Modelling the COVID-19 ICU occupancy with area-level random regression coefficient Poisson models

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COVID-19 has had disastrous consequences in all key areas of human welfare. The information and tools currently available to fight the virus, with vaccination as the main banner, have practically normalised the disease. However, the evolution of different variants, together with the weakening of the health system after years of continuous pressure and the predicted emergence of new epidemics in the not too distant future, highlight the need to develop explanatory and predictive tools that allow temporal and spatial monitoring of the rate of infection and the resulting overload of care.

Faced with the challenge posed by the scarcity and lack of homogeneity of the data collected, especially during the first year of the pandemic, the prevailing unknown nature of the virus, as well as the territorial heterogeneity in both the spread and severity of the disease, the mixed models in Small Area Estimation (SAE) are shown to be a methodological approach with great potential. These techniques can make a significant contribution to health planning, resource allocation and the implementation of non-pharmacological intervention measures.

In this context, we propose the development of random slope mixed models with the target of modelling the ICU (Intensive Care Unit) occupancy rate due to COVID-19. Given that the collapse of ICUs constitutes one of the main bottlenecks in care capacity, the estimation of this proportion is presented as one of the indicators with the greatest explanatory capacity of the overload experienced in different scenarios of contagion and severity of the disease.

Specifically, under an area-level random regression coefficient Poisson model, this work derives area-level estimators of occupied ICU bed counts and occupancy ratios, introducing bootstrap estimators of the mean squared errors. The maximum likelihood estimators of the model parameters and the mode predictors of the random effects are calculated by a Laplace approximation algorithm. Simulation experiments are implemented to investigate the behavior of the fitting algorithm, the predictors and the mean squared error estimator. The new statistical methodology is applied to aggregated data at the level of the 11 Health Areas of the Spanish Autonomous Community of Castilla y León, corresponding to a time range bounded between 2020 and 2022, defining the domains as the health area-day crossover. In these spatio-temporal areas, the explanatory capacity of the model is evaluated and an initial analysis of its predictive value is provided.

Keywords: COVID-19 ICU occupancy, Small Area Estimation, random coefficient Poisson regression models