Designing Offload Zones to reduce Offload Delay

Young European Queueing Theorists workshop

Stochastic Service Systems

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Outline

- Designing Offload Zones to reduce Offload Delay?
  - What are Offload Zones & what is Offload Delay?
  - Failure modes at CDHA's Offload Zone
  - Initial Offload Zone model
  - Future plans

Offload delay

- Offload delay is a prolongation of the interval between an ambulances arrival in the emergency department (ED) and transfer of patient care
- Typically occurs when EDs are crowded and there are no beds available

Offload delay

- Impacts on patients include:
  - delays in patient care
  - poor pain control
  - delayed time to antibiotics
  - increased morbidity and potentially increased mortality
- Impacts on EHS systems:
  - decreases the availability of ambulances for the community
  - could result in a need for additional EHS staffing to compensate

Offload delay

- It is estimated that EHS spends
  - 29,000 hours / year on offload delay
  - ~$754,000 / year
- The 90th percentile of delivery intervals in NS
  - 2002: 24 minutes 37 seconds
  - 2007: 109 minutes 2 seconds
  - 2010: 114 and 142 minutes (Halifax EDs only)

  - The Nova Scotia Gov't benchmark is 20 minutes 90% of the time

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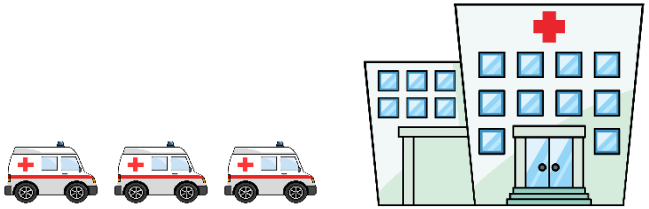
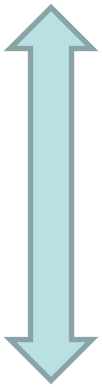
Benefits

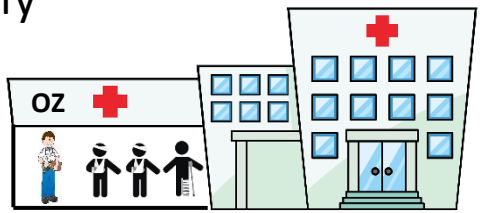
Reduced offload delay
Better ambulance coverage

If nothing changes then benefits are easy to quantify



Without the offload zone:
Ambulances queue waiting to offload their patients





With the offload zone:
Multiple patients wait with a paramedic & nurse , relieving the ambulances

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Offload Zone Anecdotes

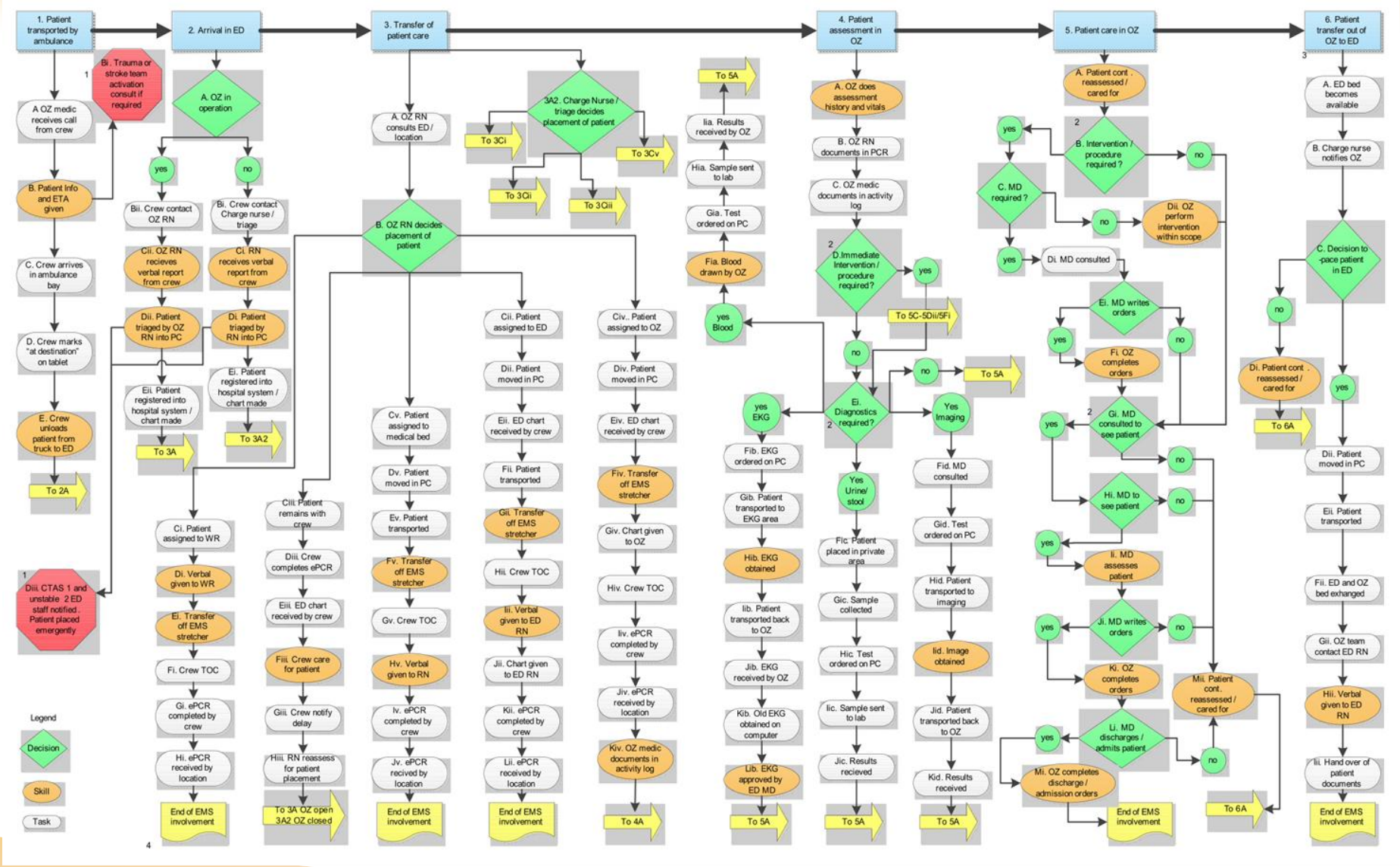
- Offload Zones are often at full capacity
- Offload delays still occur

Studies

- HFMEA - Healthcare Failure Mode and Effect Analysis
  - **Alix JE Carter MD MPH FRCPC**, Medical Director of Research EHS, Assistant Professor, Dalhousie Dept. of Emergency Medicine
  - **James B Gould BSc.,** Student Researcher, Dalhousie Dept. of Emergency Medicine
  - **Peter Vanberkel, PEng, PhD.,** Assistant Professor, Department of Industrial Engineering
  - **Jan L Jensen ACP MAHSR,** Research Leader EHS
  - **Jolene Cook MD,** EMS Fellow, Dalhousie Dept. of Emergency Medicine
  - **Steven Carrigan MPA,** Research and Statistical Officer, EHS
  - **Mark R Wheatley ACP,** Operations Manager, EHS
  - **Andrew H Travers MSc MD FRCPC,** Provincial Medical Director, EHS, Associate Professor, Dalhousie Dept. of Emergency Medicine and Community Health & Epidemiology
- Modelling
  - **Peter Vanberkel, PEng, PhD.,** Assistant Professor, Department of Industrial Engineering
  - **Corine Laan**, MSc Student, Stochastic Operations Research, University of Twente
  - **Richard J. Boucherie, PhD**., Professor, Stochastic Operations Research, University of Twente

HFMEA

1. Develop detailed process flowchart
2. Identify potential failures (patient care and throughput)
3. Rate severity
4. Rate likelihood
5. Prioritize potential failures



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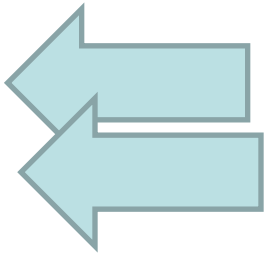
Main steps

1. Patient transported by ambulance
2. Arrival in ED
3. Transfer of patient Care from EHS to OZ
4. Patient assessment in OZ
5. Patient care in OZ
6. Patient transfer out of OZ to ED



4. Patient assessment in Offload Zone
   - EKG required?
   - Blood work required?
   - Imaging required?
   - Consult MD
   - Transport patient to receive diagnostic
5. Patient care in Offload Zone
   - Intervention required?
   - MD sees patient
   - MD writes orders

HFMEA - Results

- "High Risk Failures" related to patient care
  - Delay in assessment/patient care because of limited equipment
  - Patient not properly assessed/cared for because lack of privacy
  - …
- High Risk Failures" related to throughput
  - Patient not place in ED from OZ because patient already receiving care in OZ
  - Patient not placed in ED from OZ because ED waiting for patient to receiving some level of care from the OZ
  - …

HFMEA - Discussion

- Original intent of OZ was to reduce ambulance offload delay, however…
  - OZ provides extensive care, similar to an ED
  - Incentive to admit an OZ may be lost
  - The OZ has become an extension of the ED

  - Summed up: OZ may cause offload delay

Modelling

- How does patient selection affect the performance of the Offload Zone?

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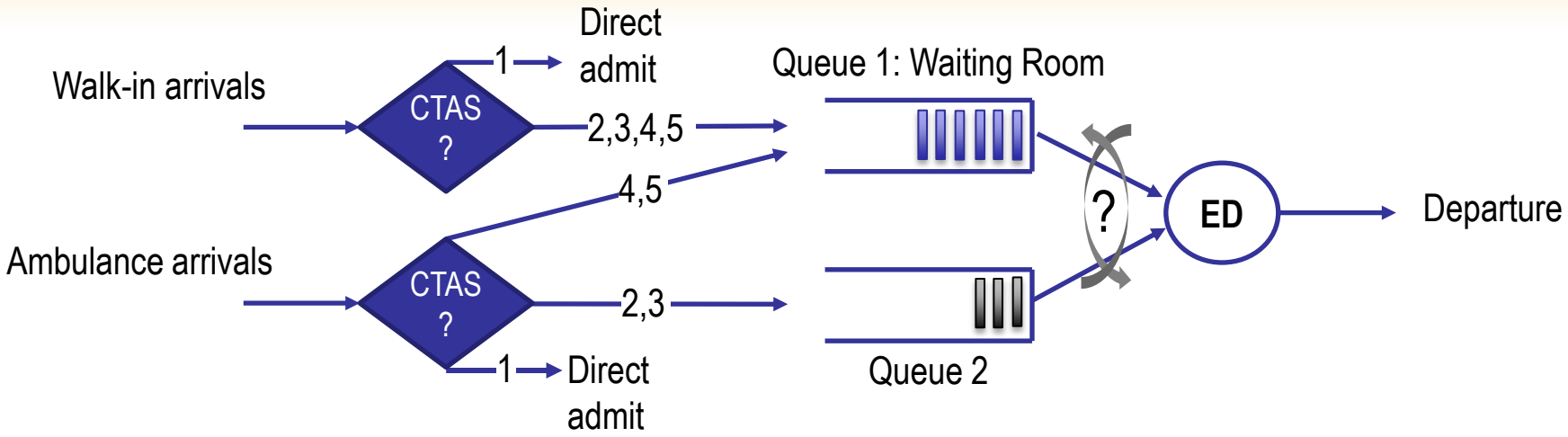

	Metric: Ambulances waiting (X)	Patient selection	Tiebreaker
Without OZ	Queue 2	Lowest CTAS	Control: Queue 2
With OZ	Max(0, Queue 2 – OZ capacity)	Lowest CTAS	Policy 1: Queue 2 Policy 2: Queue 1 Policy 3: Queue 2 with probability p_{oz}

- Ignore shorter service times due to starting treatment in OZ

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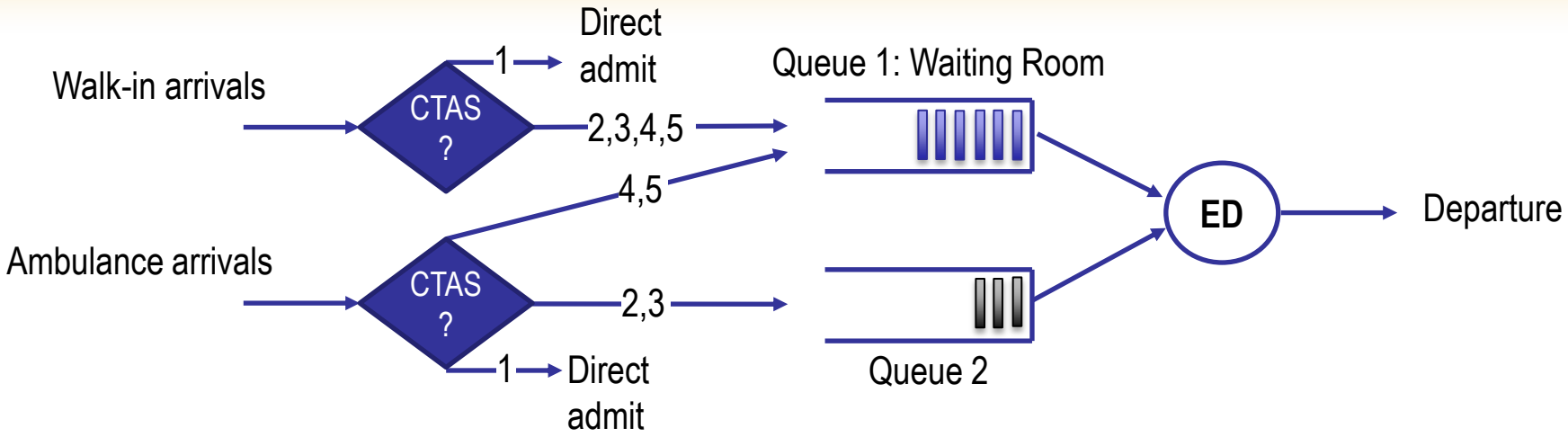
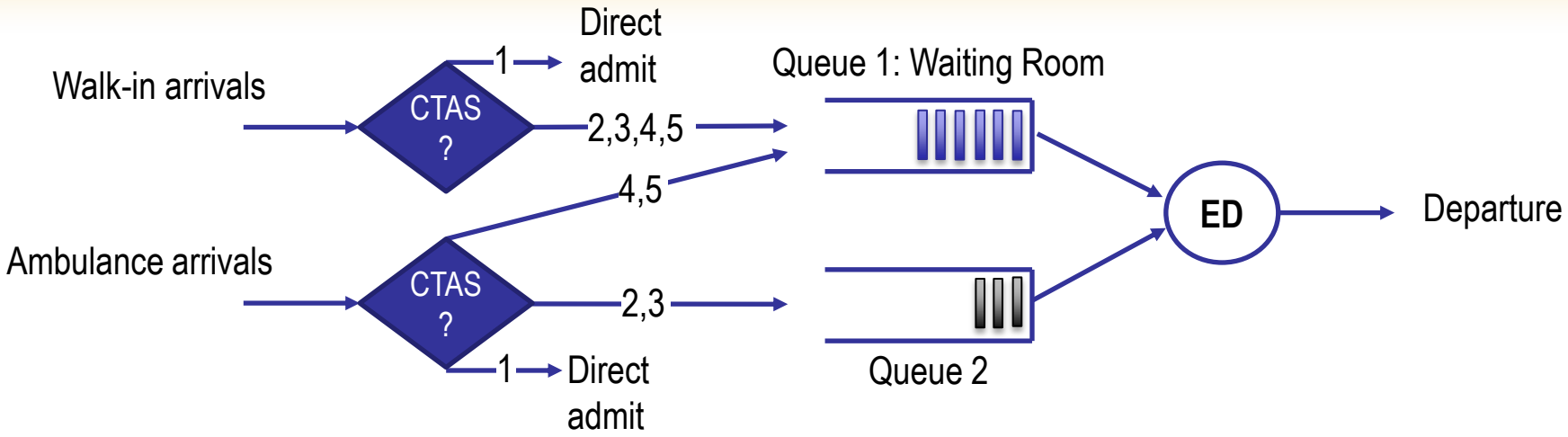


- Polling Model - single server, cyclic order
- M/G/c with multiple priority classes
- ~M/M/c with multiple priority classes
  - Patient class specific E[W] and E[L] in closed form
  - Queue Length distributions from Markov Chain



- Assumptions
  - Steady state
  - Stationary arrival process
  - System is stable
  - Poisson arrival process

Continuous Time Markov chain

- Define state space: S
- Define rates from state s to s'
- Solve limiting distribution π
  - Balance flow equations
  - Normalization equations
  - System of linear equations solver

Continuous Time Markov chain

- $S = [N_b, N_b^H, N_1, N_2, N_3]$
- Where:

N_b is ED beds in use	$\leq c$
N_b^H is ED beds in use by low CTAS patients	$\leq c$
N_1 waiting ambulance arrivals (low CTAS)	$\leq m_1$
N_2 waiting walk-in arrivals (low CTAS)	$\leq m_2$
N_3 waiting walk-in arrivals (high CTAS)	$\leq m_3$

- Assumes
  - 3 patient types
  - 2 service times: low CTAS and high CTAS

Continuous Time Markov chain

- Generator matrix, Q:

$$q_{(N_b,N_b^H,N_1,N_2,N_3),(N_b+1,N_b^H,N_1,N_2,N_3)} = \lambda_3 \qquad (N_b^H \le N_b < c; N_1, N_2, N_3 = 0)$$

$$q_{(N_b,N_b^H,N_1,N_2,N_3),(N_b+1,N_b^H+1,N_1,N_2,N_3)} = \lambda_1 + \lambda_2 \qquad (N_b^H \le N_b < c; N_1, N_2, N_3 = 0)$$

$$q_{(N_b,N_b^H,N_1,N_2,N_3),(N_b-1,N_b^H,N_1,N_2,N_3)} = (N_b - N_b^H)\mu_L \qquad (N_b^H \le N_b < c; N_1, N_2, N_3 = 0)$$

…

$$q_{(N_b,N_b^H,N_1,N_2,N_3),(N_b,N_b^H,N_1-1,N_2,N_3)} = p_{OZ} N_b^H \mu_H \qquad (N_b^H \le N_b < c; N_b^H > 0; N_1, N_2 > 0)$$

$$q_{(N_b,N_b^H,N_1,N_2,N_3),(N_b,N_b^H,N_1,N_2-1,N_3)} = (1 - p_{OZ}) N_b^H \mu_H \qquad (N_b^H \le N_b < c; N_b^H > 0; N_1, N_2 > 0)$$

…

where:

c is beds available

λ is mean arrival rate

μ is mean service rate

Continuous Time Markov chain

- Limiting distribution, π:
  - linear balance flow equations:
    - $\pi_s \sum_{s'=s} q_{s,s'} = \sum_{s'=s} \pi_{s'} q_{s',s} \; \forall s \in S$
    - $0 = \pi Q$
  - and normalizing equation:
    - $\sum_{s \in S} \pi_s = 1$
- Successive over-relaxation approximation computed with Matlab BiCGSTAB

Continuous Time Markov chain

- Metrics:
  - $\mathrm{E}[X] = \sum_{s \in \mathrm{S}} [N_1^s - b_{OZ}]^+ \pi_s$

    Where b_{OZ} is the capacity of OZ
  - $E[W] = \frac{E[X]}{\lambda_1}$
  - Queue length distribution

X is ambulances waiting

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Data

	CTAS 1	CTAS 2	CTAS 3	CTAS 4	CTAS 5
Patient type distribution[1]	1%	15%	45%	32%	7%
Fraction arriving by ambulance[2]*	78%	20.6%	20.6%	3.8%	3.8%
Average service time[3] (minutes)	155	190	110	30	20

*12% in total

[1] Capital District Emergency Services Council. Quarterly report, Oct 2012
[2] Improving access to emergency care: Addressing system issues. Ontario hospital association, 2006.
[3] Canadian Institute for Health Information. Understanding emergency department wait times, 2005.

Scenarios

		$\lambda_1, \lambda_2, \lambda_3$*	μ_H, μ_L	b_{OZ}	ED beds	m_1, m_2, m_3
No OZ	Control	0.40,1.53,1.25	0.45, 2	2	5	10, 10, 25
OZ has priority	p_{oz}=1	0.40,1.53,1.25	0.45, 2	2	5	10, 10, 25
	p_{oz}=0.95	0.40,1.53,1.25	0.45, 2	2	5	10, 10, 25
	…	0.40,1.53,1.25	0.45, 2	2	5	10, 10, 25
	p_{oz}=0.05	0.40,1.53,1.25	0.45, 2	2	5	10, 10, 25
OZ does not have priority	p_{oz}=0	0.40,1.53,1.25	0.45, 2	2	5	10, 10, 25

*$\boldsymbol{\rho = 0.98}$

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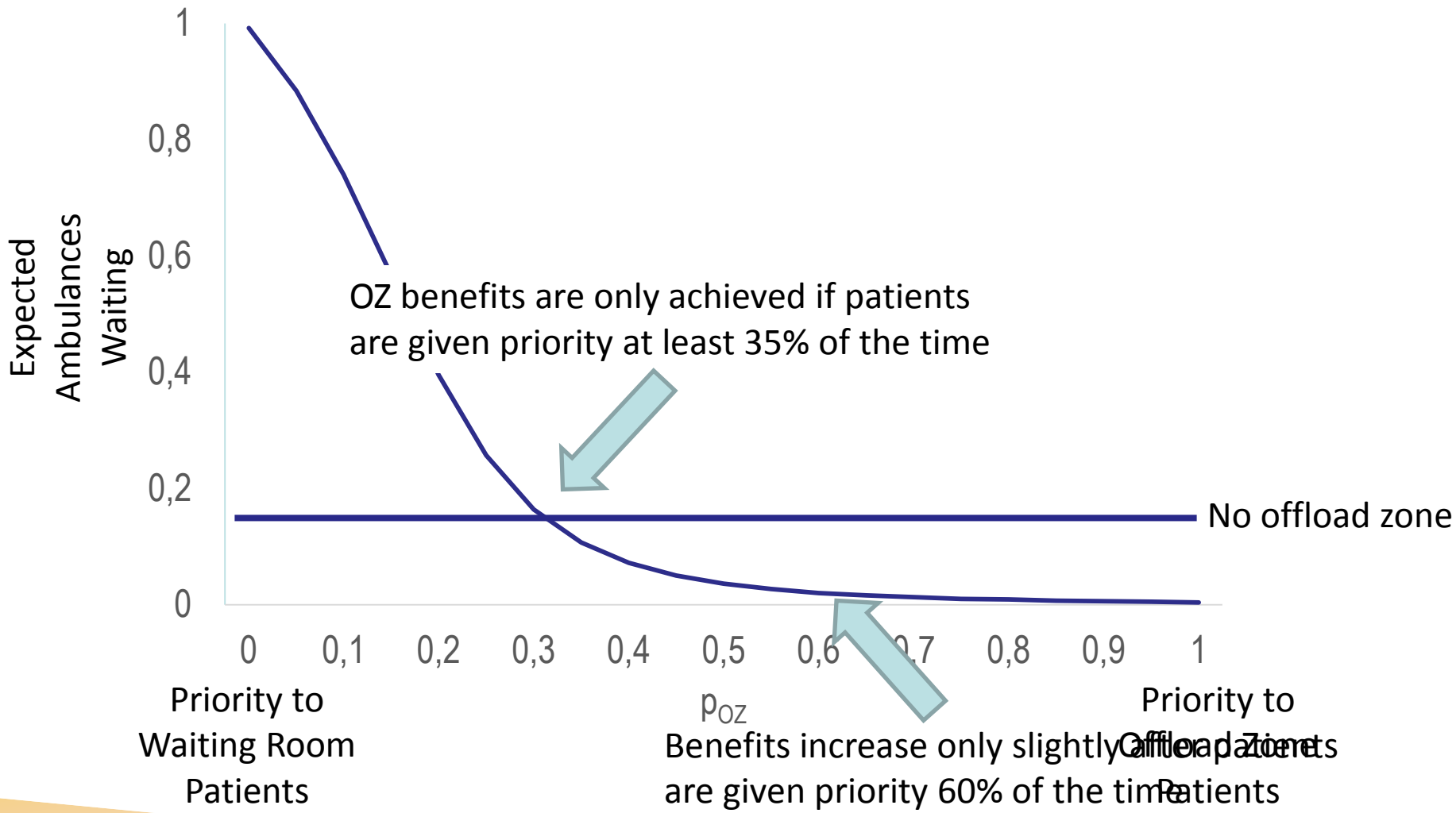
Scenarios

		$E[X]$	$P(X \geq 1)$	$P(X \geq 2)$	$P(X \geq 3)$
No OZ	Control	0.153	0.13	0.02	0.004
OZ has priority	p_{oz}=1	0.004	0.004		
	p_{oz}=0.95	0.005	0.004		
	…	…	…	…	…
	p_{oz}=0.7	0.013	0.01	0.002	
	p_{oz}=0.5	0.036	0.02	0.008	
	p_{oz}=0.3	0.164	0.08	0.041	0.022
	…	…	…	…	…
	p_{oz}=0.05	0.884	0.252	0.189	0.142
OZ does not have priority	p_{oz}=0	0.992	0.27	0.21	0.16

X is ambulances waiting



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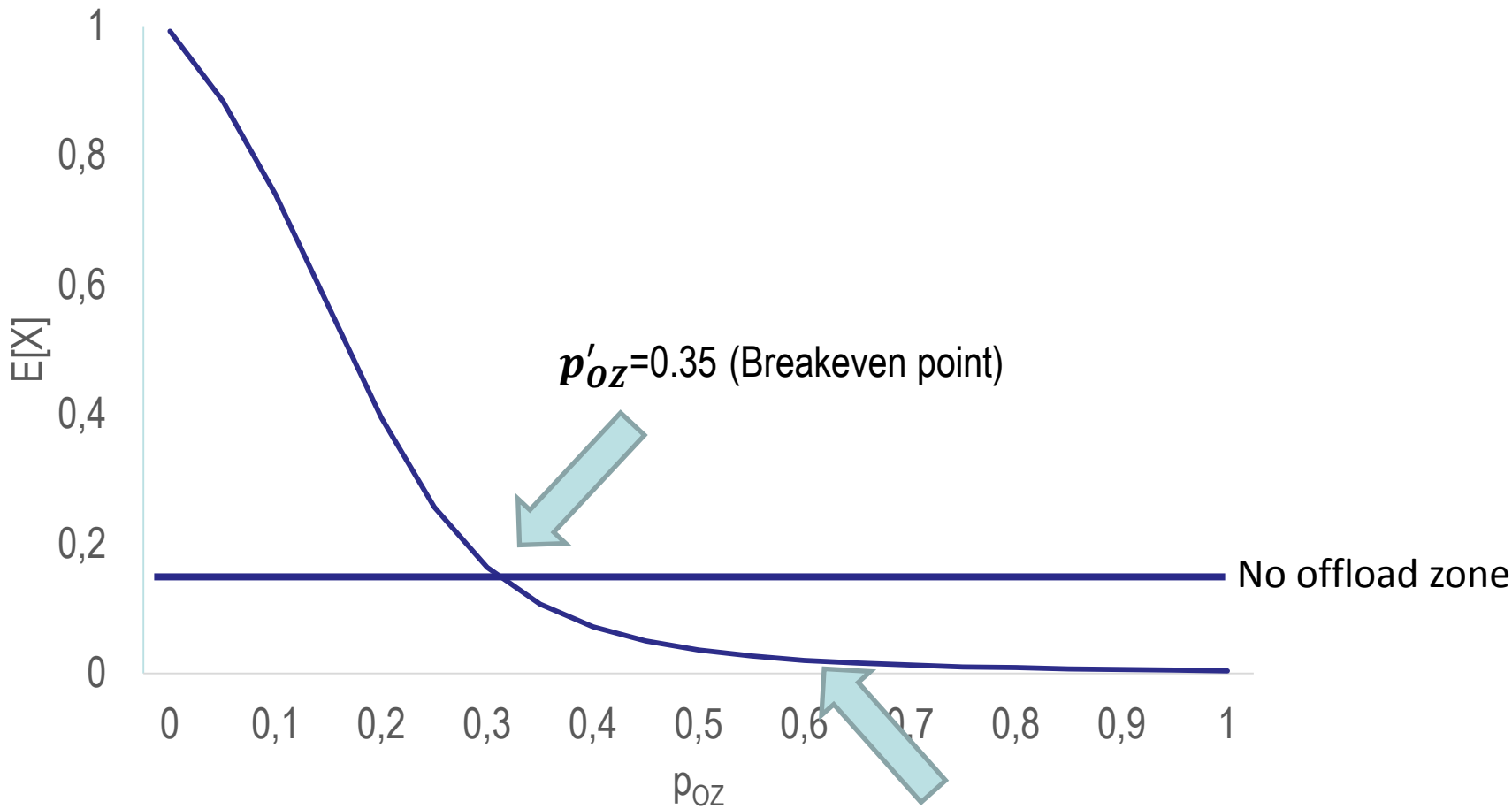

p''_{OZ}=0.6 (Diminishing returns threshold)
$\Delta E[X] < 0.005$ per 0.05 increase in p_{OZ}

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Larger problems

Run Time (seconds)	ED beds	OZ beds	m_1, m_2, m_3
687	5	2	10, 10, 25
25,606	5	2	20, 20, 50
14,161	30	2	10, 10, 25
500,540	30	2	20, 20, 50

p'_{OZ}	p''_{OZ}
0.35	0.6
0.35	0.6
0.3	0.55
0.3	0.55

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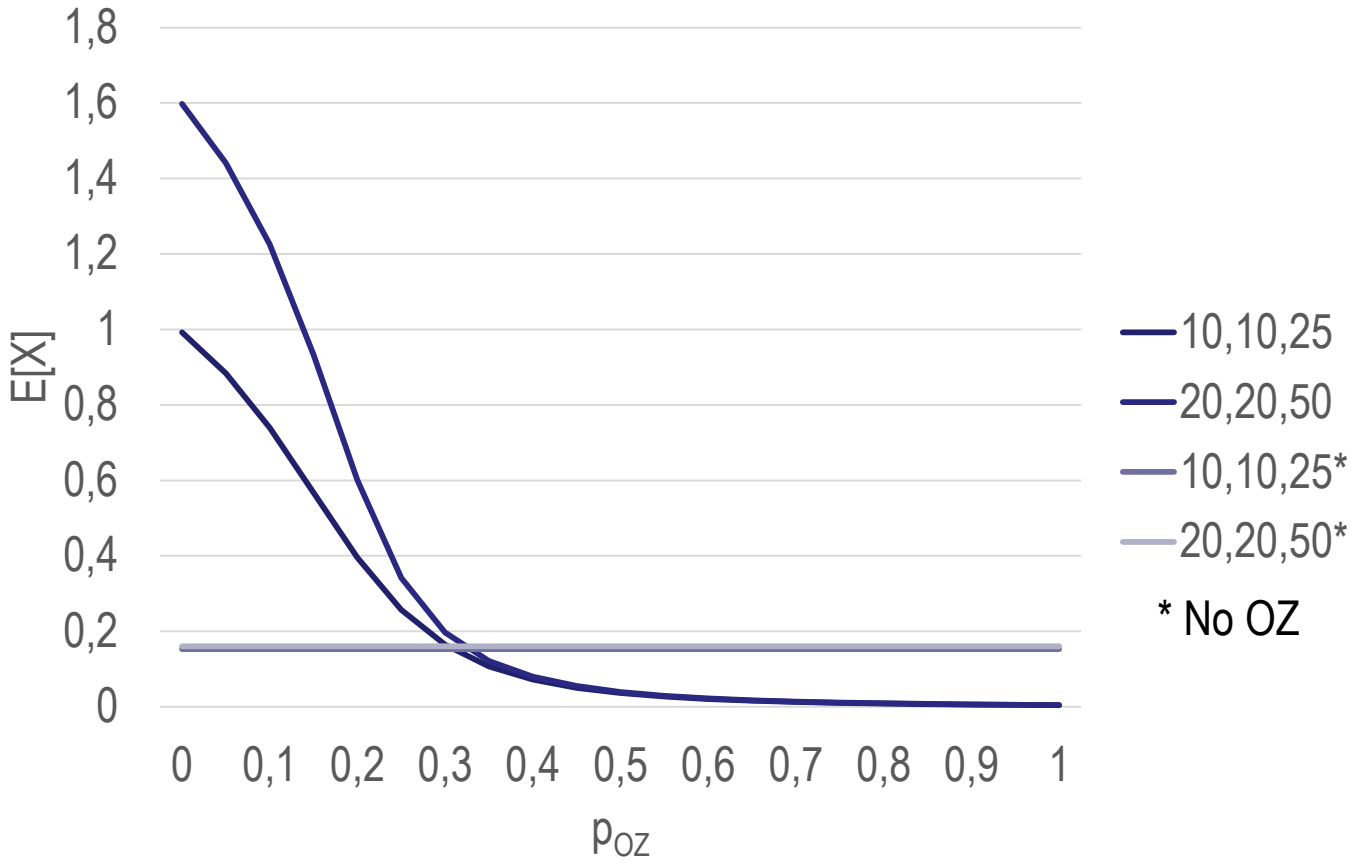
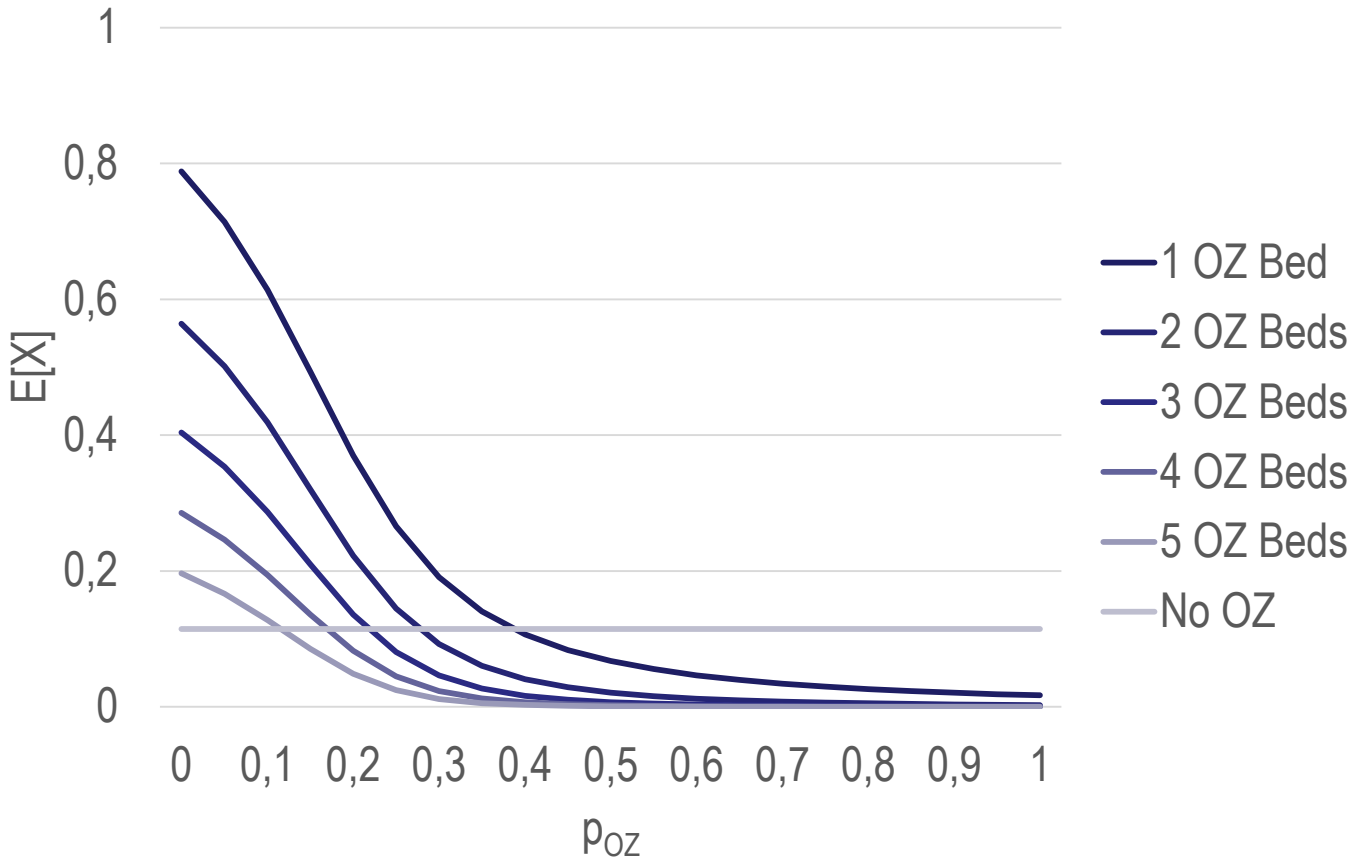
Larger problems



OZ bed capacity



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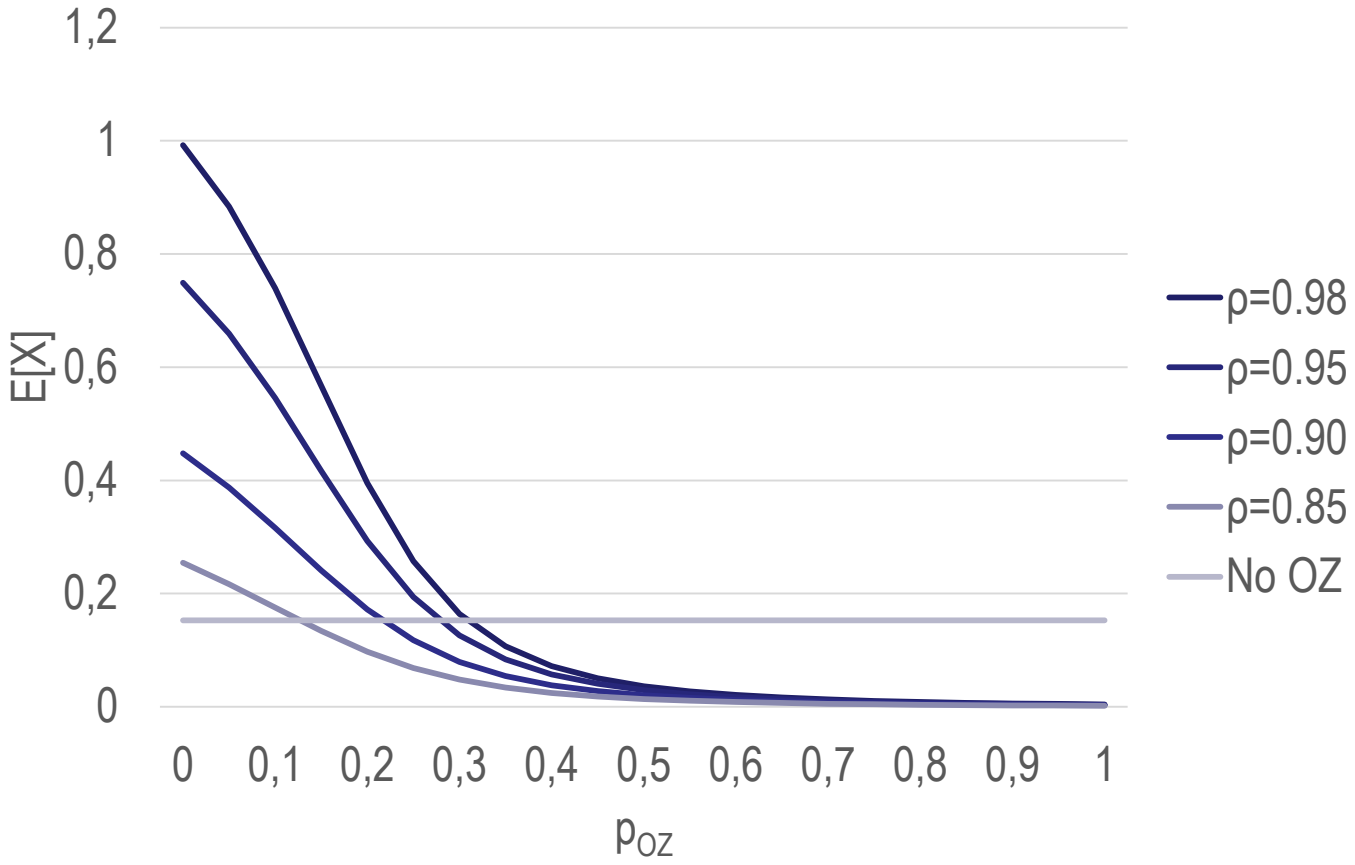
Less busy EDs



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Conclusions

- Model
  - Insensitive to reasonable queue length limits
  - Sensitive to OZ capacity
  - Sensitive to service load
- Offload Zone
  - When priority is disproportionately given to walk-in patients implementing an offload zone will actually increase offload delay
  - Depending on several factors, such as service load, number of beds and the patient mix:
    - Offload delay can be decreased if priority is given to offload zone patients at least a certain fraction of time (p'_{OZ})
    - Decreases in offload delay becomes negligible when priority is given to offload zone patients at least a certain fraction of time (p''_{OZ})

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Next steps

- Model
  - Approximate p'_{OZ} and p''_{OZ}
  - Validate with simulation*
  - Service rate distribution
- Case study
  - Detailed historical data
  - Validation with QEII or DGH ED (Actual baseline)
  - p_{OZ} to achieve NS Gov't benchmark of 20 minutes 90% of the time
- General
  - OZ bed sharing policy
- Holy Grail
  - Reserving ED beds in place of OZ

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- HFMEA: The Offload Zone to Mitigate EMS Offload Delay in the Emergency Department: A Process Map and Hazard Analysis
  - Poster Accepted at:
    - **Canadian Association of Emergency Physicians Conference**
    - **Maritime Trauma and Emergency Medicine conference**
    - **National Association of EMS Physicians**
    - **Dalhousie Division of Emergency Medical Services Research Day**
  - Journal Article:
    - **Canadian Journal of Emergency Medicine Special Issue for EMS (Under revision)**

- Modelling: The offload zone as a solution to the offload delay of the emergency medical services
  - Poster Accepted at:
    - **First International Workshop on Planning of Emergency Services**

Announcement

- The 17th Annual **Conference for Canadian Queueing Theorists and Practitioners** will be held at Dalhousie University, (Late) August 2015

- General goal: promote research and applications of queueing theory
- **Specific 2015 goal: Attract European speakers!**

- Details / Registration: email peter.vanberkel@dal.ca

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- Questions?