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METHODOLOGICAL IMPROVEMENTS OF ONLINE PANDEMIC SIMULATION FOR SHORT-TERM HEALTHCARE RESOURCE PREDICTION

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ABSTRACT

Short-term hospital resource prediction is critical during pandemic healthcare crises. Simulation models are able to mimic the dynamics of a hospital during pandemic waves and to be used as short-term hospital resource prediction tools. However, the developed simulation models have to focus on the transition period of the health system rather than the stationary state as it is usual in simulation studies. In this presentation, we relate methodological challenges faced to develop data-driven simulation models that account for the variability and uncertainty of the pandemic evolution. In particular, we focus on the proposal of new estimators of the probability of admission to the Intensive Care Unit (ICU) and the length of stay of patients in the regular ward and in the ICU. The simulation models were used daily during the COVID-19 pandemic waves by the Spanish health administrations.

1 INTRODUCTION

Pandemics bring real challenges to healthcare planners. In situations of healthcare collapse, they have to plan capacity and resources to treat both pandemic and non-pandemic patients. During the COVID-19 pandemic waves, there has been a huge increase in demand for critical hospital resources, such as healthcare personnel or acute and critical patient beds. Accurate prediction of these resources greatly aids their planning. Hospitals are known to be complex systems that evolve in a stochastic environment. In times of pandemic, uncertainty levels are intensified due to the unknown spread of the disease and its consequences for infected patients. In this context of instability, simulation emerges as a suitable analysis tool, since it is a powerful instrument capable of reproducing both the complexity of the system and the variability and uncertainty of the environment. It can also be used in combination with other analysis techniques.

Recently, simulation models have been developed to predict the resources needed in the short term to provide healthcare to patients during a pandemic (Garcia-Vicuña et al. 2021). The two main components of the simulation model are the stochastic modeling of patient admission and patient flow processes. In this work, we present the key issues to develop such a real-time decision support system and the methodological challenges that they involve. In particular, we present a new estimator of the probability of admission to the Intensive Care Unit (ICU) and the length of stay (LoS) of patients in the regular ward and in the ICU based on an expectation-maximization (EM) algorithm.

2 PANDEMIC SIMULATION MODELS: METHODOLOGICAL CHALLENGES

To be an accurate forecasting tool, the simulation model has to accurately model and simulate the patient arrival dynamics, represent the current state of the system, and efficiently estimate variables related to patient flow. These tasks lead to the following 3 methodological challenges: 1) Estimating statistical population growth models (PGM) to represent the patient arrivals to the hospital. In the first stages of the

pandemic wave, it requires a mixed estimation based on the few available data and expert opinion. A new parametrization of the PGM helps this hybrid estimation process. 2) The current state of the health system is represented by a set of state variables. The initial dynamics of the system is the main determining factor of the state of the healthcare system in the near future. Both, the representation and the way of starting the simulation depend on the available information, and suitable statistical methods have to be developed considering this availability. 3) The data-driven simulation model deals with the problem of getting reliable estimations of all the parameters that define the pathway and LoS of patients in hospital facilities in scarcity of data scenarios. The development of an efficient new estimator is considered in Section 3.

3 THE EXPECTATION-MAXIMIZATION ALGORITHM

It has been observed that each pandemic wave may have different characteristics. The age of the affected population, LoS in ICU, etc. varies from place to place and from wave to wave. These facts prevent the calibration of the simulation model parameters in advance using historical data. Since few complete patient data are available in the first days or even weeks of the wave (the vast majority of patients are still admitted to the hospital), it is essential to develop estimation methods that also take into account data from patients in the current pandemic wave, even if this information is incomplete.

We have developed an iterative procedure, based on the EM algorithm, to estimate the distribution functions of time to hospital discharge, time until admission to the ICU, as well as the probability of admission to the ICU from the ward. First, an initial estimation of the parameters is carried out by only using the fully-known data (those patients who have been discharged). In the main iteration, the estimated parameters are used to update the probability of being admitted to the ICU for each one of the patients admitted in the ward. These updated probabilities are used to calculate a new likelihood function for the parameters, which is maximized to obtain a new estimation of the probability distribution parameters. These two steps (updating ICU admission probabilities and getting and maximizing new likelihood function) are repeated until stopping criteria are met.

The results obtained by simulation show that the EM method shows a faster convergence to the real values than other parametric and non-parametric estimators which do not take advantage of all the patient information to avoid biases. Thus, the accuracy of the parameter estimation also improves the accuracy of the prediction of both hospital and ICU bed occupancy (Garcia-Vicuña and Mallor 2021).

4 RESEARCH IMPACT AND DISCUSSION

Every day during the successive waves of the COVID-19 pandemic (from March 2020 to June 2021), two local Spanish governments and the Spanish Ministry of Health used the simulation model to assist the health resource planning. The response time to help the health authorities was short because the pandemic simulation model is based on an interactive simulation model of the ICU (Garcia-Vicuña et al. 2020), developed previously for conducting the research of my Ph.D. thesis. In this research, the ethical dilemma known as the "ritual of the last bed" (Azcarate et al. 2020) is analyzed. It has arisen due to the pandemic: occupancy of the ICU was at the limit, and the physicians must decide on the admission of new patients.

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