A tool for the management of personal protective equipment during COVID-19 pandemic: Abderrahmen Mami Hospital case study

Un outil pour la gestion des équipements de protection individuelle durant la pandémie COVID-19: Cas de l'hôpital Abderrahmen Mami

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Abstract

Introduction: The COVID-19 pandemic is causing management difficulties in the Tunisian healthcare system inventory management and the supply of Personal Protective Equipment (PPE).
Aim: Calculate the number of PPE needed for MAMI Hospital Ariana (dedicated hospital to COVID patients) to avoid stock-outs.
Methods: This study proposed a calculation method of the PPE needs for the intensive care and pneumology departments. We developed a mathematical formulation of the number of PPE needed according to the number of visits per medical and other teams, their types, the number of patients, and the validity of each type of PPE.
Results: Considering as input data: the number of visits for the different intervening teams (medical, paramedical, worker or other), the capacity of the different services (number of beds), the average length of stay of patients, the validity duration of an equipment and urgent visits, the developed model generates the required number of PPE (especially surgical masks, FFP2 masks, disposables gowns and coveralls). This allows to calculate the number of personal protective equipment (PPE) needed by the Mami hospital's pharmacy in this period of COVID-19 crisis.
Conclusion: Our configurable application allowed us to calculate PPE requirements for the intensive care and pneumology departments and estimate their use duration.
Key words: COVID-19, PPE, Supply, Planning.

Résumé

Introduction : La pandémie de la COVID-19 a mis à rude épreuve la gestion dans le système de soins Tunisien, particulièrement, la gestion de stock et l'approvisionnement en équipements de protection dédiés aux personnels intervenants.
Objectif : Calculer les besoins en nombre d'équipements de protection individuelles (EPI) pour l'hôpital Abderrahmen Mami Ariana afin d'éviter les ruptures de stocks.
Méthodes : Cette étude a traité les besoins en EPI pour les services de réanimation médicale et de pneumologie. Nous avons proposé une formulation mathématique permettant de calculer ces besoins en fonction du nombre de visites effectuées par les équipes médicales et paramédicales, de leurs types ainsi que du nombre de patients et des durées de validité de l'EPI.
Résultats : En considérant comme données d'entrée : le nombre de visite pour les différentes équipes intervenantes (médicale, para médicale, ouvrier ou autre), la capacité des différents services (nombre de lits), la durée de séjour moyenne des patients, la durée de validité d'un équipement et les visites urgentes, le modèle élaboré a généré les besoins en nombre d'EPI (notamment les masques chirurgicaux, les masques FFP2, les blouses et les combinaisons à usage unique).
Conclusions : Notre application paramétrable a permis de calculer les besoins en EPI pour les départements de réanimation et de pneumologie.
Mots clés : COVID-19, EPI, Approvisionnement, Planification.

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INTRODUCTION

Medical services are facing an urgent need for tools to manage the COVID-19 crisis. This pandemic is causing management difficulties in the Tunisian healthcare system, especially for personal protective equipment (PPE) for health staff handling coronavirus patients (1).

The rational and appropriate use of medical PPE (masks, gowns, gloves) and the coordination of mechanisms for managing the PPE supply chain are strategies likely to allow optimal availability of PPE. It is, therefore, necessary to find a solution that manages the quantity of PPE needed, by using forecasts based on rational quantitative models so that the quantities requested are adapted (2-4).

To facilitate the management of PPE, the hospital's pharmacy provides a kit. A kit includes: 2 headgear, one overshoe, one overall, one gown, one plastic apron, 2 pairs of gloves and one Filtering Face Piece (FFP2) mask. To optimize the use of protective equipment, the pharmacist suggests managing each item separately. Special attention should be paid to the most critical items: medical gowns and FFP2 masks. However, the pharmacy does not have a history related to the pandemic to estimate the daily requirement for each department.

This article proposes a decision support tool for daily need estimation of PPE within the Abderrahmen Mami Hospital Pharmacy, Ariana who manages PPE and safety equipment for the different hospital departments. The focus of this paper is on PPE related to the COVID-19 circuit, especially surgical and FFP2 masks and medical gowns. Each equipment is managed by item, and for each item, the supply is done either by units or by batch.

Determining the required quantities of PPE depends on several parameters such as the number of visits (done by the medical/ paramedical staff) to treat hospitalized patients, the type of visit (programmed or urgent), the number of patients (length of stays, deaths), the number of staff per department and the validity duration of the PPE. Our objective is to develop an application that estimates the required number of PPE per day and per department while taking all these parameters into account. This will inform us about the quantities to be supplied.

Previous PPE calculators for COVID-19 patients were developed in the literature (5-7). First, a PPE Burn Rate Calculator was developed by the centers for disease control and prevention in the United States (5) to track how PPE being used at a facility. The model determined the average rate of PPE consumption per patient for each type of PPE and for all types of PPE, based on the total number of suspected and confirmed COVID-19 patients at the start of each day and the number of PPE remaining from the day before. Second an Emergency Medical Services PPE Supply Estimator was developed by the Federal Healthcare Resilience Working Group in the United States (6) to evaluate their current PPE supply and projected PPE needs in rural regions. The user enters the average number of calls per day requiring PPE, the percentage of increased calls, the numbers of PPE items utilized by a provider, and the number of providers involved in each phase of the call. The tool determines the number of PPE to supply for a set of the number of days and per area type (warm or hot). However, the number of equipment used per person does not only depend on the type of area but also on the type of personnel and its validity duration. Third, Lum et al. (7) proposed a mathematical formula to determine the number needed of gloves and masks. However, they did not consider emergencies and new admissions as well as the duration of validity of PPE.

Our tool is different from the previous PPE calculators. Our aim is to propose a generic and customizable formula to calculate number of PPE (masks and gowns) per type of department and per type of personnel to respond to recommendations of the World Health Organization (WHO) (8). Our calculation approach is different from the former studies. First, we consider several parameters including the type of visits (scheduled visits to the COVID area, urgent visits, and new admissions) and their numbers, the type of hospital department, the type of staff and their number. Second, we integrate the duration of validity of equipment as well as treatment duration per patient. Third, we consider the rate of deterioration of the COVID-19 patients' case that leads to an urgent visit. Our formula gives the possibility to change this parameter, which may vary depending on the variant of the CORONA virus and its severity. Finally, to our knowledge, this is the first tool to manage PPE requirements for a Tunisian hospital.

METHODS

We are interested in the critical devices: FFP2 mask and medical gown. In this paper, we propose a PPE Management Tool that calculates the number of devices per department, per type of human resource (doctor, nurse, worker) and per period (day, shift of X hours) based on parameters defining the activity in each department and the characteristics of each protective device

Case study

We distinguish two types of COVID-19 patients in Mami Hospital: Patients admitted to Intensive Care Unit (ICU) presenting severe clinical form (Vital distress, organ failure) and patients admitted to an Inpatient Department presenting moderate clinical forms (mild dyspnea, Respiratory Rate ≥ 30 cpm or peripheral capillary oxygen saturation (SpO2) ≤ 92% in ambient air) (9).

In each service, there are several measures to prevent transmission when caring patient with confirmed COVID-19. The use of medical PPE is one of these measures: wearing gloves, clothing protection (gowns, coverall) and face protection (surgical and FFP2 masks). For the rational use of PPE, WHO

proposes that personal PPE depends on the setting, the staff, and the type of activity (8). The surgical mask is sufficient if the treatment does not require direct or close contact with the patient and no risk of aerosolization. Wearing an FFP2 mask is necessary for aerosolization procedures such as intubation, extubation, Non-Invasive Ventilation (the administration of ventilatory support without using an invasive artificial airway), tracheotomy, bronchoscopy, Ear Nose and Throat and digestive endoscopy procedures, aerosol nebulization, nasopharyngeal sampling, and autopsy procedures (9). Hence, when treating the patient either in the hospitalization room or in ICU, the medical staff should wear the FFP2 mask. The surgical mask should be changed every 4 to 6 hours. The FFP2 mask should be changed every 4 to 8 hours (9).

To understand how PPE is used in Mami Hospital, we organized meetings with the various stakeholders: the pharmacist, medical and paramedical staff of each department. Based on these meetings, we identified the current practice of the hospital regarding the use of PPE:

- The health care workers in each department are composed of the medical team, the paramedical team, and other teams such as cleaners. Activities differ from one team to another. The health care workers carry out all necessary care for all patients in the department during a visit to minimize the need for PPE. To reduce the number of PPE used per shift, the healthcare worker remains in the department for the entire period of validity of the PPE during one shift. The breaks, lunch periods are defined such that they coincide with the end of validity of the PPE.

- The pharmacy provides the different departments the same protective equipment kits to simplify the management of protective equipment.

- PPE must be discarded after each visit.

- Some PPE have a maximum duration and must be renewed.

Therefore, the number of PPE needed per day for each department depends mainly on the number of times each team enters or visits a department. We distinguish three types of visits: regular, urgent, and following a new admission.

The case of scheduled visits

The number of scheduled visits depends on the service.

The inpatient department is managed by two teams (2 x 12 hours). Each team is composed of: a doctor, two nurses (each nurse takes care of 5 to 6 patients), and a cleaning worker. The number of visits scheduled for each team member is as follows: two per physician, two per nurse, and one visit per cleaning worker.

In ICU, the medical team makes at least two visits to patients. This team is divided into two sub-teams. Each sub-team is composed of two doctors who share the patient visit (i.e., a patient is visited by two doctors).

As we mentioned earlier, some PPE such as masks must be changed after 4 hours, other equipment such as gloves must be changed for each patient.

The number PPE needed in scheduled visits per type of personal=.

number of scheduled visits × number of personal (1+ number of times a protective equipment is renewed during a scheduled visit)

The case of urgent visit

The number of unscheduled staff visits to a department following the deterioration of patients' conditions is calculated according to the following formula:

The number of unscheduled "urgent" entries in a department = percentage of clinical deterioration x number of patients in a department .

In our study, we consider that there is a percentage of clinical deterioration of the state of the patient, which results in an emergency. An unscheduled visit to the patient presenting an emergency is needed. In fact, among the severe forms of SARS-Cov-2 (severe acute respiratory syndrome coronavirus 2), lung damage with respiratory insufficiency typically occurring after 7 to 10 days of evolution is frequent and may be accompanied by severe respiratory insufficiency (10). That is why we consider that the percentage risk of deterioration is provided for an average length of stay more than X days of COVID-19 patients in the department concerned.

A study conducted by Cecconi et al. (11) showed that a clinical deterioration occurred (29.3%) of admitted patients, including (17.2%) ICU transfers.

Illustrative example: over X= 7 days, capacity = 10 patients; 20% of patients present urgent cases (worsening of the case and need for urgent intervention). Thus, the number of urgent cases over 7 days is 2 patients.

The case of new admissions

The number of staff visits following a new admission depends on the number of new patients accepted per day in a given department.

For the ICU, the new patients are patients already in the hospital, but their condition has been deteriorated or outpatients already in serious condition. The formulation below presents the average number of new admissions to the intensive care unit. The number of new admissions is the sum of arrivals from other departments in the hospital and arrivals of urgent cases from outside. However, as this work was initiated at the start of the pandemic in March 2020, we do not yet have the data to estimate the dynamic arrival rate of urgent cases. Therefore, we initially relied on Little's formula to determine the arrival rate of emergency cases in ICU.

Number of new admissions in ICU = the number of urgent visits to the hospital ward valid for 1 or X days +number of new patients in serious condition.

For the inpatient department, we suppose that admission rate corresponds to the maximum capacity of the service. The estimate of the number of patients per day, is given by the LITTLE's LAW (12):

Number of patients admitted in the inpatient department per day = total number of hospitalized patients / average length of stay (in days)

Vekaria el al. (13) show that the length of stay for patient in the inpatient department is between 8 and 9 days. Glica el al. (14) published a study showing that the length of stay is 17 days.

As a result of the meetings held as part of this project, we agreed to assume that the length of stay in the inpatient department is 12 days and 21 days in ICU. The capacity of the inpatient department is 48 beds. So, the number of patients arriving in the inpatient department/day = 48/12= 4 patients /day.

We note that for urgent cases and new admissions, only the senior doctor is in charge.

Mathematical formulation

Given the independence of PPE, we present in the following a model for one PPE.

Notations:

- i : index of the type of Covid-19 patient i={ S: severe clinical form ,H:hospitilized };
- j : index of the type of team, j ={medical team, paramedical team, cleaning team}
- S_i : number of departments treating patient of type i ;
- $S_i \in [1..Si]$: index of the department treating the patient of type i ;
- $P_{S_i}^j$: number of persons in a team or sub-team of type j working in the department s_i ;
- D_{eq} : The validity of a protection device (in number of hours);
- D_i : The average treatment duration of a patient of type i during a visit (in hours) ;
- X_{S_i}: Total number of patients in the department s_i;
- $Xmax_i$: The maximum number of patients in department s_i that can be treated by the medical team within the validity of the equipment's protection period: $Xmax_i = \frac{D_{eq}}{D_i}$;
- $N\_regular_{s_i}$ the number of regular visits per day in the department s_i ;
- α_{s_i} : average number of emergencies needing an urgent

visit outside the regular visits in the department s_i;

- $N_{s_i\_admission}$: number of new admissions per day,
- N_{s_i} : total number of visits in the department s_i ;
- R_{s_i} : the number of times a protection device is renewed in a single visit: this is the default integer part of $\frac{X_{s_i}}{Xmax_i}$ For example if $Xs_i =10 > Xmax_i = 8 => Rs_i= 1$
$$R_{s_i} = [X_{s_i}/Xmax_i] - 1$$
- $K_{S_i}^j$: The number of protective device/day for a team of type j in the department s_i.
- K: the total number of protective device /day.

Formulas

$$K_{S_i}^j = P_{S_i}^j \times N_{s_i} + \alpha_{s_i} + N_{s_i\_admission} \quad \forall s_i \forall i, j$$

$$Where: N_{s_i} = N\_regular_{s_i} \times (1 + R_{s_i}) \times number\ of\ shifts/day$$

$$K = \sum_{i,j} \sum_{1}^{s_i} K_{S_i}^j$$

Excel Tool

To make it easier use for the pharmacy department, these formulas and parameters have been introduced into Excel spreadsheets that are organized by type of protective equipment and by department. In this file, it will be possible to determine for each device, the quantity needed per day as well as the needs per shift, per department and per unit of time (e.g., day, 8-hour shift). Figure 1 below is a screen shot of the spreadsheet that calculates the required number of FFP2. It shows Input data and outputs of the spreadsheet-based model. We also created the first spreadsheet that explains the formulae for the pharmacy head.
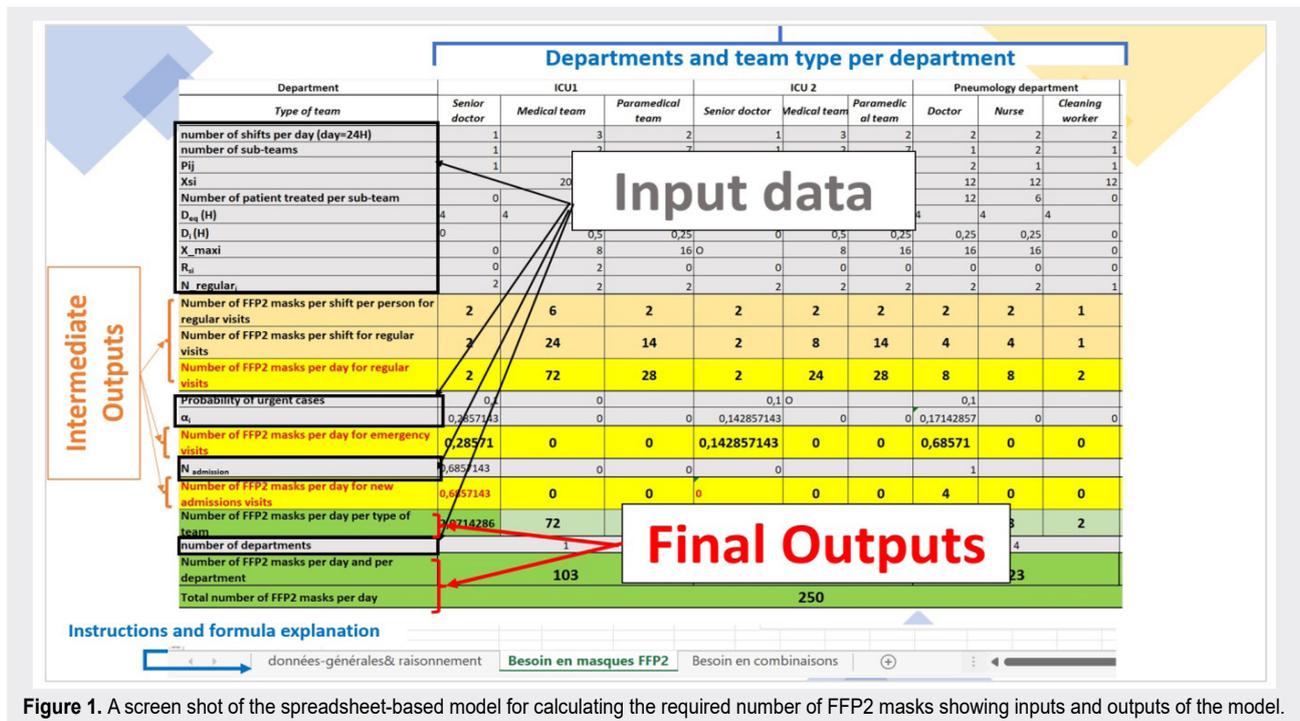

Figure 1. A screen shot of the spreadsheet-based model for calculating the required number of FFP2 masks showing inputs and outputs of the model.

RESULTS

We applied our approach for data from March 2020 during the first wave of COVID-19. The inputs of our model are presented in Table 1 for 6 departments in Hospital Mami: 2 for ICU (which we refer to as ICU1 and ICU2) and 4 for Pneumology based on data given by the pharmacology department. Gowns are renewed after each visit to a department. We considered that both Surgical and FFP2 masks are valid for 4 hours. We considered that all beds are occupied in all the departments, and 10% of patients present an emergency in ICU and pneumology departments after 7 days of their stay (based on estimations from March to April 2020). Using these data, we calculated the number of PPE needed per day and per department. The overall PPE needed per day is the sum of all the PPE per department.

We also considered that new admissions in ICU are hospitalized patients whose case deteriorated and need a transfer to ICU.

Using these data, we found that the pharmacy department needs 202 gowns and 250 FFP2 masks per day for the considered departments.

We note that the overall need is obtained by summing i) the number of PPE for ICU1, ii) for ICU2 and ii) the number of pneumology departments multiplied by the number of PPE per department.

These tendency curves allow us to estimate the number of needed PPE for any value of the percentage of deterioration.

Table 1. Data from the pharmacology department of the first wave of covid-19.

Department	ICU1			ICU2			Pneumology department		
Number of departments	1			1			4		
Type of team	S	M	P	S	M	P	Doctor	Nurse	Cleaning worker
Number of shifts per day	1	3	2	1	3	2	2	2	2
Number of sub-teams	1	2	7	1	2	7	1	2	1
$P_{S_i}^j$	1	2	1	1	2	1	2	1	1
X_{s_i}	20			10		12	12	12	12
Number of patient/sub-team	-	10	10	-	5	10	12	6	0
$N\_regular_{s_i}$	2	2	2	2	2	2	2	2	1
D_i	-	0,5	0,25	0	0,5	0,25	0,25	0,25	0

S: Senior, M: Medical Team, P: Paramedical Team

$P_{S_i}^j$: number of persons in a team or sub-team of type j working in the department S_i

X_{s_i} : Total number of patients in the department type i

N-regular S_i : the number of regumlar tours per day in the department Si

D_i : The average treatment duration of patient of type i during a visit (in hours)

Furthermore, figures 2 and 3 show that:

- for the same percentage of deterioration, the consumption of FFP2 masks is greater than that of gowns for each department,
- the overall need for PPE increases according to the percentage of the risk of deterioration.
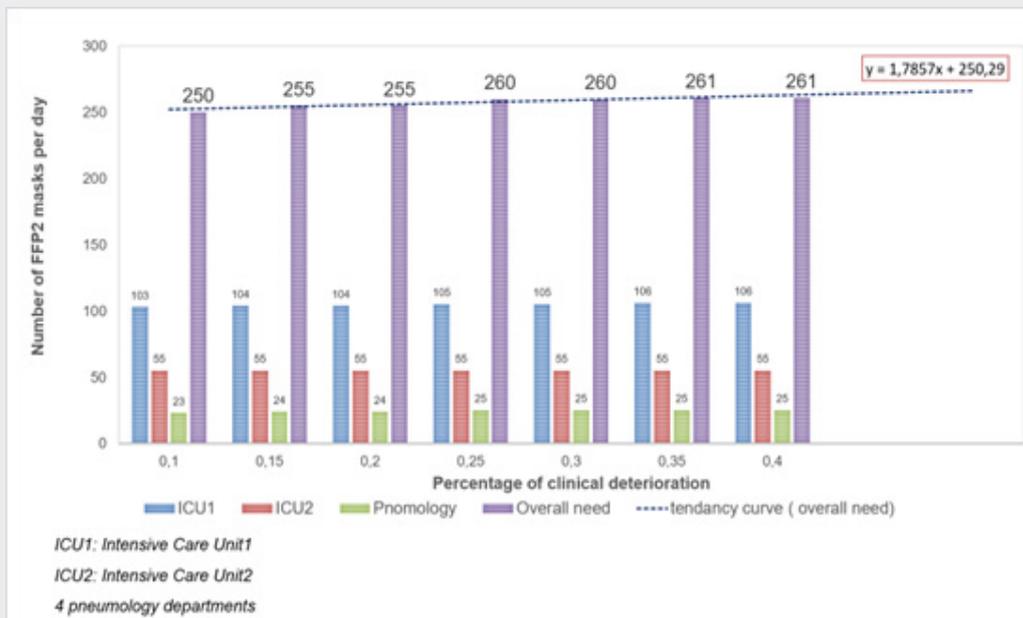

Figure 2. The number of FFP2 masks needed as function of the percentage of clinical deterioration.
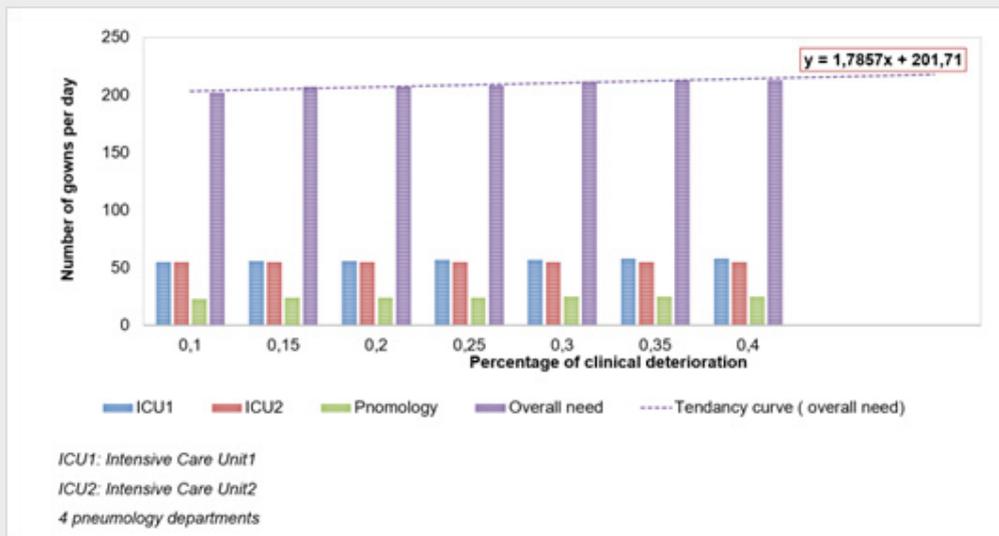
Figure 3. The number of gowns needed as function of the percentage of clinical deterioration.

At the beginning of the pandemic, the pharmacy department distributes 40 PPE kits (i.e, 40 FFP2 masks and 40 gowns) to ICU 1 (ICU2 was not opened yet) for treating 10 patients. This kit should be used for one visit only. Our results show that for 10 patients in ICU1 and without considering a risk of deterioration, 54 masks and gowns are needed per day (2 for Senior doctor, 24 for the Medical Team, and 28 for the Paramedical Team). The difference between the initial estimation and our results can be explained by the non-consideration of the duration of validity of PPE in the former one. For gowns, contrary to the masks, the number needed depends only on the number of entries to the ICU, but not on the number of patients in the unit. We note that our calculations were validated with the pharmacy department.

Figures 2 and 3 depict the total number of PPE needed per department as function of the percentage of deterioration, considering each service at its full capacity. They show that ICU1 dedicated to COVID-19 patients' needs more PPE. We present in the same figures the tendency curves of the number of PPE needed (the overall need) as function of percentage risk of deterioration:

FFP2 masks needed = y = 1,7857x + 250,29 (x: the percentage of deterioration)

Gowns needed = y = 1,7857x + 201,71 (x: the percentage of deterioration)

DISCUSSION

This paper presented an application developed to calculate the needs of each type of PPE per department in the studied hospital while considering scheduled visits, urgent visits, and visits due to new admissions.

This application was developed based on discussion with service stakeholders, which comprised five meetings with medical personnel of each department to understand the process of care COVID-19 patients and the type of PPE used in each activity by each type of personnel. A final meeting was organized to show users (pharmacy staff) how to use the application. Our application is configurable, easy-to-use, and can help the hospital to plan its supplies to avoid any shortage.

Previous PPE calculators for COVID-19 patients were developed in the literature (5-7). In (5) a dynamic spreadsheet-based model was proposed by the centers for disease control and prevention in the United States to calculate the average rate of PPE consumption (burn rate) and per patient for each type of PPE and for all types of PPE to track how PPE being used at a facility. The user must enter the total number of suspected and confirmed COVID-19 patients at the start of each day and fill the cases related to the number of PPE remaining from the day before. Based on this information, the user can estimate how long the remaining supply of PPE will last. Our calculation approach is different from the PPE Burn Rate Calculator (5): we express how to calculate the number of PPEs per day, per department and per type of medical team based on the number of visits to these departments and their nature. Furthermore, we assume the maximum capacity of the service. In addition, the number of PPEs needed depends on the rate of deterioration of the COVID-19 patients' case that leads to an urgent visit. Our formula gives the possibility to change this parameter, which may vary depending on the variant of the CORONA virus and its severity.

Second, the Federal Healthcare Resilience Working Group for Emergency Medical Services in the United States developed the PPE Supply Estimator (6) to evaluate their current PPE supply and projected PPE needs. The user enters the average number of calls per day requiring PPE, the percentage of increased calls, the numbers of PPE items utilized by a provider, and the number of providers involved in each phase of the call. The tool determines the number of PPE to supply

for a set of the number of days and per type of area (warm, hot). However, the number of equipment used per person does not only depend on the type of area as it was presented in (6) but also on the type of personnel. In fact, the estimation depends on user practices. The mode of use of protective equipment depends on the medical and paramedical team in the same area. Furthermore, some PPE are not changed from one patient to another such as masks whereas others must be changed for each patient such as gloves.

Third, Lum et al. (7), distinguish two types of PPE according to consumption mode: i) contact-based-consumption referring to the number of contacts with COVID-19 patients such as gloves, and ii) staffing-based-consumption referring to the number of staff in a shift such as masks. The authors propose a mathematical formula to determine the number needed of PPE for each type. However, they did not consider uncertainties related to emergencies and new admissions as well as the duration of validity of PPE.

Our tool is different from the previous PPE calculators. First, to our knowledge, it is the first tool to plan the supply of PPE for a Tunisian hospital. Second, we determine the needed quantity of PPE per day, considering three components: scheduled visits to the COVID-19 area, urgent visits, and visits following new admissions. Furthermore, we integrate the duration of validity of equipment as well as treatment duration per patient. Third, our tool considers the unit consumption in PPE per type of activity and per type of personnel to respond to recommendations of WHO (8). That is why the formulae proposed in our study is generic. To ensure the sustainability of our application throughout the pandemic, we permit the user to change certain parameters such as the rate of new admissions, the rate of emergencies, and the capacity of each service. These parameters may vary depending on the variant of the CORONA virus and its severity.

Our application also provides insights beyond its primary use. First, forecasting protective equipment needs is an important parameter to plan PPE supplies in order to avoid stock shortages but also to reduce its inventory. Second, using this application by Tunisian Hospitals, the central pharmacy can estimate the national needs of hospitals on PPE, and then propose a centralized request management approach to optimize stock and provide strict essential to limit wastage, overstock, and stock ruptures as recommended by WHO (8).

This study presents some limitations: (i) we did not consider all the departments of the Mami hospital, we limited to the departments most concerned by COVID, (ii) the parameters (emergency rate, number of admissions, length of stay, arrival rate, service time) are based on the estimates of the hospital's health care personnel.

Finally, researchers could conduct future research by adjusting parameters such as emergency rates, admissions rates, and length of stay of patients, which could be predicted using data science or modeled into probability distribution to capture the uncertainty inherent to health services in general and COVID-19 particularly.

CONCLUSION

The application is designed to help hospitals forecast potential requirements for Personal Protection Equipment to procure the necessary quantity to avoid stock-outs then to continue patient care. Continued efforts should leverage deliver applications that meet the specific requirements of each hospital system in terms of process and how protective equipment is used.

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