A Hospital Resources Model for Pandemic Planning & Preparedness

Caroline Green
University of Galway, Ireland
caroline.green@universityofgalway.ie

Berend Beishuizen
Centre for Infectious Disease Control, National Institute for Public Health and the Environment (RIVM), the Netherlands
berend.beishuizen@rivm.nl

Mart Stein
Centre for Infectious Disease Control, National Institute for Public Health and the Environment (RIVM), the Netherlands
mart.stein@rivm.nl

Alma Tostmann
Radboud University Medical Centre, the Netherlands
alma.tostmann@radboudumc.nl

Chantal Rovers
Radboud University Medical Centre, the Netherlands
chantal.rovers@radboudumc.nl

Daan de Jong
Radboud University Medical Centre, the Netherlands
daan.dejong@radboudumc.nl

Claudia Houareau
Robert Koch Institute (RKI), Germany
houareauc@rki.de

Knut Perseke
Robert Koch Institute (RKI), Germany
persekek@rki.de

Máire Connolly
University of Galway, Ireland
maire.connolly@universityofgalway.ie

Jim Duggan
University of Galway, Ireland
james.duggan@universityofgalway.ie

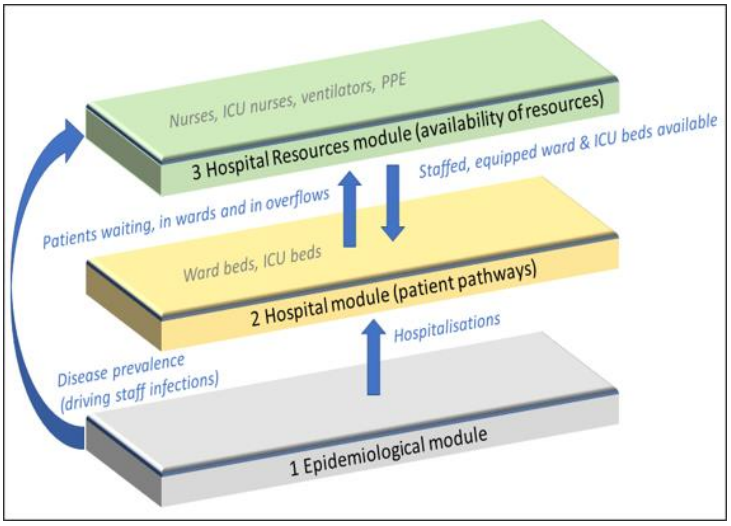
Keywords: Pandemic preparedness, system dynamics, hospital resources.

Funding Acknowledgements and Disclaimer: The study was carried out as part of the EU PANDEM-2 project. The project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement No. 883285. The material presented and views expressed here are the responsibility of the authors only. The EU Commission takes no responsibility for any use made of the information set out.

Abstract: Hospital resources are always limited and there are dependencies between resources which can cause bottlenecks. This presentation described a combined epidemiological and hospital resources model developed using the system dynamics method in collaboration with European public health agencies and hospital managers. The epidemiological model provides the stream of hospitalisations to the resource model, which models the movement of patients through the main patient pathways, namely wards, ICU and overflows. As the hospital patients occupy or consume resources, the model recalculates resource availability dynamically. Access to ward and ICU for incoming patients is constrained according to current availability of beds, nurses, ventilators and PPE. The model runs on Stella Simulator and is integrated with the Pandem-2 dashboard via APIs that support adjustments to model input parameters and return simulation results to the dashboard. Comprehensive dashboard visualisations provide estimated demand for resources over time, bed occupancy rates, peak daily demand, likely resource gaps and indicators of the level of stress on the hospital system. Interventions such as public health policies, therapeutic treatments and surge strategies can be applied singly or in combination, and their effects on key indicators compared over multiple runs, supporting complex evidence-based decision-making through experimentation.

Overview of the model: The combined epidemiological and hospital resources model, disaggregated by age, was developed by the University of Galway modelling team in collaboration with European public health agencies and hospital managers using a collaborative and iterative process. It is an exploratory model, populated with estimated resource data at the national level for two countries (Germany and the Netherlands). Alongside model building, our partners at RIVM conducted a

systematic review and DELPHI studies to identify key resources and associated parameters to include in the model. The model consisted of three interconnected modules, shown in the figure below. The epidemiological model provides a time series signal of infections which feeds hospitalisations in the hospital module. This module models patient pathways, where the movement of patients through admissions, wards and ICU is governed by disease severity model parameters and limited by resource availability. The resources module calculates capacity over time. Resources included in the model are: physical ward and ICU beds, ward and ICU nurses, physicians, ventilators, PPE, oxygen and morgue capacity. The model calculates resource capacity and availability, taking into account resource dependencies (e.g. a staffed ward bed requires a physical bed, a share of a nurse's time, and sufficient PPE).



Three types of interventions were built into the model: public health measures, therapeutic countermeasures and surge strategies. Public health measures included vaccination, testing, isolation, contact tracing, mask wearing and mobility restrictions. Therapeutic countermeasures consisted of therapeutic antivirals and previous strain vaccines. Four hospital surge strategies for use when resources run low were piloted: reducing ICU nurse-to-patient ratio and ward nurse-to-patient ratio, reducing use of PPE and increasing physical ward bed capacity by diverting it from routine use.

Presentation and use of the model: End users interact with the model via the PANDEM-2 dashboard. The design of the user interface, including presentation of model input parameters and visualisation of simulated outputs, were the result of close collaboration between the modelling team, the visual analytics and user experience team at the University of Galway, hospital managers and public health experts at RADBOUDUMC, RIVM and RKI, and the dashboard software developers. After each run, comprehensive dashboard visualisations display key indicators such as cases, hospitalisations and deaths, together with estimated demand for resources over time, bed occupancy rates, peak daily demand, likely resource gaps and indicators of the level of stress on the hospital system. Single or multiple interventions can be selected for a scenario and each of the intervention settings adjusted, to explore the simulated effects on key indicators. Results of up to six scenario runs representing different settings and combinations of interventions can be compared side-by-side, supporting complex evidence-based decision-making and learning through experimentation. The figure below contrasts hospital occupancy in two scenarios: a baseline (do nothing) scenario versus and alternative scenario in which mobility restrictions and vaccines were invoked.

PANDEM-2 Functional Exercise (FX): The model, integrated into the Pandem-2 dashboard, was an important part of the software toolkit that supported the successful PANDEM-2 FX involving two national public health institutes on March 15th - 16th 2023.

Preliminary evaluation: A 2.5-hour online workshop dedicated to modelling was held in February 2023. Feedback given by workshop participants was very positive. Summarising, of the eleven post-workshop respondents, seven were public health experts, two were hospital managers, and two were first responders. Asked to rate, on a scale of 1 to 10, if they thought the tool would be useful for pandemic planning and response, they gave a median score of 9 out of 10. 10 out of 11 of them thought the model was useful for supporting a pandemic preparedness exercise. They found the tool well organised and clearly presented, and easy to learn (median scores 9 out of 10). All found the visualisation of multiple runs informative. 10 out of 11 found the resource indicators useful. Most found the patient pathways, surge strategies and pharmaceutical interventions plausible and useful.

Conclusion: This work focussed on soliciting end user requirements for a useful resource planning tool and on capturing likely issues affecting adoption and use. Results indicate that the combined epidemiological and resources model could make an important contribution to simulation-based public health and hospital management policy development and training under certain conditions, and that further research is justified, including validation studies.

Notes: The PANDEM-2 dashboard is not yet available to the public but the underlying system dynamics model is available with this paper.

The PANDEM-2 website may be found at www.pandem 2.eu. Related publications and further details about the PANDEM-2 dashboard will be made available here.

Bibliography:

Adams LM. Exploring the concept of surge capacity. Online J Issues Nurs . 2009;14(2).

Darabi N, Hosseinichimeh N. System dynamics modeling in health and medicine: a systematic literature review. System Dynamics Review. 2020;36(1):29 73.

Hawryluk M. As Ventilators Become Crucial in Saving Lives, Repair Roadblocks Remain. Biomedical Safety & Standards. 2020;50(12):89 92.

Reymond, M., et al. (2022). Exploring the Pareto front of multi-objective COVID 19 mitigation policies using reinforcement learning. arXiv preprint arXiv:2204.05027. 2022.

Stein ML, Rudge JW, Coker R, van derWeijden C, Krumkamp R, Hanvoravongchai P, et al. Development of a resource modelling tool to support decision makers in pandemic influenza preparedness: The AsiaFluCap Simulator. BMC public health. 2012;12:870.

Sterman J. Business dynamics : systems thinking and modeling for a complex world. Boston, MA, USA: Irwin/McGraw Hill; 2000.