Report 15: Strengthening hospital capacity for the COVID-19 pandemic

J-IDEA pandemic hospital planner

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Summary

Planning for extreme surges in demand for hospital care of patients requiring urgent life-saving treatment for COVID-19, and other conditions, is one of the most challenging tasks facing healthcare commissioners and care providers during the pandemic. Due to uncertainty in expected patient numbers requiring care, as well as evolving needs day by day, planning hospital capacity is challenging. Health systems that are well prepared for the pandemic can better cope with large and sudden changes in demand by implementing strategies to ensure adequate access to care. Thereby the burden of the pandemic can be mitigated, and many lives saved.

This report presents the J-IDEA pandemic planner, a hospital planning tool to calculate how much capacity in terms of beds, staff and ventilators is obtained by implementing healthcare provision interventions affecting the management of patient care in hospitals. We show how to assess baseline capacity, and then calculate how much capacity is gained by various healthcare interventions using impact estimates that are generated as part of this study. Interventions are informed by a rapid review of policy decisions implemented or being considered in 12 European countries over the past few months[1], an evaluation of the impact of the interventions on capacity using a variety of research methods, and by a review of key parameters in the care of COVID-19 patients.

[1] Austria, Belgium, Denmark, France, Germany, Italy, Luxembourg, Norway, Spain, Sweden, Switzerland, United Kingdom

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The J-IDEA planner is publicly available, interactive and adaptable to different and changing circumstances and newly emerging evidence. The planner estimates the additional number of beds, medical staff and crucial medical equipment obtained under various healthcare interventions using flexible inputs on assumptions of existing capacities, the number of hospitalisations, beds-to-staff ratios, and staff absences due to COVID-19. A detailed user guide accompanies the planner. The planner was developed rapidly and has limitations which we will address in future iterations. It supports decision-makers in delivering a fast, effective and coordinated response to the pandemic that upholds the aims that societies have set for their healthcare systems and the medical treatment of their citizens.

We welcome feedback from users of the tool and readers of this report to help us to update the tool iteratively.

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Introduction

The COVID-19 pandemic presents health systems with a severe scarcity problem: the inevitable constraint of limited resources when demand surges. The provision of hospital care, particularly critical care (CC), is a scarce resource and rationed in most countries even in normal times (1), via explicit or implicit admission and discharge criteria (2,3), waiting times, prices, or other demand management mechanisms (3). The COVID-19 pandemic challenges existing rationing mechanisms due to an unprecedented surge in demand, particularly for CC and respiratory support that may exceed existing supply in many countries, especially during the peak of the pandemic.

Preparing hospitals for the pandemic first requires a rapid assessment of the existing capacity of the health system, to determine the baseline from which subsequent healthcare provision interventions increase capacity (1). Supply of services consists of the number of hospitals, beds, healthcare staff and medical equipment as well as the interaction between these inputs, such as increasing the number of beds which requires additional nursing staff. Improving service provision involves assessments of which inputs are variable in the short-run and can be scaled up, of whether existing resources can be used with greater efficiency, and of how investments translate into increased treatment capacity. Demand for services is determined by the number of patients that require and seek treatment. If other options to increase capacity have been exhausted, then it may become necessary to limit patients' access to care by setting criteria for priority access. These may include the prioritisation of those with the greatest expected capacity to benefit from care (4), and those most likely to survive invasive life-supporting treatments. Interventions are alternatives to dealing with an extreme scarcity of resources, and most can be implemented in conjunction.

The J-IDEA pandemic planner is a tool to calculate how much capacity in terms of beds, staff and crucial equipment is obtained by implementing interventions affecting the management of patient care in hospitals. The J-IDEA planner can be used to explore questions such as:

- How many hospitalised COVID-19 patients will result in a deficit in existing (baseline) capacity?
- What would the capacity be under various interventions with the current or expected number of COVID-19 patients?
- For a given number of hospitalised COVID-19 patients, which interventions entail a shortfall in some or all capacity components?
- For a given number of hospitalised COVID-19 patients, which interventions provide the greatest improvement in different capacity components compared to existing (baseline) capacity?
- How can a combination of interventions be leveraged to free up capacity?
- How many staff in each respective category are needed to operationalise the increases in bed capacity under different interventions?
- Under what circumstances can implemented healthcare provision interventions be scaled down (e.g. re-introduction of elective operations and closure of field hospitals)?

The planner is a practical aid that calculates the capacity consequences in simplified terms for decision-makers making difficult but necessary choices during extreme surges of demand for hospital care during the COVID-19 pandemic. The user guide for the planner is provided in the Appendix, with a detailed description of underlying assumptions. It also presents the application of the interactive planner to the health system of England, as a case study, with a summary of the results below.

Establishing existing capacity

Assessment of the existing hospital care capacity establishes the baseline before any efforts to increase resources are implemented (1). For simplicity, the planner focuses on hospital care resources that are required for the treatment of COVID-19 and similar conditions, i.e. acute respiratory distress. Data on the current staff (numbers and absences), their CC skills, beds, and breathing support, as the most critical medical equipment required to treat patients with acute respiratory distress, must be collected. As an example, the planner uses ventilators as the most crucial equipment, but this can easily be replaced by non-invasive forms of breathing support depending on circumstances. Admitted patients can be treated in general and acute (G&A) and critical care (CC) wards. The data must consider the appropriate scale, which could be at a national level, local level, or even consider a single hospital.

In the planner, nurses and medical doctors are stratified by specialism (i.e. the type of ward in which they primarily work). The medical doctor category is split further into senior and junior staff, reflecting the requirement of a senior clinical decision-maker overseeing the care of a group of patients (often, ward-based). Medical staff required for the treatment of patients in acute respiratory distress are those practising general medicine, emergency medicine and anaesthetics, although some countries have trained staff from a variety of other specialities to support critical care provision (5). Essential nurse types in G&A and CC wards vary by country, as they are employed depending on their level of training and job responsibilities, as well as country level professional regulations (6). All staff categories are measured in full-time work equivalents (FTEs), which will differ from simple headcounts if any staff are employed on a part-time basis or there are absences due to illness. In some countries, sickness absences of medical staff due to COVID-19 are high, therefore the planner allows one to consider those separately.

The baseline capacity can be determined using data from a defined period during non-pandemic times which is representative of current hospital care capacity; we give recommendations on how to estimate baseline capacity in the user guide (Appendix, *Section 3 (Inputs)*). The planner calculates the impact of capacity-enhancing interventions; optionally, numbers of expected COVID-19 patient can be input, in which case the planner estimates spare capacity or deficit in terms of beds, staff and ventilators (per 10,000 population). The user is required to input (A) *baseline* and (B) *COVID-19-related* variables if available (Table 1).

> (A) *Baseline* variables of the health system[2] being modelled reflect pre-pandemic related treatment provision in terms of the demand of beds, staff and ventilators.
>
> (B) *COVID-19 related* inputs can be based on current data or may represent assumptions of future additional demand posed by the pandemic. This includes the number of patients with COVID-19 and related conditions in CC and G&A care, as well as COVID-19 related staff sickness rates.

Capacity needs to be re-assessed continuously, particularly the capacity required to treat patients with other conditions. Admissions of patients with other conditions may reduce during the pandemic. Patients may not seek hospital care, either because they fear hospital-acquired COVID-19 infection or because they

[2] The scale of the health system can be defined by the user. For example, the scale of analysis can be at national, sub-national or local level.

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do not want to overburden hospitals. The patterns of presenting conditions may change due to widespread public health (i.e. epidemic) interventions, for example, lockdown policies may reduce road traffic accidents. The planner can be easily modified to adjust baseline estimates.

Interventions to increase capacity

The planner calculates the effects of healthcare capacity interventions that are being implemented, or under consideration, across 12 European countries. The information has been collated from national health ministry websites, health agencies, the public press and the European Observatory's Health System Response Monitor[3] and consolidated in an interactive map[4]. We identified 18 interventions, of which 13 are increasing or re-organizing the provision of care, and five manage admissions to care, particularly CC. Table 2 describes each intervention with a brief explanation, shows the countries that have implemented or considered it, and lists potential trade-offs and consideration that need to be made upon its implementation.

Examples of interventions that increase or re-organise the provision of care are providing additional beds in rapidly constructed field hospitals, repurposing G&A beds into CC beds and deploying newly qualified and final year medicine and nursing students. These interventions come with their unique trade-offs with respect to additional staff requirements, reductions in quality of care, and others. They reduce pressure on hospital capacity, particularly CC capacity. This entails admissions management and adapting care processes and patient pathways, for example, by cancelling planned non-urgent, non-cancer elective surgeries. During extreme pandemic surges, it may become necessary to prioritise scarce resources among patients requiring urgent care. In principle, this can be achieved by increasing thresholds for admissions to CC beds and treating patients in G&A wards or transferring patients to alternative care providers outside the hospital. Alternatively, thresholds for discharge may be set lower to reduce the length of stay. In such a situation, not all patients who could potentially benefit from life-supporting CC may be able to receive it (3,7). This implies that rationing mechanisms must be applied. Several countries have drawn up criteria for triage into CC in preparation for the COVID-19 pandemic (e.g. UK National Institute for Health and Care Excellence (NICE) guidelines (8)) to maximise the benefits for the largest number of people, by directing crucial resources to patients who have the greatest chance of survival. CC does not always improve the survival chances of patients, particularly as there is currently no effective treatment available and CC is limited to providing life support. Emerging evidence suggests that the efficacy of CC for COVID-19 patients is low, particularly for the sickest patients (9). Medical teams need to make difficult assessments of the (uncertain) future outcomes of alternative care pathways and apply national rationing guidelines.

[3] https://www.covid19healthsystem.org/mainpage.aspx
[4] https://microreact.org/project/9iAtQhHL6

Table 1: Summary of capacity inputs required by the user according to healthcare provision interventions currently modelled in the planner.

Key inputs	Categories	Specific variables to input			
		Staff	**Beds**	**Ventilators**	**Other**
Baseline	**Existing capacity**	• CC nurses • G&A nurses • CC senior doctors • CC junior doctors • G&A senior doctors • G&A junior doctors	• Total CC beds • CC beds occupied by non-COVID patients • Total G&A beds • G&A beds occupied by non-COVID patients	• Total ventilators	• Proportion of CC patients requiring ventilation
	Staff ratios	Beds per: • CC nurse • G&A nurse • CC senior doctor • CC junior doctor • G&A senior doctor • G&A junior doctor			
	Additional inputs				• FTE multiplier • Reference population size
COVID-19		• Sickness rate for nurses • Sickness rate for doctors	• Number of patients in CC • Number of patients in G&A care		• Proportion of CC patients requiring ventilation
Healthcare provision interventions	**Intervention-dependent**	• Additional nurses • Additional junior medical staff • Additional senior medical staff	• Additional beds • Operating theatres • Beds in operating theatres	• Additional ventilators	

Note: CC: critical care; G&A: general & acute; FTE: full-time equivalent

Table 2: Overview of healthcare provision interventions to manage admissions

	Description	Countries that implemented/ considering implementation	Modelled in J-IDEA planner	Considerations (not exhaustive)	References
Managing admissions					
Cancellation of elective operations	To reduce the number of beds occupied and staff required, non-elective surgeries are cancelled.		Yes	Increased mortality and morbidity in elective surgery and cancer patients	(10–21)
National guidelines for the prioritisation of CC resources	In situations of a severe scarcity of resources, patients are prioritised for CC following official guidelines (triage criteria vary across countries).		Yes	Ethical concerns of prioritising certain patients over others	(8,12,17,19,22–26)
Relocation of patients to hospitals in bordering countries	Patients close to the border with another country are sent abroad for hospital care.		No	Logistical, clinical and financial challenges of transporting critically ill patients	(27)
Continuity of care homes for the treatment of the elderly	Elderly people living in care homes are quarantined and treated there rather than in a hospital.		No	Logistical, clinical and financial support to care homes in caring for acutely ill elderly patients; reductions in quality of care	(28)
Set up of patient management and triage strategies	To prevent overwhelming hospital accident and emergency admissions, additional testing centres for patients can be set up.		No	Logistical, clinical and financial challenges; reductions in quality of care because care pathways are complicated	(29–32)
Increasing and reorganising care					
Setting up field hospitals	Non-hospital sites are temporarily turned into hospitals during the pandemic.		Yes	Requirements of additional staff and essential equipment; assuring the quality of care	(30,33–41)

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	Description	Countries that implemented/ considering implementation	Modelled in J-IDEA planner	Considerations (not exhaustive)	References
Use of private healthcare resources	National health systems temporarily use private healthcare resources to provide public care.		Yes	Logistical, clinical and financial challenges;	(42–46,21)
Converting operating theatres to CC wards	The space in some operating theatres is converted into CC wards with a number of beds.		Yes	Reduced capacity for surgeries; assuring the quality of care; requirements of additional staff and essential equipment	(21,47–52)
Increase CC bed capacity: Convert G&A beds to CC beds	Hospitals increase specialised bed capacity by converting some of their G&A wards into CC wards, which requires investments into specialised staff and equipment.		Yes	Requirements of additional staff and essential equipment; increased admission thresholds in hospital; assuring quality of care	(16,30,42,47,48,51,53–58)
Upskill staff to work in CC wards	G&A staff and staff from other clinical specialities are given basic training to work in CC wards.		Yes	Assuring the quality of care; logistical challenges of training staff	(30,42,59,60)
Return of former healthcare staff	Individuals who recently worked in the health system are asked to return for the duration of the pandemic.		Yes	Risk of morbidity and mortality for elderly staff; logistical challenges of appointing and training staff; assuring the quality of care	(30,47,61–69)
Deployment of newly qualified and final year medicine and nursing students	Final-year medical and nursing students may have their qualification process accelerated to enable them to start working immediately.		Yes	Assuring the quality of care; logistical challenges of appointing and training staff	(30,42,56,64–68,70,71)
Deployment of international doctors at the final stage of their conversion assessment	Doctors who qualified overseas often must take additional exams to practise in a new country. For those who are close to the end of this process could be accelerated or the final stages waived.		Yes	Logistical challenges of appointing and training staff; assuring the quality of care	(30,47,56,72)

	Description	**Countries that implemented/ considering implementation**	**Modelled in J-IDEA planner**	**Considerations (not exhaustive)**	**References**
Procurement and donations of ventilators	Additional ventilators are purchased from existing manufacturers, other manufacturers are requested to manufacture ventilators, and donations are solicited.		Yes	Financial and regulatory challenges; assuring quality of care	(12,73–82)
Procurement and donations of additional Personal Protective Equipment (PPE)	Manufacturing of additional PPE, to ensure that frontline staff are sufficiently protected.		No*	Financial and regulatory challenges; assuring quality of care	(30,42,54,75,83–88)
Efficient redistribution of PPE across hospitals	PPE is redistributed across hospitals to overcome any issues with over- and under-allocation.		No	Logistical and organisational challenges	(42,87,89–95)
Export ban on PPE	Ban on the export of PPE that a country has in stock or that is newly manufactured.		No	Political considerations	(96–100)
Financial aid to hospitals to purchase additional resources	Emergency funding provided for hospitals to procure necessary resources.		No	Financial considerations	(101–104)

Note: *captured in WHO COVID-19 Essential Supplies Forecasting Tool and the CDC PPE Burn Rate Calculator (105).

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Estimates of impact on capacity

Given the user-specified number of patients, the planner calculates the spare capacity in terms of beds, staff and ventilators per 10,000 population for each healthcare capacity intervention, with a negative number representing a deficit in capacity. To allow comparison of different interventions, the per cent change in spare capacity compared with the baseline is calculated as

$$\text{Change in spare capacity }(\%) = \frac{\text{Spare capacity in intervention} - \text{spare capacity in baseline}}{|\text{Spare capacity in baseline}|} \times 100 \qquad (1)$$

Using the beds-to-staff ratios (further detailed in the user guide), the tool can also be used to identify whether the current staff capacity is sufficient to treat all patients (both COVID-19 and non-COVID-19) once bed capacity is reached, or whether additional staff are required to safely implement the intervention. Outputs are reported numerically and graphically, to demonstrate how each intervention affects the spare capacity for beds, staff and ventilators.

The impact assumptions may not apply to other countries, therefore users can change these based on their own assessments. Users can also adjust intervention-related parameters and beds-to-staff ratio allowances at baseline. Staff are trained specifically to operate certain beds and equipment. As such, the maximum number of beds per category of staff determines the staffing levels required to provide care safely, which is a critical consideration for interventions in which bed capacities are increased. Intervention-related parameters can be modified to represent the characteristics of the particular health system and care provider of interest. The specific parameters required vary on an intervention-by-intervention basis. Some interventions, such as the use of private hospital resources, require changes in capacity estimates across all variables (beds, staff, ventilators) while others, such as procuring additional ventilators, only requires a change in one input value.

Case study: England National Health Service (NHS)

The use of the planner is demonstrated with a case study of England (see Appendix). We evaluate the introduction of the England Nightingale field hospitals with additional bed capacity in England, under the assumption that there are 69,329 COVID patients (as of April 13, 2020) (106). It is estimated that the setup of these field hospitals increases the capacity of CC and G&A beds by 500 (12%) and 8000 (8%) respectively (107,108). An assumed 1,480 COVID-19 patients in CC and 7,770 COVID-19 patients in G&A care would result in a capacity of 1.46 G&A beds per 10,000 population (up from 0.03 at the baseline), with enough appropriate staff to safely cover all G&A beds according to guidelines on safe staffing for this type of bed (109). However, as the number of patients requiring such beds grows, this spare capacity will reduce. On the other hand, there remains a deficit of -0.05 CC beds per 10,000 population under this intervention, although this is an improvement of 64% on the baseline. According to the specified staffing ratios, there is already a deficit of around 500 CC nurses at the baseline. Under this intervention, an additional 500 CC nurses would be required to safely operationalise the new CC beds in the England Nightingale field hospitals. Data for England may not apply to other countries.

Discussion

The J-IDEA planner provides users with a simple and flexible way to compare the impact of different healthcare provision interventions on the hospital sector's capacity to provide urgent care in a situation of a surge in demand. The interventions acknowledge the inevitable limitations of healthcare provision during a pandemic (8). Countries and healthcare providers are being forced to make substantial financial investments into capacity, accept reductions in the quality of care or ration hospital services, particularly within CC. For example, cancelling elective and non-cancer surgeries frees up hospital capacity, which is then reallocated to patients requiring more urgent treatment. The planner estimates how much capacity is freed up by this and other interventions. It may become necessary to prioritise between all patients requiring life-saving treatment during extreme surges in demand. The planner helps users understand the capacity that is gained by making these difficult choices and calculates corresponding increases in, for example, staffing across different categories that are required for a specific number of additional CC beds. The actual impact of healthcare interventions on beds, staff and ventilators are estimated as part of this study via an empirical analysis of English data from hospital and administrative patient records, and a review of the existing literature.

The application of the tool complements efforts in different countries to explore alternative ways of increasing capacity and allocating scarce resources during the COVID-19 pandemic. We reserve judgement on the appropriateness of the reviewed interventions. We do, however, recognise that they are associated with either difficult ethical decisions surrounding the prioritisation of care for certain patient groups (4), financial ability to sustain these efforts (110) or trade-offs between quantity and quality of care provided (111).

The planner has several limitations. The estimates of capacity increases are based on a rapid analysis of English data, and there is considerable uncertainty around the estimates and whether they are generalisable to other health systems. The sources of these estimates are listed in the Appendix. The estimation necessarily makes simplifying assumptions about healthcare delivery, which are also outlined in the Appendix. Users of the tool should ensure that they consider these assumptions when conducting any analysis using the planner.

Some important inputs, e.g. Personal Protective Equipment (PPE), are not currently modelled in the planner as they are measurable on a per diem rather than per-patient basis and require a level of granularity that is beyond the scope of this planner. There are several emerging tools available that assist with this, such as the World Health Organization COVID-19 Essential Supplies Forecasting Tool.

The planner does not consider the health impact of reductions in the quality of care that are very likely to be associated with some healthcare interventions. For instance, increasing the number of beds without appropriate adjustments to staff numbers will reduce beds-to-staff ratios with a likely adverse impact on the quality of care. The planner simply calculates the impact on beds-to-staff ratios, and it is left to the user to judge likely impact on care. Moreover, interventions which manage admissions require careful consideration. First, there will be opportunity costs arising from treatment that is not immediately provided. For example, cancelling elective operations will increase morbidity, and potentially mortality in the affected patient groups. It is not obvious that health gain is greater in patients that receive care during the pandemic than those who do not.

Prioritising patients for admission to hospital care is associated with complex bioethical considerations, which are reflected in the breadth of interventions chosen. Rationing needs to be assessed carefully with respect to existing national guidelines, such as those published by the UK National Institute for Health and Care Excellence (NICE) in preparation for the COVID-19 pandemic (8), or those of the Società Italiana di Anestesia Analgesia Rianimazione e Terapia Intensiva (SIAARTI) in Italy (25). Most guidelines emphasise the underlying principle of non-discrimination across medical conditions and socio-demographic conditions of patients. The majority attempt to maximise the benefits for the largest number of people, by redirecting crucial resources to patients who have the greatest chance of survival and remaining life expectancy. The guidelines are based on well-established literature (4,112,113). Unfortunately, CC does not always improve the survival chances of patients, particularly as there is currently no effective treatment available for COVID-19 and CC is limited to providing life support. Emerging evidence suggests that the efficacy of CC for COVID-19 patients is low, particularly for the sickest patients (9,114). Admissions of patients with other conditions may reduce during the pandemic, as patients may not seek hospital care, either due to fear of a hospital-acquired COVID-19 infection or because they do not want to overburden hospitals. The patterns of presenting conditions may change due to widespread public health (i.e. epidemic) interventions, for example, lockdown policies may reduce road traffic accidents.

The planner is a first step to help inform choices in the preparation of hospitals for the pandemic. The current format has been chosen to make it as widely usable as possible, requiring minimal inputs, assumptions and technical expertise from the user. It also allows the user to tailor parameters to specific health systems. We welcome users and readers to share further updates on capacity planning considerations and implementations in other countries with us. We hope to address some of these in future improvements of the planner and to update the planner iteratively, for example by expanding upon healthcare interventions considered by countries. A possible extension of this tool is to provide daily updates of the supply and demand of resources and potentially incorporating epidemiological forecasts.

To maximise the potential of the tool, strategic operational planning should be streamlined, for example by using a national organisation for pandemic planning. Such an organisation would be responsible for a cohesive response to emergency planning and disaster management, while also maintaining awareness to identify potential unknown threats. Access to and analysis of real-time data are necessary for successful modelling and strategic planning; improving access to such data should be coordinated by one organisation as a joint venture between governments, international governing bodies, and the private sector. Coordination and capacity planning can improve response efficiency, promote a sense of global security and support, and, ultimately, save lives.

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Author statement

PC, JCD, AL, RM, DR and NS contributed to the conception of this study, undertook the data gathering and analysis, developed and designed the planner, and wrote the report and accompanying user guides. KH conceived the idea of this study and contributed to the development and design of the planner, as well as the writing of the report. MM and PW provided guidance on the study goals and contributed to the writing of the report and user guides. SN and PG provided clinical guidance in modelling the interventions. PA and AB conducted the data analysis of the managing admission interventions. All authors reviewed the report.

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Appendix: J-IDEA pandemic hospital planner user guide

1. Introduction

The J-IDEA planner allows users to compare hospital capacity under various hospital capacity interventions, intending to inform pandemic response planning. It allows the user to explore potential shortfalls and requirements in response to the COVID-19 pandemic across three key capacity components**: beds, staff and ventilators**. The tool presents a snapshot of healthcare capacity and users can enter their forecasts on the number of expected of COVID-19 and other patients requiring care, to compare potential deficits in capacity on a particular day. Example questions the planner can be used to explore are presented in the introduction of this report.

The tool presents a snapshot of healthcare capacity and currently incorporates no epidemiological forecast of the pandemic's progression. Users are advised to read *Section 5 (Modelling Assumptions)* of this Appendix and to carefully consider whether the modelled interventions and assumptions underlying the calculations meet their setting-specific requirements. The planner is subject to change, and updated versions are expected to be published.

2. How to use this tool

The planner is implemented in a spreadsheet consisting of 5 sheets:

- Readme: provides an overview of the tool and the different hospital capacity interventions to model.
- Input (Quick): the most essential inputs to be entered by the user.
- Input (Extended): an extended version of *Inputs (Quick)*, that includes assumptions and data specific to the health care system, to be entered by the user.
- Output (numeric): numeric results and breakdown of calculations.
- Output (graphical): graphically illustrated results.

The inputs, outputs and modelling assumptions are detailed in the following sections, accompanied by a case study focusing on England for illustration. The planner is pre-populated with values for England. The current version of the planner is designed to be flexible and applicable at different healthcare levels and in various high-income settings. Users must decide whether the assumptions are relevant to their setting and whether the opportunity costs or ethical implications of the healthcare provision interventions align with societal norms. For more information on altering intervention assumptions, refer to *Section 3b (Editable intervention assumptions)*.

A Quick User Guide with step-by-step instructions and an example application is also provided with the planner.

3. Inputs

Users can choose to fill in the *Input (Quick)* or Input *(Extended)*. *Input (Quick)* highlights only the mandatory baseline and intervention values required to use the tool based on the modelling assumptions set out in Appendix Tables 1 and 2. Values entered in *Input (Quick)* are automatically copied across into the appropriate column in *Input (Extended)*. If *Input (Quick)* has blank cells for these values, then the default England value is used instead. *Input (Extended)* offers a more comprehensive data entry by allowing users to change all inputs and assumptions, allowing customisation of the intervention assumptions underpinning the England example and enabling users to create their own combination of interventions. Users should note that making changes in this sheet will override the inputs from *Input (Quick)*. To reset *Input (Quick)* functionality, users must press the *Reset Formulae* button on the *Input (Extended)* sheet. This defaults the inputs back to England values.

a. Baseline user inputs

Inputs are disaggregated into baseline and COVID-19-related inputs. A description of each input and the estimated values for England are presented in Appendix Table 1.

Baseline inputs on existing hospital capacity [Inputs (Extended) cells C16-N16]

Baseline existing hospital capacity reflects non-COVID-19 related provision and demand of beds, staff and ventilators before the modelled capacity management interventions are introduced. Baseline capacity inputs can be completed using pre-pandemic or current data. If using pre-pandemic data, users should choose the most representative data, e.g. from the corresponding month of the previous year, to account for the impact of seasonality on demand. If using current data, the user needs to know the breakdown of patients hospitalised with COVID-19 or for other reasons and the shift in the original baseline due to interventions that have already been implemented.

The tool uses staffing requirements expressed in full-time equivalents (FTEs) to account for part-time working and absence due to non-COVID related sickness and holiday. FTEs may differ from a simple headcount for this reason. If only staff headcounts are known (not FTEs) then see the *Additional inputs* rows in Appendix Table 1.

These baseline values are required inputs in *Input (Quick)* and can be entered in cells E16:E36.

See Appendix Table 1 for further details on baseline inputs.

Maximum Beds-per-Staff Ratio Allowances [Inputs (Extended) cells O16-T16]

To account for the fact that beds must be staffed by sufficient staff numbers, the user is asked to specify a maximum threshold of the number of beds that an individual member of staff from each of the 6 categories could safely cover. These thresholds are used to determine the level of staffing required by each intervention, both in terms of the number of patients currently hospitalised and in terms of overall bed capacity.

Example: if 1 G&A nurse can safely staff a maximum of 5 beds (beds-per-staff ratio = 5:1), the maximum staff ratio allowance input for Beds per G&A nurse [cell P16] is 5.

These values are assumed to be generalisable across settings and thus not required in *Input (Quick)*.

See Appendix Table 1 for further details on beds-per-staff ratios.

COVID-19 related inputs [Inputs (Extended) cells C20-G20]

COVID-19 related inputs can be based on that which is currently observed, or which represents an assumption of future pandemic progression, such as a worst-case scenario. They can also be set to 0 should the user wish to explore the impact of the different interventions for pre-pandemic levels of demand and supply.

These are required inputs in *Input (Quick)* and can be entered there in cells H16: H22.

See Appendix Table 1 for further details on COVID-19-related inputs.

Additional inputs [Inputs (Extended) cells H20-I20]

The two additional inputs required by this tool are the FTE staff multiplier and the reference population. The latter is a required input in *Input (Quick)* and can be entered there in cell H24.

See Appendix Table 1 for details on additional inputs.

b. Editable intervention assumptions [columns C-AB, rows 27-43]

In addition to adding the baseline figures, the user can alter the figures in the intervention assumptions section of the tool to better-represent their situation. For example, users can include additional increases in the modelled interventions, or extend the tool to model other interventions or scenarios combining interventions not listed here by inserting rows manually.

Parameters should be added in the respective columns, according to whether they are a figure or a percentage. The calculations in the output sheet come from the percentage change section. If users edit the figures, these are automatically converted into percentages. As described in *Section 5 (Modelling assumptions)*, where the distribution of added capacity between CC and G&A is not known, users can consider either attributing all the resource to one category or distributing the resource in line with the baseline proportions. Calculations for the latter method are already automatically implemented in cells C49:J49, and examples of both proposed solutions are highlighted in Appendix Table 2, with their implementation in the corresponding row of the planning tool. Other allocation assumptions are possible but are not modelled at present.

While *Input (Extended)* gives the user flexibility in modelling interventions, *Input (Quick)* provides only the variables required for each modelled intervention according to the assumptions outlined in Appendix Table 2. These can be entered in columns E-T, rows 43:69 of *Input (Quick)*.

Note that not all interventions are pertinent to all users, and therefore users should only change the relevant cells in either *Input (Quick)* or *Input (Extended)*. The values in *Output (Numeric)* and *Output (Graphical)* are automatically updated based on that which is entered into *Input (Extended)* (either directly or through *Input (Quick)*) and thus should do not require alteration.

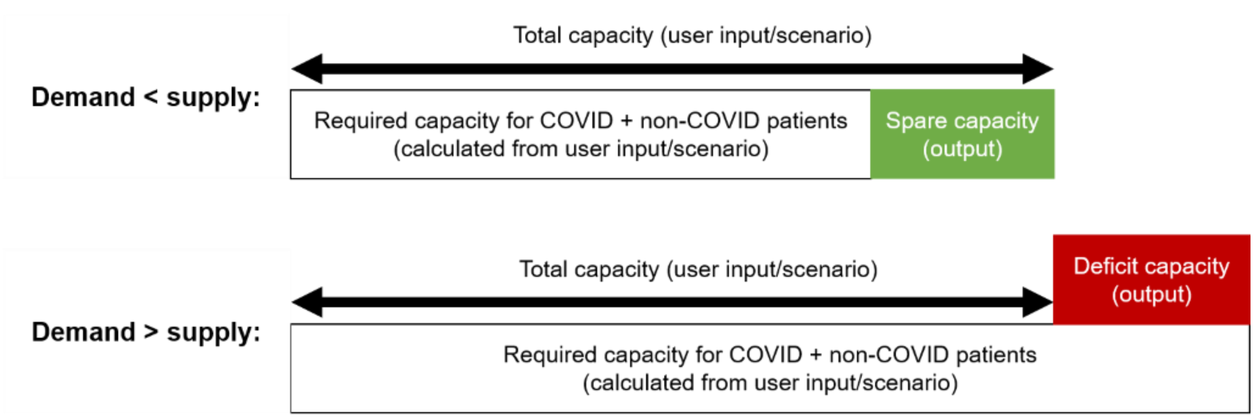
4. Outputs

a. Outputs (Numeric)

There are four general categories of outputs in the planner: spare capacity per 10,000 population [columns C-K]; per cent change in spare capacity compared to baseline [columns L-T]; the number of staff required for total bed numbers [columns U-Z]; and a staff ratio check for current patient numbers [columns AJ, AL, AN, AP, AR, AT]. An overview of the definitions of these and guidance on how they should be interpreted is provided in Appendix Table 3.

A positive value for spare capacity per 10,000 population means there is sufficient supply of this resource. A negative value indicates a deficit in capacity, i.e. a lack of this resource required to care for the total number of patients. This is further illustrated in Appendix Figure 1.

Appendix Figure 1: Illustration of the relationship between user inputs, calculations in the planning tool and outputs.



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b. Outputs (Graphical)

Space capacity per 10,000 population is also presented graphically, both on a per resource and per intervention basis. Bars are coloured according to whether there is an excess or deficit in capacity per 10,000 population, with the baseline and the zero line also highlighted in each graph.

5. Modelling Assumptions

A summary of the assumptions made in the modelled interventions in the tool can be found in Appendix Table 2. The intervention-specific changes in different capacity components have been estimated for England (Appendix Table 2) and can be adapted by the user (*Section 3b (Editable intervention assumptions)*).

For the interventions involving changes to hospital admissions, the modelled percentage increase in capacity is informed by an analysis of English Hospital Episode Statistics (HES) data (115). These values are applied to baseline inputs by reducing the bed occupancy of non-COVID-19 patients entered by the user. For the supply interventions, numeric figures found in government reports and other sources are converted into a percentage increase and applied to the input total capacity figures.

The tool distinguishes between CC and G&A beds and staff in order to acknowledge the substantial differences in care provided in these two settings. However, this granularity was not available for each figure in the presented capacity interventions, such as for the deployment of newly qualified nursing students or the use of private hospital resources. In this case, we either attributed all the resource to just one category or, where this was deemed unrealistic, distributed the resource into CC (where appropriate) and G&A according to the corresponding proportions arising from the baseline.

The number of COVID-19 patients are input by the user and represent an addition in demand to the baseline occupancy to which different capacity management interventions are applied. User inputs of COVID-19 related staff sickness rates reduce the total staff FTEs available at baseline and in all interventions.

Under each intervention, the planner calculates the level of staffing and ventilators required to care for a given number of patients based on CC and G&A bed occupancy, which feeds into the calculation of spare capacity (see *Section 4 (Outputs)*). Staff FTE requirements are calculated via multiplication of the beds-per-staff ratios. The number of ventilators required depends on the number of patients in CC, with the input allowing different assumptions for the proportion of CC patients requiring a ventilator based on their COVID-19 status.

6. Further options for adapting interventions

In many settings, a combination of the modelled interventions has already been implemented in planning for COVID-related surges. In this case, users can also use the tool to explore options for scaling down different healthcare provision interventions as the pandemic starts to tail off.

While the current version of the tool is not designed with this focus, we suggest the following approach for users interested in this question:

- On the *Input (Extended)* sheet, set the baseline inputs of existing hospital capacity [cells C16-N16] to reflect current (upscaled) provision, keeping in mind which combination of interventions this represents
- On the *Input (Extended)* sheet, change the percentages or figures for modelled increases in capacity in the different interventions to the opposite sign (e.g. from positive to negative) [columns C-AB, rows 27-43]. This then corresponds to modelling a *decrease* in capacity from 'baseline' (upscaled provision).

For example, in a setting where elective operations have been cancelled and this is reflected in baseline inputs, a user could set *Modelled increase in capacity (%)* for the *Cancellation of elective operations* intervention from 26% to -26% and from 13% to -13% for CC bed and G&A bed occupancy, respectively. In this case, the intervention represents a re-introduction of elective operations.

Appendix Table 1: Input descriptions, assumptions and example values for England. Cells references are concerning *Input (Extended)* in the planner

Input variable	Description	Assumptions	England example input value
Baseline inputs on existing hospital capacity [cells C16-N16]			
Total number of CC beds	The number of CC beds that exist at baseline on any given day. This may also be referred to as "open" beds. It is the sum of CC beds that are occupied by patients and CC beds that could be occupied but are not.	Adult CC beds for 145 reporting Acute trusts (includes intensive care and high-dependency units) (116).	4,123
Total number of G&A beds	The number of G&A beds that exist at baseline on any given day. This may also be referred to as "open" beds. It is the sum of G&A beds that are occupied by patients and G&A beds that could be occupied but are not.	G&A beds for 152 acute and Community provider trusts (117).	99,935
Number of CC beds occupied by non-COVID-19 patients	The number of CC beds that are occupied by patients with non-COVID-19-related conditions at baseline on any given day. This can also be calculated by multiplying the average baseline CC bed occupancy rate with the total number of CC beds.	The occupancy given for 145 reporting acute trusts on the 30th January 2020 (116).	3,423
Number of G&A beds occupied by non-COVID-19 patients	The number of G&A beds that are occupied by patients with non-COVID-19-related conditions at baseline on any given day. This can also be calculated by multiplying the average baseline G&A bed occupancy rate with the total number of G&A beds.	G&A beds occupancy for 152 acute and Community provider trusts (117).	91,971
Percentage of non-COVID-19 CC patients requiring ventilator	The percentage of CC patients with non-COVID-19-related conditions requiring a ventilator on any given day. *If not known, users can use the suggested value of 43%.*	Proxy for the percentage of COVID-19 CC patients requiring a ventilator based on analyses from the Intensive Care National Audit & Research Centre on the needs of UK CC patients within the first 24 hours of admission (118).	43%
Total number of ventilators	The number of ventilators that exist at baseline on any given day. It is the sum of currently used ventilators and ventilators that could be used on the day but are not.	As reported in the UK media (119).	8,175

Input variable	Description	Assumptions	England example input value
	If not known, this can be left blank, in which case interventions and outputs relating to ventilators are not available.		
Total CC nurses (FTE)	The full-time equivalent of CC nurses at baseline on any given day.	In consultation with staff at Imperial College Healthcare Trust (ICHT), Electronic Staff Records (ESR) data from April – June 2019 were filtered to select nurses usually working in CC wards (120,121). According to the number of beds in each trust, a weighted average of daily FTE was calculated for CC nurses.	3,939
Total G&A nurses (FTE)	The full-time equivalent of G&A nurses at baseline on any given day.	In consultation with staff at ICHT, ESR data from April – June 2019 were filtered to select nurses usually working in G&A wards (120,121). According to the number of beds in each trust, a weighted average of daily FTE was calculated for G&A nurses.	32,354
Total CC senior doctors (FTE)	The full-time equivalent of senior CC doctors at baseline on any given day.	In consultation with staff at ICHT, ESR data from April – June 2019 were filtered to select doctors usually working in CC wards, and if they were able to be classed as clinical decision-makers or not (120,121). According to the number of beds in each trust, a weighted average of daily FTE was calculated for senior CC doctors.	965
Total CC junior doctors (FTE)	The full-time equivalent of junior CC doctors at baseline on any given day.	In consultation with staff at ICHT, ESR data from April – June 2019 were filtered to select doctors usually working in CC wards, and if they were able to be classed as clinical decision-makers or not (120,121). According to the number of beds in each trust, a weighted average of daily FTE was calculated for junior CC doctors.	677
Total G&A senior doctors (FTE)	The full-time equivalent of senior G&A doctors at baseline on any given day.	In consultation with staff at ICHT, ESR data from April – June 2019 were filtered to select doctors usually working in G&A wards, and if they were able to be classed as clinical decision-makers or not (120,121). According to the number of beds in each trust, a weighted average of daily FTE was calculated for senior G&A doctors.	12,680

Input variable	Description	Assumptions	England example input value
Total G&A junior doctors (FTE)	The full-time equivalent of junior G&A doctors at baseline on any given day.	In consultation with staff at ICHT, ESR data from April – June 2019 were filtered to select doctors usually working in G&A wards, and if they were able to be classed as clinical decision-makers or not (120,121). According to the number of beds in each trust, a weighted average of daily FTE was calculated for junior G&A doctors.	10,293
Maximum Staff Ratio Allowances Inputs [cells O16-T16]			
Beds per CC Nurse	The maximum threshold of the number of CC beds that a single CC nurse could safely look after.	According to ICU guidelines (122).	1
Beds per G&A Nurse	The maximum threshold of the number of beds that a single G&A nurse could safely look after.	According to Royal College of Nursing guidelines (123).	5
Beds per CC Senior Doctor	The maximum threshold of the number of beds that a single CC senior doctor could safely look after.	According to ICU guidelines (122).	15
Beds per CC Junior Doctor	The maximum threshold of the number of beds that a single CC junior doctor could safely look after.	According to ICU guidelines (122).	8
Beds per G&A Senior Doctor	The maximum threshold of the number of beds that a single G&A senior doctor could safely look after.	According to Royal College of Physician guidelines (124).	15
Beds per G&A Junior Doctor	The maximum threshold of the number of beds that a single CC junior doctor could safely look after.	According to Royal College of Physician guidelines (124).	15
COVID-19-related Inputs [cells C20-G20]			
Number of COVID-19 patients in CC beds	The observed or expected number of COVID-19 patients in CC on any given day. *If the setting-specific distribution of COVID-19 patients between critical and non-critical (G&A) care is not known, e.g. because no data on COVID-19 hospital admissions are available yet, users can apply reported ratios from other settings as an assumption. For example, in an Italian study, the proportion of COVID-19 hospitalised patients that were admitted to ICU was 16% (118).*	Confirmed COVID-19 cases in CC as of 3 April 2020 reported in ICNARC report, scaled to remove admissions in Wales and Northern Ireland (118).	1,480

Input variable	Description	Assumptions	England example input value
Number of COVID-19 patients in G&A beds	The observed or expected number of COVID-19 patients in G&A care on any given day.	Derived from number of COVID-19 patients in CC and assuming that 16% of COVID-19 patients require CC.	7,770
Percentage of COVID-19 CC patients requiring ventilator	The percentage of COVID-19 patients in CC requiring a ventilator on any given day. *Note: If not known, users can use the suggested value of 63%.*	Proxy for the percentage of COVID-19 CC patients requiring a ventilator based on analyses from the Intensive Care National Audit & Research Centre on the needs of UK CC patients within the first 24 hours of admission (118).	63%
COVID-19-related sickness rate for nurses	The observed or expected percentage of nurses (CC and G&A) on sickness absence due to COVID-19 on any given day. Note that sickness absence for reasons other than COVID-19 should be accounted for in baseline inputs of existing staff FTEs (see Baseline inputs on existing hospital capacity section). COVID-19 related sickness rates are applied in addition to this in all the staffing calculations on the Output sheet, including the baseline scenario.	Media reports of the estimated overall NHS staff sickness rate, according to the Department of Health and Social Affairs (125).	8.1%
COVID-19-related sickness rate for doctors	The observed or expected percentage of doctors (CC and G&A; junior and senior) on sickness absence due to COVID-19 on any given day. Note that sickness absence for reasons other than COVID-19 should be accounted for in baseline inputs of existing staff FTEs (see Baseline inputs on existing hospital capacity section). COVID-19 related sickness rates are applied in addition to this in all the staffing calculations on the Output sheet, including the baseline scenario.	A recent survey (April 2020) by the Royal College of Physicians asked doctors to estimate recent levels of sickness, broken down into COVID and non-COVID reasons (126).	14%
Additional Inputs [cells H20-I20]			
Headcount to FTE multiplier	Multiplier to convert staff headcounts into staff FTEs. Since official announcements of additional staff numbers are often given in headcounts, the multiplier is provided to convert headcounts into FTEs, as estimated by NHS workforce data (116). This can be	Calculated by dividing the headcount of total NHS staff in December 2019 by total FTE (127).	0.88

Input variable	Description	Assumptions	England example input value
	updated by the user if necessary or omitted if not applicable.		
Reference population size for output calculation	The spare capacity output is calculated per 10,000 reference population, which the user can choose according to their purpose (e.g. country population size). Setting the reference population to 10,000 will provide the absolute spare capacity (e.g. absolute number of beds spare or deficit).	Estimated population size of England (128).	55,977,200

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Appendix Table 2: Description, assumptions and England example values for the interventions presented in the planner

Intervention	Description	Assumptions	England example intervention value
Cancellation of elective operations	To reduce the number of beds occupied and staff required, non-elective surgeries are cancelled.	• This frees up both CC and G&A beds. • An analysis of the busiest month in hospitals last year (January 2019) using Hospital Episode Statistics estimated the proportion of beds filled with non-emergency, non-maternity and non-cancer related elective patients in CC and G&A beds respectively. Thus, the proportion of beds freed from cancelling elective surgeries, not of the type above could be estimated. • This was inputted directly as a % change.	• 30% freed beds from CC. • 41% freed beds from G&A.
National guidelines for the prioritisation of CC resources	In situations of a severe scarcity of resources, patients are prioritised for CC following official guidelines (triage criteria vary across countries).	• This frees up CC beds. • An analysis of the busiest month in hospitals last year (January 2019) using Hospital Episode Statistics estimated the proportion of beds that could be freed according to the recently published NICE guidelines on CC. • This was inputted directly as a % change.	• 60% freed beds from CC.
Set up of field hospitals	Non-hospital sites are temporarily turned into hospitals during the pandemic.	• The type of beds in field hospitals are known, and if not are assumed to be G&A (95,108).	• 500 CC beds. • 8000 G&A beds.
Use of private healthcare resources	National health systems temporarily use private healthcare resources to provide public care.	• Beds are given as a generic figure and distributed according to baseline proportions (129). • Numbers of nurses and doctors are given as headcounts and not disaggregated by seniority or bed type. This is distributed according to baseline proportions and multiplied by the FTE multiplier (129). • Private hospital operating theatres are converted into CC wards, a number of which are kept open for emergencies (129,130). • The number of beds per theatre can be varied but is constant across all theatres.	• 8000 hospital beds. Using proportions of baseline beds this gives 312 CC (4%) and 7,688 G&A (96%). • 1200 ventilators. • 10,000 nurses. Using proportions of baseline nursing this gives 966 CC (11%) 7,934 and G&A (89%). • 700 doctors. Using proportions of baseline nursing this gives 24 senior CC (4%), 17

Intervention	Description	Assumptions	England example intervention value
			junior CC (3%), 321 senior G&A (52%) and 261 junior G&A (42%). • 14 operating theatres in total. Assume 50% of these are converted for use as CC beds. • Assume 2 beds per each theatre.
Conversion of operating theatres to CC wards	The space in operating theatres is converted into CC wards with a number of beds. Some operating theatres must be kept operational for emergencies.	• Hospital operating theatres are converted into CC wards, a number of which are kept open for emergencies (116). • The number of beds per theatre can be varied but is constant across all theatres.	• 2404 of operating theatres in England, calculated by assuming teaching and specialist trusts have one Tertiary hospital requiring 5 theatres open for emergency surgery. All other hospitals are assumed to be District general hospital (DGH) and require only 1 theatre open for emergencies. • Assume 2 beds per theatre.
Conversion of G&A beds to CC beds	Hospitals increase specialised bed capacity by converting some of their G&A wards into CC wards, which requires investments into specialised staff and equipment.	• A number of beds are taken from G&A and added to CC. The overall number of beds does not change.	• Arbitrary value of 2,000.
Upskill G&A staff to work in CC wards	G&A staff and staff from other clinical specialities are given basic training to work in CC wards.	• A number of nurses and junior doctors are taken from G&A and added to CC. The overall number of staff does not change.	• Arbitrary value of 2% for both. This results in the reallocation of 647 nurses and 206 junior doctors.
Return of former healthcare staff	Individuals who recently worked in the health system are asked to return for the duration of the pandemic.	• Numbers of nurses and doctors are given as headcounts and not disaggregated by seniority or bed type. This is converted into FTE via the FTE multiplier (131). • This is distributed according to baseline proportions. This accounts for the fact that although more retired doctors are likely to be senior, many may	• 6147 nurses which equate to 5471 FTE. Using proportions of baseline nurses this gives 594 CC (11%) and 4,877 G&A (89%). • 2660 doctors which equate to 2367 FTE. Using proportions of baseline nursing this gives 93 senior CC (4%), 65 junior CC

Intervention	Description	Assumptions	England example intervention value
		not be willing to take on a clinical decision-making position and thus would return as 'junior'.	(3%), 1,220 senior G&A (52%) and 990 junior G&A (42%).
Deployment of newly qualified and final year medicine and nursing students	Final year medical and nursing students may have their qualification process accelerated to enable them to start working immediately.	• Numbers of nurses and doctors are given as headcount and thus converted using the FTE multiplier (131). • The new nurses and doctors are assumed to be G&A nurses and G&A junior doctors respectively.	• 18,700 nurses which equate to 16,643 FTE G&A nurses. • 5500 doctors which equate to 4,895 FTE junior G&A doctors.
Deployment of international doctors at the final stage of their conversion assessment	Doctors who qualified overseas often must take additional exams to practise in a new country. For those who are close to the end of this process could be accelerated or the final stages waived.	• Numbers of doctors are given as headcount and thus converted using the FTE multiplier (132). • These doctors are assumed to be junior G&A doctors.	• 3,000 junior G&A doctors
Procurement of newly manufactured ventilators	Governments purchase additional ventilators, or request manufacture of ventilators, to increase the number of machines nationally.	• This is given as a usable figure and thus no further calculations are required (82).	• 20,000 ventilators.

Appendix Table 3: Overview of the outputs as presented in *Output (Numeric)* in the planner

Output variable	Description	Interpretation
Spare capacity per 10,000 population [columns C-K]	For each intervention, the spare capacity of beds, staff and ventilators is calculated by subtracting the capacity required (as described in Appendix Section 5 and Appendix Table 1) to care for the given number of COVID and non-COVID patients from the total capacity. For example, the latter involves subtracting the number of occupied beds from the total number of beds, and the number of staff FTEs needed to service these occupied beds from the total staff FTEs. The spare capacity is then divided by the reference population chosen by the user and presented as per 10,000 population.	Negative values for spare capacity per 10,000 reference population represent a **deficit** of this resource and are highlighted in red. The relationship between inputs and outputs is further illustrated in Appendix Figure 1, highlighting that a deficit occurs if the capacity required to care for all COVID and non-COVID patients exceeds the total capacity.
Per cent change in spare capacity compared to baseline [columns L-T]	The per cent change in spare capacity compared to baseline allows comparing the effect of different interventions on the spare capacity of beds, staff and ventilators for a given number of patients. This is defined as in Equation (1).	Positive percentages represent an improvement in spare capacity in the respective intervention compared to baseline; negative percentages highlight a reduction in spare capacity compared to baseline, and a 0% change means the intervention has not affected a given spare capacity output compared to baseline. Percentages can be compared across interventions to assess which intervention leads to the most substantial change.
Staff planner: staff required for total bed numbers [columns U-Z]	The minimum number of each type of staff required per total bed is based on the maximum ratio input as part of the baseline. This is compared to the current total number of staff in columns AH, AJ, AL, AN, AP and AR, which has been adjusted down based on the inputted COVID-related sickness rates.	If this is green, the current total number of staff is sufficient to treat all patients if beds reached capacity. Red means the opposite and indicates that further staff would be required to fully implement this intervention under the specified ratios.
Staff ratio check for current patients [columns AJ, AL, AN, AP, AR, AT]	The tool also provides a check as to whether the staff numbers required per occupied bed are satisfactory, again based on the maximum ratio input as part of the baseline. This is compared to the current total number of staff, which has been adjusted down based on the inputted COVID-related sickness rates.	If this is green, it means that the current total number of staff is sufficient to treat all patients currently in beds only. Red means the opposite and indicates that further staff would be required to treat current patients safely that intervention under the specified ratios.