Queues in Hospitals: Empirical Study

Mor Armony

Joint work with: Avi Mandelbaum, Yariv Marmor, Yulia Tseytlin and Galit Yom-Tov

NYU, Technion, Mayo, IBM, Columbia

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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:

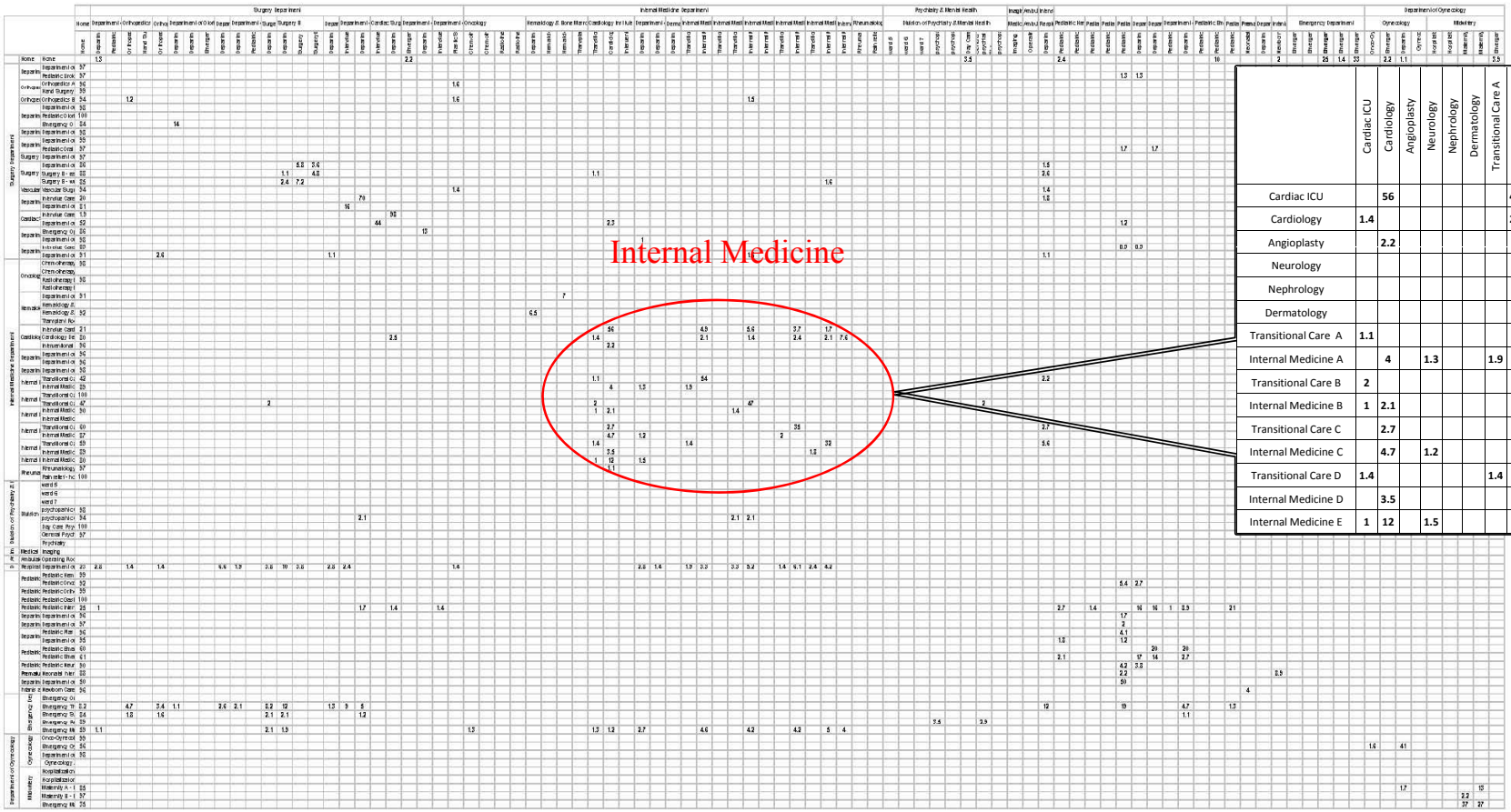
- Exploratory Data Analysis (EDA)

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

90 X 90 Matrix, Sub-Ward Resolution



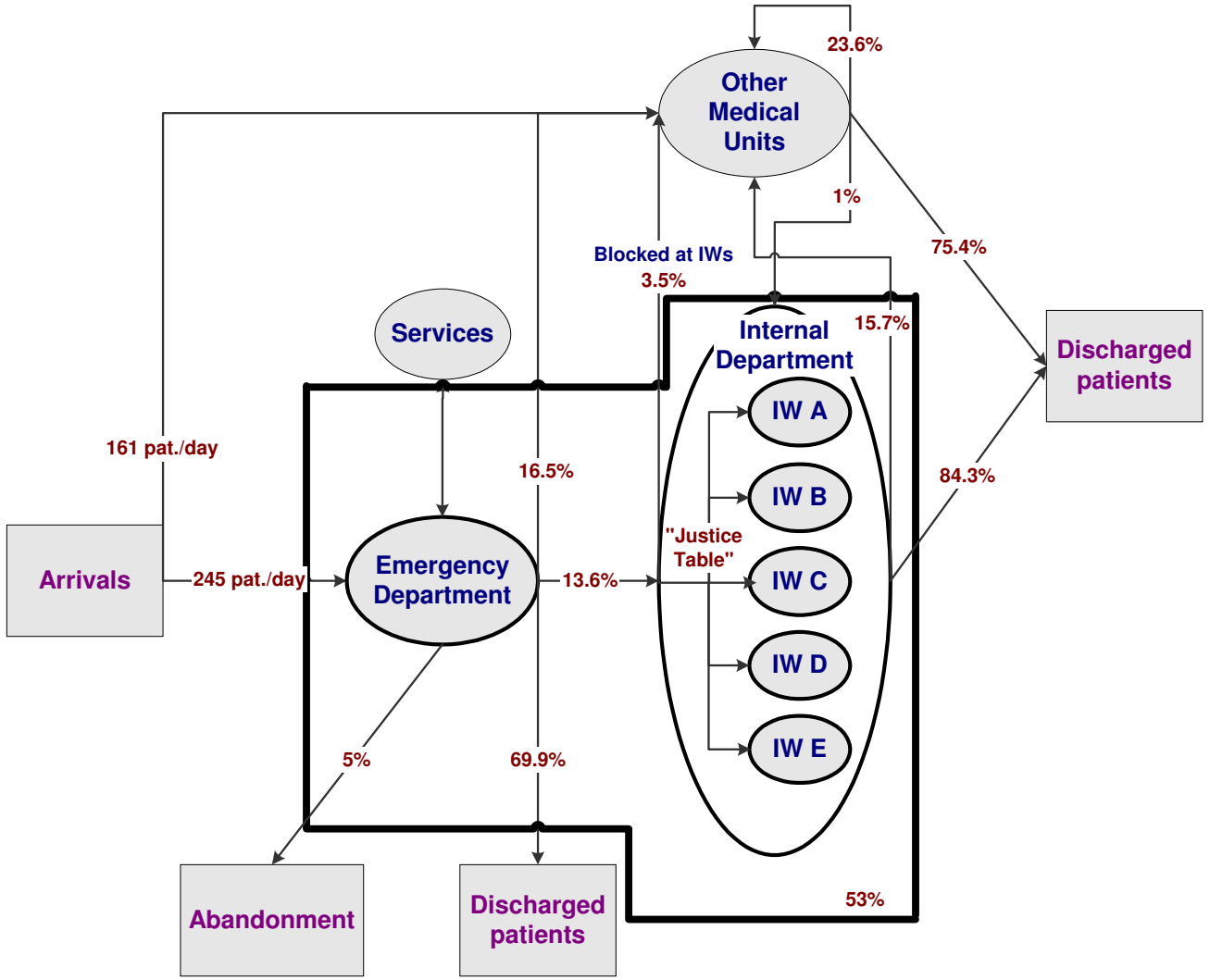
	Cardiac ICU	Cardiology	Angioplasty	Neurology	Nephrology	Dermatology	Transitional Care A	Internal Medicine A	Transitional Care B	Internal Medicine B	Transitional Care C	Internal Medicine C	Transitional Care D	Internal Medicine D	Internal Medicine E
Cardiac ICU		56					4.9		5.6		3.7		1.7		
Cardiology	1.4						2.1		1.4		2.4		2.1	7.6	
Angioplasty		2.2													
Neurology															
Nephrology															
Dermatology															
Transitional Care A	1.1						54								
Internal Medicine A		4		1.3			1.9								
Transitional Care B	2								47						
Internal Medicine B	1	2.1						1.4							
Transitional Care C		2.7										35			
Internal Medicine C		4.7		1.2							2				
Transitional Care D	1.4						1.4						32		
Internal Medicine D		3.5										1.8			
Internal Medicine E	1	12		1.5											

Our focus

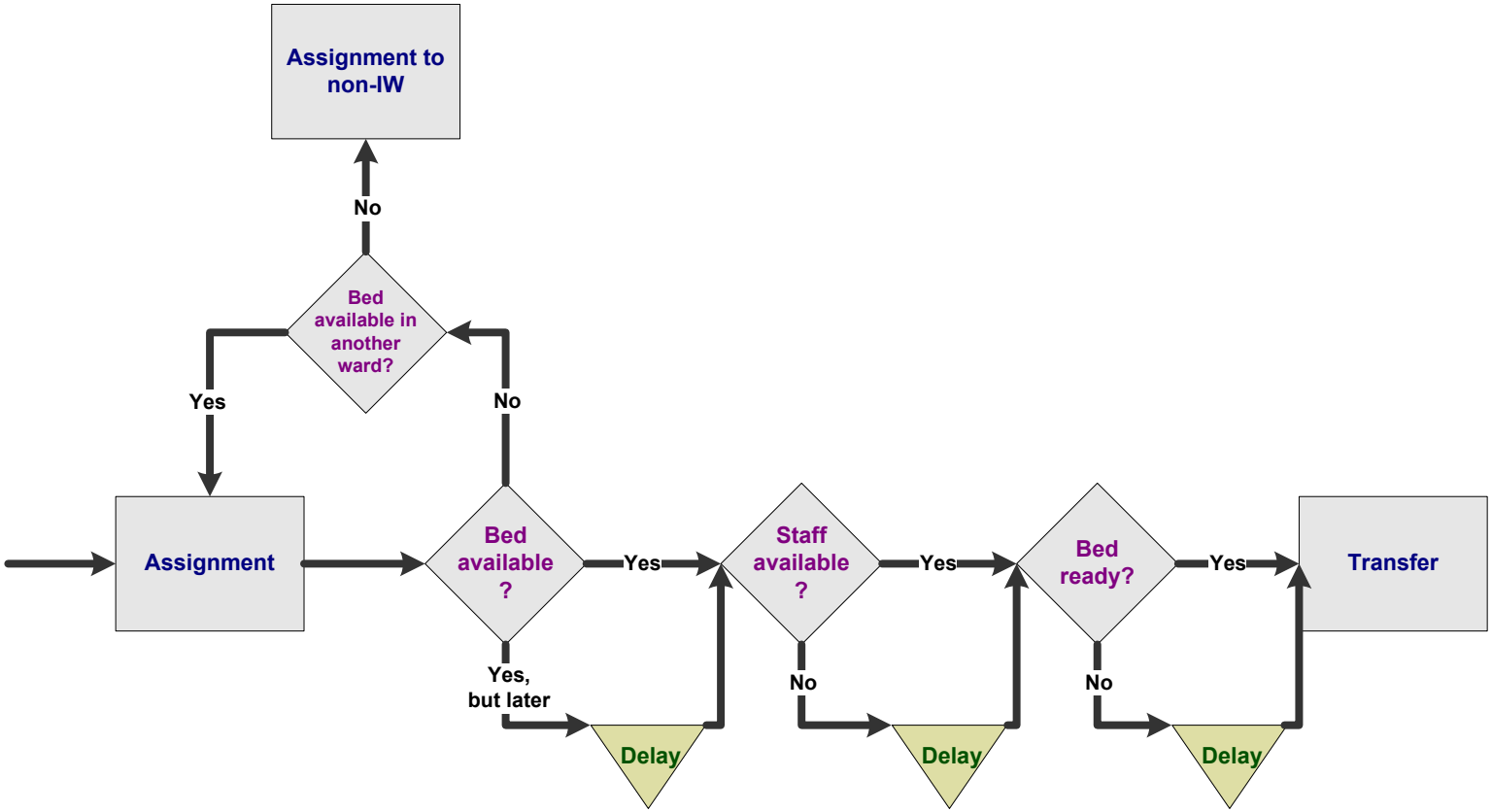
Subnetwork including: ED, IW and ED $\rightarrow$ IW

- 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

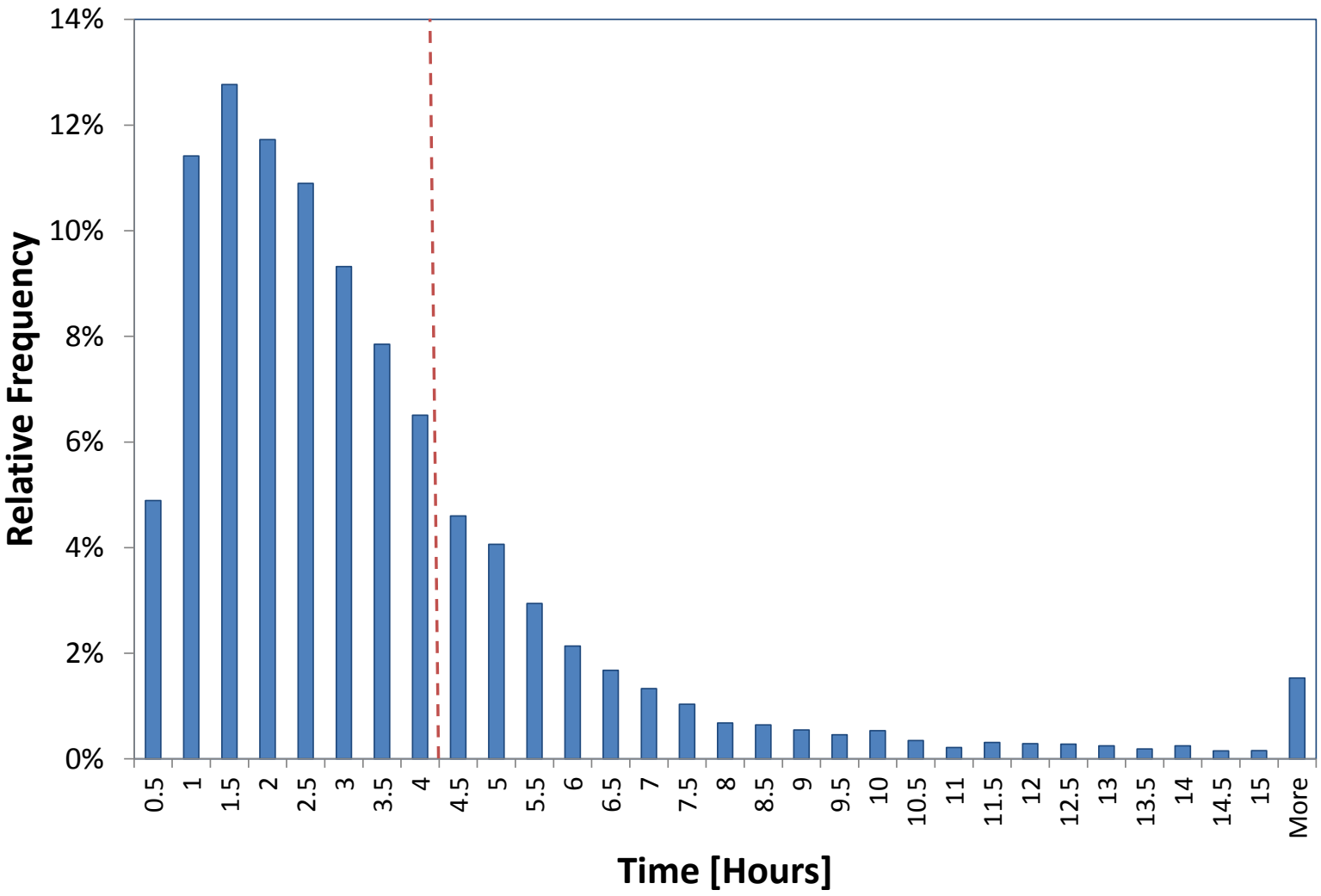
A Queueing Network View



Transfer Process

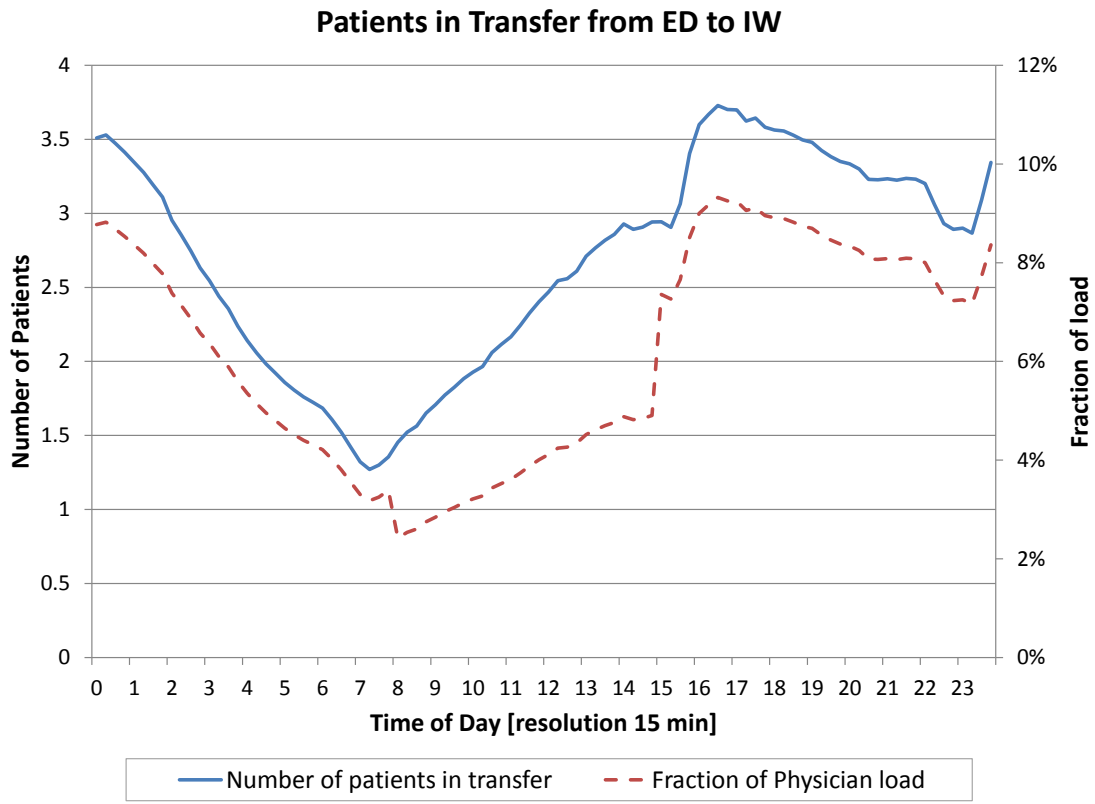


Transfer waiting times



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.

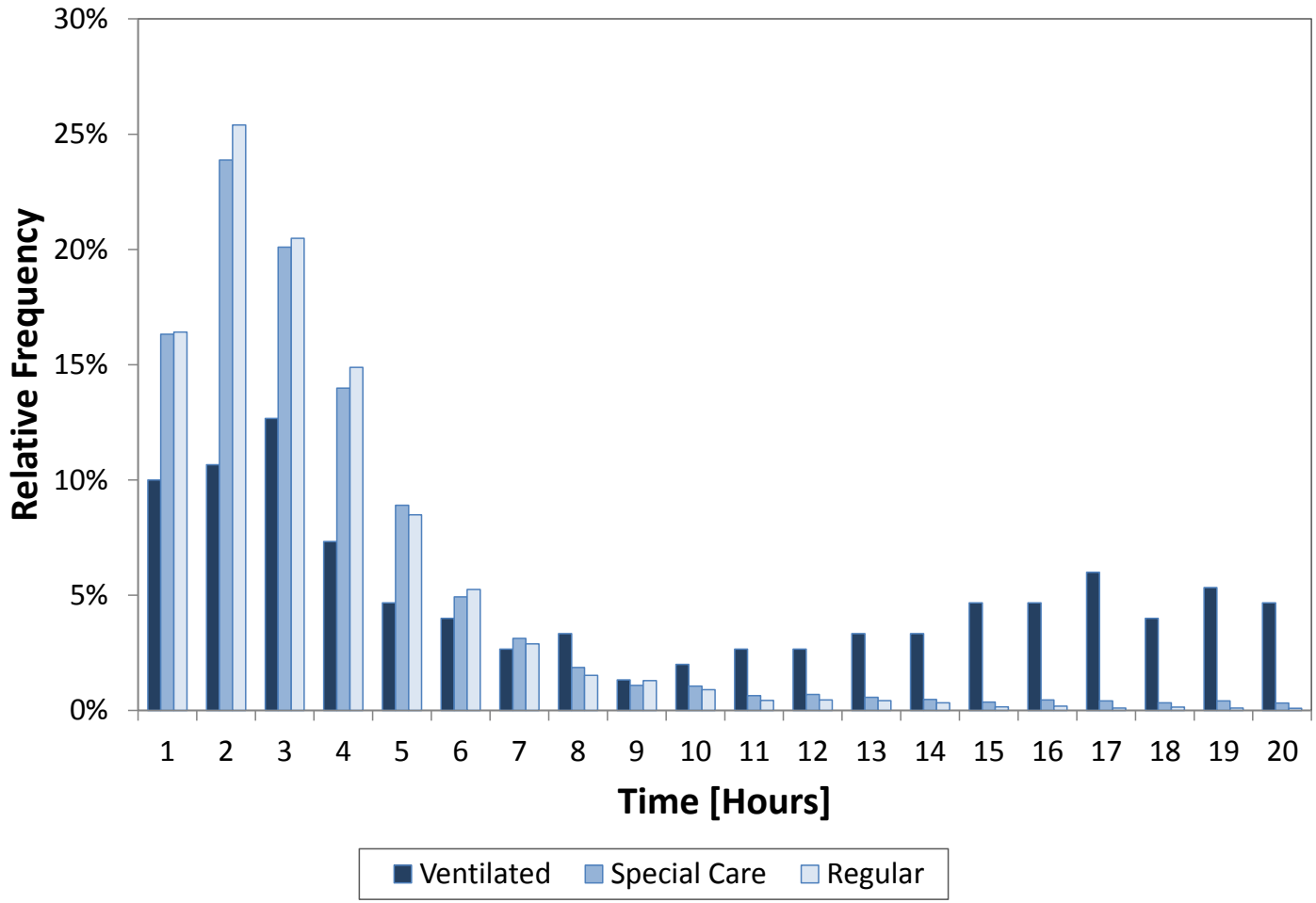


Average Transfer Delays per Patient Type

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

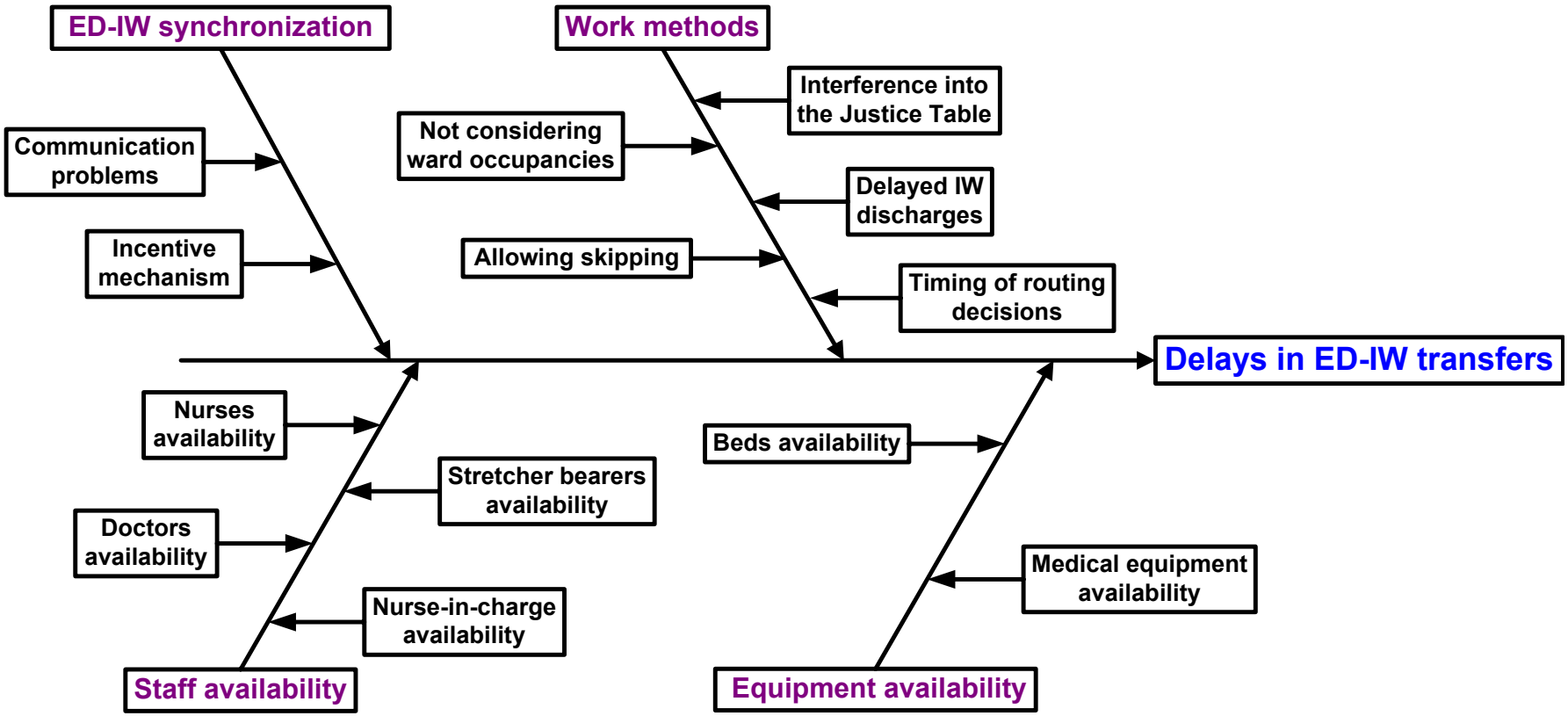
Ventilated patients should have lowest delay, but experience the highest!

Transfer waiting times by patient type

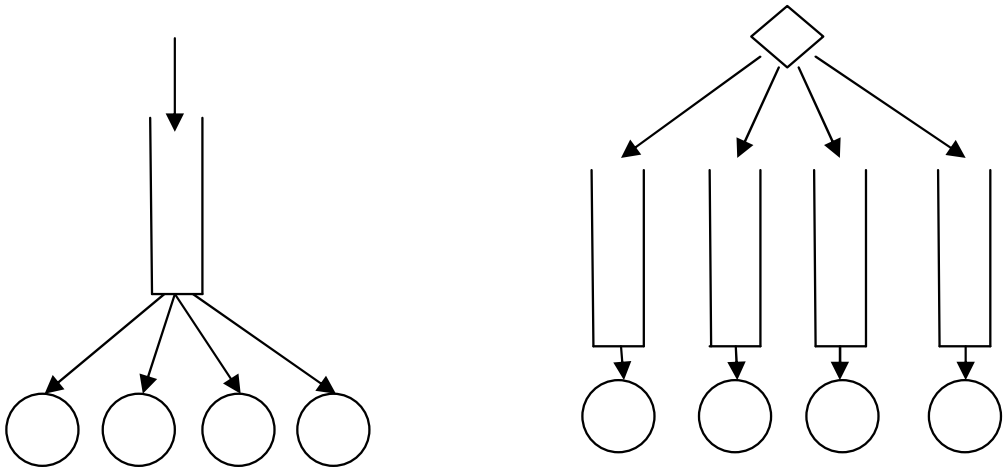


Patients need to wait for a bed, equipment, and medical staff.

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
- Fairness towards patients?

(Un)fairness towards patients

IW \ Type	Regular	Special care	Ventilated	Total
Ward A	7.57%	7.33%	0.00%	7.37%
Ward B	3.86%	5.72%	0.00%	4.84%
Ward C	7.09%	6.62%	0.00%	6.80%
Ward D	8.18%	7.48%	2.70%	7.81%
Total within wards	6.91%	6.80%	0.67%	6.80%
Total in ED-to-IW	31%	31%	5%	

Percentage of FCFS violations per type within each IW

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)

Unfairness towards wards: Patient mix

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

Justice Table allocation to IWs by patient type.

Conclusions

- 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