Patient Flow in Hospitals: A Data-Based Queueing Perspective

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Patient Flow in Hospitals as a Queueing Network

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

Our focus

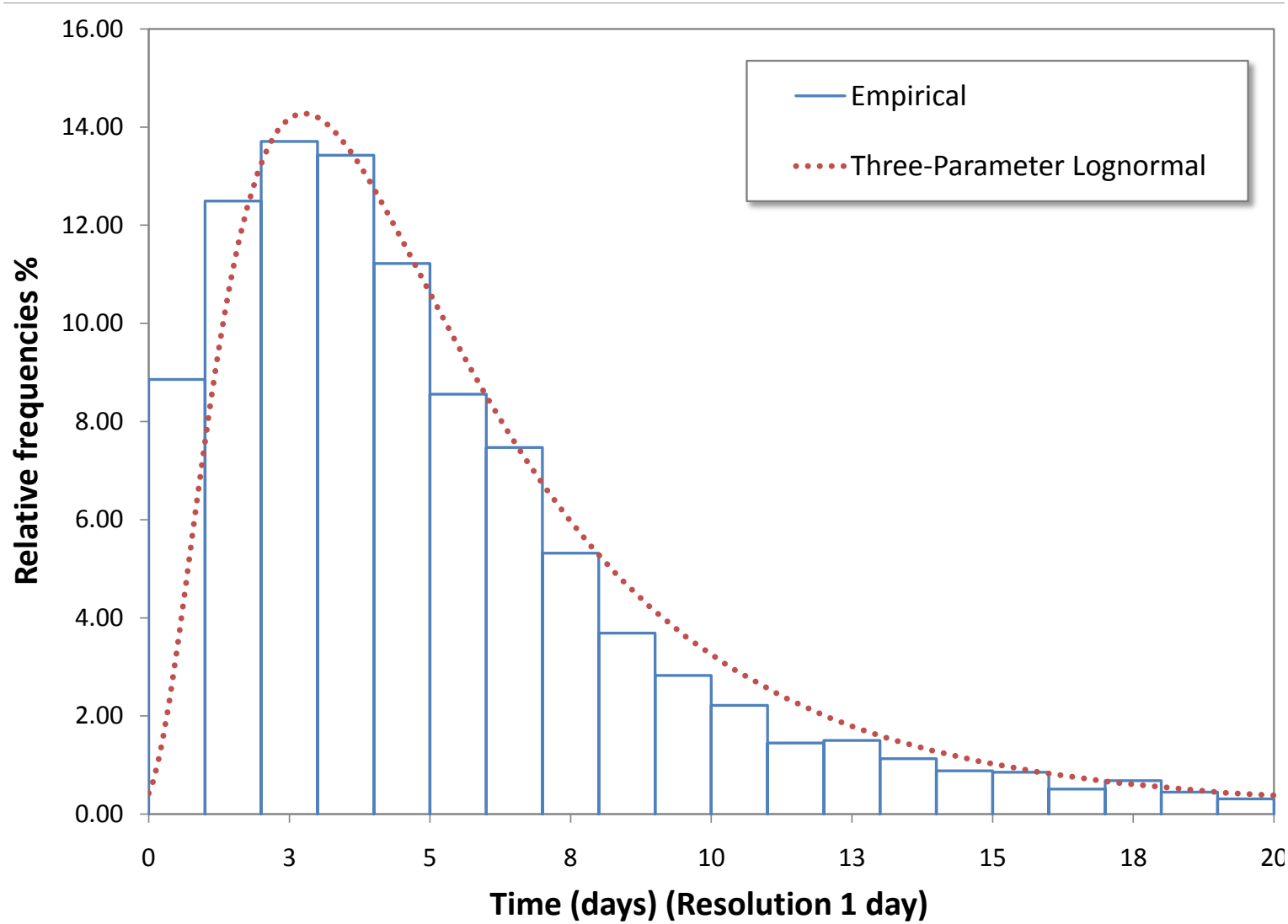
Subnetwork including: ED, IW and ED $\rightarrow$ IW

- 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

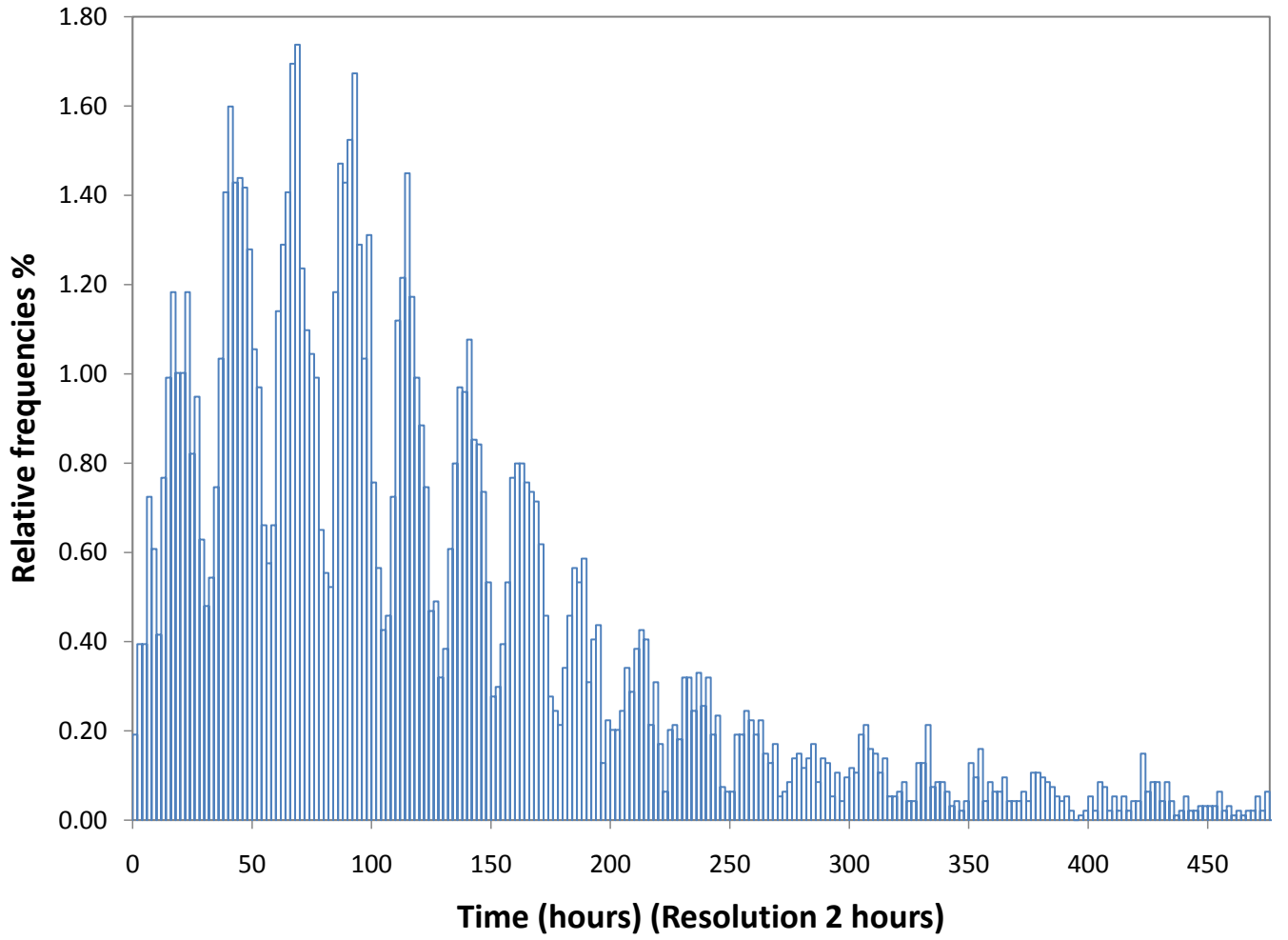
Talk Outline

- IW
  - LOS distribution
  - Routing design
  - Role of returns
- Transfer from ED to IW
  - Transfer process
  - Fork-join networks
  - Delays in transfer
  - Fairness
- Conclusions

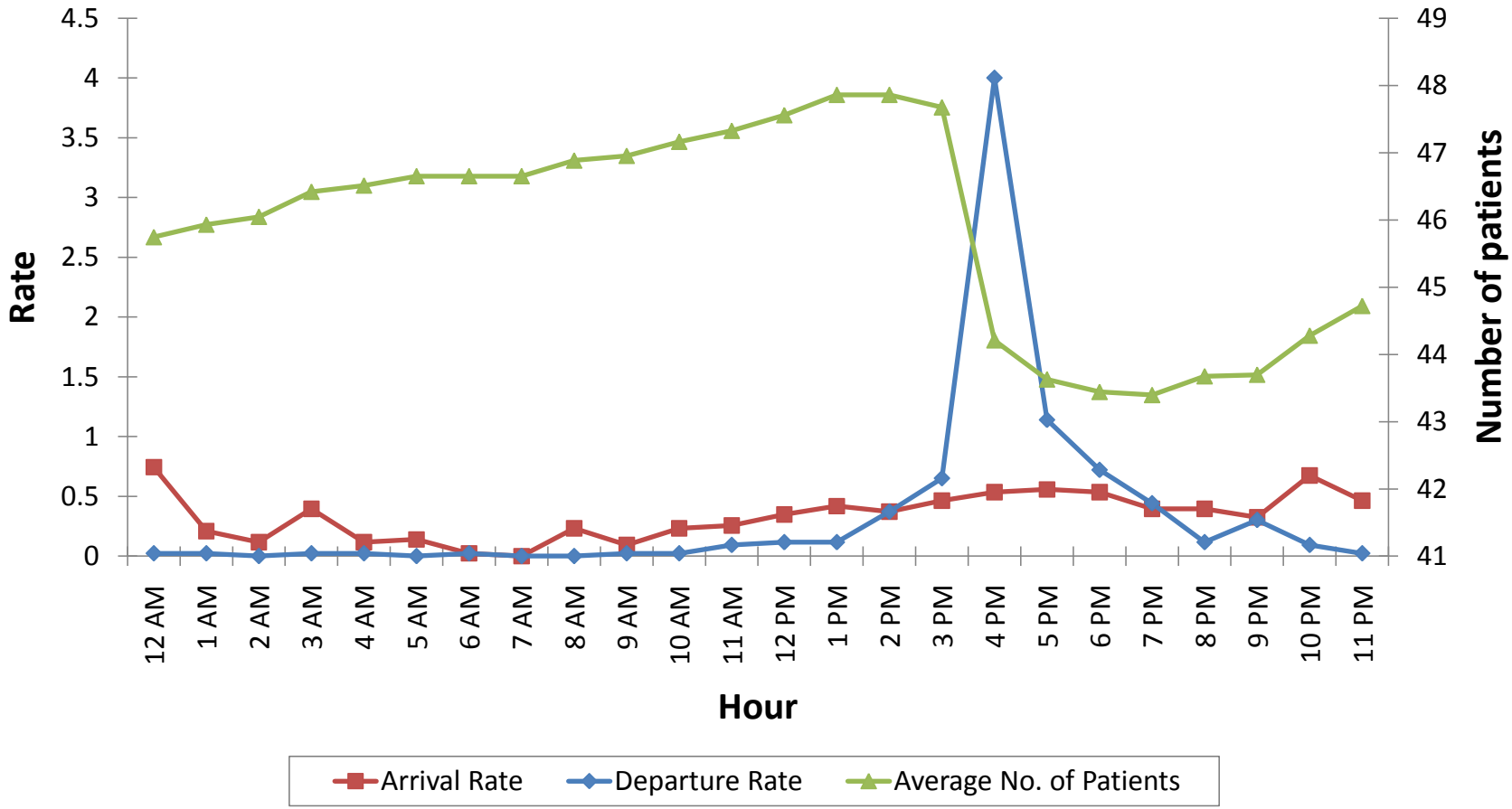
IW: LOS Distribution in days



IW: LOS Distribution in hours

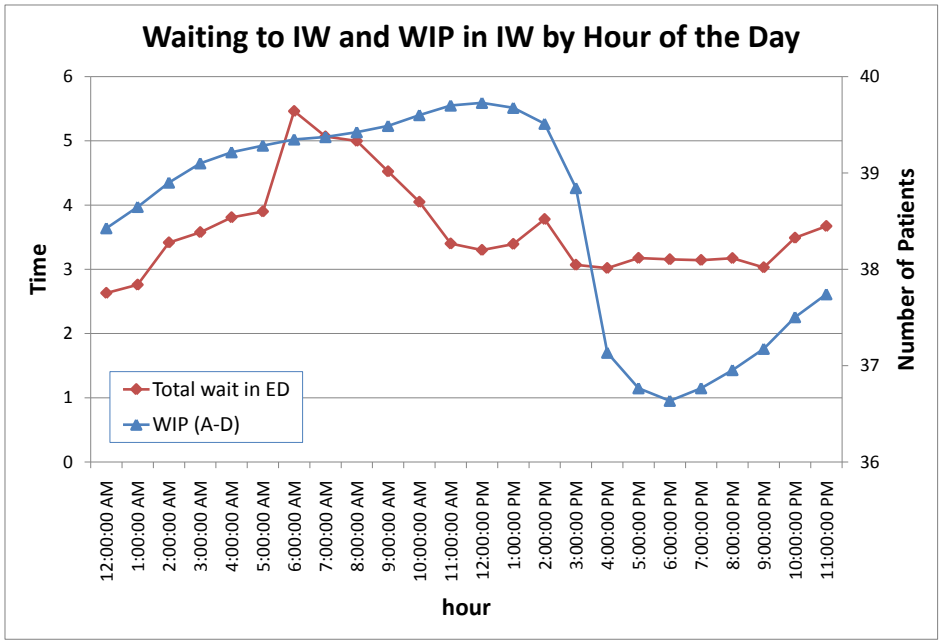


IW: Arrivals, Departures and Number of Patients

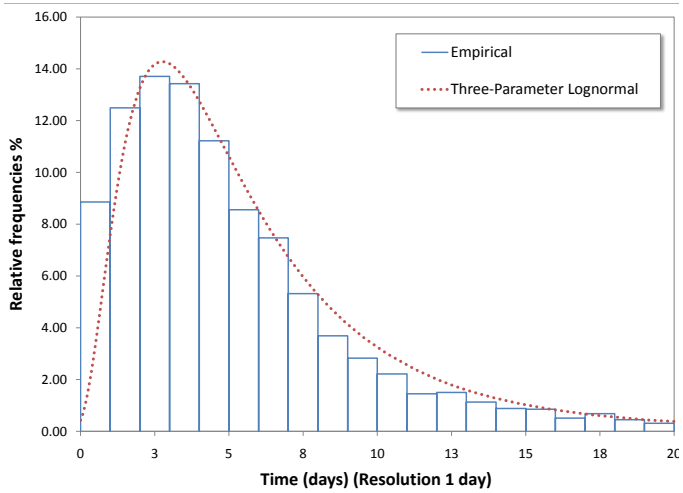


Queueing Implications

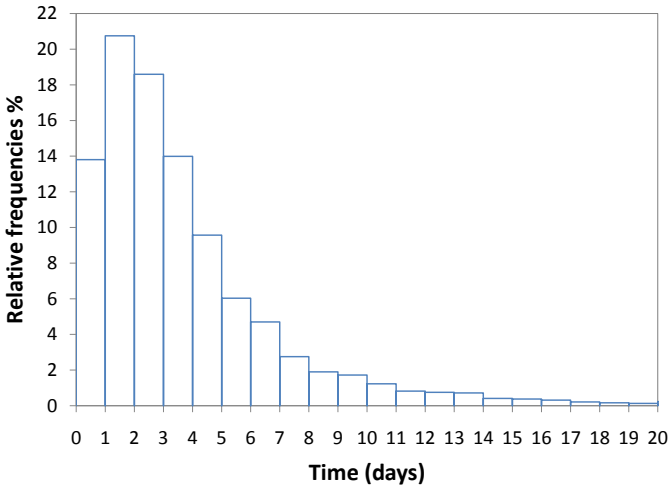
- Two relevant time scales.
- Daily time scale relevant for capacity planning and staffing.
- Hourly time scale relevant for work scheduling.



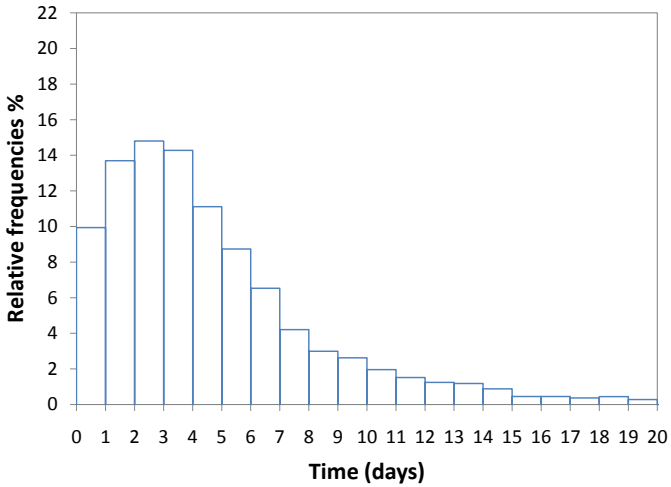
LOS Distribution of IW A-D



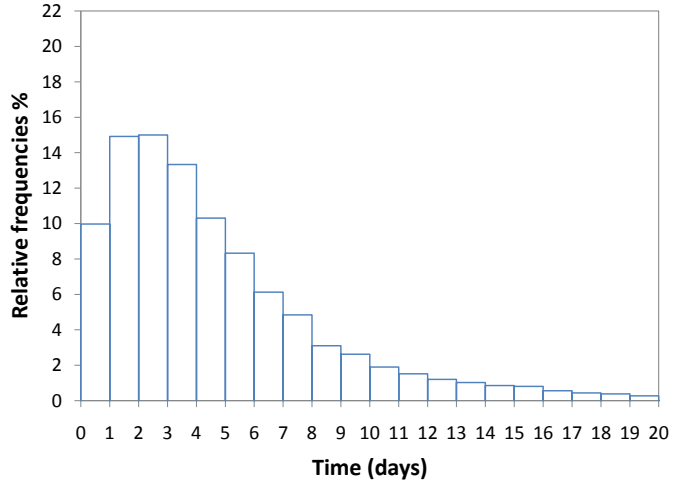
IW A



IW B

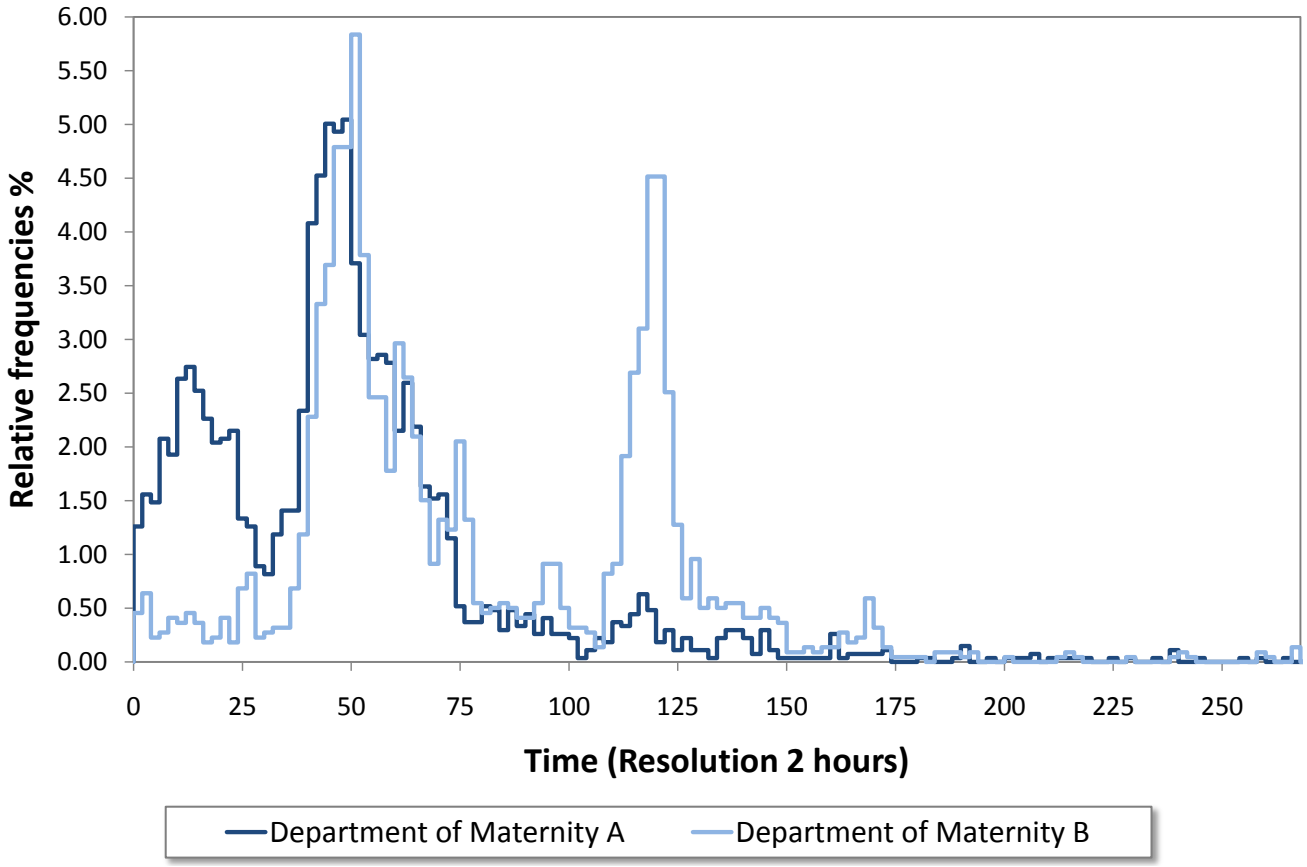


IW C

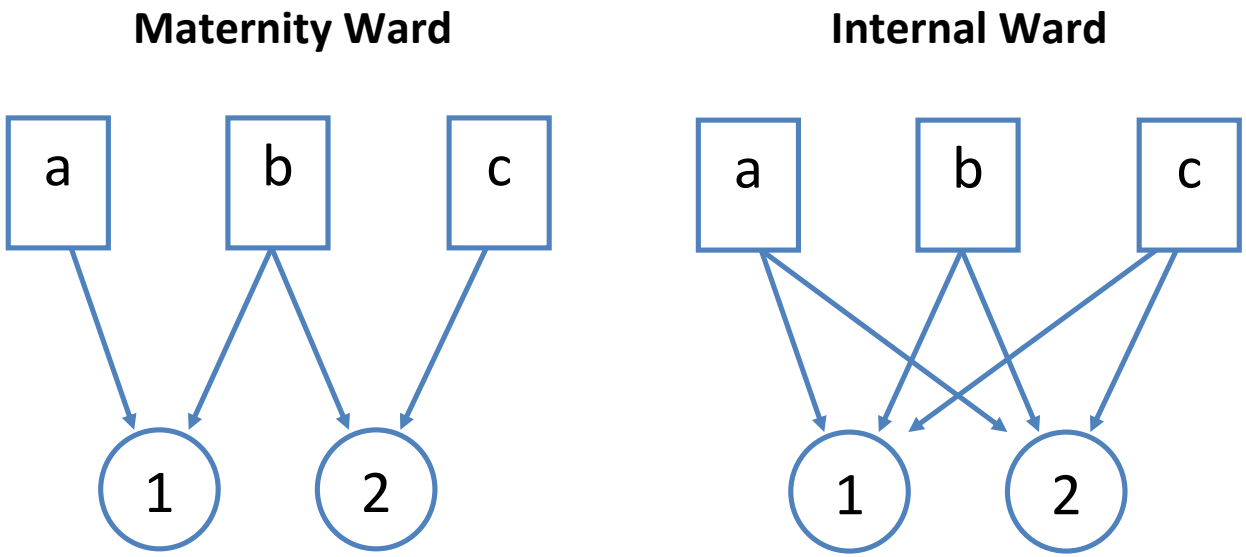


IW D

Maternity Wards: LOS distribution



Routing Schemes in Different Wards



Queueing Implications:

- Practical: What considerations determine the PSS network design?
- Research: How does the design affect LOS distribution, workload, quality of care, morale, etc,

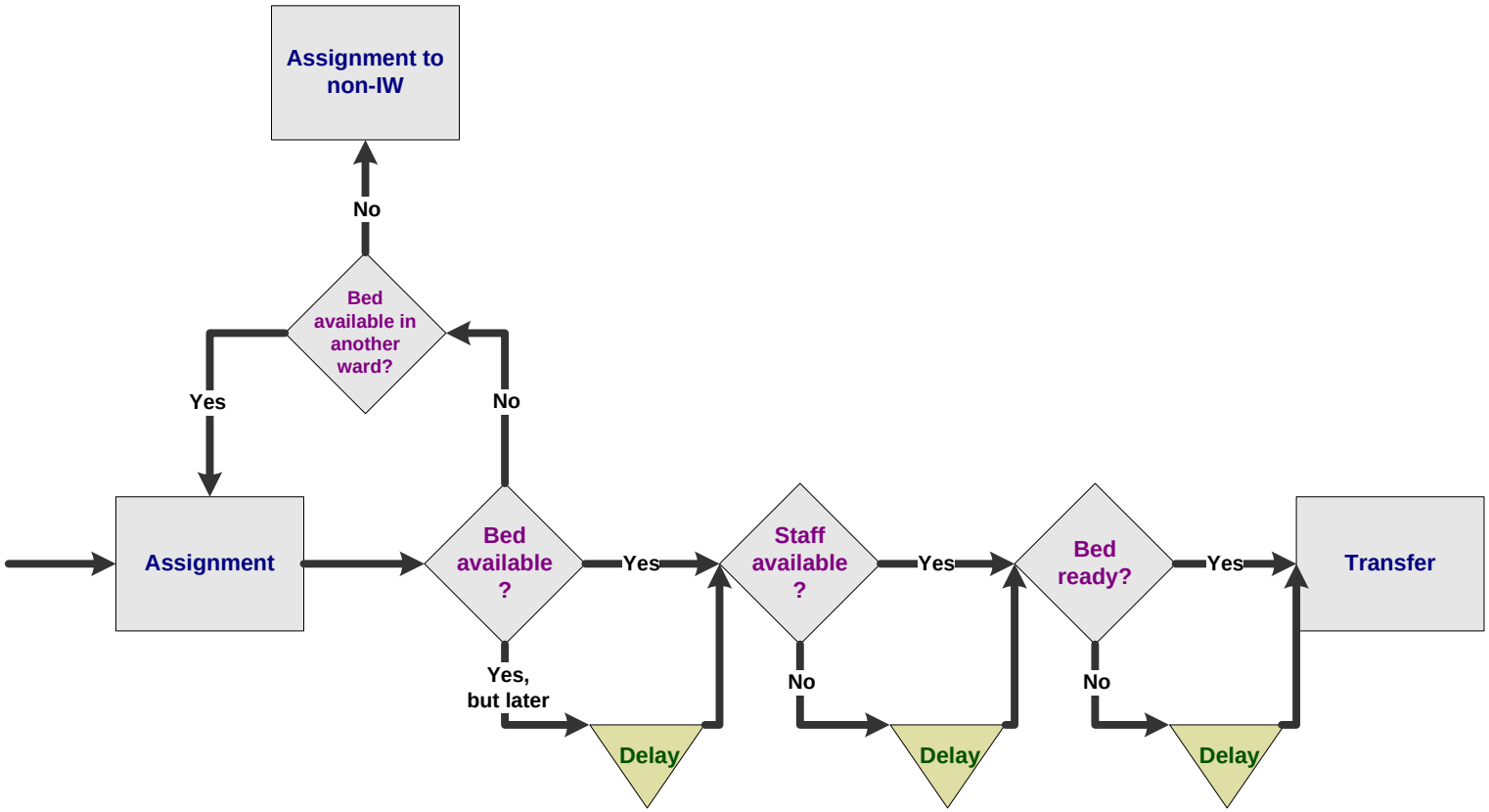
Returns to Hospitalization

Ward	No. of returns per patient (in 4 years)	Time between returns (days)	Probability of return within 3 month
Internal	1.76	208	22%
Oncology	5.76	29	76%

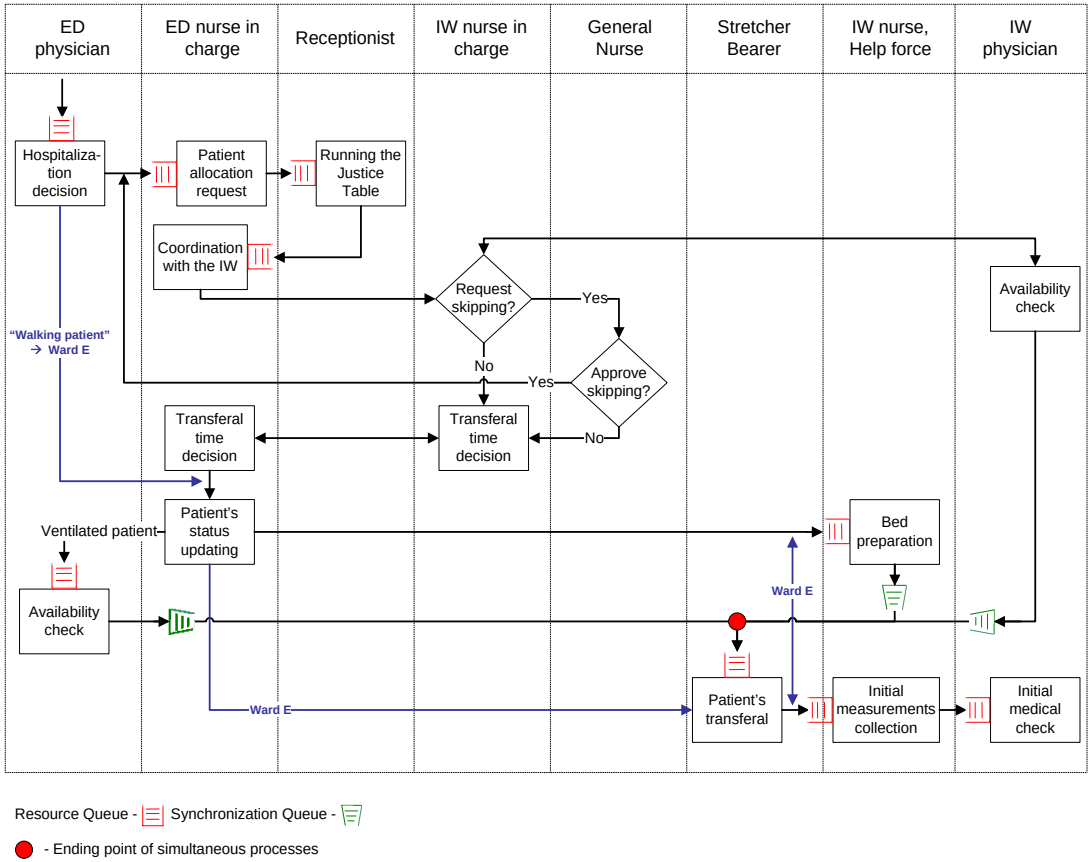
Questions:

- How does rate of return correlate with quality of care?
- Endogenous versus exogenous rate of return.
- Staffing with returns: Erlang-R: Yom-Tov & Mandelbaum (2011)

Transfer Process

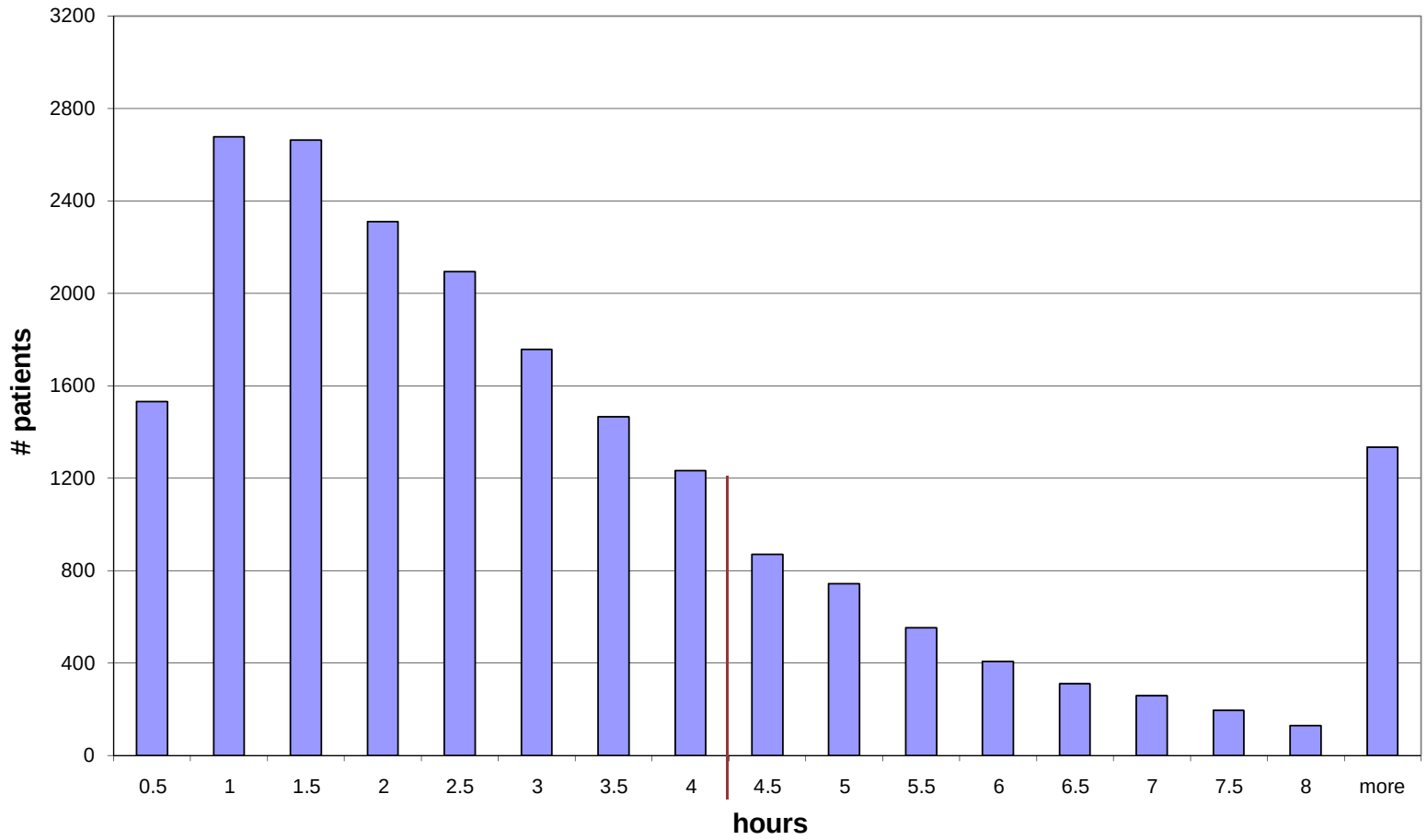


Fork-Join networks revisited



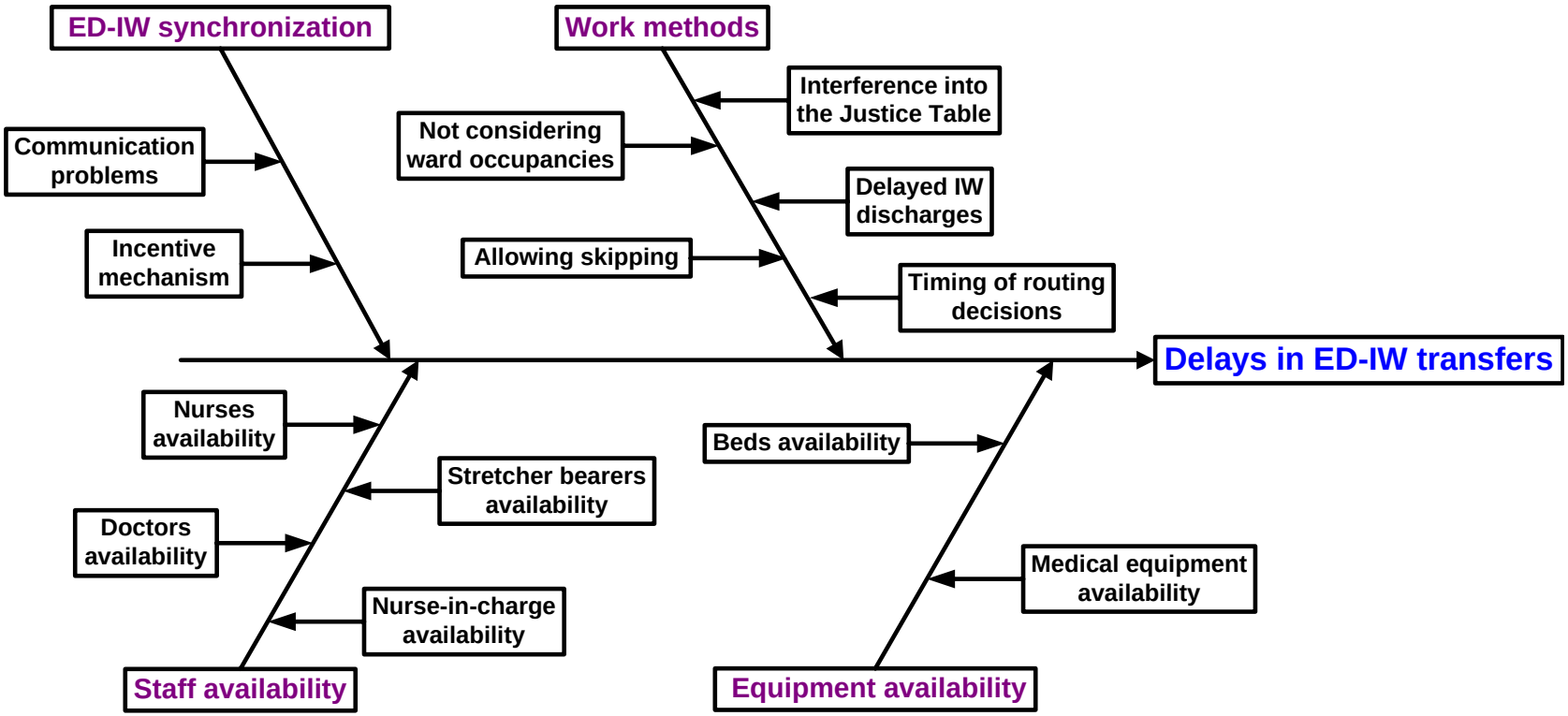
- Zviran (2008): Diffusion limits and control
- Zaied (2010): Offered load

Transfer waiting times

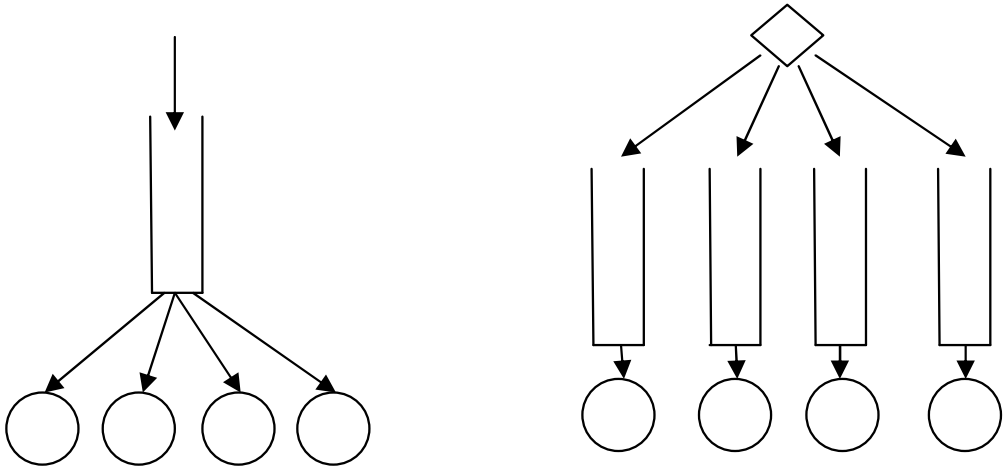


- Question: What are the implications on ED load?
- Special feature: Customers served while waiting in queue.

Delays in transfer: Cause and effect diagram



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

Internal Wards operational measures

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

- How does one explain these differences in performance?
- Is this work allocation fair?
- How is fairness defined?
- See Mandelbaum, Momcilovic, & Tseytlin (2010) and Tseytlin & Zviran (2008)

Operations regimes

Question: What is the appropriate operational regime for the IW?

- Beds: QED regime.
  - Prediction: Erlang-B in QED: $N \simeq R + \beta\sqrt{R} \Rightarrow P(block) \simeq \frac{1}{\sqrt{N}} \frac{\phi(\beta)}{\Phi(\beta)}$ and $\rho \simeq 1 - \frac{\beta + \phi(\beta)/\Phi(\beta)}{\sqrt{N}}$.
  - For our data, the QED regime predicts: $P(block) \simeq 2.9\%$ and $\rho \simeq 91.7\%$.
  - Actual numbers: $P(block) = 3.54\%$ and $\rho = 93.1\%$.
- Doctors: ED regime.
  - Average handling time for patient admission: 30 minutes.
  - Average wait for admission (once a bed is ready): 2.5 hours.

Conclusions

- Patient flow in hospitals as a queueing network
- Multiple relevant time scales
- Routing design
- Role of returns
- Fork-Join networks
- Input versus Output queues
- Push versus Pull in routing
- Customers served while in queue
- Fairness: Occupancy + Flux
- QED and ED regime co-exist in a single system.
- Operational measures should be in line with quality of care measures