Fair Balancing of COVID-19 Patients over Hospitals

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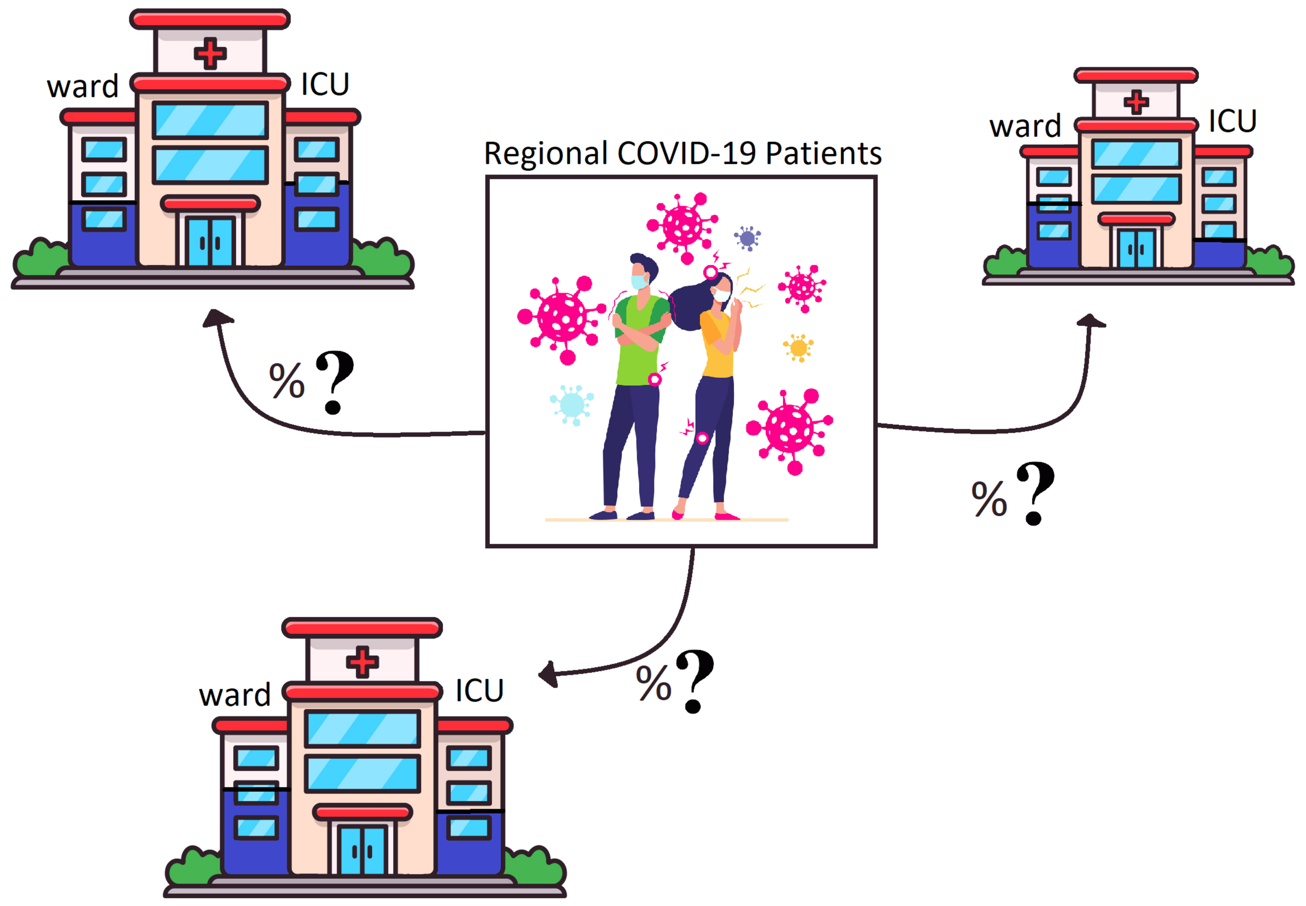
Fair Balancing of COVID-19 Patients

- COVID-19 patients get infected and demand care
- Need to be allocated to hospitals, preferably within region
- Hospital differences
  - Occupancy at COVID-19 ward and ICU
  - Capacity at COVID-19 ward and ICU
  - Length of stay and transfer probabilities ward and ICU
- How to fairly allocate COVID-19 patients to hospitals?
- What to do if patients don't fit in region?



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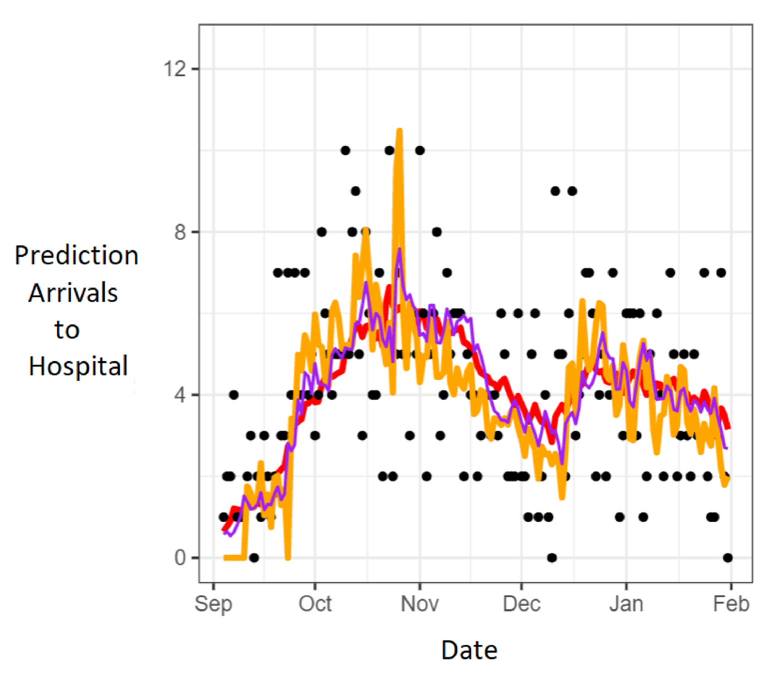
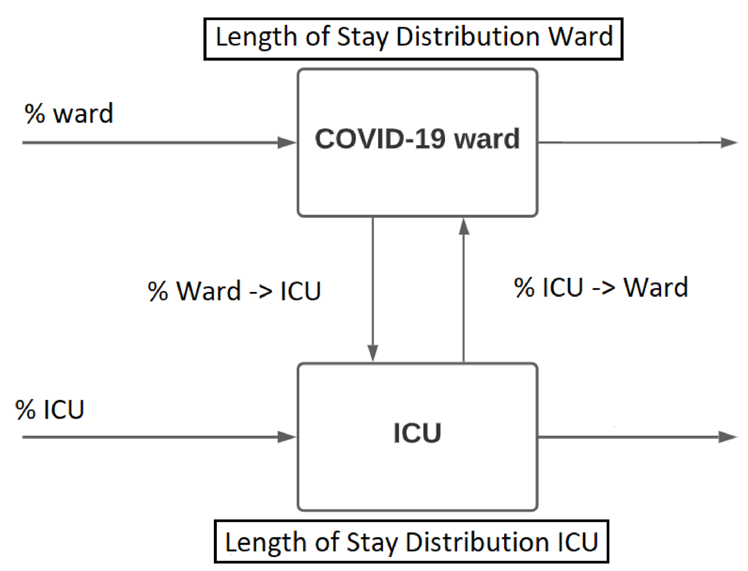
Modeling Hospital COVID-19 Occupancy

- System of two $M_t/G/\infty$ queues [1]
- Prediction arrival rate based on infections
- Estimated Length of Stay & transfer probabilities ward and ICU
- Forecast (maximum) occupancy coming days by simulation



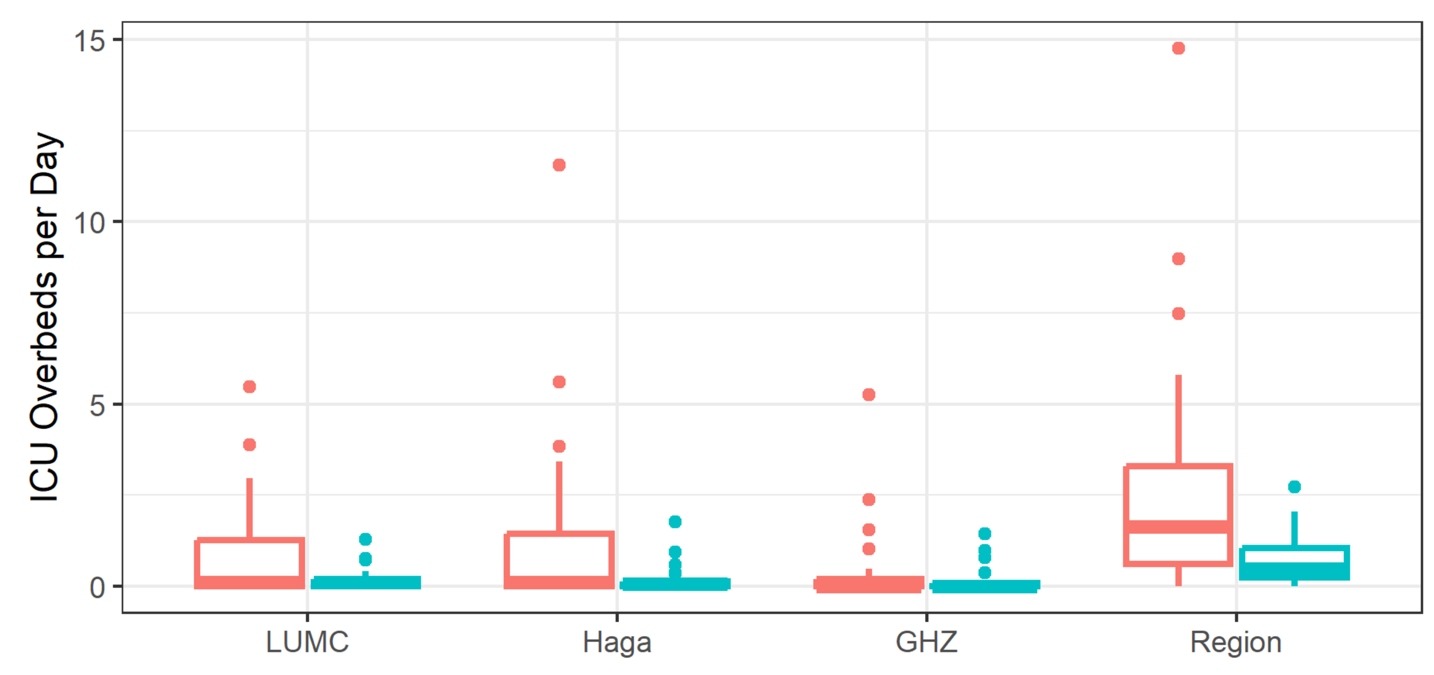


Dynamic Intra-Regional Allocation Method

- Decision is fraction $\theta_h(t)$ of regional COVID-19 patients admitted to hospital h at time s
- Preferable to admit COVID-19 patient inside respective region
- Maximal scaling of regional arrival rate such that probability capacity $\boldsymbol{n}_h^*$ is not exceeded by occupancy $\boldsymbol{N}_h$ in $[s, s+t]$ is larger than safety levels $\boldsymbol{\alpha}_h$ for hospital h:

$$\tilde{\theta}_h(s) = \max\{\theta : \mathbb{P}_{\theta,h}\left[\max_{u\in[s,s+t]} N_{hW}(u) \leq n^*_{hW} \mid \mathbf{L}_h(s) = \boldsymbol{\ell}_h\right] \geq \alpha_{hW},$$
$$\mathbb{P}_{\theta,h}\left[\max_{u\in[s,s+t]} N_{hI}(u) \leq n^*_{hI} \mid \mathbf{L}_h(s) = \boldsymbol{\ell}_h\right] \geq \alpha_{hI}\}$$

- Scaling $\tilde{\theta}_h(s)$ found by stochastic approximation [2] with simulations queueing model (parallel computation for each hospital).
- Normalization gives allocated fraction: $\theta_h(s) = \tilde{\theta}_h(s) / \sum_h \tilde{\theta}_h(s)$
- Simulation study, 8 November 2020 - 7 January 2021, three hospitals (LUMC, Haga, GHZ, region NAZ West)
- Comparison fixed allocation with dynamic allocation: smaller average and variability in amount of overbeds per day

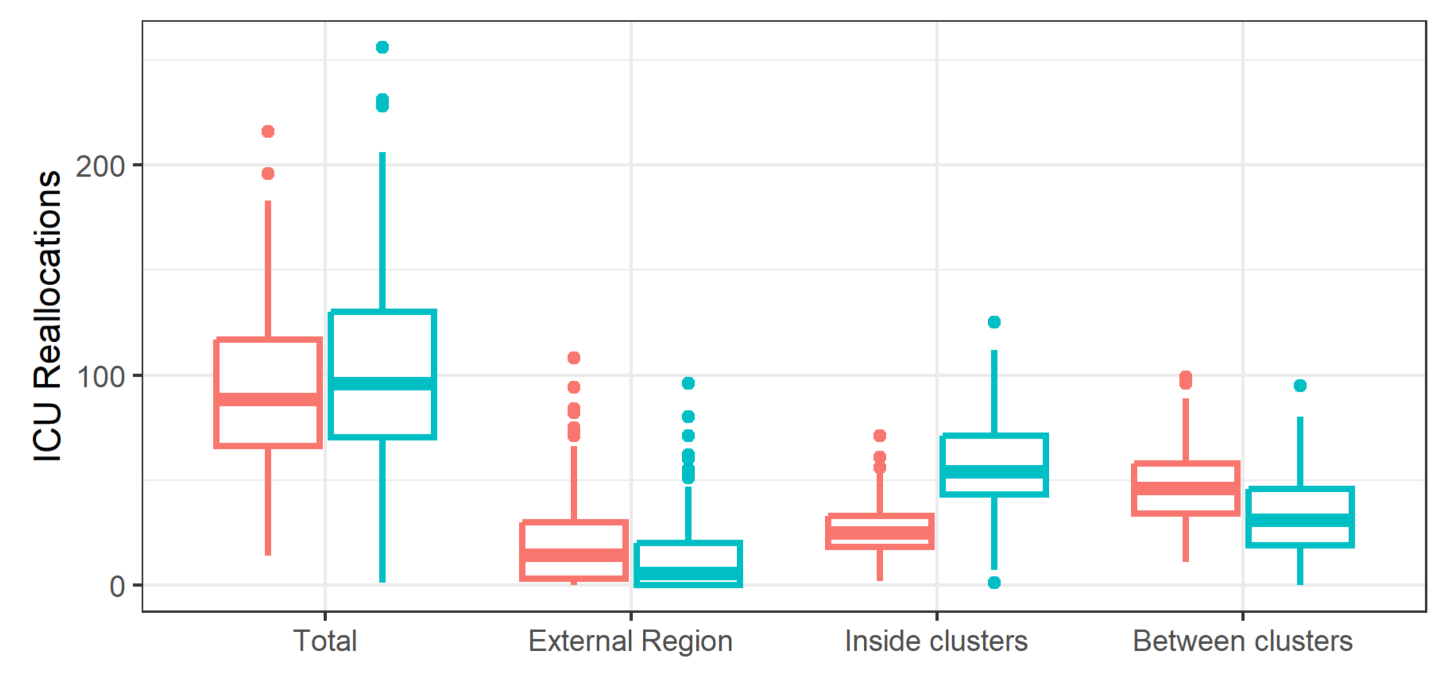


- Similar results for ward, also for the number of overbed-days

Inter-Regional Reallocation Method

- Decision is number of ward and ICU patients transferred from one region to another at each decision epoch
- Unwanted but necessary if patients don't fit in region
- Nonlinear Stochastic integer program [3] resolving current regional bed shortages while
  - balancing current and future relative remaining bed surpluses over regions
  - minimizing cost of future reallocations

- Sample average approximation with scenarios queueing model
- Simulation study, 8 November 2020 - 7 January 2021, four regions, two clusters of two nearby regions
- Comparison heuristic sending to region with free beds with program: more reallocation within clusters with same total amount



- Comparable results for quantile-based nonlinear program

Future Work

- COVID-19 capacity can be scaled up or down, how and when to scale regular care up or down to facilitate COVID-19 care in a fair way?
- Urgent regular care arrives randomly, can we use queueing model to forecast occupancy urgent regular care and use it for fair balancing?

References

[1] S. Baas, S. Dijkstra, A. Braaksma, *et al.*, "Real-time forecasting of COVID-19 bed occupancy in wards and intensive care units," *Health Care Management Science*, vol. 24, pp. 402–419, 2021.

[2] H. Robbins and S. Monro, "A stochastic approximation method," *The Annals of Mathematical Statistics*, vol. 22, no. 3, pp. 400–407, 1951.

[3] W. Klein Haneveld, M. Van der Vlerk, and W. Romeijnders, *Stochastic programming: Modeling decision problems under uncertainty*. Springer Nature, 2019.