Optimizing Hospital Capacity to Deal with Hallway Medicine

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Introduction

Hallway medicine is becoming a prominent part of patient experience at Ontario hospitals as they become more congested over time. The Ministry of Health identifies that this occurs "when patients are waiting for a hospital bed in an unconventional or unexpected location. This could be a hallway, or another space within a health facility that was not designed for using the space in this particular way."[1]

Within these highly congested hospitals, hallway medicine is practiced when there are patient surges. These surges exist due to variance in patient arrivals and their lengths of stay. Some challenges associated with hallway medicine are as follows:

- **Patients with more complex patient pathways**
- **A hospital with unbalanced bed allocations**
- **Pressure for the hospital to handle more patients**
- **Healthcare providers and caregivers that are stressed and overworked.**[2]

To help deal with excessive patient variance, I have adapted a model that decides the number of beds at each unit by minimizing the total cost of operation. This is given by the cost of service of beds and their associated waiting costs (hallway medicine).

Methods

The model is adapted from the proposed model in Hillier and Liebermann, 2017[3].

Notation	Description
b_i	Number of Beds in Unit *i*
α_i	External Patient Arrival Rate in Unit *i*
λ_i	Arrival Rate in Unit *i*
p_{ij}	Probability of Departure from Unit *i* to Unit *j*
s_i	Average Length of Stay per Patient in Unit *i*
L_i	Average Length of Unit *i* Queue
C_{b_i}	Cost of Beds in Unit *i*
C_{w_i}	Cost of Waiting in Unit *i*
$E(SC)$	Expected Service/Bed Cost per day
$E(WC)$	Expected Waiting/Hallway Medicine Cost per day
$E(TC)$	Expected Total Cost per day

Methods

To build the model, I implemented a queueing network using a G/G/s queueing model, with m hospital units. Then, I optimized it by minimizing the hospital's expected total cost per day.

Step 1: Queueing Network

- Uses inputs such as Number of Beds, Average Length of Patient Stay, and External Patient Arrival Rate, implementing queueing theory and estimating performance metrics.
- Finds performance metrics for each hospital unit. Most importantly, finds the average length of the unit queue, which represents the number of patients receiving hallway medicine.

Step 2: Optimization

- Uses the balanced queueing network to assess **E(TC)**, **E(SC)**, and **E(WC)**.
- Varied the number of beds in each unit until it finds an optimal solution that minimizes **E(TC)**.
- Proposes a solution for the optimal number of beds that improves patient care and decreases the hospital's total expected costs.

Queueing Network:
Using the external patient arrival rates and probabilities of departure, I found the arrival rates.

$$\lambda_j = \alpha_j + \sum_{j=1}^{m} \lambda_i p_{ij}$$

Using these arrival rates, I was able to calculate the performance metrics based on equations for a G/G/s queueing model.

Optimization:
Using the performance metrics to calculate the average length of the unit queue, I was able to calculate the costs and optimize the number of beds in the hospital.

Minimize: $E(TC) = E(SC) + E(WC)$, where

$$E(SC) = \sum C_{b_i} \times b_i \text{ and } E(WC) = \sum C_{w_i} \times L_i$$

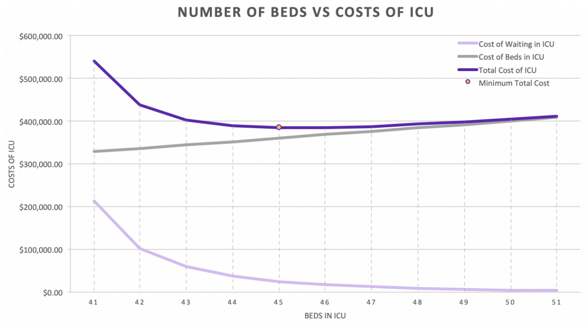
Steady-State Constraint: $b_i > \lambda_i \times s_i$

I implemented the model in Microsoft Excel using VBA and Solver, with the GRG Non-Linear engine. By adding the steady-state constraint, it ensures the model always finds the optimal solution that minimizes the expected total cost per day.

Results

Using parameters from an average teaching hospital in Ontario, I found the optimal bed allocation solution and compared its performance metrics with the original bed allocation.

Unit	Number of Beds		Total Cost of Hallway Medicine and Beds	
	Original	Optimal	Original	Optimal
ED	18	19	$254,059.47	$248,788.23
OR	8	7	$85,896.64	$85,338.55
ICU	45	45	$384,452.41	$384,452.41
SD	14	16	$115,628.75	$89,445.48
MW	70	74	$257,717.55	$234,188.36
SW	75	81	$323,994.48	$254,534.27
Total	230	242	$1,421,749.29	$1,296,747.29



Based on the results, 4 units need additional beds to reduce their cost of waiting and total costs. For example, additional beds in the ICU allow for diminishing returns to scale in the cost of waiting. Total costs decrease until there are 45 beds in the unit, where after this point, the cost of additional beds is greater than the savings in the cost of waiting, as these additional beds become idle.

For our dataset, the found solution saves the hospital an expected $125,002. The additional beds allow the hospital to be less reliant on the use of hallway medicine, as they are prepared to handle variances in patient arrivals and length of stay.

Conclusion

By adapting the model and adding the cost of waiting to the objective function, as well as the steady-state constraint, we were able to optimize hospital capacity while improving patient care.

For this dataset, I found that it is beneficial for 4 units to add additional beds. These beds decrease the hospitals congestion, allowing for it to be better equipped to handle patient variances. This results in the hospital relying less on hallway medicine and decreasing its expected total costs.

Future research can be done to see if the addition of waiting costs is a reasonable assumption in a healthcare environment. This model can be compared to models that minimize bed blockage, which are currently proposed in the literature[4,5].

References

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