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02443 Stochastic Simulation
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ARA/ara

Simulation of patient flow in hospitals

Background

An essential element in hospital planning is the decision of how many resources each ward in the hospital should have. This decision has both technical, organizational as well as political complications making the problem incredibly difficult to solve. In this project, the aim is to approach the problem from a purely technical perspective by deriving a simulation model that evaluates the implications from employing a certain distribution of bed resources.

The flow of inpatients (i.e. hospitalized patients that are expected to stay at the hospital for at least one night) often starts at the emergency department. From here, inpatients are distributed between a range of nursing wards according to their respective diagnoses, where they will receive treatment for the remaining of their stay. Inpatient nursing wards are typically regarded as a type of Erlang loss systems, i.e. queueing systems where insufficient capacity leads to either rejection or relocation to hallway-beds or alternative wards.

In this project, we consider a particular year where a hospital has been forced to create a new temporary ward due to a countrywide epidemic. Since the hospital's resources are already scarce, the hospital is forced to reallocate staff and beds from the current inpatient wards where patients are still arriving on a daily basis.

We consider a fairly small hospital containing mere 5 nursing wards, $\mathcal{W} \in \{A, B, C, D, E\}$, as well as 5 similar patient types $\mathcal{P} \in \{A, B, C, D, E\}$. Assume that each ward has a fixed capacity, M_i, and that patients of type $i \in \mathcal{P}$ arrive to ward $i \in \mathcal{W}$ with exponentially distributed inter-arrival time with rate λ_i. Similarly, assume that patients of type $i \in \mathcal{P}$ stay at the hospital for an exponentially distributed amount of time with rate μ_i.

We assume that patients are either *relocated* to an alternative ward or *lost* completely from the system, if they arrive to a ward in which all beds are occupied. Thus, when a patient of type i arrives to a ward of type i, and finds that all the beds are occupied, the patient is relocated to an alternative ward $j \in \mathcal{W}$ with probability p_{ij}, where $\sum_{j \in \mathcal{W}} p_{ij} = 1$. Note that the length-of-stay is not affected by the ward in which the patient is admitted. Lastly, if all beds in the alternative ward j are occupied, the patient is lost from the system.

Parameters

Patient arrival rates, length-of-stay and ward capacities are presented in Table 1 below.

Ward and patient type	Bed capacity	Arrivals per day (λ_i)	Mean length-of-stay ($1/\mu_i$)	Urgency points
A	55	14.5	2.9	7
B	40	11.0	4.0	5
C	30	8.0	4.5	2
D	20	6.5	1.4	10
E	20	5.0	3.9	5
F^*	*To be decided*	13.0	2.2	*Not relevant*

Table 1: Parameters associated with each ward and patient type. Ward F^* denotes the new ward and the urgency points (column 5) reflects the "penalty" if a patient of type i is not admitted in Ward i.

The relocation probabilities associated with patients of type $\mathcal{P}$ to wards of type $\mathcal{W}$ are presented in Table 2 below.

$\mathcal{P}$ \ $\mathcal{W}$	A	B	C	D	E	F^*
A	-	0.05	0.10	0.05	0.80	0.00
B	0.20	-	0.50	0.15	0.15	0.00
C	0.30	0.20	-	0.20	0.30	0.00
D	0.35	0.30	0.05	-	0.30	0.00
E	0.20	0.10	0.60	0.10	-	0.00
F^*	0.20	0.20	0.20	0.20	0.20	-

Table 2: Probability, p_{ij}, of relocating a patient of type $i \in \mathcal{P}$ to an alternative Ward $j \in \mathcal{W}$. Includes the new Ward F^*.

Primary tasks

1. Build a simulation model that simulates the patient flow in the hospital as a function of the bed distribution and the aforementioned parameters.
2. Create a new ward (F^*) in the system and allocate a minimal number of the current bed resources to the new ward. Ensure that at least 95% of the type F^* patients are hospitalized in Ward F^*. Use the "urgency points" from Table 1 to balance the solution (prioritize wards that need beds more than other wards).
3. Assess the implications of creating Ward F^*.

Primary performance measures

- Estimate the probability that all beds are occupied on arrival, the expected number of admissions, and the expected number of relocated patients for each ward in the hospital.
- Use the urgency points (cf. Table 1) and the expected number of relocated patients to assess the distribution of beds.

Sensitivity analysis

- Test the system's sensitivity to the length-of-stay distribution by replacing the exponential distribution with the log-normal distribution. Test the new distribution by gradually increasing the variance (e.g. $\sigma_i^2 = 2/\mu_i^2$, $3/\mu_i^2$ and $4/\mu_i^2$).

- Test the system's sensitivity to the distribution of beds in the hospital.
- Evaluate the result of increasing the total amount of beds in the system to for instance 170 or 180 beds. Also, what would be the result of having fewer beds?