for inpatient vs. "outpatient" care

## Diagnostic calculations

### Equipment inputs

- *Useable quantity/kit (minus wastage):* This calculates the "useable" extractions in a lab extraction kit and RT-PCR tests in a RT-PCR kit that considers wastage (user input on Inputs tab)
- *Mid-calculations, based on model calculations:* This calculates the number of tests conducted (both manual tests separately as well as all testing modalities), the number of hospital facilities in-use, and the number of "facility weeks" in operation throughout the forecasting period. These midpoint calculations feed into the Equipment Quantification section below, which calculates the lab testing and sample transport needs over the forecast period

### Equipment quantification

This section calculates the supply forecast for diagnostic equipment that is calculated on a per facility, per test, or per week basis – dependent on the relevant inputs in the 'Inputs' tab and the relative variables (number of facilities, number of tests, and number of weeks of forecast) respectively.

### Oxygen Calculations

This section calculates the maximum O2 flow rate at maximum occupancy through pulling in the total number of severe beds and critical beds occupied during the forecast period, capped by the total available in the country/setting. It multiplies these bed numbers through by the entered input on LPM per severe and critical patients to give a total.

### Patient Calculations

*Inputs:* This section provides reference values and inputs for the doubling rate options (described above) and clinical attack rate options (described above).

*Epi curve calculations:* These series of calculations are used when running an 'Exponential growth' infection growth scenario. These calculations will help pinpoint the current point of the outbreak on an exponential curve defined by the specified doubling time. This can then be used to calculate how many weeks remain until the clinical attack rate population is reached to define a maximum forecast period.

*Scenario running:* These values take inputs from 'User Dashboard' to use as source material for indexing in the 'SUMMARY TABS ->' to populate the relevant week columns.

### Diagnostics maximum testing capacity

This section calculates the maximum number of diagnostics tests that can be conducted per day in a given country/setting based on the user inputs for the number of active platforms and shift patterns, combined with default assumptions on the throughput per shift.

## Blank sheets

The tool contains four blank and unlocked worksheets that users can manipulate and use during the forecasting period

## Hidden tabs

### Lists

This tab simply details lists for any data validation criteria, alongside providing details on values selected in drop downs through index matching.

### Staffing from HRH tool

This tab is the reference material for calculating HCW/patient ratios for inpatient care and screening/triage. It is taken from the WHO Health Workforce Estimator tool (HWFE)[23] as of 14th April 2020.

### Diagnostics module

This tab includes detailed back calculations for calculating the total available testing capacity for COVID-19. The tab contains the reference values on machine placements by country (see Labs and Testing section of Inputs tab for more information on this table). It also contains the calculations for allocating test kits for procurement according to available capacity and the additional capacity that would be added if users choose to input new device placements on the Inputs tab.

### Daily contacts by Country

This tab provides reference values for the estimated number of contacts each person in each country has based on Prem et al., 2017[24], discussed in the SIR-model methodology section above, which is used as a default input to the SIR model.

WHO continues to monitor the situation closely for any changes that may affect this interim guidance. Should any factors change, WHO will issue a further update. Otherwise, this interim guidance document will expire 2 years after the date of publication.

WHO reference number: WHO/2019-nCoV/Tools/Essential_forecasting/Overview/2021.1

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[23] http://www.euro.who.int/en/health-topics/Health-systems/pages/strengthening-the-health-system-response-to-covid-19/surge-planning-tools/health-workforce-estimator-hwfe

[24] Prem K, Cook AR, Jit M. Projecting social contact matrices in 152 countries using contact surveys and demographic data. PLoS Comput Biol. 2017;13(9):e1005697. Published 2017 Sep 12. doi:10.1371/journal.pcbi.1005697