When Are Doctors Most Needed in the Emergency Room: Risk-Adaptive Physician Shift Scheduling

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Emergency Departments

- High congestion together with extended waiting time in the Emergency Departments.

Figure 1: ED Waiting Area

Waiting time

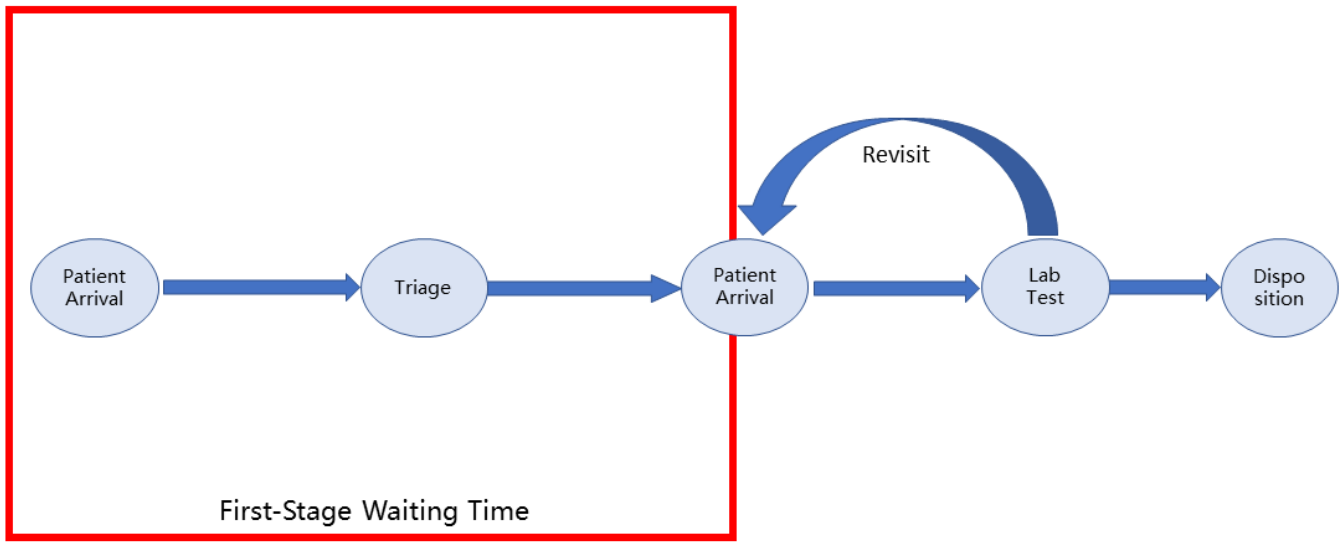


Figure 2: Patients Flow in ED

Long Waiting time for Patients

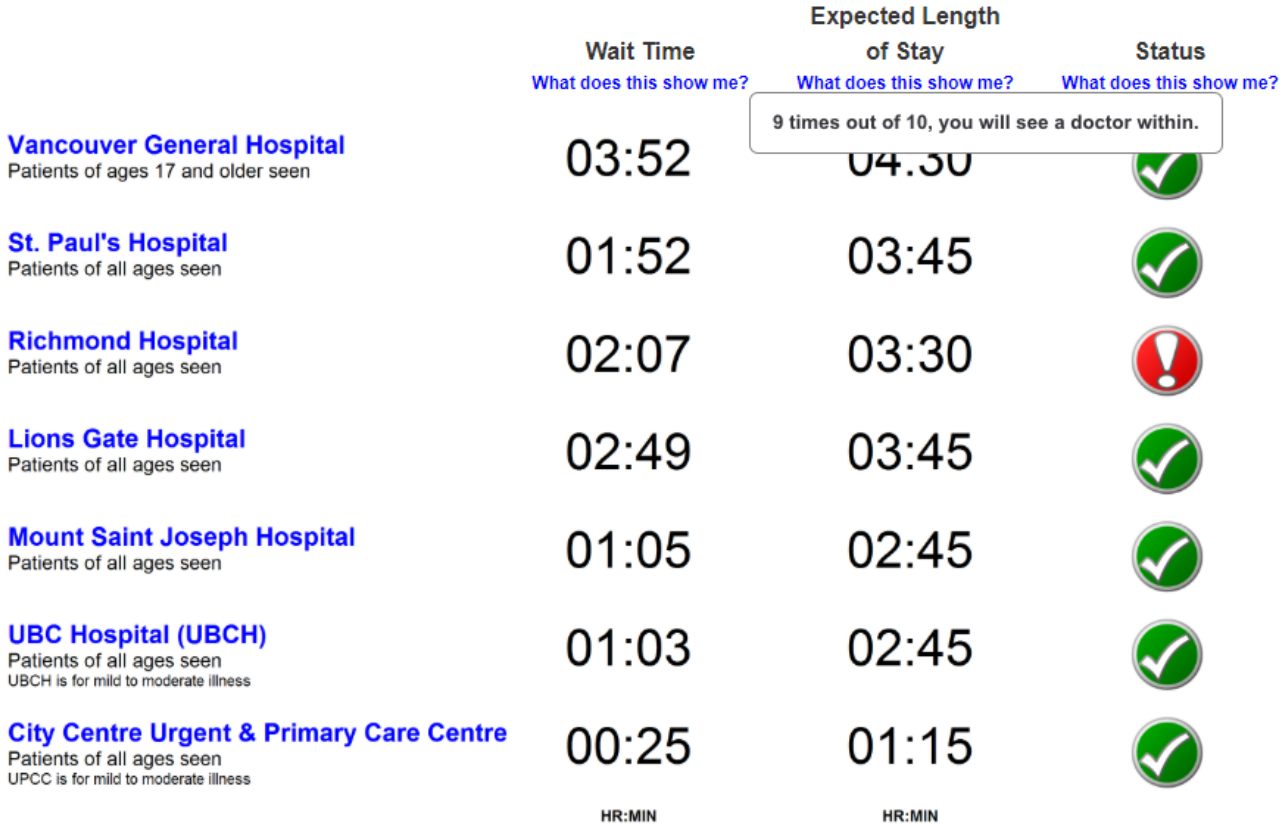


Figure 3: A snapshot of the ED waiting time announcement (edwaitingtimes.ca).

Bottleneck Resources in ED

- ED bottleneck resources: physicians, beds, etc.
- The long waiting time has multiple reasons: inefficient staffing schedules, insufficient beds at inpatient unit, etc.

Since we focus on the first-stage waiting time (Time to See MD), we focus on physicians.

Research Question

How can we adjust physicians' shifts to achieve better outcome?

ED Waiting Census

Figure 4: The average of waiting census (2018-2019).

The Current Schedule

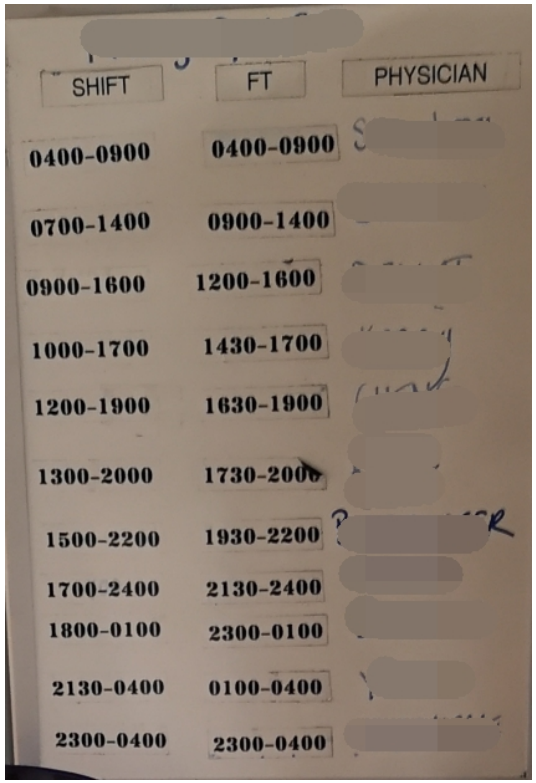


Figure 5: The Intra-day Physician Shift at SPH.

Demand-Based Scheduling

- ED administrator sets the physician schedules based on historical arrival data.
- Congestion-Minimization Way of Thinking.

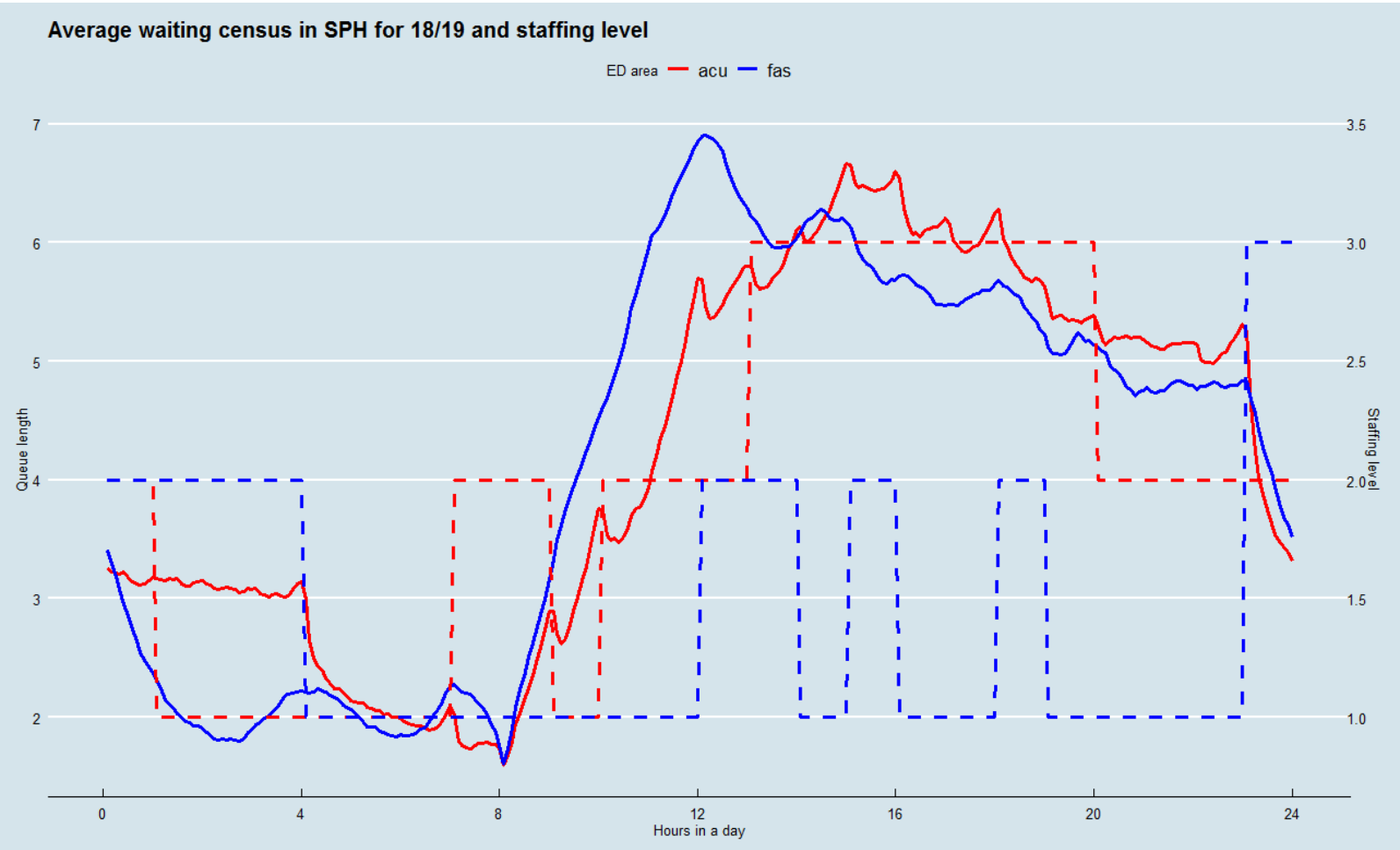


Figure 6: Average waiting census and staffing level at SPH (2018-2019).

Is Congestion-Minimization the Right Objective?

The underlying assumption for congestion minimization is that the waiting cost is linear in cumulative waiting time and is identical for all patients. However, is this the truth?

Patient mix

Case 1: three triage-2 patients at 1pm;
Case 2: three triage-3 patients at 4pm.
It is better to set the shift to cover 1pm rather than 4pm.

Convex waiting cost

Case 1: two triage-2 patients have waited ten and thirty minutes, respectively at 1pm;
Case 2: two patients with the same physical attributes have waited twenty minutes at 4pm.
It is better to cover 1pm rather than 4pm.

The Waiting Cost is Nonlinear and Patient Specific

- Most congested period $\neq$ Most costly period.
- Cost depends on individual attributes.
- The cost is convexly increasing in waiting time. (Osuna et al. (1985), Bernstein et al. (2009), Saghafian et al. (2014)).

Challenges in Measuring the Waiting Cost

- The "waiting cost" here includes physiological risks as well as the potential social impact and lacks of a clear measurement.
- Calibrating the comprehensive and integrated waiting cost of patients in the first stage is not easy: short time, not enough data collected. (different from the inpatient unit)

Our Proposed Method for Measuring Waiting Cost

- Assumption: physician picks patients for cost minimization.
- We use physician's decisions to infer the waiting cost of patients in an indirect way, i.e., the physician-perceived cost for patients.

Overview of the Work

- We first estimate the patients' waiting cost based on a framework.

  Ding Y, Park E, Nagarajan M, Grafstein E. Patient prioritization in emergency department triage systems: An empirical study of the canadian triage and acuity scale (CTAS). Manufacturing & Service Operations Management. 2019 Oct;21(4):723-41.

- We then formulate a stochastic optimization to minimize the total waiting cost (estimated) and derive the optimal physician shift.

  Ding Y, Jin Y, Hunte G. When are doctors most needed in the emergency department? Risk-adaptive physician shift scheduling. Working paper.

Literature Review

Based on methodology: three streams of literature on ED operations.

- Queueing. Green et al. (2006), Tezcan et al. (2010), Huang et al. (2015), Baron et al. (2019), Chan et al. (2019), Bijvank et al. (2019), Liu and Sun (2019), Sun et al. (2019), Chen et al. (2019).
- Optimization. Ikegami et al. (2003), Gutjahr et al. (2007), Burke et al. (2014), Saghafian et al. (2015), Liu et al. (2018), He et al. (2019), Rastpour et al. (2020).
- Empirical. Green et al. (2013), Kim et al. (2014), Batt et al. (2017), Baron et al. (2019), Ding et al. (2019).

- The doctors observe the same information as we researchers do.

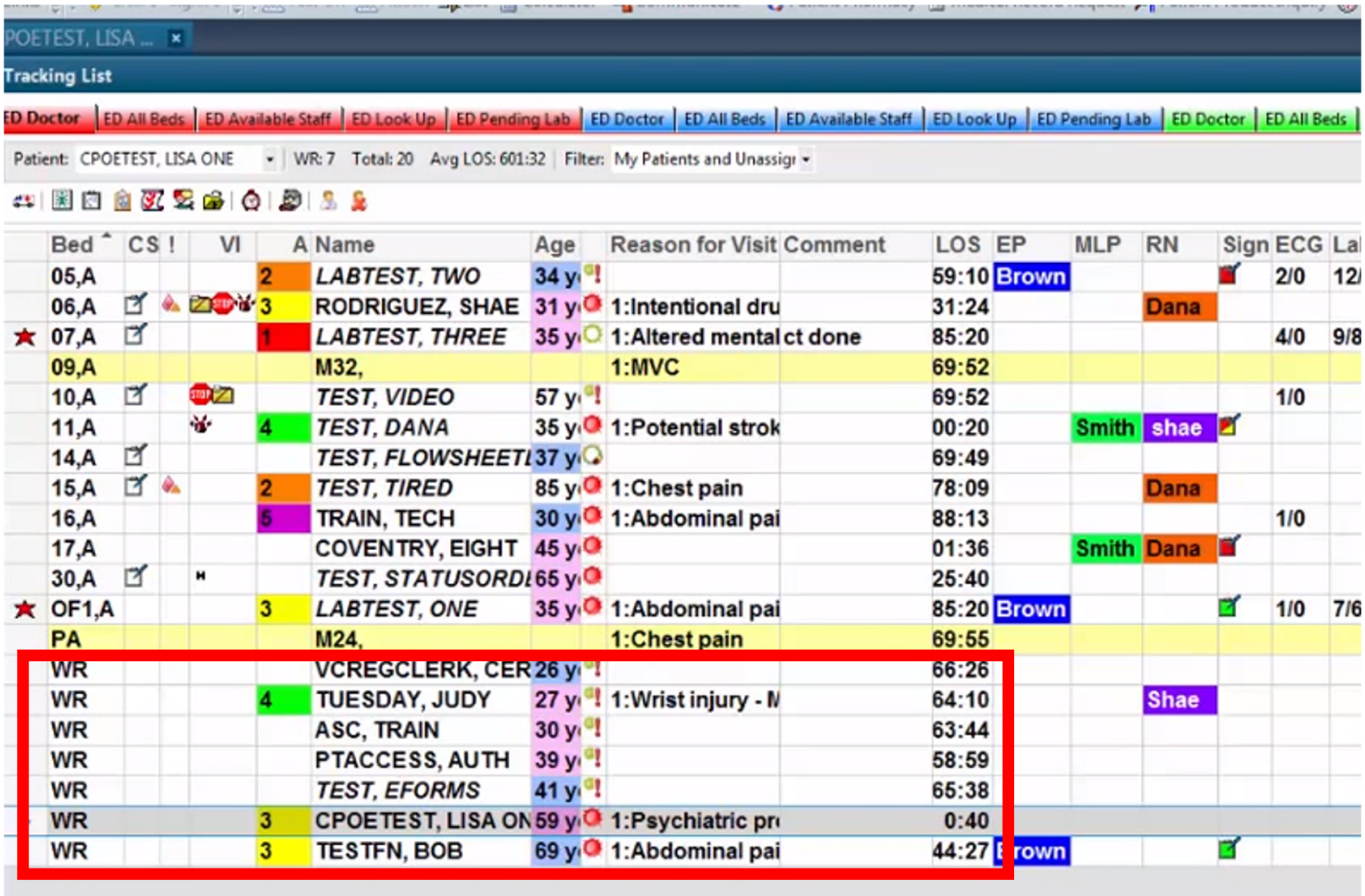


Figure 7: A snapshot of the Patient Care Information System (PCIS).

Estimated Marginal Waiting Cost Function

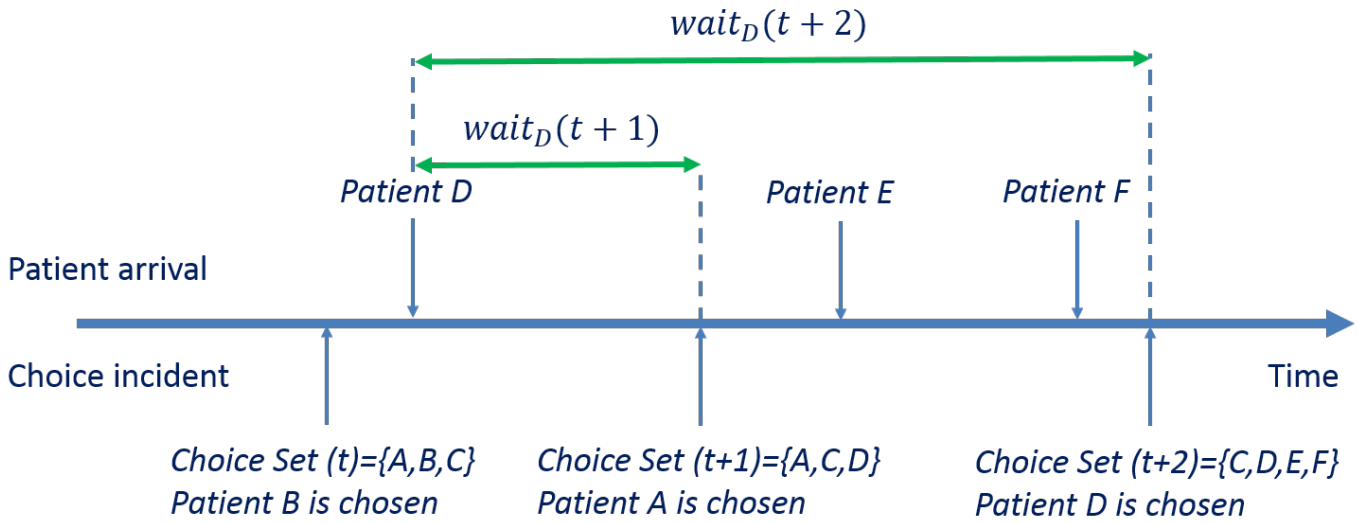
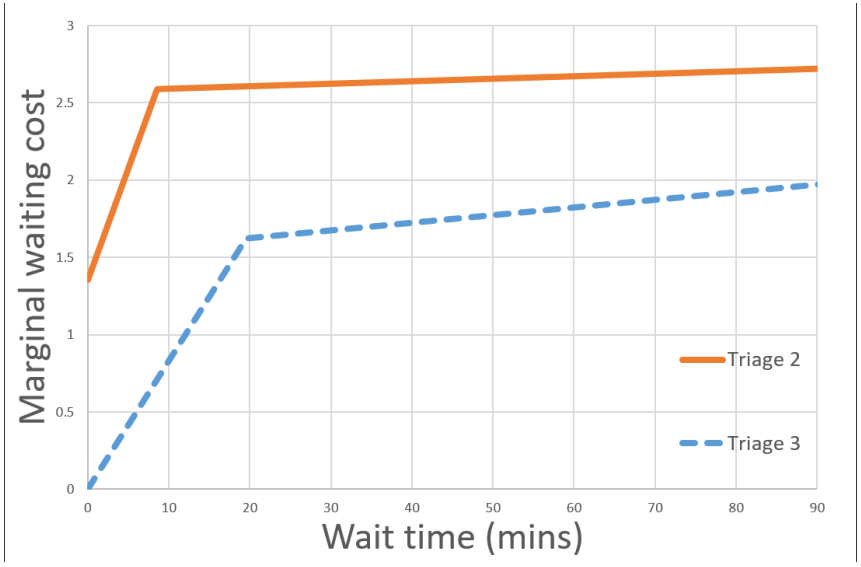


Figure 8: An approximate diagram of the estimated MWC

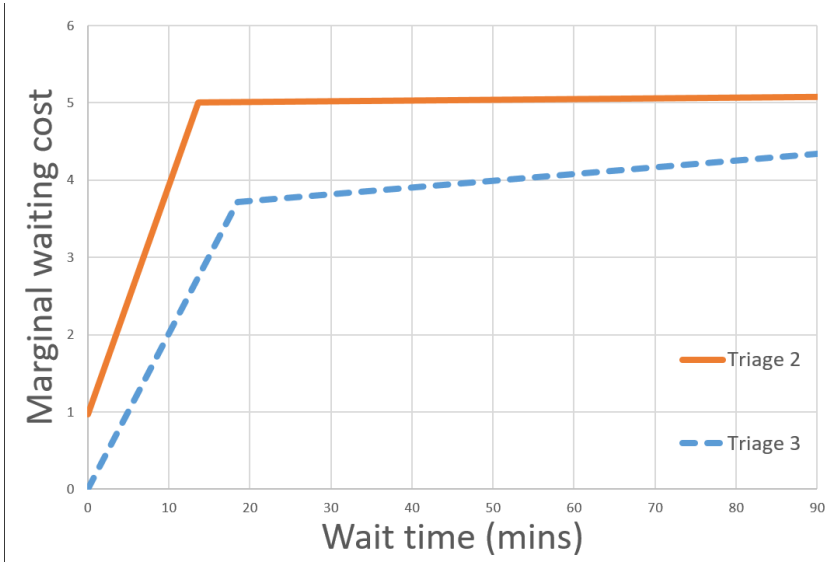
Available Dataset

- The data is at the patient visit level where each observation corresponds to a single patient visit to the ED.
- 1.2 million observations and 121 variables from April 2016 till March 2019 (fiscal year).
- Covers 6 major EDs in Metro Vancouver.

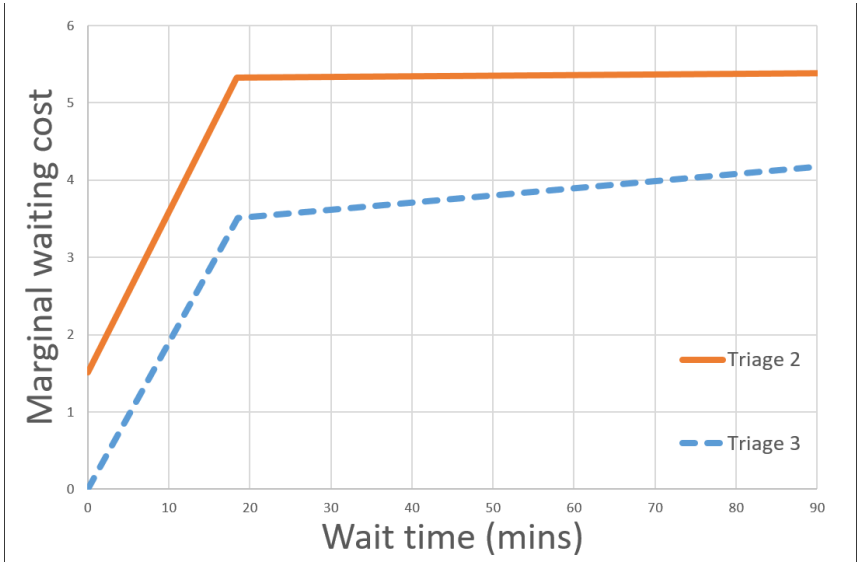
Estimated Marginal Waiting Cost

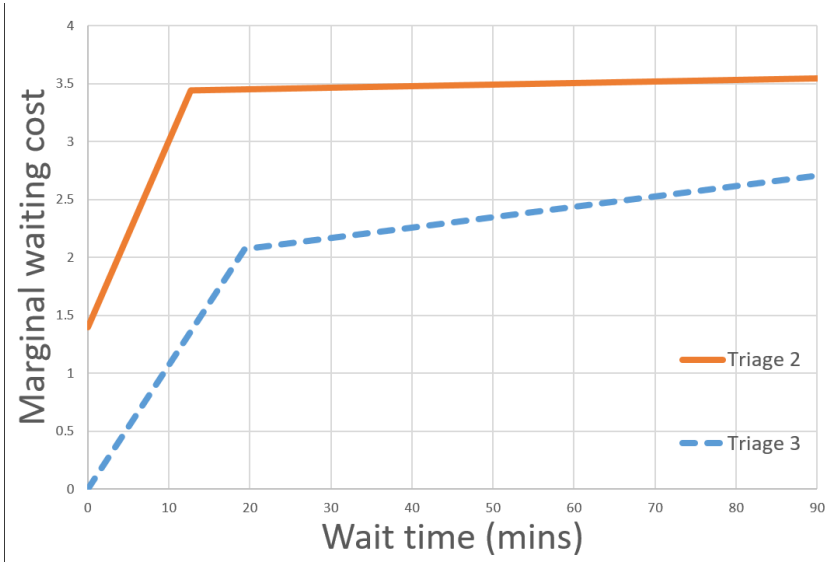


(a) ED A



(b) ED B





CTAS Fractile Response Objective

CTAS score	Triage	Target	Fractile
1	Resuscitation	Immediately	98%
2	Emergent	15 minutes	95%
3	Urgent	30 minutes	90%
4	Less urgent	60 minutes	85%
5	Non-urgent	120 minutes	80%

The Physician-Demand Index

- Using the estimated patient cost, we can infer which period is most costly.
- **Interpretation**: The index represents the reduction in the total waiting cost by adding one additional physician pick at certain time of a day.
- We search for the optimal shift adjustment using the *physician-demand* index.

Index Formulation

$$\text{Index}(t) \equiv \int_t^{\gamma(t)} \max_{i \in \text{Choiceset(s)}} C_i'(s)ds,\ \gamma(t) = \inf\{s | s \geq t, Q(s) = 0\},$$

Index Computation Results

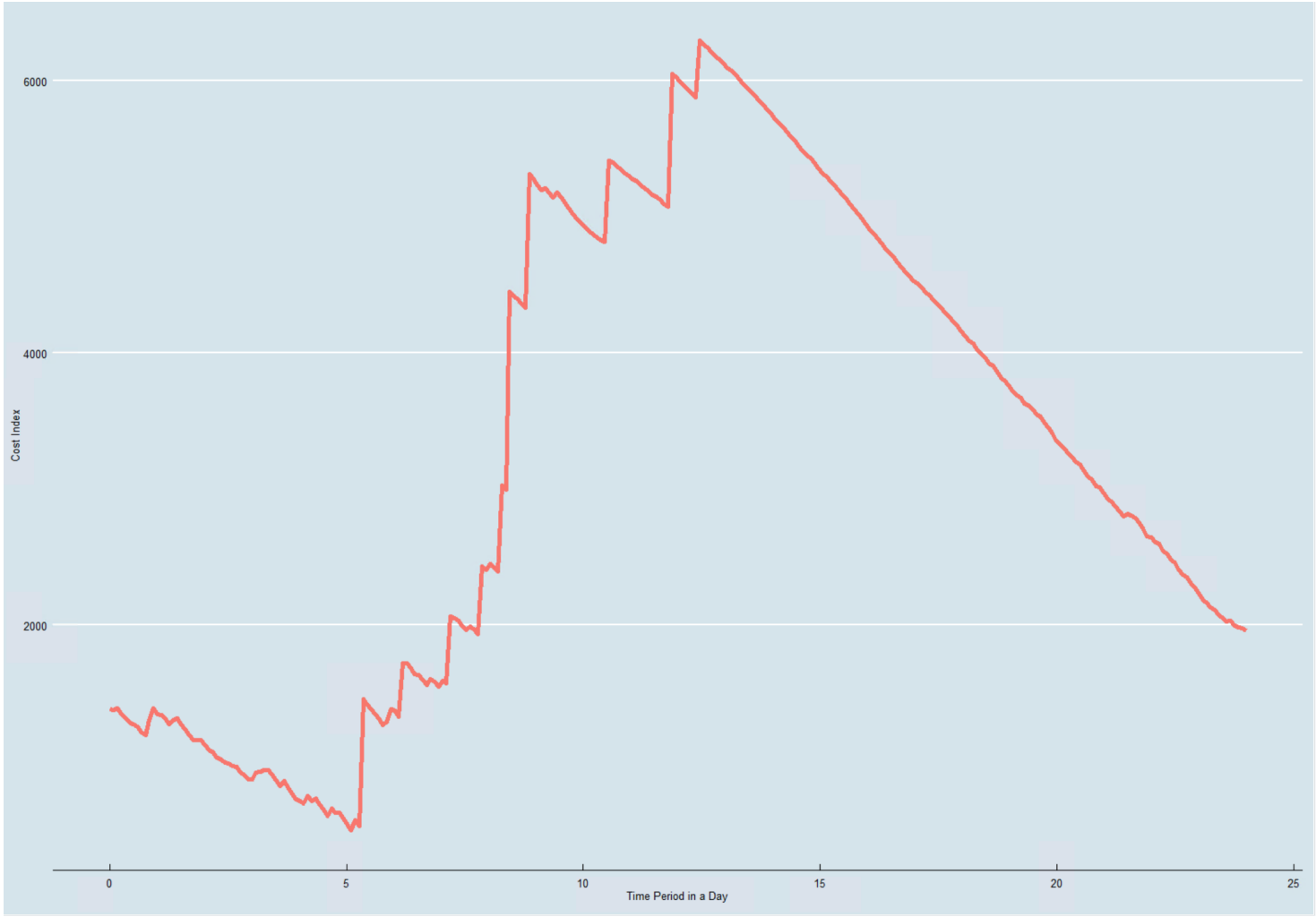


Figure 10: The average index of two weeks along one day.

Adjusting Current Staffing Schedules

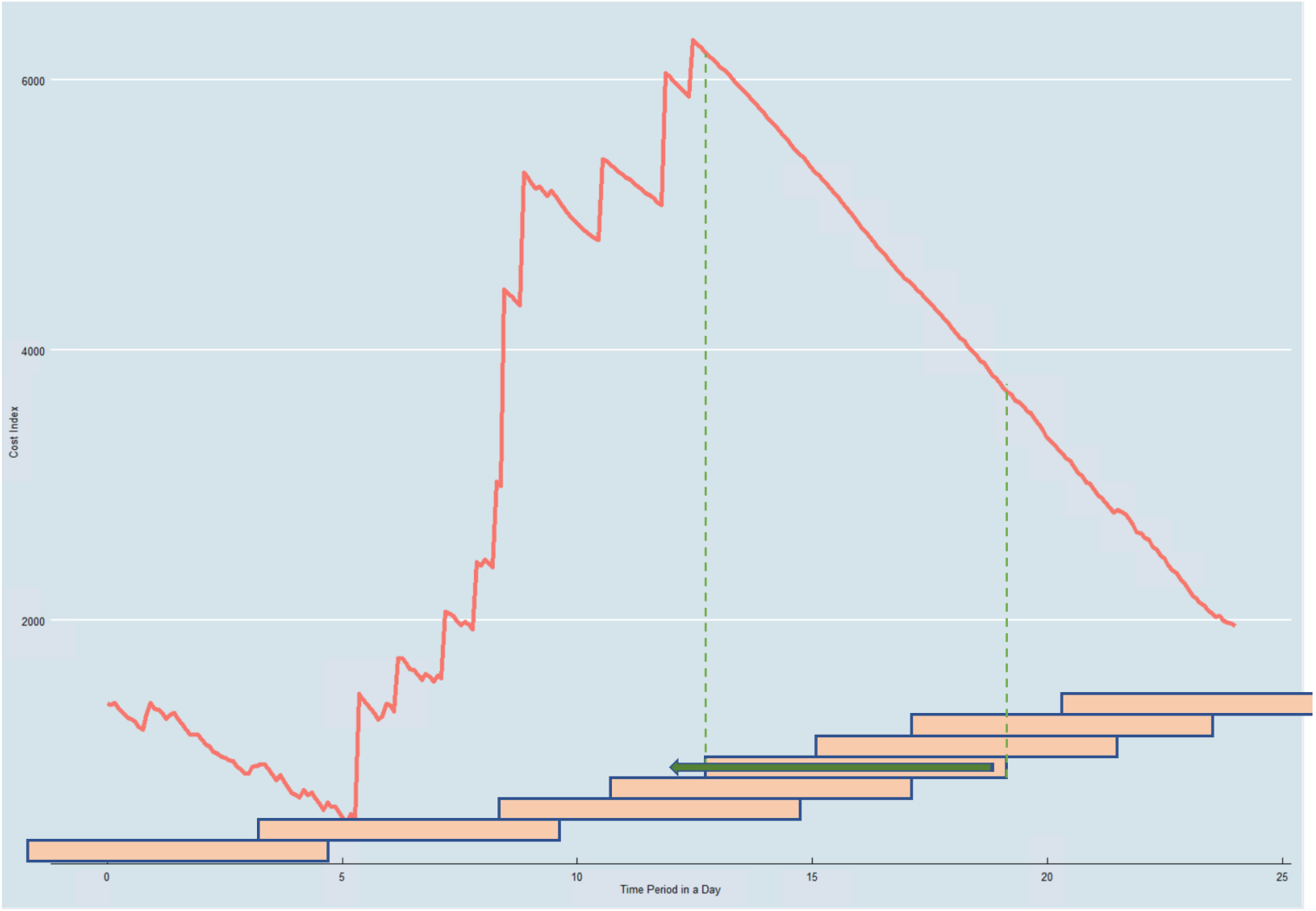


Figure 11: Likely change of the current staffing schedules.

Adjusting Current Staffing Schedules

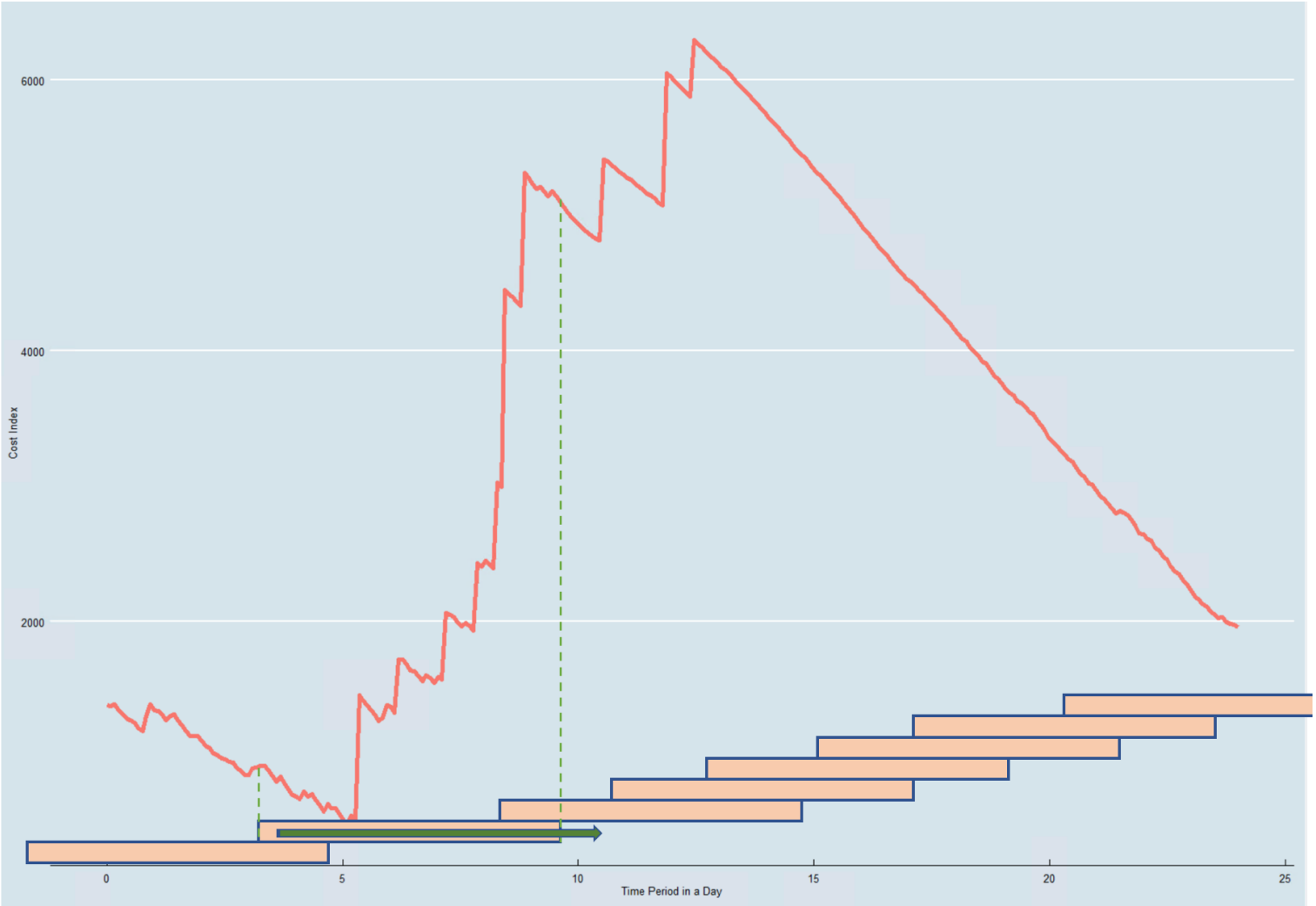


Figure 12: Likely change of the current staffing schedules.

Future Directions

- Robust check for the model by considering seasonality, physician heterogeneity
- Running simulations to compare the performance of the index policy, an ad hoc policy and the current policy.
- We plan for implementation at our collaborating hospital.

THANK YOU !