Dynamic Queue Management for Hospital Emergency Room Services

Kar Way Tan  
School of Information Systems  
Singapore Management University (SMU)  
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Supervisor: Prof Hoong Chuin LAU, SMU
Problem we face today

1. Large number of non-emergency patients
2. Long wait-time
3. Public education campaign has not worked

Note: 4 levels of acuity
P1 – Critically ill
P2 – Severe condition
P3 – non-emergency, mild to moderate symptoms
P4 – non-emergency, no threat to life

Source: http://yourhealth.asiaone.com/content/ae-units-flooded-non-emergenc-cases
The numbers are still going up...

Every year for the past five years, it has been going up by 5.4 per cent, which is an additional 36,000 visits, said an MOH spokesman.

Source: http://yourhealth.asiaone.com/content/ae-units-flooded-non-emergency-cases

How could Emergency Room (ER) cope?

1. How to manage the demand to improve average patient length-of-stay without increasing the number of doctors?
2. How to supply enough resources to that will adapt to demand requirements?
3. How to manage demand and supply collectively?
Framework of Dynamic Queue Management

Demand-side Queue Management: Dynamic Patient Prioritization

Supply-side Queue Management: Dynamic Resource Adjustment

Integrated Dynamic Queue Management

Decision-makers

Historical & Real-time data (from live systems)
Objective: To improve service at ambulatory area

- The aim is to meet hospital’s desired service quality, e.g. serve P3/P4 patients within length-of-stay (LOS) of x minutes

*Note: LOS is typically defined as the time when the patient joins the ER to the point he/she is discharged*
Emergency Room Process in our Model

New patients joining the queue to see doctor

Queue to doctors

Review Patients re-entering (a.k.a Re-entrants) the queue to be reviewed by the same doctor

Registration ➔ Triage ➔ Consultation by Doctor ➔ Discharge or Admission

Investigative tests and/or treatment
Application of strategies to process

1) Demand-Side Queue Management:
   Dynamic priority-patient queue with strategies, $S_i$

2) Supply-Side Queue Management:
   Dynamic Resource adjustment strategies, $X_j$

- Registration
- Triage
- Consultation by Doctor
- Investigative tests and/or treatment
- Discharge or Admission

Queue to doctors
Contributions

1. Framework that seamlessly integrate strategies from both demand and supply perspectives.
   - dynamic patient prioritization
   - Proactive or dynamic staffing

2. Effective use of both historical and real-time information for decision-support.
Demand Queue Management: Dynamic Patient Prioritization

- Demand-side Queue Management: Dynamic Patient Prioritization
- Supply-side Queue Management: Dynamic Resource Adjustment
- Integrated Dynamic Queue Management
Queueing model

Patient arrival rate, \( \lambda_f(t) \)

Dynamic priority-queue with strategy, \( S_i \)

Consultation with Doctor with service rate, \( \mu_n \) (new) and \( \mu_r \) (re-entrant)

Patient discharge probability \((1-b)\)

Patient discharge probability \((1-b)\)

Patient discharge probability \((1-b)\)

Investigation tests or treatment with service rate, \( \delta \)

Probability of test/treatment, \( b \)

c_k: est. consultation time based on \( \mu_n \)

\( d_k \): target LOS = hospital’s desired service level

\( t_k \): additional time incurred to go for test / treatment

\( r_k \): remaining time = \( d_k - e_k + t_k \)

\( c_k \): est. consultation time based on \( \mu_r \)

Note: Any-time in the process, \( r_k \) can be \( \leq 0 \) \( \rightarrow \) patient has spent longer time in ER than his desired service time
Prioritization strategies

- **Shortest-consultation-time-first (SCON)**
  - intuition is to first clear the patients who has the least estimated consultation service time

- **Shortest-remaining-time-first (SREM)**
  - to meet service quality to complete the process for each patient within a given target LOS

- **MIXED** is the combination of both strategies
Supply Queue Management: Dynamic Resource Adjustment

- Demand-side Queue Management: Dynamic Patient Prioritization
- Supply-side Queue Management: Dynamic Resource Adjustment
- Integrated Dynamic Queue Management
Queueing model now includes the resuscitation and critical care area

- Patient arrival rate, $\lambda_b(t)$
- Number of doctors required, $S_b(t)$
- Doctor staffing strategies, $X_j$
- Number of doctors, $S_f(t) \leq S_{\text{max}}(t) - S_b(t)$
- Each doc has service rate, $\mu$
- Patient discharge probability (1-$b$)
- Investigation tests or treatment with service rate, $\delta$
- Probability of test/treatment, $b$

$S_b(t)$ is computed via staffing rule

$S_{\text{max}}(t)$ - The max # of doctors that can be deployed at ED at time $t$
and include the constraints

1. Resuscitation/Critical Care Area Service Guarantee
   \[ S_f(t) \leq S_{\text{max}}(t) - S_b(t) \text{ for all } t \]

2. Physical Ambulatory Room’s constraint
   \[ S_f(t) \leq \text{Room}_{\text{max}} \text{ for all } t \]

3. Service level constraint (soft)
   \[ \overline{LOS}(t) \leq \text{LOS}_{\text{max}} \text{ for all } t \]
Four doctor’s supply strategies

**Proactive**

- HIST – Based on staffing rule using historical arrivals
- HIST-OPT (Based on historical arrivals. Optimization search for schedule with min violation to service level constraint)

**Dynamic**

- DYN – Based on staffing rule using real-time arrivals
- DYN-OPT (Based on historical and real-time data. Optimization search for short-term planned schedule for horizon of H (e.g. 8) hours)
Integrated Dynamic Queue Management

- Demand-side Queue Management: Dynamic Patient Prioritization
- Supply-side Queue Management: Dynamic Resource Adjustment
Integrated Framework

Live System/Data

Analytical Model

Optimization model

Decision Support Model

Decision-maker

Optimization model

Queue Management Module

Symbiotic simulator

Demand-side - Dynamic Patient Queue Prioritization parameters

Supply-side - Dynamic resource adjustment parameters
Live System and Data

- Consists of the various IT systems and databases that support the live operation of ER and supporting departments.

- Registration
  - Reads and records patient’s visit info
  - Patient care system

- Triage
  - Read and record specific test information
  - X-ray system
  - Blood system
  - Others (e.g. cardio system)

- Consultation by Doctor
  - Investigative tests and/or treatment
  - Patients’ information

- Discharge or Admission
  - Reads patient’s info and bed/ward info
  - SAP ERP
• Snapshot of the live data $\rightarrow$ Historical data
• Analytics performed on Historical data $\rightarrow$ *Historical Process Data and Process Models*
• Historical Process Data consists of ER process parameters such as
  – Time-varying arrival rates
  – Service rates of triage
  – Service rates of doctors
  – Service rates of treatment/tests
  – Probability of re-entrance.
Decision Support Model

1. Analytical Model on Historical Process Data
2. Live Data
3. Optimization model
4. Symbiotic simulator

Physical Systems

HIST Schedule (Requires 1)

Dynamic Queue Prioritization parameters
Dynamic resource adjustment parameters

Decision Makers

HIST-OPT Schedule (Requires 1+3)
DYN-OPT Schedule (.Requires 1,2,3,4)

Dynamic Prioritization (Requires 2)
DYN Schedule (Requires 2)
Effects of demand-side strategies on supply-side strategies

- Each hour has a maximum deployable number of doctors
- Based on Wilcoxon Signed-Rank Test, SCON, SREM and MIXED all perform significantly better than FIFO under HIST and DYN
Effects of supply-side strategies on each of the demand-side strategies

- We use 3 different types of arrival rates - high, normal and low.
- High load – doubled for Thursdays, Fridays, Saturdays and Sundays.
  Low load – halved for Thurs, Fri, Sat and Sun.
- Dynamic method has proven to better react to demand changes.
Cost analysis for MIXED strategy

- Dynamic method may incur slightly more doctors under high load condition.
- Dynamic method can significantly reduce the number of doctor’s required when demand is low, yet giving a performance similar to proactive method.
- Dynamic method is effective in ability to cope with demand surges and cut cost when demand is low.
Conclusion

• Single-faceted queue management strategies (either demand-side or supply-side) is not sufficient to provide a holistic approach
• Combining strategies from both sides can be done seamlessly to reap benefits from both sides.
• There is value to leverage on both real-time and historical data.
• The framework allows decision makers to play a role in achieving the target service quality by selecting strategies that suit the ER
Thank you for your attention