Mitigating the impact of applying isolation requirements in hospital bed assignment

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Healthcare Associated Infections (HAIs)

Infections that patients acquire while hospitalized

Estimated annual impact in the USA (CDC, 2014):

- 1 in 25 hospital patients has at least one HAI
- 721,800 infections occurring in acute care hospitals in 2011
- 75,000 deaths due to HAIs in 2011
- $USD 30 billion in cost in 2007 (CDC, 2010)
- increase LOS

The young and the old are at most risk

HAIs: Diseases and organisms

- Vancomycin-resistant Enterococci (VRE)
- Vancomycin-resistant Staphylococcus aureus (VRSA)
- Carbapenem-resistant Enterobacteriaceae (CRE)
- Influenza
- Staphylococcus aureus
- Methicillin-resistant Staphylococcus aureus (MRSA)
- Acinetobacter
- HIV
- Norovirus
- Hepatitis

HAI prevention

Affects hospital admission and bed management processes due to the need to implement:

- sanitation protocols, and
- isolation requirements (IR)

IR

Protocols that hospitals use to ensure that patients do not pose a risk of infecting other patients

Place patients preferably in a single room or in a multi-occupancy room with patients infected by the same pathogen

Implementation of IR is harder in units with multi-occupancy rooms

Figure : multi-occupancy room

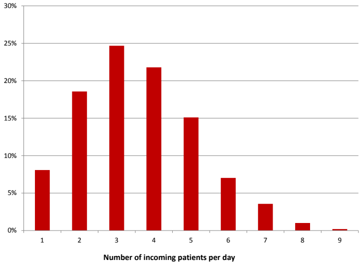
Figure : single room

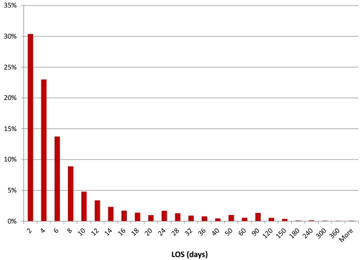
This presentation focuses in units that have multi-occupancy rooms or a mix of multi-occupancy and single rooms

The Pulmonary Care Unit (PCU) at Rochester General Hospital

- 400 bed hospital
- PCU provides acute respiratory care services
- Most patients arrive to PCU from the intensive care unit
- PCU's utilization: 90-100%
- PCU's configuration:
  - 8 single rooms
  - 10 double rooms
  - Total capacity: 28 patients
- PCU controls 7 isolation requirements:
  - pathogens: MRSA, VRSA, CRE, Influenza, Hepatitis, HIV
  - single gender per double room

PCU's characteristics





Incoming patient demand

μ: 2.6 patients /day
σ: 1 patient/ day

LOS

μ: 10.7 days
σ: 4.9 days

Based on 5 years of PCU history

Internal movement

When a previously admitted patient must exchange his/her room with another patient in the unit to accommodate new incoming patients

Internal movements cannot happen between any two patients assigned to single rooms

The situation at RGH

- Over a 5 year period, the number of internal movements (830) account for **20.3%** of all transfers and admissions (4,079) to the PCU
- There are up to 4 internal movements per admitted patient, with up to 9 during the Winter season
- Each movement requires 80 minutes for room disinfection

Issues with internal movements:

- affect service quality perception
- distract nursing time from patient care
- expose patients to HAIs

Challenges for PCU administrators

Operational - several times a day

Who to admit? How to assign rooms to patients so that those in most need are hospitalized with the least number of internal movements?

Strategic- sporadic

What is the unit configuration that allows admitting as many critical patients as possible while mitigating the number of internal movements?

Bed assignment problem

Given a number of new patients seeking admission to a hospital unit:

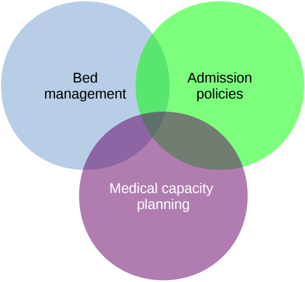
Determine who to admit, and if there is a need to re-assign patients to rooms through internal movements to accommodate new patients and satisfy all isolation requirements

Goal

- Prioritize hospitalization of most critical patients
- Mitigate the number of unnecessary internal movements

Previous studies

- Dumas (1984)
- Clerkin and Fos (1995)
- Harper and Shahani (2002)
- Shmueli et al (2003)
- Enrst et al (2004)
- Aickelin and Dowsland (2004)
- Nguyen et al (2005)
- Vermeulen et al (2009)
- Vanhoucke and Maenhout (2009)
- Cardoen et al (2010)
- Demeester et al (2010)
- Howell et al (2010)
- Ceshcia and Schaerf (2011)
- Conforti et al (2011)
- Guerriero and Guido (2011)
- Pinker and Tezcan (2013)



Healthcare economics
Simulation studies

Do not consider the need to administer isolation requirements

Bed assignment problem

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Bed assignment under isolation constrains (BAUIC)

Sets:

Q_a	set of patients already admitted to the unit in day $t_o - 1$
Q_n	set of incoming patients at time t_o
Q	set of all patients (i.e., $Q = Q_a \cup Q_n$)
W_1	set of single rooms
W_2	set of multi-occupancy rooms
T	triage room (represents current location(s) of patients seeking entry to the unit)
D	discharge room (represents destination(s) of patients discharged from the unit)
W	set of all available rooms, $W = T \cup D \cup W_1 \cup W_2$
G	set of genders (i.e., male, female)
I	set of isolations controlled in the unit
N_j	number of beds available in room $j \in W$

Parameters:

g_i gender of patient $i \in Q$ ($g_i \in G$)

k_i isolation type of patient $i \in Q$ ($k_i \in I$)

h_i critical state of patient $i \in Q$, relative to other patients in Q

β relative importance of patient criticality for assigning beds

ϕ relative importance of internal movements for assigning beds

$$y_{ij} : \begin{cases} 1 & \text{if a patient } i \in Q \text{ was already assigned to} \\ & \text{a bed in room } j \in W \text{ in } t_o - 1 \\ 0 & \text{o.w.} \end{cases}$$

$$m_{ij} : \begin{cases} 1 & \text{if a patient } i \in Q \text{ was assigned to a bed in} \\ & \text{room } j \in W \text{ and should not be moved} \\ 0 & \text{o.w.} \end{cases}$$

Decision variables:

$$x_{ij} : \begin{cases} 1 & \text{if a patient } i \in Q \text{ is assigned to a bed in room } j \in W \\ 0 & \text{o.w.} \end{cases}$$

$$z_i : \begin{cases} 1 & \text{if a patient } i \in Q_a \text{ is moved to a different room} \\ 0 & \text{o.w.} \end{cases}$$

$$\lambda_{gj} : \begin{cases} 1 & \text{if a patient of gender } g \in G \text{ is assigned to a bed in room } j \in W \setminus W_1 \\ 0 & \text{o.w.} \end{cases}$$

$$\tau_{k_i j} : \begin{cases} 1 & \text{if a patient with isolation needs } k_i \in I \text{ is assigned to a bed in room } j \in W \setminus W_1 \\ 0 & \text{o.w.} \end{cases}$$

BAUIC model

Maximize criticality in the unit + Minimize number of internal movements

$$\text{Maximize} \qquad \beta \sum_{j \in W_1 \cup W_2} \sum_{i \in Q} h_i x_{ij} - \phi \sum_{i \in Q_a} z_i \tag{1}$$

s.t.

All patients must be assigned to a room

$$\sum_{j \in W} x_{ij} = 1 \qquad \forall\ i \in Q \tag{2}$$

Track internal movements

$$z_i \geq y_{ij} - x_{ij} \qquad \forall\ i \in Q_a,\ j \in W_1 \cup W_2 \tag{3}$$

Only patients with the same gender can share a multi-occupacy room

$$x_{ij} \leq \lambda_{g'j} \qquad \forall\ i \in Q,\ j \in W_2,\ g' = g_i \tag{4}$$

$$\sum_{g \in G} \lambda_{gj} \leq 1 \qquad \forall\ j \in W_2 \tag{5}$$

Only patients with the same isolation (pathogen) -if any- can share a double room

$$x_{ij} \leq \tau_{k'j} \qquad \forall\ i \in Q,\ j \in W_2,\ k' = k_i \tag{6}$$

$$\sum_{i \in I} \tau_{ij} \leq 1 \qquad \forall\ j \in W_2 \tag{7}$$

Room capacity cannot be exceeded

$$\sum_{i \in Q} x_{ij} \leq N_j \qquad \forall\ j \in W \tag{8}$$

Admitted patients cannot be moved to triage

$$x_{iT} = 0 \qquad \forall\ i \in Q_a \tag{9}$$

Patients cannot be discharged without being assigned a room

$$x_{iD} = 0 \qquad \forall\ i \in Q_n \tag{10}$$

Internal movements between two single-room patients are not allowed

$$\sum_{j_2 \in W_1 : j_1 \neq j_2} x_{ij_2} = 0 \qquad \forall\ i \in Q,\ y_{ij_1} = 1,\ j_1 \in W_1 \tag{11}$$

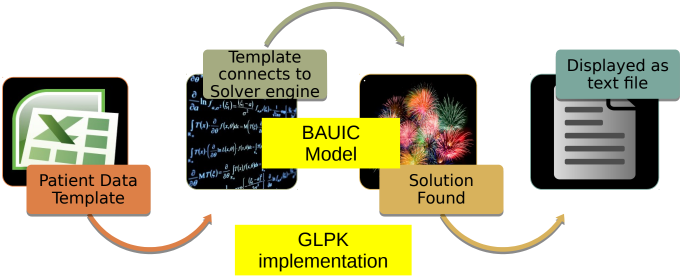
Patients with movement restrictions should not be moved

$$x_{ij} \geq m_{ij} \qquad \forall\ i \in Q,\ j \in W \setminus (T \cup D) \tag{12}$$

Assumptions

- Incoming patient demand is realized before making a bed assignment decision
- Presence of infective pathogens is determined before admission
- Patient characteristics (i.e., criticality and isolation) requirements do not change between decision epochs

Operational challenge



Strategic challenge: Monte Carlo simulation

For each of the 18 unit configurations:

- simulated 75 years of unit utilization using the PCU's LOS, and incoming patient arrival rate
- use uniform distributions to generate isolation requirements, gender, criticality, and movement limitations for admitted and incoming patients
- at the beginning of each simulated day we discharge patients who have stayed in the unit beyond their expected LOS
- for each simulated day solve the BAUIC model to determine the best way to accommodate incoming demand
- statistics on utilization and the number of internal movements were collected

Benchmark configuration

8 double rooms + 10 single rooms

Change in internal movements for the benchmark configuration (8 single + 10 double rooms) after BAUIC

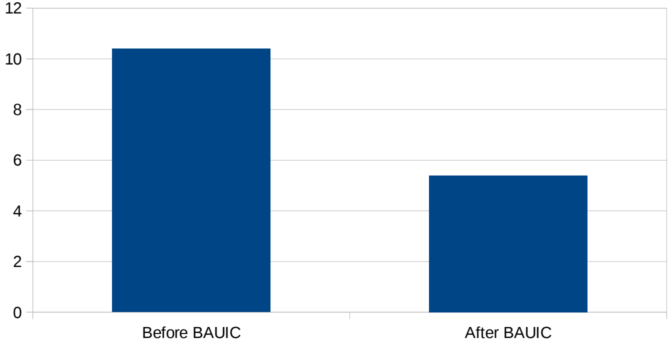
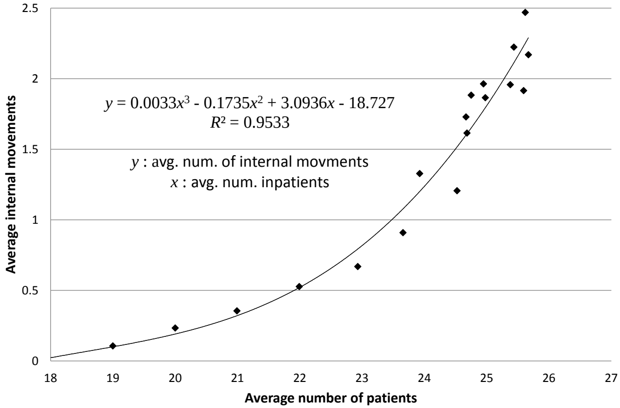
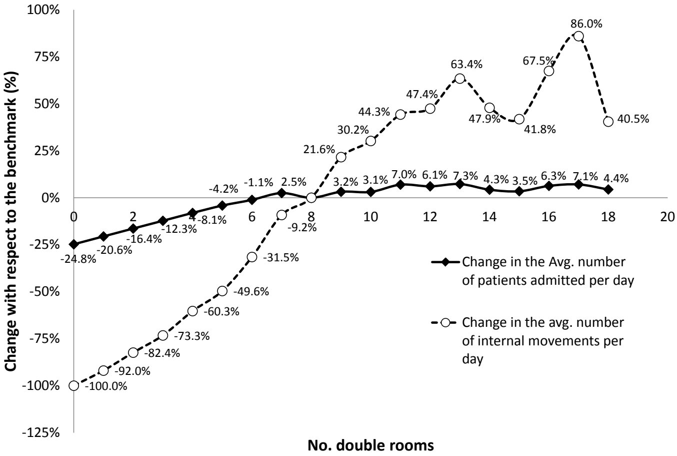


Figure : Expected internal movements per day

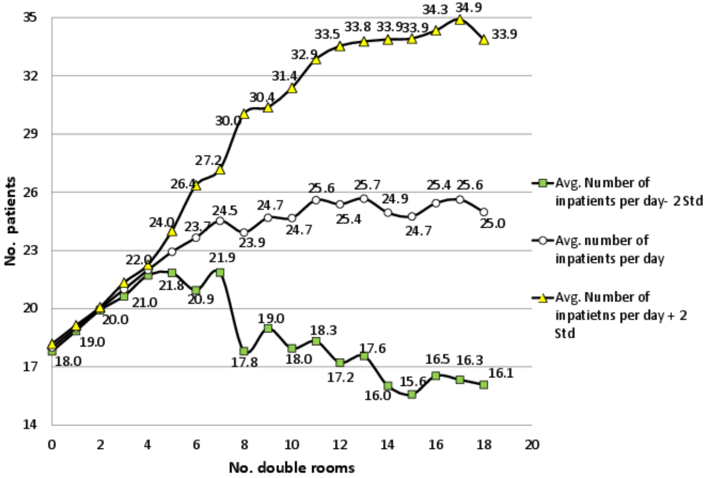
Expected number of internal movements is a function of the number of admitted patients



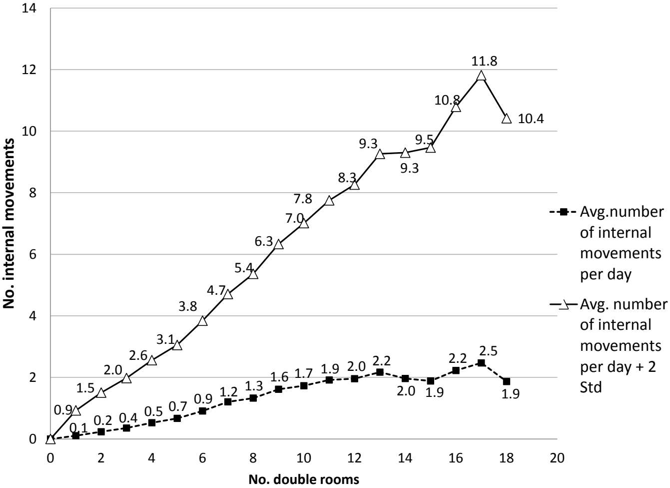
Admissions and internal movements increase at different rates with more double rooms



Number of admissions and its variability as a function of the number of double rooms



Number of internal movements and its variability as a function of the number of double rooms



Ensuring service level

Increasing capacity through double rooms can be more beneficial than coping with the consequences of dealing with internal movements.

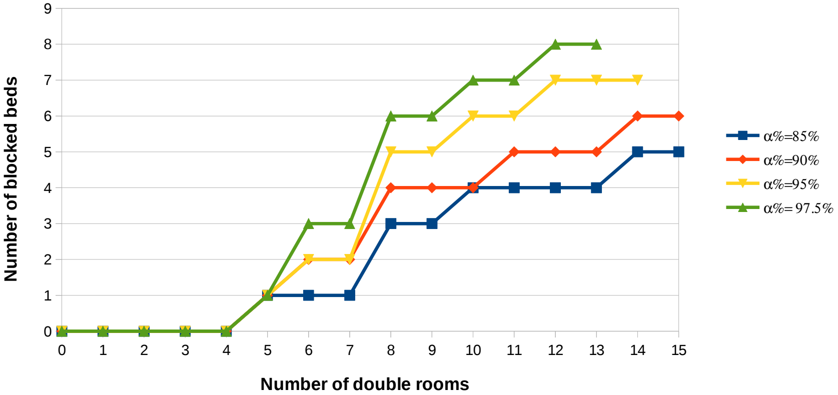
- Hospital units must quantify any necessary additional resources to deal with the variability induced by more double rooms.

Blocking rooms - Safety stock

minimum resources necessary ensure a service level of α% (i.e., $(1-\alpha)$% probability that the unit will not be able to cope with incoming patient demand due to insufficient resources

$$ss = Z_\alpha \sigma_d \sqrt{L}$$

Additional number of beds needed for ensuring an $\alpha\%$ service level



Conclusions and ongoing work

- Increasing the number of double rooms increases unit capacity but also the difficulty to manage the unit
- The ability to screen a larger number of diseases prior to a hospital admission can severely affect bed assignment processes and could result in upstream bottlenecks, unless the bed assignment process is improved and considers IR
- The incidence of some of the HAIs is seasonal, and hence any modeling efforts must be implemented as a continuous process
- Seasonal patterns of patient demand and HAIs must be taken into account for further studies

Questions and comments

Thank you