Queues in Hospitals: Empirical Study

Mor Armony

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NYU, Technion, Mayo, IBM, Columbia
Network features:
- Customers: Patients
- Servers: Beds, equipments, medical staff
- Stations: Medical units

Research Questions:
- Special features of this network
- Implications on queueing modeling and theory

Methodology:
- Exploratory Data Analysis (EDA)
Our data

Data description:

- Anonymous Israeli hospital with 1000 beds and 45 medical units
- 75,000 patients are admitted annually
- Years data collected: 2004 - 2008
- Individual patient level data, time stamps (admission, transfers and discharge)
- Acknowledgement: Anonymous Hospital and
### 90 X 90 Matrix, Sub-Ward Resolution

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</thead>
<tbody>
<tr>
<td>Cardiac ICU</td>
<td>Cardiology</td>
<td>Angiology</td>
<td>Neurology</td>
<td>Nephrology</td>
<td>Dermatology</td>
<td>Transitional Care A</td>
<td>Internal Medicine A</td>
<td>Transitional Care B</td>
<td>Internal Medicine B</td>
<td>Transitional Care C</td>
<td>Internal Medicine C</td>
<td>Transitional Care D</td>
<td>Internal Medicine D</td>
<td>Internal Medicine E</td>
<td></td>
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<tr>
<td>56</td>
<td>4</td>
<td>1.3</td>
<td>5.4</td>
<td>15</td>
<td>6.7</td>
<td>1.2</td>
<td>2</td>
<td>1.6</td>
<td>3.5</td>
<td>1.8</td>
<td>1.5</td>
<td>3</td>
<td>1.5</td>
<td>1.5</td>
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**Internal Medicine**

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Our focus

Subnetwork including: ED, IW and ED $\rightarrow$ IW

- **Substantial size:**
  - 53% patients entering the hospital stay within this subnetwork.
  - 21% of those, are hospitalized in an IW

- **Nearly isolated:**
  - ED Arrival are all external
  - 93% of IW arrivals are either external or from within the subnetwork.

- **Relatively simple:**
  - One ED
  - Five IWs (A-E)
  - IW A-D identical in scope capabilities
A Queueing Network View

- **Arrivals**
  - 245 pat./day
  - 161 pat./day

- **Emergency Department**
  - 13.6%
  - 69.9%
  - 5%

- **Services**
  - Blocked at IWs 3.5%
  - Other Medical Units

- **Internal Department**
  - IW A
  - IW B
  - IW C
  - IW D
  - IW E
  - "Justice Table" 16.5%
  - 53%

- **Discharged patients**
  - 84.3%
  - 75.4%

- **Abandonment**
  - 23.6%

**INFORMS 2011**

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Transfer Process

1. Assignment to non-IW
2. Bed available in another ward?
   - Yes
   - No
3. Assignment
4. Bed available?
   - Yes
   - Yes, but later
   - Delay
5. Staff available?
   - Yes
   - No
   - Delay
6. Bed ready?
   - Yes
   - No
   - Delay
7. Transfer
Transfer waiting times
Why are delays problematic?

- Patients do not receive proper care.
- They are exposed to other diseases.
- ED overcrowding.
- Impose extra load on ED medical staff.

![Graph showing patients in transfer from ED to IW over time]

Legend:
- Blue line: Number of patients in transfer
- Red dashed line: Fraction of Physician load

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### Average Transfer Delays per Patient Type

<table>
<thead>
<tr>
<th>Patient Type</th>
<th>Average Delay (hrs)</th>
<th>Standard Deviation</th>
<th>% delayed up to 4 hours</th>
<th>% Delayed more than 10 hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>3.00</td>
<td>2.53</td>
<td>77%</td>
<td>2%</td>
</tr>
<tr>
<td>Special Care</td>
<td>3.33</td>
<td>3.16</td>
<td>74%</td>
<td>5%</td>
</tr>
<tr>
<td>Ventilated</td>
<td>8.39</td>
<td>6.59</td>
<td>41%</td>
<td>41%</td>
</tr>
<tr>
<td>All Types</td>
<td>3.22</td>
<td>2.98</td>
<td>75%</td>
<td>4%</td>
</tr>
</tbody>
</table>

Ventilated patients should have lowest delay, but experience the highest!
Patients need to wait for a bed, equipment, and medical staff.
Delays in ED-IW transfers: Cause and effect diagram

- ED-IW synchronization
  - Communication problems
  - Incentive mechanism
- Work methods
  - Not considering ward occupancies
  - Allowing skipping
  - Interference into the Justice Table
  - Delayed IW discharges
  - Timing of routing decisions
- Delays in ED-IW transfers
  - Nurses availability
  - Doctors availability
  - Staff availability
  - Stretcher bearers availability
  - Nurse-in-charge availability
  - Beds availability
  - Equipment availability
  - Medical equipment availability
Routing: Input versus output queues

- Single line system is more efficient
- Reality requires multiple lines
- Patients require care even when in queue
- Push versus Pull
- Fairness towards patients?
(Un)fairness towards patients

<table>
<thead>
<tr>
<th>IW</th>
<th>Type</th>
<th>Regular</th>
<th>Special care</th>
<th>Ventilated</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward A</td>
<td></td>
<td>7.57%</td>
<td>7.33%</td>
<td>0.00%</td>
<td>7.37%</td>
</tr>
<tr>
<td>Ward B</td>
<td></td>
<td>3.86%</td>
<td>5.72%</td>
<td>0.00%</td>
<td>4.84%</td>
</tr>
<tr>
<td>Ward C</td>
<td></td>
<td>7.09%</td>
<td>6.62%</td>
<td>0.00%</td>
<td>6.80%</td>
</tr>
<tr>
<td>Ward D</td>
<td></td>
<td>8.18%</td>
<td>7.48%</td>
<td>2.70%</td>
<td>7.81%</td>
</tr>
<tr>
<td>Total within wards</td>
<td></td>
<td>6.91%</td>
<td>6.80%</td>
<td>0.67%</td>
<td>6.80%</td>
</tr>
<tr>
<td>Total in ED-to-IW</td>
<td></td>
<td>31%</td>
<td>31%</td>
<td>5%</td>
<td></td>
</tr>
</tbody>
</table>

Percentage of FCFS violations per type within each IW
### Internal Wards operational measures

<table>
<thead>
<tr>
<th></th>
<th>Ward A</th>
<th>Ward B</th>
<th>Ward C</th>
<th>Ward D</th>
</tr>
</thead>
<tbody>
<tr>
<td>ALOS (days)</td>
<td>6.5</td>
<td>4.5</td>
<td>5.4</td>
<td>5.7</td>
</tr>
<tr>
<td>Mean occupancy</td>
<td>97.8%</td>
<td>94.4%</td>
<td>86.8%</td>
<td>91.1%</td>
</tr>
<tr>
<td>Mean # patients per month</td>
<td>205.5</td>
<td>187.6</td>
<td>210.0</td>
<td>209.6</td>
</tr>
<tr>
<td>Standard capacity (# beds)</td>
<td>45</td>
<td>30</td>
<td>44</td>
<td>42</td>
</tr>
<tr>
<td>Mean # patients per bed per month</td>
<td>4.58</td>
<td>6.38</td>
<td>4.89</td>
<td>4.86</td>
</tr>
<tr>
<td>Return rate (within 3 months)</td>
<td>16.4%</td>
<td>17.4%</td>
<td>19.2%</td>
<td>17.6%</td>
</tr>
</tbody>
</table>

- How does one explain these differences in performance?
- Is this work allocation fair?
- How is fairness defined?
## Unfairness towards wards: Patient mix

<table>
<thead>
<tr>
<th>IW\Type</th>
<th>Regular</th>
<th>Special-care</th>
<th>Ventilated</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward A</td>
<td>2,316 (50.3%)</td>
<td>2,206 (47.9%)</td>
<td>83 (1.8%)</td>
<td>4,605 (25.2%)</td>
</tr>
<tr>
<td>Ward B</td>
<td>1,676 (43.0%)</td>
<td>2,135 (54.7%)</td>
<td>90 (2.3%)</td>
<td>3,901 (21.4%)</td>
</tr>
<tr>
<td>Ward C</td>
<td>2,310 (49.9%)</td>
<td>2,232 (48.2%)</td>
<td>88 (1.9%)</td>
<td>4,630 (25.4%)</td>
</tr>
<tr>
<td>Ward D</td>
<td>2,737 (53.5%)</td>
<td>2,291 (44.8%)</td>
<td>89 (1.7%)</td>
<td>5,117 (28.0%)</td>
</tr>
<tr>
<td>Total</td>
<td>9,039 (49.5%)</td>
<td>8,864 (48.6%)</td>
<td>350 (1.9%)</td>
<td>18,253</td>
</tr>
</tbody>
</table>

Justice Table allocation to IWs by patient type.
Patient flow in hospitals as a queueing network
Input versus Output queues
Push versus Pull in routing
Fairness towards customers (definition?)
Customers served while in queue
Fairness: Occupancy + Flux