Health Information and Quality Authority

An tÚdarás Um Fhaisnéis agus Cáilíocht Sláinte

Identification of demand models for estimating the quantities of personal protective equipment (PPE) required for optimal patient care in the context of COVID-19

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About the Health Information and Quality Authority

The Health Information and Quality Authority (HIQA) is an independent statutory authority established to promote safety and quality in the provision of health and social care services for the benefit of the health and welfare of the public.

HIQA's mandate to date extends across a wide range of public, private and voluntary sector services. Reporting to the Minister for Health and engaging with the Minister for Children, Equality, Disability, Integration and Youth, HIQA has responsibility for the following:

- **Setting standards for health and social care services** — Developing person-centred standards and guidance, based on evidence and international best practice, for health and social care services in Ireland.
- **Regulating social care services** — The Chief Inspector within HIQA is responsible for registering and inspecting residential services for older people and people with a disability, and children's special care units.
- **Regulating health services** — Regulating medical exposure to ionising radiation.
- **Monitoring services** — Monitoring the safety and quality of health services and children's social services, and investigating as necessary serious concerns about the health and welfare of people who use these services.
- **Health technology assessment** — Evaluating the clinical and cost-effectiveness of health programmes, policies, medicines, medical equipment, diagnostic and surgical techniques, health promotion and protection activities, and providing advice to enable the best use of resources and the best outcomes for people who use our health service.
- **Health information** — Advising on the efficient and secure collection and sharing of health information, setting standards, evaluating information resources and publishing information on the delivery and performance of Ireland's health and social care services.
- **National Care Experience Programme** — Carrying out national service-user experience surveys across a range of health services, in conjunction with the Department of Health and the HSE.

Contents

List of abbreviations used in this report

AMRIC	Antimicrobial Resistance and Infection Control
CDC	Centers for Disease Control and Prevention
CHW	community healthcare worker
COVID-19	coronavirus disease 2019
ED	emergency department
EMS	emergency medical services
EVD	Ebola virus disease
FFP2	filtering face-piece 2
FFP3	filtering face-piece 3
HCW	health care worker
HIQA	Health Information and Quality Authority
HSE	Health Service Executive
ICU	intensive care unit
ILI	influenza-like illness
IPC	infection prevention and control
LTC	long term care
MERS	middle east respiratory syndrome
PPE	personal protective equipment
PRISMA	preferred reporting items for systematic reviews and meta-analyses
SARS	severe acute respiratory syndrome
SEIR	susceptible-exposed-infectious-recovered
SIR	susceptible-infectious-recovered
UK	United Kingdom

USA	United States of America
VHF	viral haemorrhagic fever
WHO	World Health Organization

1 Background

An optimal supply of personal protective equipment (PPE) is necessary to protect healthcare workers and patients and support infection prevention and control practices. Predicting PPE demand is important to inform supply chain management. Appropriate models are required to maximise the use of resources and ensure there is no oversupply or shortages.

In the context of COVID-19 and the PPE requirements required for optimal patient care, the HIQA COVID-19 evidence synthesis team was requested to undertake this review by the Antimicrobial Resistance and Infection Control (AMRIC) team within the Health Service Executive (HSE).

The review addresses the following question:

'What models are available that estimate expected PPE requirements for health and social care workers in the context of COVID-19?'

2 Methods

A detailed summary of the methods used in this review is provided in the protocol: Identification of demand models for estimating the quantities of personal protective equipment (PPE) required for optimal patient care in the context of COVID-19.

A systematic literature search of published peer-reviewed articles and non-peer-reviewed pre-prints was undertaken using the search strategies detailed in the protocol. The following electronic databases were searched: MEDLINE (EBSCO), EMBASE (OVID) and Europe PMC, with no language restrictions applied. The search was limited to articles published in the last 10 years (from 19 August 2011 to 19 August 2021). All potentially eligible papers were exported to Covidence (www.covidence.org) for single screening of titles, abstracts, and full texts for relevance based on the inclusion and exclusion criteria outlined in the protocol.

A grey literature search was conducted in Google (https://www.google.com/) on 17 August 2021 using the using the key words, "personal protective equipment (PPE)", "model", "calculator" and "tool". On 25 August 2021, searches of the grey literature database 'OpenGrey' and Google Scholar were conducted using the search string "(PPE OR personal protective equipment) AND (model OR modelling)". The 'OpenGrey' search was limited to articles published in the last 10 years. The first five pages of results from both Google and Google Scholar were screened. On 23 August 2021, the websites of the 14 government and public health agencies outlined in the protocol were searched.

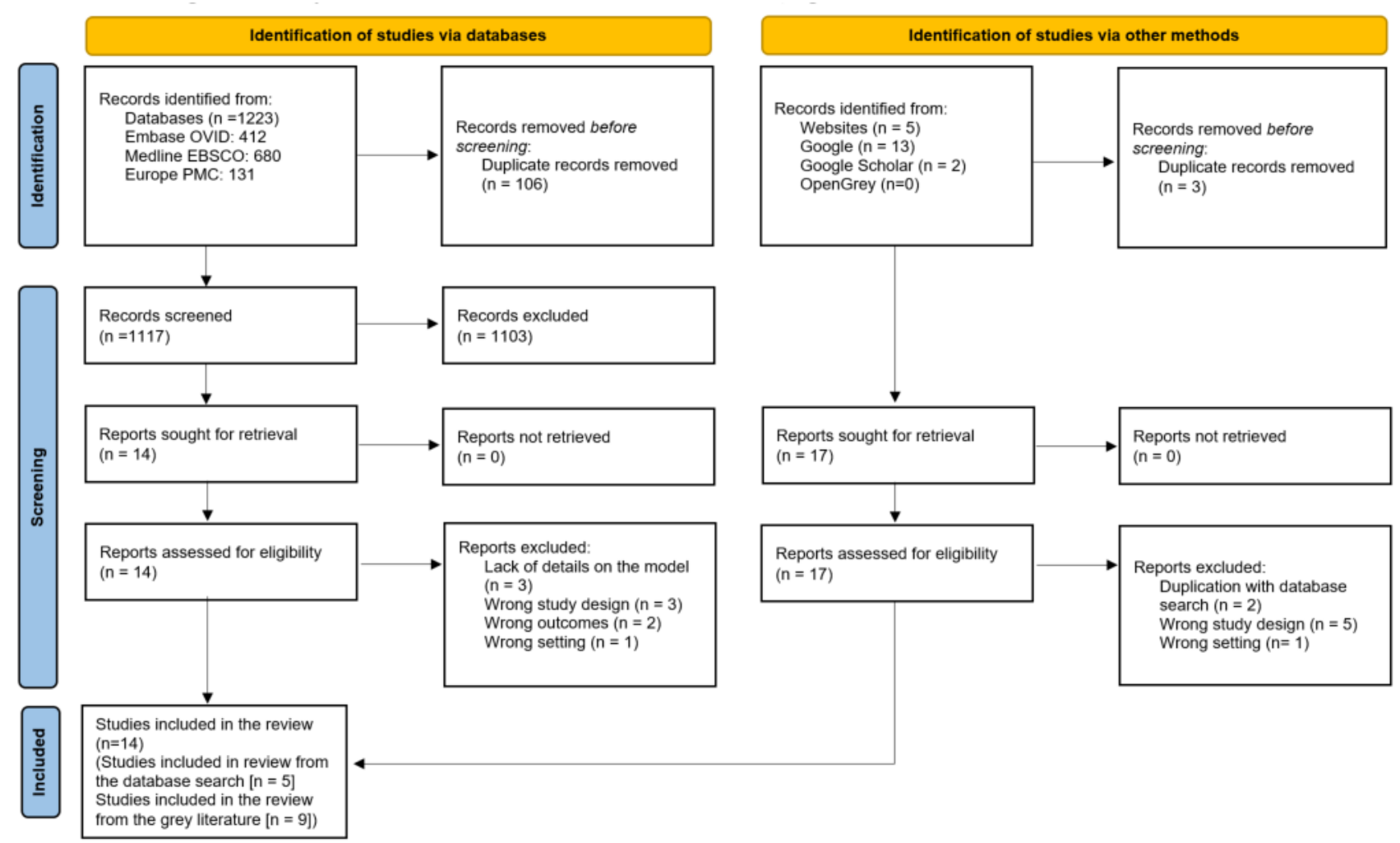
Data extraction of included studies was completed by a single reviewer and checked by a second reviewer. No quality appraisal or critical review of the assumptions, performance or parameters underpinning the models was undertaken as per the agreed scope.

3 Results

3.1 Search results

The database searches resulted in 1,223 citations. Following removal of duplicates, 1,117 citations were screened for relevance against the inclusion criteria outlined in the protocol, with 14 full-texts assessed for eligibility, five of which were considered eligible for inclusion. An additional nine studies were identified from the grey literature search. In total, 14 studies reporting on 13 separate models (eight models,[1-8] one technical report[9] and five journal articles[10-14]), were identified for inclusion in this review. One article[10] identified details a model,[7] both of which are described in the report. See Figure 1 for a PRISMA flow diagram of the included studies.

Figure 1 PRISMA flow diagram of included studies.



From: Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, et al. The PRISMA 2020 statement: an updated guideline for reporting systematic reviews. BMJ 2021;372:n71. doi: 10.1136/bmj.n71. For more information, visit: http://www.prisma-statement.org/

3.2 Models

A total of eight models were identified in the search; seven excel-based and one web-based. Forecasting PPE demand in the context of COVID-19 was the focus of six of the eight models.[1-4, 7, 8] One model forecasted over a range of disease areas including pandemic influenza, novel influenza, middle east respiratory syndrome (MERS), severe acute respiratory syndrome (SARS), Ebola virus disease (EVD) and viral haemorrhagic fever (VHF).[6] Another was modelled in the context of EVD only.[5]

All eight models included the hospital setting (for example, emergency department, screening/triage, inpatient, outpatient, ICU and non-ICU).[1-8] One model also included nursing homes and emergency medical services (EMS) settings.[1] Another model included isolation[3] (at home or at a community facility [for example, a hotel] for mild to moderate cases) and laboratory settings.[3] Two models included settings where testing takes place.[2, 3] One model is applicable across all settings that require PPE.[8] No models specifically allowed for general practice, primary care or homecare settings.

Two models identified were published before 2020,[5, 6] four in 2020,[1, 2, 4, 7] and two in 2021.[3, 7] The sources of these models include; a global organisation,[3] three from national public health agencies based in the USA,[5, 6, 8] three universities, two based in the USA and one in Lebanon,[1, 2, 4] and a private healthcare analytics company based in the USA.[7] Data extraction of the identified models is provided in Table 1.

3.3 Technical Report

One technical report was identified detailing a model which focuses on forecasting PPE requirements in the context of COVID-19 for hospitals, long-term care facilities, EMS, fire rescue, law enforcement and correction facilities. The model was designed by the Maryland Emergency Management Agency, a state agency within the Maryland Military Department in the USA.[9] Data extraction of the identified technical report is provided in Table 2.

3.4 Journal Articles

There were five journal articles identified that detailed PPE demand models; two excel-based,[12, 14] one web-based[10] and two that did not provide this information.[11, 13] One article identified in the database search[10] discussed a model that was identified in the grey literature search.[7] One article included was published before 2020,[12] three in 2020[10, 11, 14] and one in 2021.[13]

Four of the five articles focused on PPE demand in the context of COVID-19[10-14] and one in the context of an influenza pandemic.[12] Of the five journal articles identified, two detailed models from the USA,[10, 12] two from Canada[13, 15] and one from Germany.[10]

All five models included the hospital setting,[10-14] and two specifically included acute care within hospitals.[11, 12] One model included nursing homes,[12] and settings involving first responder groups (for example, emergency medical services, police officers, and firefighters).[12] Data extraction of the identified journal articles is provided in Table 2.

Table 1 Data extraction of models which are accessible to use or download via the internet

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
Title: WHO COVID-19 Essential Supplies Forecasting Tool (COVID-ESFT) v4[3] **Model source:** World Health Organization (WHO) **Website/URL:** **https://www.who.int/publications/i/item/WHO-2019-nCoV-Tools-Essential-forecasting-2021-1** **Last updated:** 14 April 2021 **Model design:** Excel-based	**Disease area:** COVID-19 **Setting(s):** Inpatient (inpatient care of severe or critical patients) Screening/triage (initial screening and triage of suspected cases) Isolation (at home or at a community facility [for example, a hotel] for mild to moderate cases) Laboratories (laboratories where tests are processed or conducted)	**Model aim:** The model aims to aid governments, partners and stakeholders in the estimation of essential supplies to respond to the ongoing COVID-19 pandemic. Essential supplies forecasted include PPE, hygiene and infection prevention and control (IPC) commodities, biomedical equipment for case management, diagnostic reagents and equipment, essential pharmaceuticals for supportive care, and consumable medical supplies. **Overview of the model:** Model selection ▪ The user can select their home country and the model will self-populate with the healthcare information specific to that country (for example, number of healthcare workers per bed). Alternatively, the user can manually input infrastructure and staff assumptions in the 'inputs' tab. The tool is best suited for estimating essential supply needs over a short period (not defined), but can be used for longer periods at an increased risk of uncertainty. ▪ It is recognised that there is a broad range of health care workers (HCWs) involved in the response to COVID-19 but due to limitations in	**Model design/layout:** There are 21 tabs in the model spreadsheet including: ▪ a 'disclaimer' and 'tool overview' tab ▪ five tabs of parameter inputs ▪ three summary output tabs (detailing commodity requirements per week (including PPE) and weekly forecasts of the number of HCWs, tests, and hospital beds which may be needed) ▪ five tabs for the number of patients (based on model selection, case estimation method and forecasting method selected) ▪ six tabs detailing the sources for the individual country input data. **Input parameters:** HCWs and staff ▪ number of HCWs in the country/region

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
	Population(s): Health care workers (medical practitioners, physicians, nurses and paramedical practitioners) Cleaners Caregivers (patient carers such as a parent or spouse) Paramedics and ambulance drivers Patient (suspected case or diagnosed case of COVID-19) Optional: Non-COVID essential services (essential medical services unrelated to COVID-19 such as community healthcare workers, midwives, dentists	availability of data, only nurses and doctors are included in the main model. ▪ Including PPE requirements of non-COVID essential services is optional. This includes midwives, dentists, laboratory scientists, physiotherapists, community healthcare workers (CHWs), traditional and complementary medical personnel, doctors and nurses that are not involved in the treatment of COVID-19. In this instance PPE usage is informed by experts at the WHO, but can be adjusted manually. Model assumptions ▪ The model makes several assumptions for the reference case, but these can be manually overridden by the user. For example, the reference case assumes that 60% of HCWs and staff are caring for COVID-19 patients and that 40% of all cases are mild. ▪ The model also makes assumptions that the user cannot override. For example there are four patient states: mild, moderate, severe and critical and the model does not allow for transitions between states. Several assumptions underpin this model which the WHO outlines in the overview of the model. ▪ PPE usage assumptions were initially provided by the WHO Operational Support Logistics, based on	▪ proportion of HCWs not activated for COVID-19 care ▪ proportion of HCWs treating hospitalised COVID-19 inpatients ▪ proportion of HCWs screening and triaging suspected COVID-19 cases ▪ number of HCWs per bed ▪ number of cleaners per bed ▪ number of ambulance personnel per bed ▪ number of biomedical engineers per bed ▪ cases screened/triaged per HCW per day ▪ number of informal care givers for severe/critical patients treated at hospital ▪ number of informal caregivers for mild/moderate patients isolating. Hospital and care infrastructure ▪ number of hospital beds in country ▪ proportion of hospital beds not allocated for COVID-19 care.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
	and nurses and doctors who are not involved with COVID-19 care)	rational use of items on the COVID-19 Disease Commodity Package.[16] These assumptions were subsequently updated by the IPC experts at WHO. Methods of forecasting ▪ Users can select from multiple methods of forecasting numbers of infections over time. This includes a manual entry option, the Imperial Susceptible-Exposed-Infectious-Recovered (SEIR) Model and the Susceptible-Infectious-Recovered (SIR) Model. ▪ Users can also select a clinical attack rate – very low, low, medium, high or manual input and testing strategy. The user can select either the testing of "all suspected cases" or "targeted testing". The tool is not recommended for use as an epidemiological model.	▪ proportion available for severe COVID-19 patients ▪ proportion available for critical COVID-19 patients ▪ length of stay by case severity Laboratories and testing ▪ number of days worked by laboratory staff ▪ number of hours in a work day ▪ max testing capacity per day ▪ number of laboratory staff in the country ▪ proportion of laboratory staff available for COVID-19 testing ▪ number of laboratories conducting COVID-19 testing ▪ number of laboratory staff per laboratory ▪ number of cleaners per laboratory. Epidemiological inputs ▪ known cumulative cases ▪ case severity (proportion of mild, moderate, severe and critical cases)

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
			▪ dependent on the method of forecasting infections selected Hygiene ▪ chlorine, high test hypochlorite 70% ▪ alcohol-based hand rub ▪ liquid soap ▪ bio-hazardous bag. PPE ▪ gown, protective ▪ scrubs, tops ▪ scrubs, pants ▪ apron, disposable ▪ apron, heavy duty, reusable ▪ gum boots ▪ gloves, heavy duty ▪ gloves, examination ▪ gloves, surgical ▪ goggles, protective ▪ face shield ▪ respirator ▪ mask, medical / surgical for health worker ▪ mask, medical / surgical for patient.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
			Optional ▪ country/territory ▪ hygiene and PPE for non-COVID essential services (for example, HCWs not involved in COVID-19 care). **PPE Outputs:** Total quantity and cost, per day, by PPE type (over the duration modelled) for COVID-19 care and non-COVID essential services is provided by setting and for each population group (for example, HCWs, cleaners, CHWs etc.).
Title: CDC PPE Burn Rate Calculator Version 2[8] **Model source:** Centers for Disease Control and Prevention (CDC) **Website/URL:** https://www.cdc.gov/coronavirus/2019-ncov/hcp/ppe-	**Disease area:** COVID-19 **Setting:** Can be used across all settings that require the use of PPE.	**Model aim:** Spreadsheet-based model that aims to help healthcare facilities plan and optimise the use of PPE in response to COVID-19. Non-healthcare facilities such as correctional facilities may also find this tool useful. **Overview of the model:** The tool will calculate the average consumption rate, also referred to as a "burn rate" for each type of PPE entered in the spreadsheet. This information can then be used to estimate how long the remaining supply of PPE will last, based on the average consumption rate (burn rate). The calculator can also help facilities to project future needs.	**Model design/layout:** There are eight tabs in the model spreadsheet, one each for: ▪ instructions ▪ the burn rate calculator ▪ total PPE on-hand ▪ total PPE on-hand graph ▪ units used per day graph ▪ number of days' supply remaining graph ▪ average burn rate graph ▪ average PPE used per patient graph.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
strategy/burn-calculator.html **Last updated:** March 2021 **Model design:** Excel-based **Country:** USA		How the calculator works:[17] ▪ Starting at day 1, the number of units of each type of PPE in stock and the number of units of PPE received should be entered. ▪ The user also has the option to enter the number of suspected or confirmed COVID-19 patients at the start of each day. ▪ The PPE supply from the day prior is subtracted from the current day (Day 2-Day 1) and entered considering the resupply. ▪ As additional data is added, the daily use of PPE is used to calculate the average consumption rate of the previous five days. ▪ The number of units of PPE entered is divided by the consumption rate to calculate the number of days' supply remaining. ▪ If the user has inputted the number of suspected or confirmed cases at the start of each day, the average PPE used per patient will be displayed.	**Input parameters:** PPE ▪ gown (various sizes) ▪ surgical mask ▪ gloves (various sizes) ▪ respirator (various types) ▪ face shield ▪ other (the user can input various other PPE types to suit their needs). **PPE Outputs:** Total number of units used per day by PPE type (also presented graphically). Number of days' supply remaining by PPE type (also presented graphically). Consumption rate (burn rate) of PPE by type in units per day (also presented graphically). Average PPE used by type per patient (also presented graphically).
Title:	**Disease area:** COVID-19	**Model aim:**	**Model design/layout:**

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
Worksheet for calculating national PPE need for COVID-19[1] **Model source:** Johns Hopkins Bloomberg School of Public Health **Website/URL:** https://www.centerforhealthsecurity.org/resources/COVID-19/PPE/PPE-assumptions **Last updated:** April 2020 **Model design:** Excel-based **Country:** USA	**Setting(s):** Hospital ▪ ICU ▪ non-ICU ▪ emergency department (ED). Outpatient Nursing homes Emergency medical services (EMS) **Population(s):** Hospital staff ED staff Outpatient staff Nursing Home staff EMS staff	The model aims to calculate PPE requirements for a 100-day wave of infection with sustained suppression measures. **Overview of the model:** The model uses predictions of rates of infection, hospital admission, ICU admission and deaths to calculate PPE requirements. All input parameters can be manually entered by the user. The assumptions underpinning the model are based on a combination of actual counts of use in practice and the expert judgment of ICU clinicians. The model assumes that COVID-19 patients are separated from non-COVID-19 patients. With the exception of the emergency medical department, the assumption is made that gloves are changed with every patient encounter. PPE assumptions are as follows by setting: ▪ PPE use in hospitals: ○ ICU: • Gowns: a single gown is worn for 4 hours by each HCW assigned to a COVID-19 ward, unless it becomes visibly soiled. Accounting for all HCWs involved in the care of an ICU patient, 20 gown changes per patient per day.	The model spreadsheet consists of one tab containing all calculations and outputs. **Input parameters:** Epidemiological inputs ▪ Number of: ○ clinical cases ○ hospital admissions ○ ICU admissions ○ deaths. ▪ Rate of: ○ case fatality ○ attack ○ hospital admission. PPE ▪ PPE type: ○ gloves ○ gowns ○ N95 respirators ○ simple masks ▪ PPE changes: ○ per patient per day ○ per patient visit per day ○ per EMS call-out. **PPE Outputs:**

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
		• Simple masks: 10 changes per patient per day. • N95 respirators: a single mask is worn for 4 hours by each HCW assigned to the care of COVID-19 patients. N95s are used only by healthcare workers in proximity (3 feet) to COVID-19 patients. 6 changes per patient per day. ○ Non-ICU: • Gowns: a single gown is worn for 4 hours by each HCW assigned to a COVID-19 ward, unless it becomes visibly soiled. Accounting for all HCWs involved in the care of a non-ICU patient, 20 gown changes per patient per day. • Simple masks: 10 changes per patient per day. • N95 respirators: worn only for intubations, nebuliser treatments, and other aerosol-generating procedures. Average of 2.6 changes per patient per day. ▪ PPE use in emergency departments: ○ Gowns: a single gown is worn for 4 hours by each HCW assigned to the care of COVID-19 patients, unless it becomes visibly soiled. Average of one gown change per patient attending the ED.	PPE outputs for each setting are grouped into the 4 PPE types and presented as overall requirements per type. PPE by setting can also be found amongst the calculations.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
		○ Simple masks: a single mask is worn for 4 hours by each HCW assigned to the care of COVID-19 patients, unless it becomes visibly soiled. Average of one mask change per patient attending the ED. ○ N95 respirators: worn only for intubations, nebuliser treatments, and other aerosol-generating procedures. ▪ PPE use in outpatient settings: Assumes that 25% of COVID-19 cases will seek an in-person outpatient visit (considering many cases may be handled by telemedicine). ○ Gowns: average of one change per visit. ○ Simple masks: average of one change per visit. ○ N95 respirators: respirators worn only for intubations, nebuliser treatments, and other aerosol-generating procedures. ▪ PPE use in nursing homes: Assumes a 10% attack rate in nursing homes. ○ Gowns: average of 3 changes per visit. ○ Simple masks: average of 1.5 changes per visit. ○ N95 respirators: not anticipated to be used in this setting. ▪ PPE use by emergency medical services staff:	

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
		Assumes that 10% of COVID-19 hospital admissions arrive by ambulance. ○ Gloves: 2 gloves for each crew member per call-out. ○ Gowns: one gown for each crew member per suspected COVID-19 call-out. ○ Simple masks: one mask for each crew member per call-out. ○ N95 respirators: one respirator for an average of one crew member for each suspected COVID-19 call-out.	
Title: Personal Protective Equipment Calculator for COVID-19[4] **Model source:** Perelman School of Medicine University of Pennsylvania **Website/URL:** https://penn-chime.phl.io/ **Last updated:** 30 April 2020	**Disease area:** COVID-19 **Setting(s):** Hospital ▪ ICU ▪ Step-down ▪ Floor ▪ ED **Population(s):** Nurse Resident Attending	**Model aim:** This model aims to forecast PPE requirements during the COVID-19 pandemic. **Overview of the model:** The tool uses forecasted patient admission and census information as its inputs and generates the predicted consumption of PPE critical for the care of COVID-19 patients as its output. The tool also allows the user to tailor the inputs to represent the specific situation relevant to their hospital or healthcare system. The underlying calculations are based on PPE consumption data that was collected at the University of Pennsylvania. The tool allows hospitals and health systems to make projections using three pre-populated scenarios. These scenarios (standard, contingency, and crisis)	**Model design/layout:** There are 4 tabs in the model spreadsheet: ▪ cover sheet which contains a link to instructions ▪ input data (projected hospitalised/ICU/ventilated patients, new admissions and census data) ▪ interface (choose a scenario) ▪ output. **Input parameters:** ▪ Number of: ○ COVID-19 patients hospitalised ○ COVID-19 patients in ICU

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
Model design: Excel-based **Country:** USA	Respiratory Therapist	correspond to projections for PPE use under increasingly strict PPE conservation policies. These scenarios were developed in consultation with providers across several different hospital departments to ensure that they capture realistic assumptions about how PPE materials are used in standard care within a hospital and what would constitute reasonable PPE conservation strategies when there are PPE shortages.	○ COVID-19 patients on ventilators ○ new COVID-19 admissions. ▪ Staff ○ nurse ○ resident ○ attending ○ respiratory therapist. ▪ PPE ○ N95 ○ surgical mask ○ gloves (pairs) ○ gowns ○ booties ○ bouffant cap ○ disposable eye protection powered air-purifying respirator (PAPR). Scenario Assumptions (based on 'scenario' selected but can be customised): ▪ Staffing-based calculation assumptions: ○ patient to staff ratios ○ shift length (in hours) ○ number of shifts permitted per item of PPE.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
			▪ Contact-based calculation assumptions: ○ number of contacts with patients per day ○ number of contacts permitted per item of PPE. **PPE Outputs:** Daily and cumulative PPE forecasts are presented by PPE type.
Title: Hospital Resource Calculator for COVID-19[7] **Model source:** Chicago Healthcare Analytics **Website/URL:** https://rush-covid19.herokuapp.com/ **Last updated:** March 2020 **Model design:** Web-based	**Disease area:** COVID-19 **Setting:** Hospital **Population:** Hospital staff	**Model aim:** The aim of this calculator is to allow a hospital to understand its resource use; including beds, ICU beds, ventilators, and PPE in USA states. **Overview of the model:** This calculator can be used to calculate the number of net new COVID-19 patients seen by a system each day, how many of these patients will require hospitalisation and plan for forecasted resource use. It can also help to forecast the demand for PPE over time based on patient volume. The model is most effective for a 7 day window, and the uncertainty for the prediction increases the further the forecast is projected. In areas with state wide initiatives like 'shelter at home', the model will not factor those initiatives in.	**Model design/layout:** Web page has three subpages ▪ COVID calculator ▪ employee forecasts ▪ instructions and details. **Input parameters:** ▪ Hospital variables ○ ICU beds ○ non-ICU beds ○ percentage of new cases presenting to the hospital ○ percentage admitted ○ percentage admitted to ICU ○ daily number of transfers admitted ○ percentage of transfers admitted to ICU

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
			○ percentage of ICU patients on ventilators ○ non-ICU length of stay ○ ICU length of stay ○ ICU mortality rate ○ time lag in hospital visitation. ▪ PPE ○ glove surgical ○ glove exam nitrile ○ glove exam vinyl ○ mask face procedure anti fog ○ mask procedure fluid resistant ○ gown isolation XL yellow ○ mask surgical anti fog ○ face shield full anti-fog ○ particulate filter respirators. **PPE Outputs:** PPE requirements are presented in a table by PPE type on a per day basis.
Title: COVID-19 AUBMC Surge needs Calculator[2] **Model source:**	**Disease area:** COVID-19 **Setting:** Hospital inpatient ICU	**Model aim:** This model is a resource needs forecasting tool. It aims to estimate potential requirements for essential supplies to respond to the current COVID-19 pandemic. The calculated resource requirements include, in-patient beds, ventilators, ICU beds and PPE for both admitted cases and testing.	**Model design/layout:** There are 6 tabs in the model spreadsheet: ▪ disclaimer ▪ tool overview ▪ peak active cases (input)

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features

American University of Beirut Medical Center
 	
Website/URL:
https://www.aub.edu.lb/fm/vmp/Documents/COVID-19_AUBMC_SURGE_NEEDS_CALCULATOR.xlsx
 	
Last updated:
2020
 	
Model design:
Excel-based
 	
Country:
Lebanon
	Testing
	
	Population:
	Hospital staff and patients
		Overview of the model:
		This calculator helps guide users through the required inputs and assumptions that are needed in order to calculate supply needs. The calculator intends to give an estimate of the supply needs and possible shortages at peak periods of the pandemic. Supplies are forecasted based on the time horizon selected by the user (max 200 days). Overall patient numbers are used primarily for forecasting bulk essential supply needs. The calculator is not intended to be used as an epidemiological model.
			▪ PPE (input and output)
			▪ ventilators (input and output)
			▪ hospital beds (input and output).
			
			Input parameters for PPE estimation:
			▪ percentage of patients on a ventilator
			▪ duration of pandemic (days)
			▪ average number of admitted patients
			▪ average number of additional tested patients per day
			▪ PPE:
			  ○ plastic gown
			  ○ gloves
			  ○ surgical face mask
			  ○ face shield
			  ○ N95 mask.
			
			PPE Outputs:
			COVID-19 PPE requirements are presented by type as:
			▪ per patient per day
			▪ per ICU patient per day
			▪ average total per day
			▪ total for admitted cases
			▪ total for testing

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
			▪ total needed (admitted cases and testing) ▪ average needed per day (admitted cases and testing).
Title: Hospital PPE Planning Tool[6] **Model source:** Assistant Secretary for Preparedness and Response (ASPR) (US Department of Health and Human Services) **Website/URL:** https://files.asprtracie.hhs.gov/documents/asprtracie-hospital-ppe-planning-tool.xlsx **Last updated:** 2018 **Model design:** Excel-based **Country:**	**Disease area:** 1. Pandemic influenza 2. Special Respiratory Pathogen (MERS/ SARS/ Novel Influenza) 3. Ebola Virus Disease/Viral Hemorrhagic Fever (EVD/VHF) **Setting(s):** Pandemic Influenza ▪ Inpatient ▪ ED MERS or SARS or Novel Influenza ▪ initial evaluation ▪ hospitalised patient	**Model aim**: The Hospital PPE Planning Tool is designed to help hospitals determine approximate PPE needs based on special pathogen category (described across) and a number of facility specific variables. It is not intended as a clinical tool and should be used as a pre-incident planning tool, not during an outbreak. **Overview of the model:** The tool is intended as a starting point for facility planners to estimate the minimum PPE that may be required based on the role the hospital has in the community (does the hospital provide screening only or screening and hospitalisation). It does not account for PPE required for training and replacing PPE that is contaminated, damaged, or otherwise rendered unusable in the course of patient care. It also does not consider that higher levels of PPE may be warranted in selected situations (such as during airway management). The tool should be considered in conjunction with other planning tools, resources, information, and facility and community-wide preparedness efforts.	**Model design/layout:** There are 7 tabs in the model spreadsheet, one for each of the disease areas and associated settings: ▪ overview ▪ EVD initial evaluation/stable patient ▪ EVD Hospitalised/unstable patient ▪ MERS/ SARS/ Novel influenza initial evaluation ▪ MERS/SARS/ Novel hospitalised patient ▪ pandemic influenza inpatient ▪ pandemic influenza ED. Each tab contains: ▪ Directions for use ▪ Section 1: Staffing inputs (the number of persons per shift for each role and the number of shifts per day for each role)

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
USA	EVD/VHF ▪ initial evaluation/ stable patient ▪ hospitalised /unstable patient. **Population(s):** Hospital staff: ▪ nurse ▪ doctor ▪ healthcare assistant ▪ environmental services ▪ laboratory technician ▪ respiratory therapist ▪ radiologist ▪ electrocardiogram technician ▪ trained observer ▪ other (includes spiritual care,	The tool's outputs are based on the inputs in Section 1 of each tab regarding staffing (type of personnel, length of shifts) and types of PPE commonly used by the facility and the assumptions in Section 2 about the types and amounts of PPE needed for the type of special pathogen and patient status. Users of the tool should make adjustments to the assumptions when warranted based on their knowledge of their facility, community, and their level of preparedness. Users should also be aware that pre-incident assumptions may not hold true during an incident. Changes to the assumptions may dramatically affect the accuracy of the outputs. Portions of this tool are based on the CDC Ebola PPE Calculator (described below),[5] which was developed to assist healthcare facilities in estimating their PPE needs when managing a patient with Ebola virus disease. However, this tool expanded upon the CDC PPE Calculator and added additional variables and scenarios to provide healthcare facilities with a broader tool.	▪ Section 2: PPE Assumptions (by type) ▪ Section 3: Outputs (total PPE needed by role for duration of outbreak). **Input parameters:** ▪ Staff ○ floor nurses ○ ICU nurses ○ doctors ○ healthcare assistants ○ environmental services ○ laboratory technician ○ respiratory therapy ○ radiology ○ ECG technician ○ other (biomedical, other medical/surgical personnel, spiritual care). ▪ PPE ○ gloves ○ shoe covers ○ gowns ○ N95 respirators. **PPE Outputs:**

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
	biomedical, and other medical/surgical personnel as required.		Total PPE requirements for the number of days modelled and per shift. PPE requirements are presented by staff type and PPE type for each disease area and associated setting.
Title: US Centers for Disease Control and Prevention (CDC) – Ebola PPE Calculator[5] **Model source:** CDC **Website/URL:** https://www.cdc.gov/vhf/ebola/healthcare-us/ppe/calculator.html **Last updated:** August 2015 **Model design:** Excel-based **Country:**	**Disease area:** Ebola **Setting(s):** Hospital **Population(s):** Hospital staff ▪ nurses (with patient contact) ▪ doctors (with patient contact) ▪ trained observer ▪ environmental services (person responsible for cleaning/ decontaminating the patient's room while the patient is present)	**Model aim:** The PPE calculator tool is designed to help estimate the amount of PPE that hospitals may need to manage the care of one patient hospitalised with Ebola. **Overview of the model:** The model determines the amount of PPE a hospital needs for a multi-disciplinary healthcare team managing a patient with Ebola. The model considers various factors associated with the care of an Ebola patient including: ▪ configuration of the healthcare team and intended interaction with the patient ▪ acuity of the patient ▪ length of shifts ▪ number of required breaks for staff wearing PPE ▪ waste management strategy ▪ isolation unit location and support strategies ▪ lab location ▪ laboratory testing demand ▪ length of the patient's hospital stay	**Model design/layout :** There are 3 tabs in the model spreadsheet: ▪ Overview ▪ PPE Summary (incl. output) ○ Required input – number of persons required by role and number of shifts per person per day. ▪ PPE Assumptions ○ Required input - estimated PPE (by type) required per role per shift. **Input parameters:** ▪ Staff ○ nurses ○ doctors ○ trained observer ○ environmental services ○ laboratory technician.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
USA	▪ laboratory technician.	▪ hospital protocols for products. In the model, hospital inventory needs must be assessed on a case by case basis because the ability to stockpile large amounts of PPE may be limited. It is recommended that facilities determine an appropriate interval for monitoring of minimum PPE requirements (for example, every 8 hours). The assumptions in the tool are based on input provided by subject matter experts involved in the Ebola response.	▪ PPE o gown (disposable, impervious) o coverall o glove (ex. cuff) o glove exam o boot/shoe cover o resistant apron o powered air purifying respirator (PAPR) o PAPR shroud o PAPR battery o N95 respirator o surgical hood o face shield. **PPE Outputs:** PPE requirements by type are presented as the number of each unit required per shift for each type of hospital staff.

Table 2 Data extraction of models described within technical reports and the literature.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
Author: Furman et al. **Title:** Prediction of personal protective equipment use in hospitals during COVID-19[13] **Journal:** Health Care Management Science **DOI:** https://doi.org/10.1007/s10729-021-09561-5 **Country:** Canada **Publication status/date:** Peer-reviewed	**Disease area:** COVID-19 **Setting(s):** Hospital **Population(s):** Hospital staff	**Model aim:** To estimate the total clinical workload of a hospital department, to then predict the demand for PPE. **Overview of the model:** The admission of patients to a medical department was modelled using multiple independent queues. Each queue represented a class of patients with similar treatment plans and hospital length of stay. The total workload of each class was estimated, from which estimates were derived for the expected amount of PPE required over a specified time horizon using PPE guidelines. The modelling approach is flexible; it can be deployed at multiple scales (departmental, hospital, regional) and in multiple settings (outbreaks or regular operations). The general framework can accommodate the wide variability in patient volumes between institutions, differences in the nature of typical patient and doctor interactions at the ward-level, and distinct hospital policies governing default PPE usage in non-patient encounters (for example, mandatory masking at all times). The model assumes that the total hospital capacity is always sufficient to meet demand.	**Model design/layout:** ▪ Not provided **Input parameters:** ▪ Patients' acuity level ▪ Clinical diagnosis ▪ Length of stay ▪ PPE ○ gloves ○ gowns ○ surgical masks ○ N95 masks ○ face shields ○ bouffant caps ○ boot covers. **PPE Outputs:** Prediction of PPE usage by type as a function of the number of clusters.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
April 2021			
Author: Pfenninger and Kaisers **Title:** Provisioning of personal protective equipment in hospitals in preparation for a pandemic[14] **Journal:** Der Anaesthetist **DOI:** https://doi.org/10.1007/s00101-020-00843-1 **Country:** Germany **Publication status/date:** Peer-reviewed September 2020	**Disease area:** COVID-19 **Setting:** Hospital **Population:** Hospital staff	**Model aim:** The primary goal of this study was to develop a tool to predict the stock of PPE required at a trans-regional university hospital for a certain period of time during the COVID-19 pandemic. **Overview of the model:** PPE consumption per patient in ICU or in an infection ward was calculated based on the following data from the Ulm University Hospital: ▪ Total PPE consumption of healthcare workers' for April 2020 recorded by the materials management department ▪ Number of patients suffering from COVID-19 and their number of treatment days ▪ Actual number of medical staff for ICU and infection wards. From the amount of PPE necessary for every patient in ICU or in an infection ward, a PPE calculator was created in which the estimated amount of PPE was calculated with the input variables "number of patients in ICU", "number of patients in infection ward" and "length of stay". To validate the PPE calculator, the actual consumption of PPE for May 2020 at the Ulm University hospital was compared to the theoretically calculated demand by the PPE calculator.	**Model design/layout:** ▪ Excel based **Input parameters:** ▪ Number of patients in ICU ▪ Number of patients in infection ward ▪ Length of stay ▪ PPE ○ gloves nitrile (various types and sizes) ○ FFP2/EN149 ○ FFP2 with flat valve ○ FFP3/EN149 ○ green mask with elastic band ○ safety glasses ○ visor ○ gown ○ overall (liquid-tight) ○ visitor smock ○ respirator ○ gloves. **PPE Outputs:** Estimated consumption per day and per patient in ICU and in the infectious ward.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
(Paper translated from German using google translate)			
Author: Locey et al. **Title:** An interactive tool to forecast US hospital needs in the coronavirus 2019 pandemic[10] **Journal:** JAMIA Open **DOI:** https://doi.org/10.1093/jamiaopen/ooaa045 **Country:** USA **Publication status/date:** Peer–reviewed August 2020	**Disease area:** COVID-19 **Setting:** Hospital **Population:** Hospital staff	**Model aim:** A web application, discussed above (Table 1)[7] was developed for US states and territories to predict the spread of COVID-19 and to provide forecasts for hospital visits, admissions, discharges and to anticipate needs for intensive care unit (ICU) and non-ICU beds, ventilators, and PPE in US hospitals. **Overview of the model:** The application was developed in response to the needs of the Rush University System for Health in anticipation of COVID-19 cases and subsequent surges. It is designed to be interactive and easy to use for hospital leaders, healthcare workers and government officials. The application aggregates reports of cumulative cases across US states and territories, state and territory population sizes based on US Census Bureau data (2010–2019), dates of COVID-19 arrival from state and territory health agencies, and testing and hospitalisation levels. Users can choose from a suite of models to predict the spread of COVID-19 and can modify a large set of inputs to obtain forecasts for their institution, examine variability in forecasts over time, download forecast data for further analysis, and explore trends in hospitalisation and testing.	**Model design/layout:** ▪ Web-based application. **Input parameters:** ▪ Hospital variables ○ ICU beds ○ non-ICU beds ○ percentage of new cases presenting at hospital ○ percentage of admissions ○ percentage of admissions to ICU ○ daily number of transfers admitted ○ percentage of transfers admitted to ICU ○ percentage of ICU patients on ventilators ○ non-ICU length of stay ○ ICU length of stay ○ ICU mortality rate ○ time lag in presentation to hospital. ▪ PPE ○ glove surgical

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
		After entering expected per patient daily values for PPE items, PPE forecasts are produced by multiplying the expected PPE values by their respective patient type across the forecasted census.	○ glove exam nitrile ○ glove exam vinyl ○ face mask procedure anti-fog ○ face mask procedure fluid resistant ○ surgical mask anti-fog ○ face shield full anti-fog ○ isolation gown XL yellow ○ particulate filter respirators. **PPE Outputs:** PPE forecasts are presented graphically by type in the web application. Users can also download data pertaining to each forecast. These csv files are dynamically updated upon any changes to their associated graphs or tables.
Title: MEMA COVID-19 Burn Rate Projection Planning Tool[9] **Organisation:** Maryland Emergency	**Disease area:** COVID-19 **Setting(s):** Hospitals Long-Term Care (LTC) facilities	**Model aim:** The development of the Maryland Burn Rate Projection Planning Tool was driven by the need to support several critical planning factors: ▪ a single tool for projecting PPE burn rate across the state ▪ an intuitive tool requiring no special training ▪ accurate data-driven projections. **Overview of the model:**	**Model design/layout:** ▪ Not provided. **Input parameters:** ▪ Total number of hospital beds occupied by positive COVID-19 patients ▪ Number of COVID-19 hospitalised patients 24, 48, and 72 hours ago

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
Management Agency **Website/URL:** https://mema.maryland.gov/Documents/MEMA_COVID-19-Burn-Rate-Projection-Tool-Report.pdf **Publication date:** June 2020	Emergency Medical Service (EMS) and fire rescue Law enforcement and correction **Population:** Staff in the above specified settings	The process of developing the model entailed the cataloging of thousands of daily PPE burn rate reports of 6,500 patients from around the state. This dataset allowed the team to construct a forecasting tool that used formulas built on real-world data collected over two months during the peak of the initial COVID-19 response. Features of the model include: ▪ projected changes in hospitalisations ▪ state-wide burn rate across critical infrastructure functions such as hospitals and LTC facilities ▪ burn rate projections per county for use by county level emergency planners.	▪ Total number of EMS response calls for the past 24 hours. ▪ PPE ○ gowns ○ masks ○ gloves ○ N95 ○ face shields ○ goggles. **PPE Outputs:** 14-day projections of PPE requirements are calculated. PPE needed to support a single patient for one day in a hospital or LTC facility is calculated.
Author: Barrett et al. **Title:** A model to estimate demand for personal protective equipment for Ontario acute care hospitals during the COVID-19 pandemic[11]	**Disease area:** COVID-19 **Setting(s):** Acute hospital setting ▪ Emergency Department (ED) ▪ ICU ▪ Ward **Population:**	**Model aim**: This model was designed to inform COVID-19 pandemic capacity planning in acute care. **Overview of the model:** Health system modelling was used to predict PPE demand in acute care settings, informed by interviews and direct observation of hospital administrators and healthcare workers (HCWs) caring for COVID-19 patients. An existing health state transition model[15] that predicts COVID-19 ED visits and hospitalisations in	**Model design/layout:** ▪ Not provided. **Input parameters:** ▪ Epidemiological data ▪ Clinical practice patterns ▪ PPE ○ surgical masks ○ N95 mask ○ gloves ○ gloves (extended) ○ face shield ○ face shield with drape

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
Journal: medRxiv **DOI:** https://doi.org/10.1101/2020.04.29.20085142 **Country:** Canada **Publication status/date:** Pre-print 5 May 2020	Acute hospital staff	Ontario, Canada, was extended, and based on the region's population, the number of observed confirmed cases of COVID-19, and observed trajectories of case numbers, the model estimated the number of new cases of COVID-19 predicted to present to the ED daily from 6 March to 5 May 2020. In the model, cases were either sent home or admitted to hospital based on disease severity, and moved through the acute care hospital system occupying ward or ICU beds, with or without mechanical ventilation, based on probabilities derived from reported and observed data. To determine the amount of PPE utilised per patient, patient "touchpoints" were estimated. A touchpoint is defined as any time a HCW enters a patient room or is required to physically interact with a patient or their environment, during which PPE may be required. For each in-patient hospital setting, the number of patient touchpoints were estimated within a 24-hour period, for each type of HCW, given the COVID-19 status of the patient (confirmed, suspected or negative), and whether the patient received invasive mechanical ventilation or was being turned prone. "PPE bundles" (list of required PPE) were created for a confirmed case, a person under investigation, or non-infected patients based on Public Health Ontario guidance for PPE use during the COVID-19 pandemic.	○ gowns. **PPE Outputs:** Total PPE requirements by type over a 60-day period near the height of the pandemic.

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
		The total PPE consumption per patient was calculated as the product of daily touchpoints and PPE bundles.	
Author: Carias et al. **Title:** Potential Demand for Respirators and Surgical Masks During a Hypothetical Influenza Pandemic in the United States[12] **Journal:** Clinical Infectious Diseases **DOI:** https://doi.org/10.1093/cid/civ141 **Country:** USA **Publication status/date:** Peer-reviewed	**Disease area:** Influenza pandemic **Setting(s):** Hospital: ▪ ICU ▪ General wards (GW) ▪ ED ▪ Outpatient care settings Nursing homes First responders (EMS, police officers, and firefighters) **Population(s):** Hospital staff Nursing home staff First responders Patients with suspected infection	**Model aim:** The model aims to inform planning for an influenza pandemic by estimating demand for N95 filtering face piece respirators (respirators) for healthcare and EMS personnel and surgical masks for patients. **Overview of the model:** A spreadsheet model was developed in which the number of influenza cases was estimated using four standardised pandemic scenarios, with two attack rates (20%, 30%) and two levels of severity (defined by hospitalisation, ED visits and EMS transportation rates). For each of the 4 pandemic scenarios, 3 respirator distribution scenarios were modelled: ▪ base case demand ▪ intermediate demand ▪ maximum demand In the base case, demand for respirators was assumed proportional to the number of patients over time until shortly after the pandemic peaked and then constant thereafter. Demand was estimated by multiplying the predicted number of pandemic patients per day by the number of times patients had contact with workers. In the intermediate case, it was assumed that respirator use increased proportionally to the epidemic curve and	**Model design/layout:** ▪ Excel-based. **Input parameters:** Dependent on scenario modelled ▪ Percentage of cases ○ hospitalised ○ admitted to the ED ○ transported by EMS. All scenarios ▪ Pandemic case to ILI case multiplier ▪ Percentage of cases that seek outpatient care ▪ Percentage of hospitalisations requiring ICU ▪ Length of stay (days) ▪ ED ▪ ICU ▪ general ward. ▪ Workforce ○ hospital workers/% with patient contact ○ outpatient HCWs/% with patient contact

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
May 2015	with the pandemic strain	in the maximum demand case it was assumed that the demand was constant throughout the pandemic. For all scenarios, the number of surgical masks required for source control in all settings (hospital, nursing homes, outpatient settings, and EMS) was estimated by multiplying the weekly number of influenza-like illness (ILI) patients by the number of masks per patient per day and by the number of days that patients would spend in each setting. Assumptions in the model: ▪ Patients in ICUs had contact with 12 to 16 HCWs per day, hence, 12 to 16 respirators would be needed in the ICU per patient per day. ▪ Patients in general wards had contact with 8 HCWs per day. ▪ Length-of-stay of 8 to 10 days for ICU patients, and 7 to 11 days for general ward patients. ▪ HCWs in EDs, out patients' settings, as well as first responders, use 4 respirators per day at the beginning of the pandemic. ▪ The number of workers having contact with pandemic patients would proportionally increase as the number of pandemic patients increased (following the epidemic curve upward). After the pandemic has peaked, it is assumed that the number of workers using respirators would remain fixed.	○ ED workers/% with patient contact. ○ EMS workers/% with patient contact ○ nursing home workers/% with patient contact ○ police officers in US (millions)/% with public contact ○ firefighters in US (millions)/% with public contact. ▪ Demographics ○ USA population ○ Percentage of USA population aged ≥ 65 years in nursing homes. ▪ Number of masks worn in: ○ ICU (per patient/day) ○ general ward (per patient/day) ○ ED (per worker/day; per patient/day) ○ outpatient (per worker/day; per patient visit) ○ nursing homes (per patient) ○ EMS (per worker/day; per patient/day) ○ police (per worker/day)

Characteristics	Disease Area Setting Population	Overview	Model/Calculator/Tool features
		▪ 90% of first responders, 67% of HCWs in outpatient settings, 25% of nursing home workers, and 100% of ED workers would have contact with patients. ▪ 40% to 56% of all pandemic patients would seek medical care.	○ fire personnel (per worker/day). **PPE Outputs:** Total respirator demand as the sum of demand in all settings for the duration of the pandemic for all scenarios. Surgical masks demand as the total needed for patients with ILI or with the pandemic strain of influenza.

4 Summary

This review identified 13 relevant demand models (described across 14 separate documents) estimating personal protective equipment (PPE) requirements in hospital and community settings in the context of COVID-19. While the models identified consider a diverse range of settings, the majority relate to secondary and tertiary care facilities. Three of the 13 models identified include nursing homes or long-term care facilities and one model allows for the optional inclusion of non-COVID essential services including community healthcare workers. Eight of the 13 included models were developed in the USA, two in Canada, one in Germany, one in Lebanon and one was developed by a global organisation.

Consistent with the agreed upon scope, no comparison of the assumptions and parameters underpinning the models was undertaken. Similarly, an evaluation of the literature comparing the performance of the various models was not carried out.

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