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

An overview of the structure, methodology, and assumptions used

Interim guidance
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World Health Organization

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:

[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

[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.

[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

[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

[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

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