Electronic Companion to Vertical Patient Streaming in Emergency Departments

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EC.1. Proofs

All proofs for equations, theorems and lemmas, where applicable, are given below.

Proof of Lemma 1

Denote the cumulative distribution functions (CDF) of departures from the VPP and direct arrivals to the ED (i.e., after triage) by $F_a(t)$ and $F_b(t)$, respectively. The probability of an arrival at time $T \leq t$ can be written as:

$$\begin{aligned} F_{a\cup b}(t) &= \Pr\{T \leq t\} = \Pr\{\text{departure from VPP} < t\} \cup \Pr\{\text{direct arrival} \leq t\} \\ &= F_a(t) + F_b(t) - F_a(t)F_b(t) \end{aligned}$$

The direct arrival interarrival time distribution is an exponential distribution with rate $(1-\tau)\lambda$. Hence,

$$F_b(t) = 1 - e^{-(1-\tau)\lambda t}$$

To find $F_a(t)$, we leverage the results from Tang (1994). Denote $\lambda_v = p(\tau)\tau\lambda$. We have:

$$\text{Vacation length CDF} = V(t) = 1 - e^{-t/u}$$

$$v(\lambda_v) = \int_0^\infty e^{-\lambda_v x} dV(x) = \frac{1}{1+\lambda_v u}$$

$$\widetilde{V}(t) = \frac{\int_0^\infty V(t+x)\lambda_v e^{-\lambda_v x} dx - v(\lambda_v)}{1 - v(\lambda_v)} = 1 - e^{-t/u}$$

$$p_0 = \frac{(1-\lambda/\mu_V)\Big(1 - v(\lambda_v)\Big)}{\lambda_v u}$$

$$F(t) = 1 - e^{-\lambda_v t}$$

$$G(t) = 1 - e^{-\mu_V t}$$

Finally, Equation 21 from Tang (1994) shows the interdeparture time CDF of the VPP in steady state:

$$F_a(t) = (1-p_0)G(t) + p_0 \int_0^t dF(x) * dG(x) * d\widetilde{V}(t)$$

Finally, $f_a(t) = dF_{a\cup b}(t)/dt$.

□

Proof of Lemma 2

It can be shown that the functional form of the receiver operating characteristic (ROC) curve of Equation 4 is as follows:

$$TPR(FPR \mid k_1, \alpha) = \begin{cases} \dfrac{(1-\alpha-\alpha k_1)}{(1-\alpha)k_1} FPR, & \text{if } 0 \le FPR < k_1 \\ \dfrac{(1-\alpha-k_1)+\alpha k_1 FPR}{(1-\alpha)(1-k_1)}, & \text{Otherwise.} \end{cases} \tag{EC.1}$$

where, TPR and FPR are the true positive rate and false positive rate, respectively.

The AUC is calculated by integrating the ROC curve, which results in the following:

$$AUC = \int_0^1 TPR(FPR \mid k_1, \alpha) dFPR = 1 - \frac{k_1}{2(1-\alpha)} \tag{EC.2}$$

□

Proof of Theorem 1

If $u = 0$, the LOS of the main ED, LOS_E, then becomes the sojourn time of an $M/M/1$ queue since its arrival follows an exponential distribution with rate λ_E, and can be calculated as follows:

$$LOS_E = \frac{1}{1-\lambda_E}.$$

In addition, note that in reality, $\mu_V >> 1$ because the average time spent in the VPP is in the order of $\sim$ 10 minutes, while that of the ED is $\sim$ 200 minutes. Therefore, although the VPP is an $M/M/1$ queue (with no vacation), we can further simplify the VPP by assuming that it is an $M/M/\infty$ queue with a service rate of μ_V. This is essentially the equivalency of an $M/M/1$ queue with an $M/M/\infty$ queue when the rate at which customers arrive is much less than the service rate, and therefore, practically, a queue rarely forms. In this case, the LOS of the VPP, LOS_V, is:

$$LOS_V = \frac{1}{\mu_V}.$$

Hence, the overuse and underuse costs defined in Equations 9 and 10, can be reduced to Equations EC.3 and EC.4, respectively.

$$C_O(\tau \mid k_1, \lambda, \mu) = \frac{1}{\mu_V}. \tag{EC.3}$$

$$C_U(\tau \mid k_1, \lambda, \mu) = \frac{1}{1-(1-\tau+p(\tau)\tau)\lambda} - \frac{1}{\mu_V} \tag{EC.4}$$

Substituting Equations EC.3, EC.4, 7 and 8 in Equation 11 yields the total cost function to be minimized, C_T:

$$C_T(\tau \mid \alpha, k_1, \lambda, \mu_V) = \begin{cases} -\dfrac{\alpha\lambda+\mu_V}{\lambda\mu_V} + \dfrac{\tau}{\mu_V} + \dfrac{1-(1-\alpha)\lambda}{\lambda\Big(1-\lambda+(1-k_1)\lambda\tau\Big)}, & \text{if } \tau \le \alpha \\ \dfrac{A+B\tau+C\tau^2}{\mu_V\Big(-1+\alpha+\lambda+\alpha\lambda(-2+\alpha+k_1-k_1\tau)\Big)}, & \text{if } \tau > \alpha \end{cases} \tag{EC.5}$$

where:

$$\begin{aligned} A &= -\alpha\Big(-1+\alpha+\lambda+\alpha(-2+\alpha+k_1)\lambda+k_1\mu_V\Big) \\ B &= \Big(-1+\alpha+\lambda+\alpha(-2+\alpha+k_1+\alpha k_1)\lambda+\alpha k_1\mu_V\Big) \\ C &= -\alpha k_1\lambda \end{aligned}$$

The τ that minimizes Equation EC.5 is the optimal fraction of patients that must be routed to the VPP.

We begin by ensuring that C_T is convex for all combinations of $(\alpha, k_1, \lambda, \mu_V)$ in their allowable range. We verify that:

- C_T is continuous at $\tau = \alpha$;
- $\partial^2 C_T/\partial\tau^2 \ge 0$ in both $\tau \le \alpha$ and $\tau > \alpha$ (i.e., second-order condition).

Thus, the function is continuous and convex for all parameters. Next, we find the first-order condition (FOC) that minimizes C_T. We do this separately for $\tau \le \alpha$ and $\tau > \alpha$. For notational convenience, we define:

$$C_1(\tau \mid \alpha, k_1, \lambda, \mu_V) = -\frac{\alpha\lambda+\mu_V}{\lambda\mu_V} + \frac{\tau}{\mu_V} + \frac{1-(1-\alpha)\lambda}{\lambda\Big(1-\lambda+(1-k_1)\lambda\tau\Big)}, \quad \tau \le \alpha$$

$$C_2(\tau \mid \alpha, k_1, \lambda, \mu_V) = \frac{A+B\tau+C\tau^2}{\mu_V\Big(-1+\alpha+\lambda+\alpha\lambda(-2+\alpha+k_1-k_1\tau)\Big)}, \quad \tau > \alpha$$

Case 1: $\tau \leq \alpha$

Setting $\partial C_1/\partial \tau = 0$, we obtain a unique solution for that minimizes C_1:

$$\tau_1^* = \frac{1-\lambda}{(-1+k_1)\lambda} + \sqrt{\frac{(-1+\lambda-\alpha\lambda)\mu_V}{(-1+k_1)\lambda^2}}, \tag{EC.6}$$

where τ_1^* exists when the following conditions hold:

$$\begin{aligned} &0 < \alpha < \frac{1}{2} \quad \text{(for all } \alpha\text{'s)} \\ &\frac{1}{2} < k_1 < 1-\alpha \\ &2 < \mu_V < \mu_1 \\ &\lambda_1 < \lambda < \lambda_2, \end{aligned}$$

where μ_1 and λ_1 are defined in Proposition 3 and λ_2 is defined as:

$$\begin{aligned} \lambda_2(\alpha, k_1, \mu_V) = \\ &\frac{2-\alpha(-1+k_1)(-2+\mu_V)+(-1+k_1)\mu_V}{2\Big(1-\alpha(1-k_1)\Big)^2} - \\ &\frac{-\sqrt{(-1+k_1)\mu_V\Big(4\alpha k_1(-1+\alpha-\alpha k_1)+(1-\alpha)^2(-1+k_1)\mu_V\Big)}}{2\Big(1-\alpha(1-k_1)\Big)^2} \end{aligned}$$

Outside of the range where the FOC has a unique solution, τ_1^* is either 0 or α, which we determine based on whether $\partial C_1/\partial \tau$ is positive or negative. This algebra yields the following boundary solutions when $0 \leq \tau \leq \alpha$:

$$\tau_1^* = \begin{cases} \alpha, & \text{if} \quad 0 < k_1 < \frac{1}{2}, \quad \text{since} \quad \partial C_1/\partial\tau \leq 0 \\ \alpha, & \text{if} \quad \mu_V > \mu_1, \quad \text{since} \quad \partial C_1/\partial\tau \leq 0 \\ 0, & \text{if} \quad 0 < \lambda < \lambda_1, \quad \text{since} \quad \partial C_1/\partial\tau \geq 0 \\ \alpha, & \text{if} \quad \lambda_2 < \lambda < 1, \quad \text{since} \quad \partial C_1/\partial\tau \leq 0 \end{cases} \tag{EC.7}$$

Case 2: $\tau \geq \alpha$

Setting $\partial C_2/\partial \tau = 0$, we obtain

$$\tau_2^* = \frac{-1+\alpha+\lambda+\alpha\lambda(-2+\alpha+k_1+k_1\sqrt{-\frac{(-1+\alpha)(1+(-1+\alpha)\lambda)\mu_V}{\alpha k_1\lambda^2}})}{\alpha k_1 \lambda}, \tag{EC.8}$$

where τ_2^* exists when the following conditions hold:

$$0 < \alpha < \frac{1}{2},$$

$$0 < k_1 < 1 - \alpha,$$
$$\max\{2, \mu_2\} < \mu_V < \mu_4,$$
$$\lambda_3 < \lambda < \lambda_4;$$

where, $\lambda_3, \lambda_4, \mu_2, \mu_4, k_A$ are defined as:

$$\lambda_3(k_1, \alpha, \mu_V) = \frac{1}{2}\left(\frac{2 - \alpha(2 + k_1(-2 + \mu_V))}{(1 + \alpha(-1 + k_1))^2} - \sqrt{-\frac{\alpha^2 k_1^2 \mu_V (4 + \alpha(-4 + 4k_1 - \mu_V) + \mu_V)}{(-1 + \alpha)(1 + \alpha(-1 + k_1))^4}}\right),$$
$$\lambda_4(\alpha, k_1, \mu_V) = \frac{1 - \alpha - \alpha k_1 \mu_V}{(-1 + \alpha)^2},$$
$$\mu_2(\alpha, k_1) = \frac{1 - \alpha}{k_1},$$
$$\mu_4(\alpha, k_1) = \frac{1 - \alpha}{\alpha k_1}$$
$$k_A(\alpha) = \frac{(2 - \alpha) - \sqrt{3 - 2\alpha}}{1 - \alpha}$$

Outside of the range where the FOC has a unique solution, τ_2^* is either 1 or α, which we determine based on whether $\partial C_2/\partial \tau$ is positive or negative. This algebra yields the following boundary solutions when $\alpha \le \tau \le 1$:

$$\tau_2^* = \begin{cases} \alpha, & \text{if} \quad \lambda < \lambda_3 \quad \text{since} \quad \partial C_2/\partial \tau \ge 0 \\ \alpha, & \text{if} \quad k_1 < k_A \text{ and } \mu_V < \mu_2, \quad \text{since} \quad \partial C_2/\partial \tau \ge 0 \\ 1, & \text{if} \quad \max\{2, \mu_3\} < \mu_V \text{ and } \max\{0, \lambda_4\} < \lambda < 1 \quad \text{since} \quad \partial C_2/\partial \tau \le 0 \end{cases} \tag{EC.9}$$

where, μ_3 and k_A are defined as:

$$\mu_3(\alpha, k_1) = \frac{1 - \alpha}{k_1}$$
$$k_A(\alpha) = -\sqrt{\frac{3 - 2\alpha}{(-1 + \alpha)^2}} + \frac{-2 + \alpha}{-1 + \alpha}.$$

Note that the region $\mu_2 < \mu_V < \mu_3$ and $\lambda > \lambda_4$ does not exist. Therefore, for the sake of simplicity we do not further break down the state space in the remainder of the proof.

With the optimal τ obtained when $0 < \tau < \alpha$ or $\alpha < \tau < 1$, we finally merge the regions to find τ^* for each combination of parameters.

We realize the following relationship:

$$0 < k_A < \frac{1}{2} < 1 - \alpha.$$

Note that when $k_1 < \frac{1}{2}$, $\tau_1^* = \alpha$ and C_1 is decreasing. Therefore, $\tau^* = \tau_2^*$ from Case 2.

When $k_1 \ge \frac{1}{2}$, we observe:

$$2 < \mu_2 < \mu_1 < \mu_4.$$

Note from Equation EC.7 that when $k_1 \geq \frac{1}{2}$ and $\mu_V > \mu_1$, $\tau_1^* = \alpha$ and C_1 is decreasing. Therefore, again, $\tau^* = \tau_2^*$ from Case 2.

However, when $k_1 \geq \frac{1}{2}$ and $\mu_V < \mu_1$, the solutions from Case 1 can be the overall solution to τ^*. Observe that the following relationship holds when $\mu_V < \mu_1$:

$$0 < \lambda_1 < \lambda_2 < \lambda_3 < \lambda_4$$

Further, note that when $\lambda_2 < \lambda$, $\tau_1^* = \alpha$ and C_1 is decreasing. Therefore, again, $\tau^* = \tau_2^*$ from Case 2. Also, note that when $\lambda < \lambda_3$, $\tau_2^* = \alpha$ and C_2 is increasing; therefore, $\tau^* = \tau_1^*$ in this case. Hence, overall, when $\lambda < \lambda_2$, $\tau^* = \tau_1^*$.

Table EC.1 summarizes the optimal threshold τ^* for all parameter combinations.

Finally, before we conclude our proof, we verify that the queue stability conditions are met across our parameter domain.

For the VPP queue to be stable, we require: $\rho_V = \frac{\tau\lambda}{\mu_V} < 1$. Given the parameter constraints $\mu_V > 2$ and $\lambda \in (0,1)$, it easily follows that for any $\tau \in [0,1]$:

$$\rho_V = \frac{\tau\lambda}{\mu_V} \leq \frac{\lambda}{\mu_V} < \frac{1}{2} < 1.$$

Thus, the VPP queue is guaranteed to be stable for any value of τ in the feasible domain.

Similarly, we require $\rho_{ED} = (1-\tau)\lambda + p(\tau)\tau\lambda < 1$ for the main ED queue to maintain stability. By replacing $p(\tau)$, for $\tau \leq \alpha$, we have:

$$\rho_{ED} = (1-\tau)\lambda + k_1\tau\lambda = \lambda(1-(1-k_1)\tau).$$

Since $k_1 < 1-\alpha$ and $\alpha < 0.5$, we know that $k_1 < 0.5$, which means $1-k_1 > 0.5$. Therefore, ρ_{ED} decreases as τ increases from 0 to α, and $\rho_{ED} \leq \lambda < 1$.

Finally, in the case where of $\tau > \alpha$, after simplification:

$$\rho_{ED} = \lambda\left(1 - \tau + \frac{(\tau-\alpha)(1-\alpha) + \alpha k_1(1-\tau)}{(1-\alpha)}\right) = \lambda\left(1 - \alpha + \frac{\alpha k_1(1-\tau)}{1-\alpha}\right)$$

Since $0 < \alpha < 0.5$ and $0 < k_1 < 1-\alpha$, we can establish:

$$\rho_{ED} \leq \lambda(1 - \alpha + \frac{\alpha k_1}{1-\alpha}) < \lambda \tag{EC.10}$$

Therefore, $\rho_{ED} < \lambda < 1$ for all $\tau \in [0,1]$. This confirms that both the VPP and main ED queues remain stable for all optimal threshold values τ^* characterized, without requiring additional explicit stability constraints.

□

k_1	μ_V	λ	τ^*
$k_1 < k_A$	$2 < \mu_V < \mu_2$	$0 < \lambda < 1$	α
	$\mu_2 < \mu_V < \mu_4$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2
		$\lambda_4 < \lambda < 1$	1
	$\mu_4 < \mu_V$	$0 < \lambda < 1$	1
$k_A < k_1 < 1/2$	$2 < \mu_V < \mu_4$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2
		$\lambda_4 < \lambda < 1$	1
	$\mu_4 < \mu_V$	$0 < \lambda < 1$	1
$1/2 < k_1 < 1-\alpha$	$2 < \mu_V < \mu_1$	$0 < \lambda < \lambda_1$	0
		$\lambda_1 < \lambda < \lambda_2$	τ_1
		$\lambda_2 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2
		$\lambda_4 < \lambda < 1$	1
	$\mu_1 < \mu_V < \mu_4$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2
		$\lambda_4 < \lambda < 1$	1
	$\mu_4 < \mu_V$	$0 < \lambda < 1$	1

Table EC.1 Optimal threshold τ^* for all parameter combinations.

EC.1.1. *Proof of Proposition 1*

To prove Proposition 1 we must show that the area for which $\tau^* = \alpha$ is decreasing with k_1.

For this, it suffices to show that the μ_V and λ ranges in which $\tau^* = \alpha$ are both decreasing with k_1. Referring to Table EC.1, these ranges can be readily found. The following statement is true, and thus proves Proposition 1.

For all $0 < \alpha < \frac{1}{2}$, $0 < \lambda < 1$, $0 < k_1 < 1 - \alpha$, $\mu_V > 2$:

$$\begin{cases} \frac{\partial\left(\mu_4(k_1,\alpha)-\mu_2(k_1,\alpha)\right)}{\partial k_1} < 0 \\ \frac{\partial\left(\mu_4(k_1,\alpha)-\mu_1(k_1,\alpha)\right)}{\partial k_1} < 0 \\ \frac{\partial\lambda_3(k_1,\alpha,\mu_V)}{\partial k_1} < 0 \\ \frac{\partial\left(\lambda_3(k_1,\alpha,\mu_V)-\lambda_2(k_1,\alpha,\mu_V)\right)}{\partial k_1} < 0 \end{cases} \tag{EC.11}$$

□

Proof of Lemma 3

For each region in Table EC.1, note that when $\tau* = 0$ or $\tau* = \alpha$ or $\tau* = 1$, $\dfrac{\partial \tau^*}{\partial \mu_V} = 0$ and $\dfrac{\partial \tau^*}{\partial \lambda} = 0$. For regions where $\tau* = \tau_1$ or $\tau* = \tau_2$, it can also easily be shown that:

$$\begin{cases} \dfrac{\partial \tau_2}{\partial \mu_V} > 0 \\ \dfrac{\partial \tau_2}{\partial \lambda} > 0 \\ \dfrac{\partial \tau_1}{\partial \mu_V} > 0 \\ \dfrac{\partial \tau_1}{\partial \lambda} > 0 \end{cases}$$

Also recall that when $k_1 < 1/2$: $0 < \lambda_3 < \lambda_4$ and $2 \leq \mu_2 < \mu_4$; and when $1/2 < k_1 < 1 - \alpha$: $0 < \lambda_1 < \lambda_2 < \lambda_3 < \lambda_4$ and $2 \leq \mu_1 < \mu_4$ so the regions where $\tau^* = 0 < \tau_1 < \alpha < \tau_2 < 1$ are also increasing in μ_V and λ.

□

Proof of Proposition 2

Proposition 2 can be readily inferred from Table EC.1. □

Proof of Proposition 3

Proposition 3 can be readily inferred from Table EC.1. □

Lemma EC.1

LEMMA EC.1. $\dfrac{\partial \mu_2}{\partial k_1} < 0$, $\dfrac{\partial \mu_4}{\partial k_1} < 0$, *and* $\dfrac{\partial \lambda_4}{\partial k_1} < 0$.

Lemma EC.1 can be readily inferred from Theorem 1 and the resulting Table EC.1. □

EC.2. Machine Learning Model Development and Validation

This section provides additional details on the development and evaluation of the ML models summarized in Section 6.3. We describe the training and testing procedures, hyperparameter tuning, and bootstrapping setup, along with the extended performance results and robustness checks that complement the main analysis.

Leveraging the data from our partner hospital, we train binary classification models to predict whether a patient's care will require the use of an ED bed. We compare logistic regression with regularization (to avoid overfitting), classification trees (CART), random forest, gradient boosted trees (XGBoost), support vector machines (SVM), and multi-layer perceptron (MLP) (Hastie et al. 2009, Breiman et al. 2017, Breiman 2001, Chen and Guestrin 2016, Cortes and Vapnik 1995, Rosenblatt 1958). We tune the model hyperparameters by maximizing the K-fold cross-validation AUC using a bayesian optimization framework Head et al. (2020).

To train and objectively evaluate the derived models, we perform bootstrapping by creating multiple training and testing set partitions (Pedregosa et al. 2011). As noted in Section 6.2, all observations associated with no need for an ED bed (VPP eligible) consistently remain in the same set for all bootstrapped partitions since we restrict the golden labels in the testing set and the synthetic labels in the training set. Bootstrapping is conducted for all remaining samples (not VPP eligible) associated with needing an ED bed. The latter are randomly assigned to either the training set or the testing set such that the ratio between positive and negative samples remains the same between the two partitions of each iteration. We compute the average value and standard deviation of the AUC on the testing set for the five random partitions of the data (see Table EC.2).

Algorithm	Mean AUC	Std. of AUC
CART	0.8442	0.0024
Regularized logistic regression	0.8220	0.0051
Random forest	0.8458	0.0025
XGBoost	0.8446	0.0028
MLP	0.8451	0.0023
SVM	0.8324	0.0015

Table EC.2 Mean and standard deviation of the AUC metric on the testing set across all ML algorithms considered. The reported numbers correspond to the average performance on five random splits of the data.

EC.3. Simulation of the ED Flow

To test the validity of the findings obtained from our simplified model (Section 5) and also to gain deeper insights, we developed a simulation model of the ED flow and calibrated it with hospital data. Section EC.3.1 describes the simulation model and steps taken in validating it. Section EC.3.2 showcases how to map the analytical model for the VPP presented in Sections 4–5 to a real-world ED and identify the resulting optimal routing policy. Section EC.3.3 highlights the differences between three distinct routing rules for the VPP. In Section EC.3.4, we conduct a sensitivity analysis to evaluate the impact of a physician self-assignment system on the LOS of the VPP-based ED. In Section EC.4 at the main body of the manuscript, we extend our simulation environment to (a) compare the VPP design with other ED flow approaches introduced in the Introduction (e.g., LOS and PIT) and (b) generate insights into when, and for which hospitals, the VPP design is advantageous.

EC.3.1. Data-Driven Simulation Model: Development and Validation

We develop a simulation model of the old Mayo Clinic ED based on the operational constraints of the system and the clinical characteristics of the population it serves. Our aim is to design a realistic virtual test bed of the ED, where we can test the impact of different routing and prioritization protocols on patients' average LOS and waiting time.

Arrival Process. We assume that the arrivals to the ED follow a non-stationary Poisson process with a dynamically changing rate during the day, following the empirical arrival rates of the ED presented in Figure EC.6. The arrival rate in our simulations is specified for each ESI class, ranging from one to five, and for each hour of the day.

Patient Population. Each simulated arrival is sampled from a synthetic pool of patients based on the ED records, using the synthetic data vault (SDV) framework (Patki et al. 2016). The SDV process involves three consecutive parts: (1) data extraction and processing (DataNavigator); (2) generative model development (Modeler); (3) synthetic data creation (Sampler). SDV first estimates the distribution of each individual feature and the covariance between all independent variables in the dataset. Subsequently, the algorithm selects between a set of common distributions, including the truncated Gaussian, the uniform, or the beta distribution, the one that best matches the real data according to the p-values of the Kolmogorov-Smirnov test. Thus, the shape of the chosen cumulative distribution function for each feature is determined by the significance level of the statistical test. Finally, a Gaussian Copula function is applied to characterize the joint distribution of all derived random variables, ensuring that the shape of different distributions does not influence the covariance estimates. The SDV approach allows us to generate a realistic synthetic patient population that approximates the patient volume and mix that is served for each hour of the day at our partner hospital.

Simulating Assignments to VPP and ED (Current Practice). In the current practice, all arriving patients are assigned to a physician using a randomized round-robin algorithm. This assumption is relaxed in Section EC.3.4 where we explore the implications of a physician self-assignment system. Patients are also triaged and then sent to the waiting area. By default, patients waiting will be taken to an ED bed and served by their assigned physician. However, when a physician becomes available, she considers the pool of patients assigned to her who are still in the waiting area and assesses whether they can be served in the VPP. If the physician decides that a patient can be served in the VPP, the physician requests that the patient be moved to the VPP. We model this ad-hoc selection as a Bernoulli process, where the probability of success (i.e., selection to the VPP) is a function of each patient's ESI level and hour of the day. We observe that this Bernoulli process matches our data relatively well (see Table EC.3). It also ensures that patients are served in the VPP (in the simulated environment) only during the hours in which the VPP is open. Upon completion of the VPP visit, depending on the value of the test results, patients may either (a) be sent to the main ED queue for additional ED care, or (b) get discharged to go home directly from the VPP. The overall patient flow is based on Figure 1.

Our simulation analyses extend the analytical framework presented earlier to consider a system that involves multiple physicians. We leverage the overall patient arrival rate to the ED and the

Hour of the Day	ESI=1	ESI=2	ESI=3	ESI=4	ESI=5
0	0.00%	0.00%	0.00%	0.78%	0.00%
1	0.00%	0.50%	0.00%	0.00%	0.00%
2	0.00%	0.00%	0.00%	0.00%	0.00%
3	0.00%	0.00%	0.00%	0.00%	0.00%
4	0.00%	0.00%	0.00%	0.00%	
5	0.00%	0.00%	0.00%	0.00%	0.00%
6	0.00%	0.00%	0.00%	0.00%	0.00%
7	0.00%	0.00%	0.00%	0.00%	0.00%
8	0.00%	0.00%	0.31%	0.97%	0.00%
9	0.00%	0.11%	1.01%	2.40%	13.33%
10	0.00%	2.09%	4.95%	10.41%	15.79%
11	0.00%	4.46%	12.14%	21.05%	26.09%
12	0.00%	5.16%	17.20%	24.59%	68.75%
13	0.00%	5.00%	16.17%	28.57%	33.33%
14	0.00%	5.83%	15.05%	24.07%	31.25%
15	0.00%	3.86%	13.82%	20.06%	30.00%
16	0.00%	5.70%	11.92%	17.88%	40.00%
17	0.00%	3.98%	11.00%	13.83%	10.53%
18	0.00%	1.68%	6.64%	9.60%	18.18%
19	0.00%	1.54%	2.07%	6.19%	16.67%
20	0.00%	0.94%	1.05%	1.48%	4.55%
21	0.00%	0.20%	0.69%	1.15%	6.25%
22	0.00%	0.00%	0.39%	0.51%	0.00%
23	0.00%	0.33%	0.00%	0.00%	0.00%

Table EC.3 Proportion of patients served in the VPP of the old Mayo ED during the study period for each ESI level.

average number of physicians working at any given hour from our data. Our approach considers the "competition" among physicians for utilizing the VPP, rendering it a shared resource in the ED.

Service Process. Once a patient has been seen in the VPP, tests are ordered. We assume that VPP patients will have to wait for their tests to be completed to determine whether they need to be served in the main ED. We extract disposition times and test times from our data and observe that for about half of the ED visits (49.5% for Main ED patients and 53.7% for VPP patients), a test has been ordered prior to the physician's first contact (see Fig. EC.10). Hence, we assume that a patient's service time begins from the earlier of first physician contact and first ordered test, and ends when a patient is either admitted to the hospital or discharged to go home. Also, we observe that for about 10% of patient visits, a test result becomes ready after the disposition decision is made. Since these have a low percentage of occurrence, we exclude them from the service duration and do not assume they cause further delays once the disposition decision has been made. Since ED service includes both treatment and testing, we also incorporate, as system parameters, the average testing and treatment durations separately for each ESI level and hour of the day. We

assume that these durations follow time-varying exponential distributions, with means extracted from our data.

In addition, we model the probability that a patient is admitted to an inpatient unit after ED service based on ESI levels, and calibrate it using our data. Patients admitted to an inpatient unit after ED service often experience a "boarding time," which involves waiting in the ED until an inpatient bed becomes available. We model this using a log-normal distribution (see, e.g., Saghafian et al. (2023)) with means and standard deviations as functions of ESI and the hour of the day (obtained from our data).

Validation. To validate our simulation model and ensure that it provides a realistic benchmark to the baseline (i.e., observed values from the current practice) at the Mayo Clinic, we perform a series of comparisons by making use of two well-defined metrics of operational performance. Specifically, we focus on average waiting time and LOS and calculate them both for the overall population and for each ESI level. We run the simulation for ten years and discard the first three years as a transient period. We compute the hypothesis test statistic for the two metrics of interest, comparing whether the baseline observed from our data has a different distribution compared to what we obtain from our simulation. As shown in Table EC.4, all p-values for the differences are large (> 0.5), indicating that the simulated system accurately approximates the current practice of the Mayo Clinic. This can also be seen by noting that the difference between the baseline and simulation in terms of both the overall average LOS and waiting time metrics is less than a minute. Hence, our simulation environment provides a realistic test bed to evaluate the impact of our proposed VPP design compared to both the current VPP design and alternative ED patient flow approaches (e.g., FT and PIT) discussed earlier.

	LOS			**Wait**		
Group	**Baseline**	**Simulation**	**p-value**	**Baseline**	**Simulation**	**p-value**
All	238	238	0.583	36	36	0.748
ESI=1	192	183	0.139	11	12	0.16
ESI=2	276	274	0.221	24	25	0.155
ESI=3	237	239	0.161	42	41	0.254
ESI=4	153	153	0.748	42	42	0.788
ESI=5	87	85	0.759	37	37	0.888

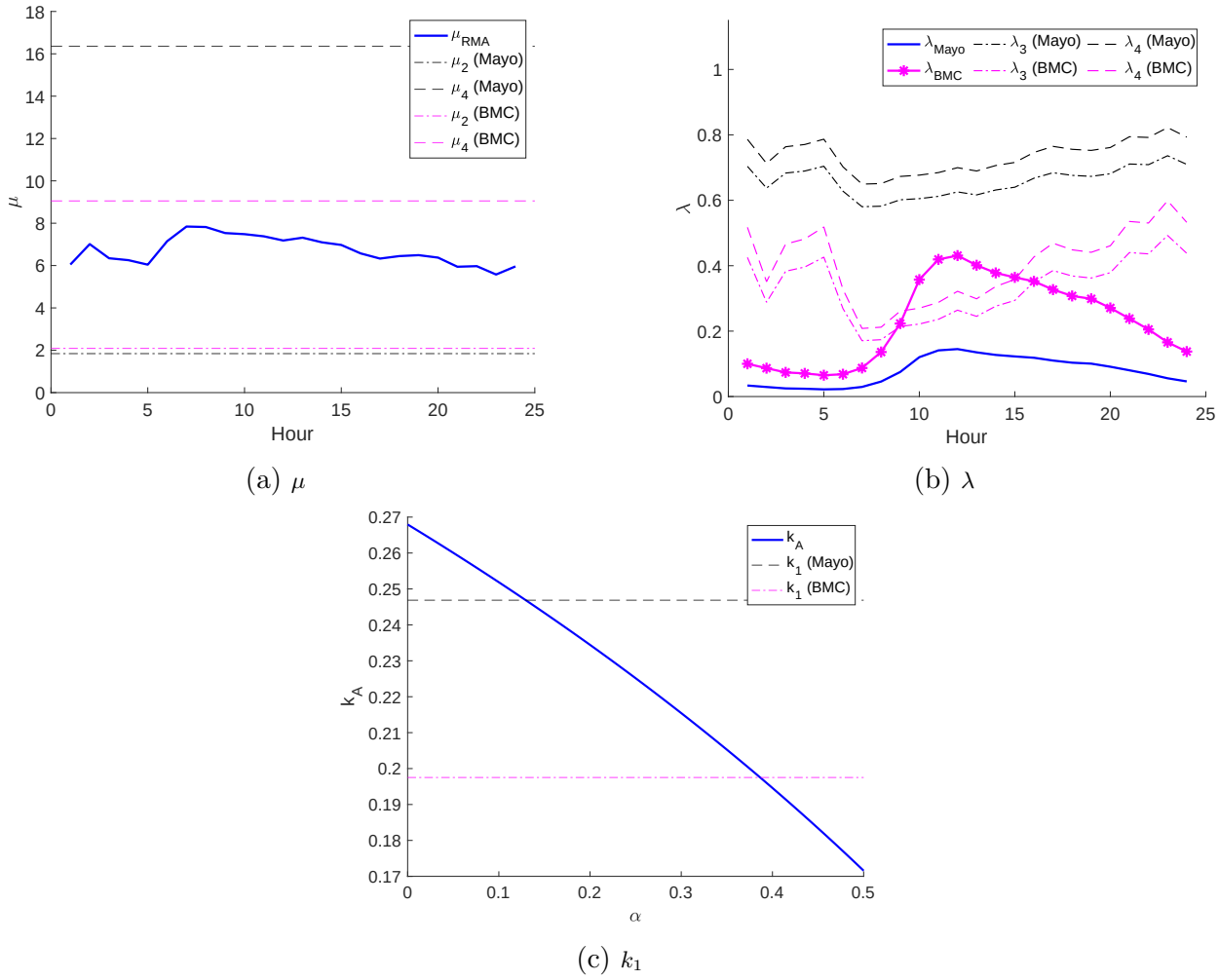
Table EC.4 Comparison of average LOS and waiting time (minutes) between the simulated and baseline values.

EC.3.2. Mapping the Analytical Model to Real-World Healthcare Systems

To identify the optimal VPP design for the old ED of our partner hospital using our analytical model (Section 4), we need to specify the values of $\alpha, k_1, \mu_V, \lambda$ (see Table EC.1).

The old ED at Mayo Clinic Arizona. To compute α, we use the dependent variable of the proposed ML model (Section 6.2). Specifically, we note that the care of the 9,796 patients out of the 49,350 did require an ED bed, and thus, we set our baseline α to 19.85%. Using this value, we next leverage Equation (6), which indicates that $k_1 = 0.2469$. As shown in Figure EC.1c, at the Mayo Clinic we are at the regime where $k_A < k_1$. We next determine μ_V, which reflects the relative speed of the VPP compared to the main ED. By design, physicians who serve patients in the VPP strive to complete the consultation within 20 minutes. Assuming this time constraint on average, we can focus only on the average service rate of the main ED per hour of the day and make use of it to obtain the ratio between μ_V and μ_E. Our analysis shows that, at our partner hospital, the service rate of the VPP is six to eight times that of the main ED. Thus, on average, the service duration in the main ED is between 120 minutes and 160 minutes, depending on the hour of the day (see Figure EC.1a). From Proposition 2, we next compute the values of μ_2 and μ_4, verifying that $\mu_2 < \mu_V < \mu_4$. Following Table 1, we observe that our partner hospital falls in the policy regime where $\tau^* = \alpha$ for all $0 < \lambda < \lambda_3$ (Figure EC.1b). Figure EC.1 illustrates the sensitivity analysis on the system parameters to ensure that the proposed policy is robust to data perturbations and hourly changes during the day.

The ED at the Boston Medical Center (BMC). We also repeat our analysis for BMC, using their data to create yet another benchmark and show how the optimal VPP routing policy depends on the hospital characteristics. BMC primarily serves a higher portion of underprivileged population compared to the Mayo ED with greater racial diversity (Bertsimas et al. 2020). In addition, the proportion of patients that require an ED bed is low due to the high prevalence of low acuity cases. Leveraging the findings of Feizi et al. (2023), we approximate BMC's α by scaling Mayo's α by the ratio of ESI-4 and ESI-5 patients served in BMC to that of Mayo clinic. We also approximate the hourly arrival rates by scaling up Mayo's hourly arrival rate by the ratio of annual patient volume at BMC to that of Mayo (Mackenzie Bean 2023). We further assume that the trained ML model achieves the same performance as the one presented in Section 6.3. As shown in Figure EC.1c, we are in the regime where $k_A > k_1$. Moreover, if we hypothesize that BMC was able to provide an equivalent amount of resources (rooms and physicians) to achieve the same μ_V as the Mayo ED, then $\mu_2 < \mu_V < \mu_4$ would still apply. However, the average arrival rate λ_{BMC}, changes the optimal regime throughout the day. Specifically, as illustrated in Figure EC.1b, $0 < \lambda < \lambda_3$ between 4.00 pm and 9.00 am ($\tau^* = \alpha$); $\lambda_3 < \lambda < \lambda_4$ between 9.00 am and 9.30 am as well as between 3.00 pm and 4.00 pm. ($\tau^* = \tau_2$); $\lambda_4 < \lambda$ during the hours of 9.30am and 3.00pm ($\tau^* = 1$). This setting highlights the potential variability of the optimal policy throughout the day. In practice, the ED administrators of the BMC, could approximate the optimal design by implementing $\tau^* = \alpha$ during the hours of low demand and increasing it to $\tau^* = 1$ throughout the morning and afternoon hours, leveraging the VPP as a screening tool for any patient in the ED.



(a) μ (b) λ

(c) k_1

Figure EC.1 Sensitivity analysis of the Mayo Clinic ED system parameters.

EC.3.3. Combined Routing and Patient Prioritization

Our analyses in the previous section shed light on the best policies that should be followed in practice for routing patients to the VPP. However, among patients that are routed to the VPP, an ED can follow various prioritization mechanisms. Augmenting patient routing policies with prioritization rules might yield significant benefits in practice. To gain insights into suitable rules that allow for both routing and prioritization, we consider three implementable policies and compare them with the current practice at the Mayo Clinic. Specifically, we consider the following policies:

- **Baseline**: This scenario simulates the current practice at the Mayo Clinic. The implementation of the VPP operation is guided by the empirical data as described in Section EC.3.1.
- $\boldsymbol{\tau^*}$**(ESI)**: Following the design presented in Figure 2, under this policy, all patients with $\hat{\gamma} < \tau^*$ are routed to the VPP, where $\hat{\gamma}$ is obtained from the ML model. Furthermore, among patients with $\hat{\gamma} < \tau^*$, priority is given to patients with a lower ESI level. That is, patients are (a) routed to the VPP based on the ML model's score and (b) prioritized there based on their ESI level.

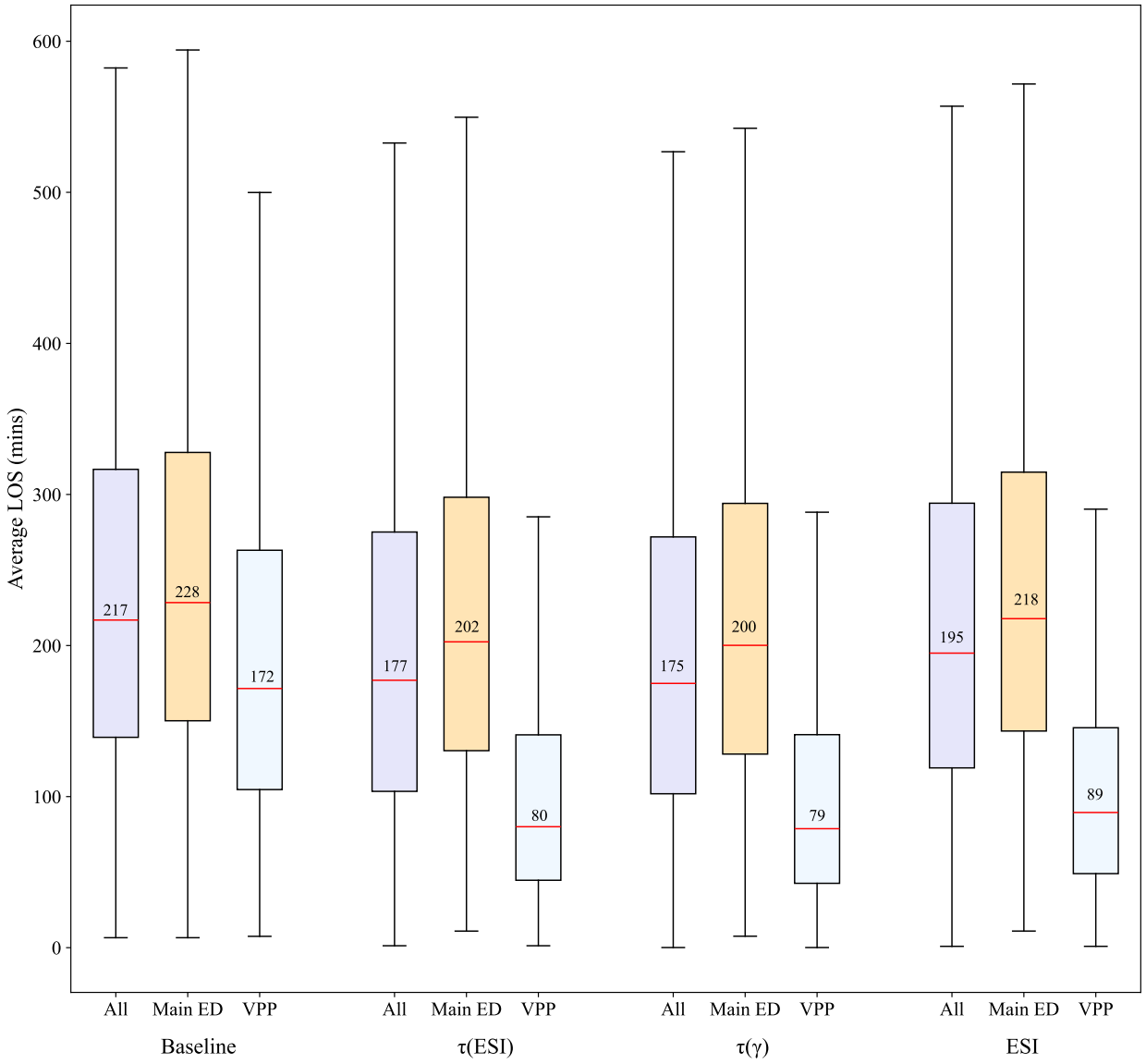


Figure EC.2 Average LOS of all patients, patients served in the main ED, and patients served in the VPP at the old Mayo Clinic ED.

- $\boldsymbol{\tau}^*(\hat{\boldsymbol{\gamma}})$: Similar to the previous policy, patients with $\hat{\gamma} < \tau^*$ are routed to the VPP. However, instead of ESI, prioritization is done based on the predicted score, $\hat{\gamma}$. That is, both routing and priority decisions for utilizing the VPP are based on the ML model's output.
- **ESI**: Under this policy, both routing and priority decisions are based on the ESI level. In particular, all patients with ESI>3 (i.e., low acuity patients) are routed to the VPP. Under this policy, we assume that the ML model is not implemented, and instead, a strict rule based on ESI is used (similar to how EDs make use of their FT units).

Figure EC.2 shows that all of the three policies considered ($\boldsymbol{\tau}^*$(**ESI**), $\boldsymbol{\tau}^*(\hat{\boldsymbol{\gamma}})$, **ESI**) lead to substantial improvements in the overall system's performance compared to current practice. This is

to some extent expected, given that in the current practice at our partner hospital VPP routing and priority decisions are made in an ad-hoc manner by individual physicians. Furthermore, we observe that the $\boldsymbol{\tau}^*(\hat{\boldsymbol{\gamma}})$ policy results in an average LOS of 177 minutes, which corresponds to a 18.4% reduction compared to the current practice. We observe small differences between $\boldsymbol{\tau}^*(\hat{\boldsymbol{\gamma}})$ and $\boldsymbol{\tau}^*(\mathbf{ESI})$. This is mainly because ESI is the primary driver of risk for $\hat{\gamma}$ (see the SHAP graph in Figure EC.9). Hence, there are only minor differences between these two prioritization policies. However, we observe that both of these lead to significant benefits compared to the **ESI** policy, highlighting that using the ML model and following a data-driven VPP design is superior to an ESI-based rule that blindly sends the low acuity (ESI>3) patients to the VPP. Similar findings are uncovered when we focus on the average waiting time in the system.

Put together, these results indicate that our partner hospital should change the current practice of routing patients to the VPP. In particular, we find that making use of the ML model to obtain predicted risk scores and following the $\boldsymbol{\tau}^*(\hat{\boldsymbol{\gamma}})$ policy can go a long way. The results of our analysis for the BMC ED are summarized in Figure EC.3. The simulation leads to a similar conclusion, suggesting that the $\boldsymbol{\tau}^*(\hat{\boldsymbol{\gamma}})$ policy yields the greatest overall reduction of LOS in the system.

EC.3.4. Patient Assignment System Sensitivity Analysis

In this section, we relax the hypothesis that the ED uses a rotational patient assignment system to compare the impact of the VPP design in an ED with physician self-assignment. This setting allows us to evaluate the system's performance when physicians are tasked with choosing which patients to treat, rather than relying on an automated round-robin assignment system.

Modeling a self-assignment system in an ED simulation requires capturing the complex decision-making processes of physicians and their interactions with the ED environment. The key challenge lies in accurately representing the heuristics that physicians use to select patients and how these decisions impact the overall efficiency and effectiveness of the ED. In the absence of data from such a system, we assumed the following process for self-assessment: Following the approach presented in (Traub et al. 2016b) and leveraging productivity estimates for ED physicians from the literature (Joseph et al. 2018), we assume that each physician begins their shift with a random allocation of up to three patients in their queue depending on the number of patients waiting at the ED. After starting their shift, physicians are subsequently tasked with choosing a new patient to treat as soon as the treatment of one of their existing patients is marked as completed. Patients are then ranked by each physician first based on ESI and subsequently based on waiting time. Thus, we assume that physicians will first prioritize a patient of higher acuity (lower ESI), in line with the ED general prioritization rules, and then choose within the ESI category the patient with the longest waiting time.

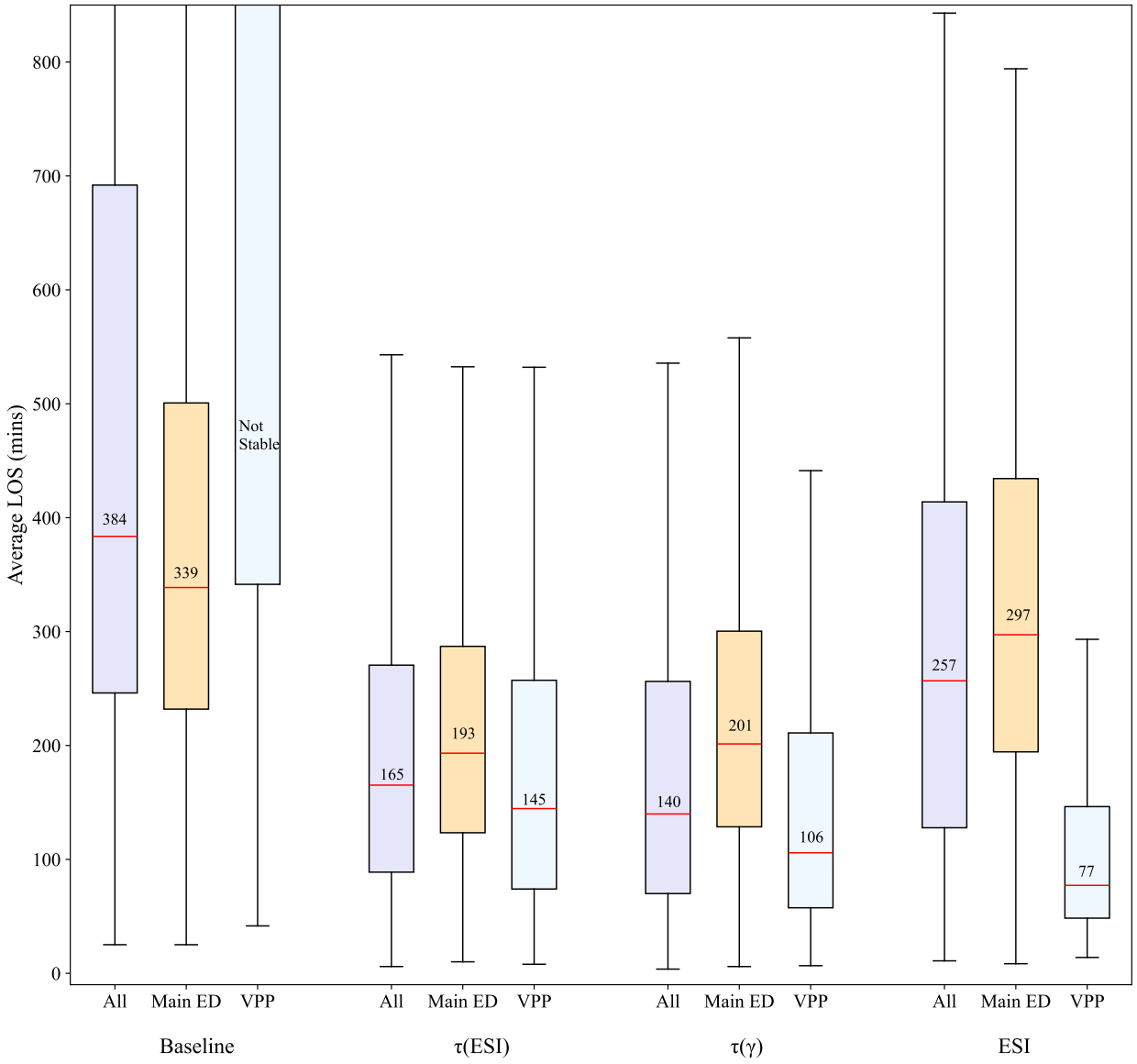


Figure EC.3 Average LOS of all patients, patients served in the main ED and patients served in the VPP at the BMC ED.

We apply the self-assignment rule in the $\tau^*(\hat{\gamma})$ version of the old Mayo ED system (see Section EC.3.3 for a description). In accordance with the literature (Traub et al. 2016b, Hirshon et al. 1996), our sensitivity analysis reveals higher variation in the expected ED performance when patient assignment is driven by physicians rather than a rotational algorithm. However, we do not identify substantial differences in the average LOS for all patients in the ED between the two patient assignment approaches, as the average LOS ranges between 172 and 178 minutes for the self-assignment policy across different randomized runs of the simulation. These results provide evidence that under both patient assignment approaches the proposed VPP design can lead to considerable improvements in patient LOS compared to the baseline.

We would like to acknowledge that there might be multiple alternative designs of a self-assessment patient assignment process. For example, the presented approach does not assume any strategic or heterogeneous physician behavior. Nevertheless, these findings provide supporting evidence regarding the generalizability of the proposed queueing model beyond an ED with a rotational patient assignment algorithm. To further verify the benefit of the VPP design, additional retrospective and prospective studies are needed in EDs with an active physician self-assignment protocol.

EC.4. What Hospitals Should Introduce a VPP Unit?

To test the validity of the findings obtained from our analytical model from Section 5 and gain deeper insights, we leverage the simulation model as a realistic virtual test bed of the ED, where we evaluate the effect of different routing, prioritization, and streaming protocols on patients' average LOS and waiting time. In this section, we turn to the research question: for what hospitals does the best VPP design outperform other ED flow designs such as FT and PIT? To address this question, we leverage data from the Mayo Clinic Arizona to simulate the operations of the old ED, generating counterfactual non-VPP designs, including FT-based and PIT-based streaming approaches introduced in Section 1. Furthermore, since the population of patients served by an ED differs from one hospital to another, we also conduct a sensitivity analysis on the main characteristics of the patient population served by the ED. Thus, we generate insights into when and for which hospitals the VPP design is advantageous.

EC.4.1. Introducing the FT, VPP, and PIT Flow Designs

Before describing the simulation design, we first introduce and discuss the key differences between FT and PIT patient flow designs. Table EC.5 summarizes their main differences in terms of who triages patients, how low-complexity patients are initially determined (i.e., the selection criteria), and whether the selected low-complexity patients are separated from the rest of the patients and assigned to a dedicated queue.

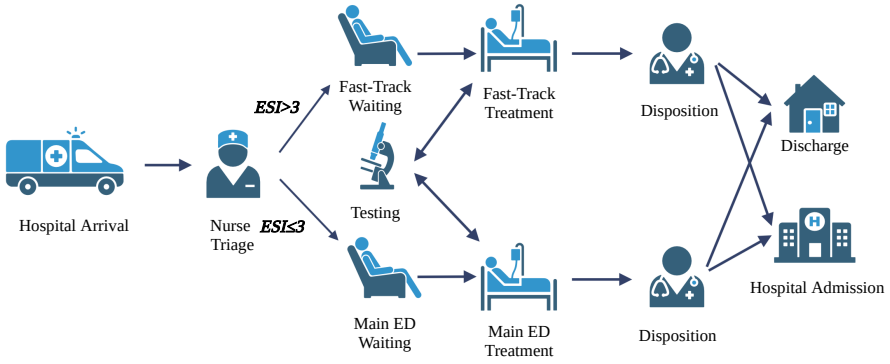
In an FT model, arriving patients are first triaged and assigned an Emergency Severity Index (ESI) from one (most urgent) to five (least urgent) by a triage nurse (see also Figure EC.4a).[1] Patients with an ESI greater than three are routed to a separate dedicated queue to be treated in a section of the ED called the FT. In some hospitals, FT providers comprise nurse

Model	Triage Staff	Assumed Low-Complexity	Dedicated Queue	Test Ordering
FT	RN	ESI > 3	Yes	Yes
PIT	PA/MD	All patients	No	Yes
VPP	RN	Doctor's discretion	No	Yes

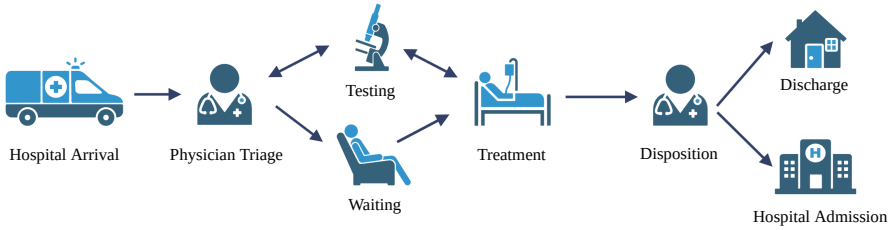
Table EC.5 A Comparison Between FT, VPP, and PIT.

Notes. RN: Registered Nurse, PA: Physician Assistant, MD: Medical Doctor

practitioners or physician assistants dedicated to managing patients in that section of the ED. The main idea of the FT design is to avoid having low acuity patients (who often have shorter "processing times") wait behind high acuity ones.



(a) Fast-Track (FT) design.



(b) Physician in Triage (PIT) design.

Figure EC.4 Illustration of alternative ED patient flow designs.

In a PIT model, as the name suggests, a medical provider licensed to order tests and perform the treatment (e.g., physician or advanced practice provider) is assigned to the triage stage working alongside a registered nurse (see Figure EC.4b). PIT systems essentially provide more flexibility and a higher degree of responsibility to the stage of triage, leveraging medical experts with more advanced training. In addition to assigning an ESI score, (a) ED tests can be initialized during triage, and (b) patients who do not need sophisticated ED care are identified and discharged. Thus, triage providers have the discretion to disposition patients directly. The PIT model has various benefits and drawbacks, as discussed in the literature (Franklin et al. 2021) and has also been implemented in various formats over time (Traub et al. 2015, 2016a). The operational success of such systems depends on local contextual factors, and thus, mixed empirical results have been reported in the literature (Benabbas et al. 2020).

[1] In some EDs, patients classified as ESI-1 (and occasionally ESI-2) often arrive via ambulance and are directly taken to a trauma bay or bed where a medical team, rather than just a triage nurse, is awaiting them.

EC.4.2. Design of the Counterfactual Streaming Protocols

First, we outline the core assumptions we make to simulate performance under the counterfactual designs of patient streaming. We design the FT and PIT based on Feizi et al. (2023) and Franklin et al. (2021), respectively, which employ these policies in their study settings. Below we provide details on the implementation of the FT and PIT policies:

- **Fast-Track (FT)**: All patients with ESI>3 are routed to dedicated beds in the FT section of the department while only patients with ESI≤ 3 use the resources available in the main ED. We assume that at any hour, the FT is staffed with half as many physicians in the main ED and that one patient at a time can be served by an FT worker.
- **Physician-In-Triage (PIT)**: All patients are first seen by a physician during the triage stage, and only patients who require ED care will be sent to the queue. Triage physicians may also initiate the tests. In implementing the PIT policy, we assume that there are always two physicians at the triage stage and that the examination time of a physician is similar to that of an VPP. However, the main ED will operate with two fewer physicians during the hours in which it was originally staffed with over two physicians.

Our analysis attempts to match all three patient streaming systems in terms of the number of resources (i.e., the total number of beds and physicians) throughout a simulated day. Thus, it is possible, under specific conditions, to study scenarios under which at least one of the approaches leads to an unstable system (see Table EC.6). Note that inevitably we must have two beds working simultaneously and additional physicians in simulating the FT since, by design, it must operate with two separate sections (FT and main ED). To perform a realistic comparison across the VPP, FT, and PIT approaches, we leverage the synthetically generated data from the Mayo Clinic.

EC.4.3. LOS Comparisons Across Varying Levels of Acuity

In Table EC.6, we compare the impact of FT, PIT, and our proposed VPP design which uses $\tau^*(\hat{\gamma})$ (see Section EC.3.3) on the LOS across all patients served, patients served only in the FT/VPP, and patients served in the main ED. In addition, to generalize our insights beyond the context of our partner institution, we generate synthetic populations of ED patients by altering the distributions of ESI levels. We extend our analysis to account for different distributions of the patient population age in Section EC.4.4. We focus on these two factors, mainly because they constitute two of the most predictive patient characteristics, as shown in Figure EC.9, that are associated with the likelihood of requiring an ED bed. For the feature of patient acuity, we split the synthetically generated patient population into distinct groups based on their ESI level (1 to 5). Subsequently, guided by other ED environments described in the literature, we uniformly sample without replacement from each of the subgroups to generate patient populations of varying severity

and care needs that approximate different community profiles that can be served by an ED (Wong et al. 2021, Xu et al. 2009, Araz et al. 2019). We let the mean ESI range from 2.39 and 3.37 (see Table EC.6), allowing us to present results for EDs where the patient population that might differ from our partner ED.

Population	Mean ESI	FT	PIT	VPP
All	2.39	274.7 (273.6, 275.8)	Not Stable	260.8* (259.8,261.9)
	2.76	233.6 (232.7, 234.4)	1277.0 (1253.5, 1300.5)	207.5* (206.6,208.4)
	3.03	Not Stable	260.9 (259.8, 261.9)	209.9* (208.5,211.2)
	3.37	Not Stable	174.0* (173.5, 174.5)	Not Stable
	Mayo ED	232.9 (232.1, 233.8)	785.1 (773.8, 796.4)	204 (201.0,207)*
Main ED	2.39	288.6 (287.5, 289.7)	Not Stable	273.3* (272.3,274.4)
	2.76	249.2 (248.2, 250.1)	1419.1 (1392.9, 1445.4)	233.9* (232.9,234.9)
	3.03	Not Stable	297.2 (296.0, 298.4)	219.9* (218.5,221.3)
	3.37	Not Stable	198.8* (198.2, 199.3)	Not Stable
	Mayo ED	245.6 (244.7, 246.6)	861.4 (848.8, 873.9)	230.3* (229.3, 231.2)
FT/VPP	2.39	96.6* (95.2, 98.1)	Not Stable	119.9* (116.9,122.8)
	2.76	164.6 (163.1, 166.2)	114.9 (113.6, 116.3)	110.3* (108.9,111.7)
	3.03	Not Stable	104.8* (103.9, 105.7)	202.2 (200.1,204.3)
	3.37	Not Stable	99.1* (98.4, 99.7)	Not Stable
	Mayo ED	173.5 (171.9, 175.2)	124.2 (122.8, 125.7)	109.2* (107.2, 111.2)

Table EC.6 Average LOS and 95% confidence intervals (indicated in parentheses) per patient subgroup across different ED flow designs. Four synthetic patient populations with varying mean ESI scores are considered in addition to the Mayo Clinic baseline sample. We indicate with an asterisk the best performing system for each population subgroup.

Overall, our results presented in Table EC.6 show that given a fixed amount of ED resources, the optimal VPP design outperforms the FT and PIT designs for EDs that serve a patient population with low to medium-high mean ESI scores. However, when the patient body served in the ED has a low prevalence of acute and critical conditions (i.e., involves a low fraction of low ESI level patients), our results suggest that the PIT system is the most suitable design. This is because the flow of patients to the VPP significantly increases as the patient population shifts toward lower acuity patients (higher mean ESI values), rendering the VPP design unstable. This suggests that the VPP design is more suitable for trauma centers or regular teaching hospital EDs, but the PIT system might be the preferred design in community hospitals where a higher fraction of patients are of low acuity. Finally, as shown in Table EC.6, we find that the FT approach faces the same problem as the VPP design in EDs with a high fraction of low acuity patients. The simulation outcomes also validate the findings from our analytical model: in cases of very high arrival rates to the ED, all patients should be first routed to the VPP, making the VPP and PIT designs similar in their functioning and performance.

For a given simulation setup (i.e., ESI distribution) and patient streaming approach, we do not observe high variability, as shown by the 95% confidence intervals. However, across different streaming systems, we do observe high levels of variation in the expected LOS of the ED. This is attributed to the fact that we have restricted the number of resources to be constant and equal to those present in the old Mayo Clinic ED at the time the retrospective dataset was recorded. Performance variability is most pronounced in the case of PIT. Although it can outperform the FT and VPP in populations with predominantly low-acuity cases, it becomes unstable and highly inefficient without additional physicians as the proportion of acute cases increases. By keeping the resources constant, we highlight the adaptability of the VPP model in different ED environments and demonstrate its robustness under varying conditions. This can be a particularly valuable feature for healthcare administrators, as it is often very challenging to adaptively change staff and bed resource availability in the ED.

EC.4.4. LOS Comparisons Across Varying Levels of Patient Age

Building on the sensitivity analysis on the distribution of the patient population's level of acuity, we extend our results to the patient age. To this end, we conduct a series of simulations in which we alter the age distribution such that the average patient age lies in the set $\{40, 50, 60, 70\}$.

Population	Mean Age	FT	PIT	VPP
All	40	263.3 (262.2, 264.4)	456.7 (453.1, 460.3)	190.2* (189.3,191.0)
	50	253.1 (252.1, 254.1)	536.9 (532.0, 541.9)	192.6* (191.7,193.5)
	60	247.4 (246.5, 248.3)	616.8 (610.4, 623.2)	196.0* (195.1,196.9)
	70	243.1 (242.2, 244.0)	1092.7 (1072.5, 1112.8)	198.2* (197.3,199.0)
	Mayo ED	232.9 (232.1, 233.8)	785.1 (773.8, 796.4)	203.0* (202.2, 203.8)
Main ED	40	239.4 (238.4, 240.3)	509.2 (505.1, 513.2)	224.5* (223.5,225.6)
	50	241.1 (240.1, 242.0)	599.4 (593.8, 605.1)	226.3* (225.2,227.3)
	60	243.1 (242.2, 244.1)	687.2 (680.0, 694.4)	227.8* (226.8,228.8)
	70	244.2 (243.3, 245.2)	1223.9 (1201.1, 1246.7)	229.5* (228.4, 230.5)
	Mayo ED	245.6 (244.7, 246.6)	861.4 (848.8, 873.9)	229.1* (228.1, 230.0)
FT/VPP	40	332.6 (329.6, 335.7)	115.6 (114.5, 116.8)	110.7* (109.6,111.9)
	50	290.1 (287.4, 292.8)	115.8 (114.6, 117.0)	110.1* (108.9,111.2)
	60	261.5 (259.2, 263.9)	115.8 (114.6, 117.1)	111.6* (110.4,112.8)
	70	239.1 (237.0, 241.2)	117.6 (116.4, 118.9)	112.4* (111.2, 113.5)
	Mayo ED	173.5 (171.9, 175.2)	124.2 (122.8, 125.7)	111.2* (110.8, 111.6)

Table EC.7 Average LOS and 95% confidence intervals (indicated in parentheses) per patient subgroup across different ED flow designs. Four synthetic patient populations with a varying mean age at admission are considered in addition to the Mayo Clinic baseline sample. We indicate with an asterisk the best performing system for each population subgroup.

Table EC.7 illustrates that, given a certain set of resources, the age distribution does not impact the ranking of the three design approaches considered. Of note, the average LOS of all patients in

the system increases (decreases) when the distribution shifts to older populations in the case of the VPP and PIT (FT). The opposite trend in the FT is driven by the system behavior outside of the main ED. The average LOS of patients served in the FT significantly decreases for older populations, contrary to the case of PIT and VPP where the performance does not significantly change due to age variations. When focusing on the main ED patients, we observe that the LOS measure under PIT significantly increases for older populations. In the case of FT and VPP, we still observe an increase in the average LOS but with a smaller variation.

Our results indicate that the VPP patient flow design maintains a relatively stable LOS across varying age demographics, suggesting a higher level of adaptability compared to the FT and PIT. This stability underscores the potential utility of a data-driven VPP approach in managing variations in patient demographics within healthcare systems.

EC.5. The VPP Implementation Protocol and Study Design at the Mayo Clinic

In this Section, we provide additional information regarding the prospective implementation of the proposed VPP protocol at the Mayo Clinic.

EC.5.1. Detailed Overview of the Tree-Based VPP Implementation Protocol

Implementing the optimal VPP design obtained in the analytical and simulation models in a real-world emergency department setting requires both (i) integration of the ML model into the electronic health record (EHR) system, and (ii) dynamic calibration of the classification threshold τ based on real-time operational conditions (e.g., arrival rates and staffing levels). While technically feasible, this type of EHR-integrated ML deployment demands substantial resources and organizational change (Panch et al. 2019). To mitigate this limitation and to enable a timely transition to an optimized use of the VPP both in our partner ED and in other EDs, as described in Section 7.1, we leverage our findings and develop an interpretable and concise protocol that approximates the optimal policy with high precision while greatly simplifying the decision process.

The derivation of the protocol uses the analytical and simulation models described in Sections 4–5 and EC.3 to produce a labeled dataset, linking patient-level features with optimal routing decisions under varying system states. This dataset is then used to train an interpretable decision tree that can be implemented directly in clinical practice. The detailed derivation is as follows.

1. **Mapping observations to ED conditions:** We link each empirical patient record from the original curated Mayo Clinic ED dataset (October 2018–December 2019) to simulated operational conditions representing the ED state at the time of triage. For each patient, we use the recorded arrival time to extract, from the baseline simulation of the Mayo Clinic ED, the distribution of system states (arrival rate λ, service rate μ, number of patients in the waiting room, and total ED occupancy) at the corresponding hour of day across all simulated days. We then uniformly sample (with replacement) one of these simulated days to assign the operational parameters describing the ED environment at that moment. The curated observations are used in the next two steps to derive the policy labels and a summary metric capturing the operational status of the ED.
2. **Constructing system-aware labels:** Using the sampled operational parameters and the analytical model parameters (α, k_1), we compute the optimal threshold τ^* following Theorem 1. We then apply the ML model, presented in Section 6, to generate a predicted probability of bed need for the patient. If this predicted probability exceeds τ^*, we assign the label "Route to main ED;" otherwise, we assign the label "VPP eligible." Thus, we devise a label that captures the optimal routing policy for each patient observation in the old Mayo Clinic ED dataset.

3. **Defining ED overcapacity status:** Building on the simulated ED state linked to each observation in Step 1, we introduce a binary variable "ED in Overcapacity" that summarizes the current load condition according to our partner hospital's official saturation and overcapacity guidelines (Table EC.10). For each patient, we evaluate the sampled system state (arrival rate, waiting-room count, waiting time, and total occupancy) against the hospital's operational thresholds. The flag is set to 1 if any of the following conditions are met: (i) more than ten patients are waiting for an ED bed, (ii) median waiting time exceeds 60 minutes, or (iii) total ED occupancy surpasses 90% of staffed capacity. The resulting variable serves two purposes. First, it provides a simple, directly observable measure of real-time congestion that is already tracked in the EHR, allowing the protocol to adjust routing decisions based on current system load without requiring continuous numerical inputs (e.g., arrival rates). Second, by including this binary indicator, the approximate policy can replicate the adaptive behavior of the optimal analytical model, while remaining straightforward to implement in practice.
4. **Training the decision tree:** We construct a training dataset combining patient-level triage features (ESI, chief complaint, age group, and vital sign indicators), the "ED in Overcapacity" variable, and the system-aware routing label described above. We train a classification tree using the CART algorithm (Breiman et al. 2017), performing five-fold cross-validation and a grid search over hyperparameters (maximum depth, minimum samples per leaf) to avoid overfitting. The configuration minimizing the mean validation error is selected as the final model.
5. **Post-processing and clinical validation:** The resulting tree is then reviewed by the Mayo Clinic emergency physicians and nurses to ensure clinical coherence and usability. Leaves predicting "VPP eligible" were subdivided into the *high-priority* and *low-priority* VPP pathways, informed by clinical consensus. This collaborative refinement ensures that the final protocol aligned with established clinical safety standards and could be executed seamlessly within existing triage and patient flow processes.
6. **Evaluation:** Using the held-out testing set from our sample population, the approximated tree-based VPP protocol reproduces the analytically optimal routing in 95.7% of cases, with deviations concentrated among moderate-acuity (ESI 3) patients under high congestion. This high level of agreement indicates that the simplified, interpretable protocol preserves nearly all of the operational efficiency of the analytically optimized model while substantially reducing implementation complexity.

Figure 6 in the main body illustrates in the main manuscript the resulting tree-based protocol approximating the optimal policy.

EC.5.2. Prospective Implementation: Study Design

The Mayo Clinic Arizona hospital had experienced increasing ED patient volumes over recent years, so the Arizona Bold Forward initiative included an approximate doubling of ED patient care beds. In anticipation of further increased volumes, our partner hospital hired additional emergency physicians and allied health staff to cover the new beds for the 2022 opening. Nurse practitioners, physician assistants, external residents, and medical students occasionally rotate through the new ED but are not permitted to manage patients independently.

The prospective implementation study was conducted within this expanded facility, which provided sufficient staffing and capacity to test the VPP protocol under realistic and stable operational conditions. To verify that any observed performance differences were attributable to the intervention rather than to exogenous changes in patient mix or resource levels, we compared the pre-trial and trial samples along demographic and clinical patient features as well as operational system characteristics.

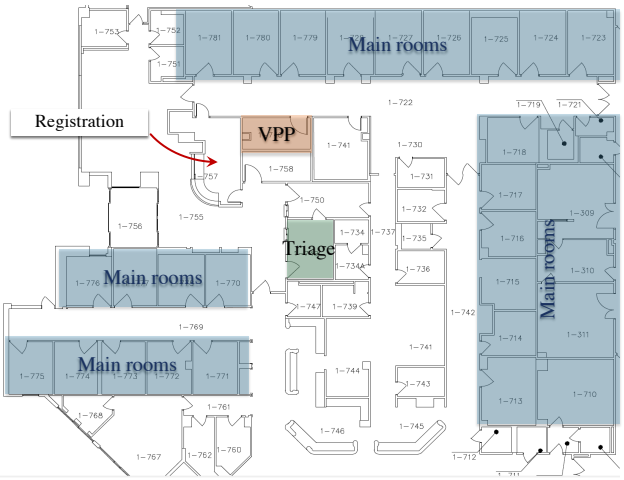
Tables EC.11 and EC.12 summarize the chief complaints reported at triage and attending physician assignments for these periods, respectively. Our results indicate that the distributions of all patient characteristics reported at the time of triage, with the exception of systolic blood pressure and administered medical procedures during the ED visit, are similar between the pre-trial and trial phases. Moreover, patient outcomes, such as disposition post-ED visit and ED return rate (with or without readmission to hospital), also do not significantly differ between the two periods. In addition to ensuring a similar distribution of patient characteristics, the selected timeline allowed the ED to ensure equivalent availability of resources and arrival patterns to the system (see Table EC.13). Of note, nurse staffing levels are adaptively modified throughout the day as a function of ED occupancy.[2] The distribution of arrival and discharge rates across all time windows did not vary with statistical significance between the two periods.

Dependent Variables: Consistent with the objectives of the ED management and the operations management literature, our key dependent variables are two measures of the patient's LOS at the ED: (1) the ED time from arrival to disposition (Feizi et al. 2023); and (2) the ED time from arrival to ED departure (Lim et al. 2024). ED time from arrival to disposition is measured as the time from a patient's arrival to the ED to the time the attending physician indicated the completion of care and either admitted the patient to the hospital or discharged them to return home or be transferred to another healthcare facility. This outcome excludes hospital bed availability from impacting results. ED time from arrival to ED departure measures the total LOS of the patient in

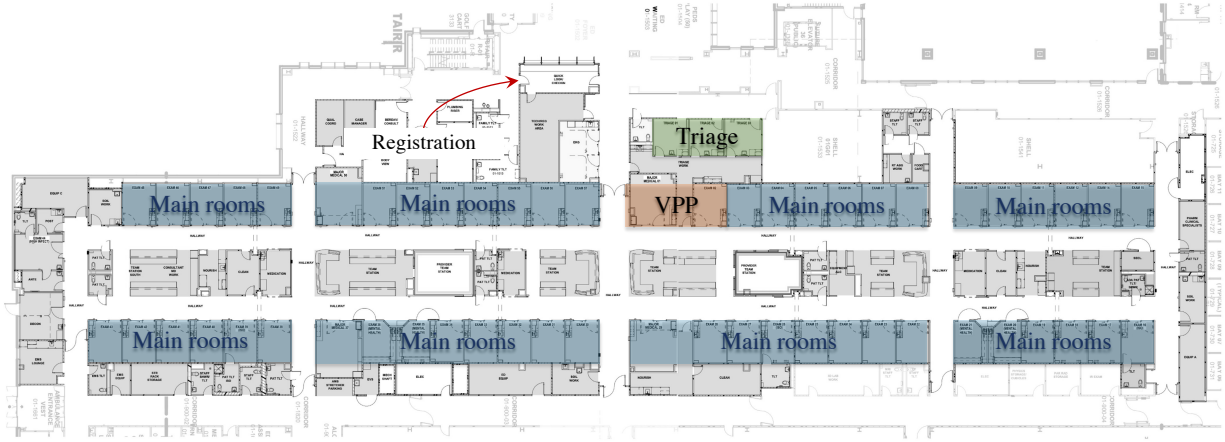
[2] Differences between the pre-trial and trial nurse staffing levels can be attributed to the intervention effect. Our data records do not include the initial nurse schedule for either trial period, and thus, we only observe the staffing levels post-daily adjustments.

the ED, ending when the patient physically departs from the ED. This time includes the boarding time for admitted patients and time to complete paperwork for discharge patients (Feizi et al. 2023). We log-transform the outcome measures because these distributions are close to log-normal (Brown et al. 2005, Saghafian et al. 2023) and right skewed (Song et al. 2015). To complement our primary findings, in Sections EC.8.1-EC.8.2, we also study the effect of the redesigned VPP on quality of care performance metrics. Specifically, we study separately the ED revisit rate with and without admission within 72 hours from ED departure (Lerman and Kobernick 1987). ED returns within 72 hours are often linked to premature discharges, missed diagnoses, or other shortcomings in the initial treatment or discharge plan. Thus, this metric is frequently used as a key indicator of quality of care.

EC.6. Additional Figures and Tables



(a) Old Mayo Clinic Arizona ED.



(b) New Mayo Clinic Arizona ED.

Figure EC.5 Physical room layout.

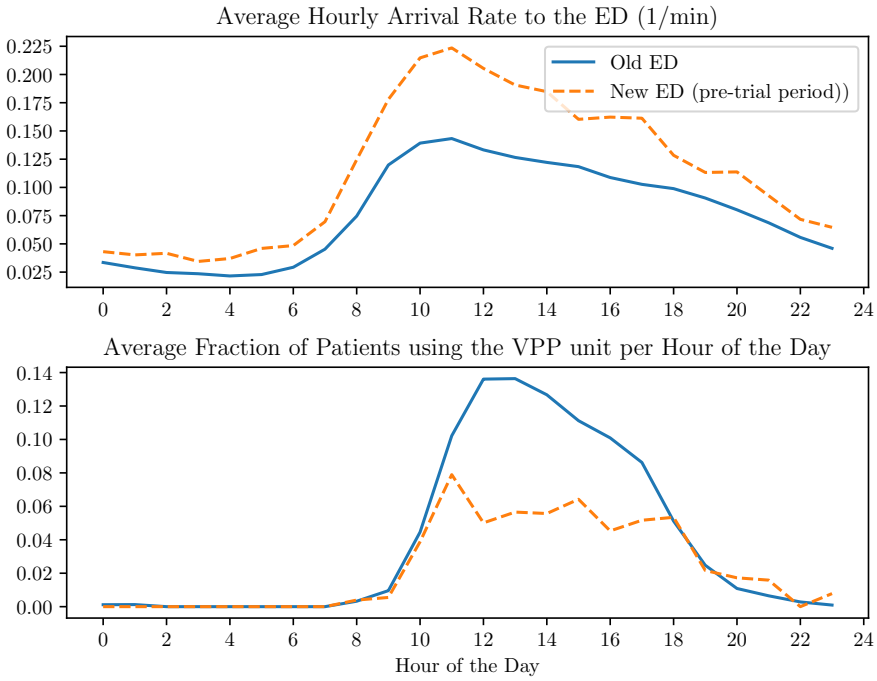


Figure EC.6 Average hourly arrival rate to the main ED and the VPP in the two datasets.

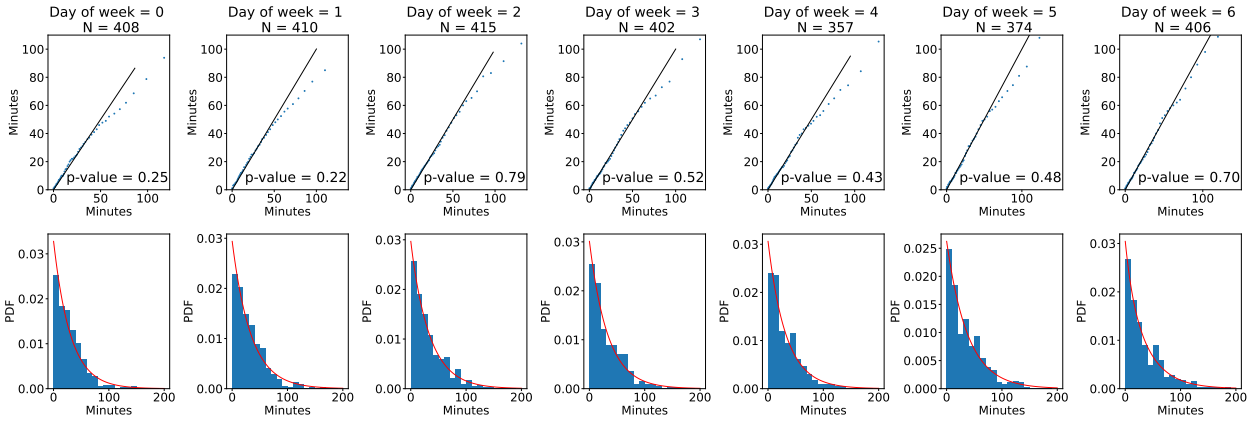


Figure EC.7 Matching interarrival time distribution of main ED with Equation 2.

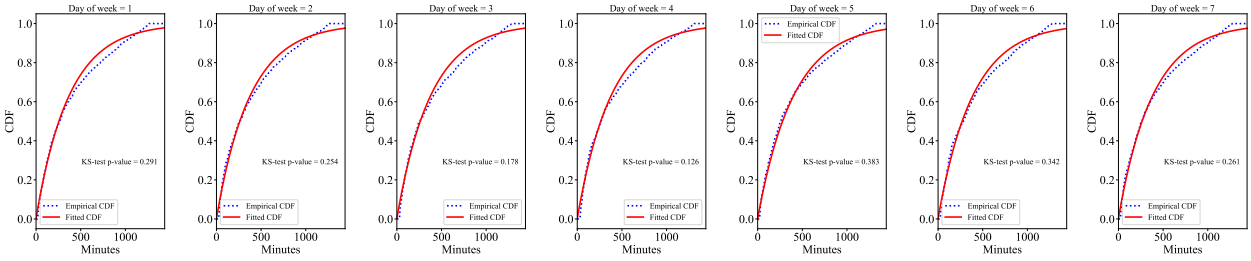


Figure EC.8 Matching the analytical and empirical CDF of arrival times to the main ED.

Independent Variable	Type	Distribution Information	% Missing
Demographic Information			
Arrival Age	Numeric	61.0 (43.0-74.0)	0.00%
Race White	Binary	43672.0 (88.5%)	0.00%
Race Asian	Binary	1407.0 (2.9%)	0.00%
Race Black or African American	Binary	2037.0 (4.1%)	0.00%
Race Choose Not to Disclose	Binary	518.0 (1.0%)	0.00%
Race Other	Binary	1687.0 (3.4%)	0.00%
Gender Male	Binary	22950.0 (46.5%)	0.00%
Acuity Score and Vitals at Triage			
ESI	Numeric	3.0 (2.0-3.0)	0.10%
SPO2	Numeric	98.0 (96.0-99.0)	0.30%
Diastolic Blood Pressure at Triage	Numeric	80.0 (72.0-89.0)	0.60%
Pulse Rate at Triage	Numeric	83.0 (72.0-96.0)	0.50%
Respiratory Rate at Triage	Numeric	18.0 (16.0-20.0)	0.50%
Systolic Blood Pressure at Triage	Numeric	136.0 (121.0-153.0)	0.60%
Temperature at Triage	Numeric	36.7 (36.5-36.9)	2.40%
Chief Complaint Categories			
Abdominal Complaints	Binary	6456.0 (13.1%)	0.00%
Abnormal Test Results	Binary	1829.0 (3.7%)	0.00%
Allergic Reaction	Binary	262.0 (0.5%)	0.00%
Back or Flank Pain	Binary	2642.0 (5.4%)	0.00%
Breast Complaints	Binary	61.0 (0.1%)	0.00%
Cardiac Arrhythmias	Binary	1055.0 (2.1%)	0.00%
Chest Pain	Binary	3679.0 (7.5%)	0.00%
Dizziness/Lightheadedness/Syncope	Binary	1969.0 (4.0%)	0.00%
Ear Complaints	Binary	254.0 (0.5%)	0.00%
Epistaxis	Binary	260.0 (0.5%)	0.00%
Exposures, Bites, and Envenomations	Binary	261.0 (0.5%)	0.00%
Extremity Complaints	Binary	5389.0 (10.9%)	0.00%
Eye Complaints	Binary	730.0 (1.5%)	0.00%
Falls, Assaults, and Trauma	Binary	2399.0 (4.9%)	0.00%
Fatigue and Weakness	Binary	1548.0 (3.1%)	0.00%
Fevers, Sweats or Chills	Binary	1908.0 (3.9%)	0.00%
Gastrointestinal Issues	Binary	3359.0 (6.8%)	0.00%
Genital Complaints	Binary	683.0 (1.4%)	0.00%
Medical Device or Treatment Issue	Binary	481.0 (1.0%)	0.00%
Medication Request	Binary	76.0 (0.2%)	0.00%
Neurological Issue	Binary	3457.0 (7.0%)	0.00%
Other	Binary	808.0 (1.6%)	0.00%
Other Pain	Binary	794.0 (1.6%)	0.00%
Psychiatric Complaints	Binary	206.0 (0.4%)	0.00%
Shortness of Breath	Binary	3050.0 (6.2%)	0.00%
Skin Complaints	Binary	2347.0 (4.8%)	0.00%
Upper Respiratory Symptoms	Binary	1941.0 (3.9%)	0.00%
Urinary Complaints	Binary	1446.0 (2.9%)	0.00%

Table EC.8 Summary statistics of all patient characteristics for the population sample from the old Mayo Clinic Arizona ED. For continuous variables, we report the average and the 95% confidence interval. In the case of binary variables, the table shows the count of observations where the feature is present and in parentheses the percent over the entire population. The last column includes the percent of missing values in the dataset for each independent variable.

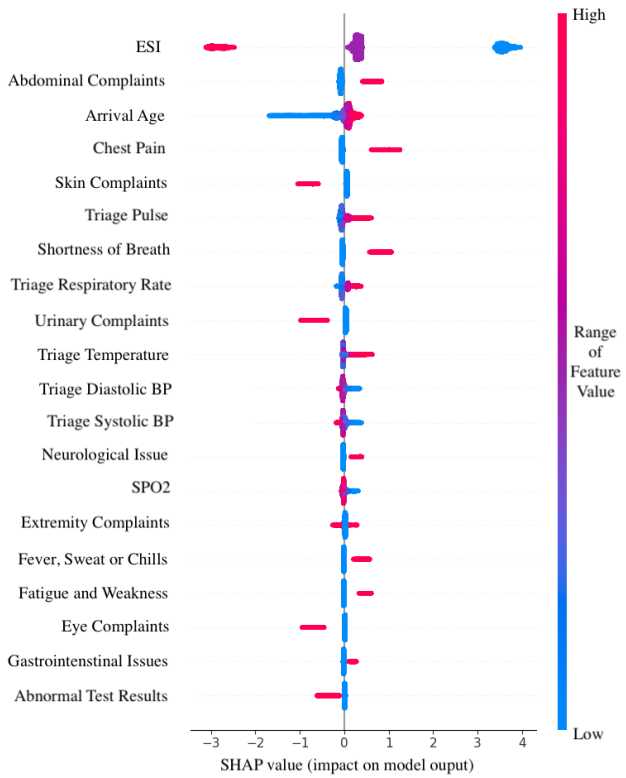


Figure EC.9 **SHAP Plot for random forest models summarizing the contribution to risk prediction of the 20 most important features.**

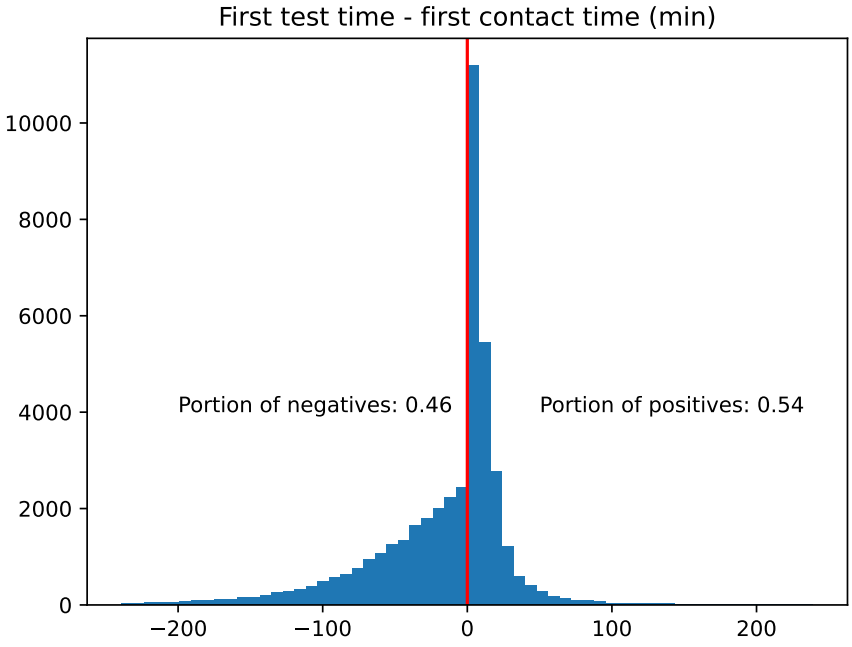


Figure EC.10 **Time from first contact to first test. Negative values indicate that test was ordered prior to contact with physician.**

	ESI 1	ESI 2	ESI 3	ESI 4	ESI 5
Strict FIFO Compliance (%)	98.22	78.22	67.59	88.68	97.60
Relaxed FIFO Compliance (%)	99.80	95.84	91.25	98.26	100.00

Table EC.9 Empirical validation summary of the FIFO assumption for the patient service order using the retrospective dataset from the old Mayo Clinic ED.

Note: This analysis aims to validate the First-In-First-Out (FIFO) assumption in the order patients receive care within each physician's queue based on the time of arrival. The analysis is conducted separately for each ESI category and focuses on the order in which physicians initiate their patients' treatment. The first two rows reflect the percentage compliance averaged across all physicians, weighted by the number of patients treated by each physician. Strict FIFO compliance indicates that the FIFO order based on the time of arrival was strictly adhered to in the order of care. Relaxed FIFO Compliance allows for permutations of up to one patient, meaning the physician could switch the order of only one patient. Based on these findings, the high percentages of both strict and relaxed FIFO compliance across all ESI levels indicate that the FIFO principle is generally adhered to in practice within each physician's queue.

Capacity	**Conditions**
Normal Operations	1. Patients in the waiting room for <20 minutes. 2. Number of patients in the ED is less than available ED beds.
Minor Overcapacity	1. Waiting room time 21-90 minutes OR; 2. Waiting room with 10 patients OR; 3. Number of ED patients exceed available ED beds by 10 (e.g., admitted patients waiting for a bed assignment) OR; 4. Team leader discretion.
Major Overcapacity	1. Waiting room time >90 minutes OR; 2. Waiting room with >20 patients OR; 3. More than 40 new patient arrivals in 2 hours OR; 4. Number of ED patients exceed available ED beds by 20 (e.g., admitted patients waiting for a bed assignment) OR; 5. Team leader discretion.

Table EC.10 Internal guidelines for activation of overcapacity and saturation plans for the new Mayo Clinic Arizona ED.

Chief Complaint	**Pre-Trial (N = 5,522)**	**Trial (N = 5,493)**	**p-value**
Cardiac Arrhythmias	2.41%	2.42%	p>0.05
Falls, Motor Vehicle Crashes, Assaults, and Trauma	5.36%	5.21%	p>0.05
Extremity Complaints	9.60%	9.90%	p>0.05
Shortness of Breath	6.50%	6.01%	p>0.05
Other	0.72%	0.67%	p>0.05
Abdominal Complaints	12.51%	13.18%	p>0.05
Abnormal Test Results	4.78%	5.10%	p>0.05
Chest Pain	7.61%	7.41%	p>0.05
Neurological Issue	6.52%	6.41%	p>0.05
Fevers, Sweats or Chills	2.75%	2.71%	p>0.05
Skin Complaints	4.40%	4.77%	p>0.05
Urinary Complaints	2.77%	2.89%	p>0.05
Genital Complaints	1.65%	1.46%	p>0.05
Foreign Body	0.16%	0.11%	p>0.05
Upper Respiratory Symptoms	4.98%	3.95%	p<0.01
Dizziness, Lightheadedness, and Syncope	3.48%	3.93%	p>0.05
Fatigue and Weakness	2.79%	3.02%	p>0.05
Allergic Reaction	0.62%	0.40%	p<0.05
Eye Complaints	1.47%	1.57%	p>0.05
Epistaxis	0.43%	0.62%	p>0.05
Back or Flank Pain	5.38%	5.41%	p>0.05
Medical Device or Treatment Issue	1.14%	1.22%	p>0.05
Gastrointestinal Issues	6.75%	6.77%	p>0.05
Ear Complaints	0.85%	0.47%	p>0.05
Other Pain	2.06%	1.78%	p>0.05
Post-Op Issue	0.83%	0.73%	p>0.05
Psychiatric Complaints	0.47%	0.55%	p>0.05
Substance Abuse Issues	0.33%	0.51%	p>0.05
Breast Complaints	0.04%	0.11%	p>0.05
Medication Request	0.11%	0.16%	p>0.05
Unknown	0.13%	0.02%	p>0.05
Exposures, Bites, and Envenomations	0.33%	0.46%	p>0.05
Circulatory Issue	0.07%	0.07%	p>0.05

Table EC.11 Summary of chief complaints reported at triage in the pre-trial and post trial periods. We report the percentage prevalence of each binary variable, along with p-values derived from the chi-squared test. P-values>0.05 suggest no significant differences in the distributions between the two periods.

MD ID	Pre-Trial (N = 5,522)	Trial (N = 5,493)	p-value
A	4.84%	3.73%	p<0.001
AA	2.03%	2.55%	p<0.05
AB	1.96%	1.84%	p>0.05
AC	1.83%	2.04%	p<0.05
AD	1.70%	0.86%	p<0.001
AE	1.70%	2.77%	p<0.001
AF	1.68%	2.60%	p<0.001
AG	1.56%	1.38%	p<0.001
AH	1.30%	0.75%	p<0.01
AI	1.01%	0.55%	p<0.01
AJ	0.69%	3.90%	p<0.001
AK	0.53%	1.00%	p<0.05
B	4.24%	3.90%	p<0.05
C	4.15%	3.51%	p<0.001
D	3.89%	3.82%	p>0.05
E	3.71%	4.35%	p<0.001
F	3.68%	3.09%	p>0.05
G	3.62%	3.82%	p<0.05
H	3.57%	3.48%	p>0.05
I	3.53%	3.11%	p>0.05
J	3.53%	2.35%	p<0.001
K	3.51%	3.79%	p>0.05
L	3.44%	3.68%	p>0.05
M	3.26%	3.79%	p>0.05
N	3.24%	2.71%	p>0.05
O	3.04%	3.44%	p<0.05
P	3.01%	3.08%	p>0.05
Q	2.95%	3.33%	p>0.05
R	2.90%	2.77%	p>0.05
S	2.90%	2.59%	p>0.05
T	2.79%	1.51%	p<0.001
U	2.44%	2.35%	p>0.05
V	2.44%	1.80%	p<0.001
W	2.43%	2.68%	p>0.05
X	2.41%	2.29%	p>0.05
Y	2.37%	2.28%	p<0.001
Z	2.12%	2.53%	p>0.05

Table EC.12 Summary of attending physician assignments in the pre-trial and post trial periods. We report the percentage prevalence of each binary variable, along with p-values derived from the chi-squared test. P-values>0.05 suggest no significant differences in the distributions between the two periods.

Variable	**Pre-Trial (N = 34 days)**	**Trial (N = 34 days)**	**p-value**
Nurses Hours (day)	537.54 (30.16)	521.30 (32.82)	$p < 0.05$
Nurse Shifts (day)	44.62 (2.23)	43.26 (2.43)	$p < 0.05$
MD Hours (day)	111.75 (6.32)	113.90 (7.77)	$p > 0.05$
MD Shifts (day)	13.15 (0.74)	13.40 (0.91)	$p > 0.05$
ED Rooms Available (day)	56 (0)	56 (0)	$p > 0.05$
ED Rooms Utilized (day)	55.28 (3.00)	54.39 (4.42)	$p > 0.05$
Arrival rate (hour) (12am-6am)	12.26 (4.36)	11.94 (3.62)	$p > 0.05$
Arrival rate (hour) (6am-12pm)	51.44 (6.47)	48.80 (9.88)	$p > 0.05$
Arrival rate (hour) (12pm-6pm)	63.88 (10.45)	59.40 (11.00)	$p > 0.05$
Arrival rate (hour) (6pm-12am)	34.82 (7.28)	36.80 (9.59)	$p > 0.05$
Discharge rate (hour) (12am-6am)	5.12 (2.37)	5.14 (2.39)	$p > 0.05$
Discharge rate (hour) (6am-12pm)	16.21 (4.39)	17.14 (3.66)	$p > 0.05$
Discharge rate (hour) (12pm-6pm)	58.56 (5.85)	55.51 (7.83)	$p > 0.05$
Discharge rate (hour) (6pm-12am)	82.53 (15.35)	79.14 (16.80)	$p > 0.05$
Patients in the ED (12am-6am)	4.80 (2.10)	4.78 (1.89)	$p > 0.05$
Patients in the ED (6am-12pm)	19.83 (3.48)	19.53 (4.41)	$p > 0.05$
Patients in the ED (12pm-6pm)	50.31 (7.68)	44.41 (11.48)	$p < 0.05$
Patients in the ED (6pm-12am)	35.28 (8.54)	32.74 (8.90)	$p > 0.05$
Patients in treatment in the ED (12am-6am)	3.47 (1.64)	3.43 (1.45)	$p > 0.05$
Patients in treatment in the ED (6am-12pm)	14.09 (2.33)	13.77 (2.83)	$p > 0.05$
Patients in treatment in the ED (12pm-6pm)	29.34 (3.77)	26.10 (5.06)	$p < 0.01$
Patients in treatment in the ED (6pm-12am)	18.26 (4.01)	16.98 (4.34)	$p > 0.05$
Patients waiting for discharge (12am-6am)	0.96 (0.51)	0.95 (0.50)	$p > 0.05$
Patients waiting for discharge (6am-12pm)	3.37 (1.18)	3.33 (1.15)	$p > 0.05$
Patients waiting for discharge (12pm-6pm)	14.42 (3.32)	13.31 (4.25)	$p > 0.05$
Patients waiting for discharge (6pm-12am)	14.27 (4.62)	13.07 (4.63)	$p > 0.05$
Patients in VPP (12am-6am)	0.00 (0.00)	0.00 (0.01)	$p > 0.05$
Patients in VPP (6am-12pm)	0.05 (0.10)	0.36 (0.16)	$p < 0.001$
Patients in VPP (12pm-6pm)	0.20 (0.25)	0.52 (0.21)	$p < 0.001$
Patients in VPP (6pm-12am)	0.04 (0.07)	0.16 (0.13)	$p < 0.001$

Table EC.13 Summary of operational ED characteristics and patient arrival patterns aggregated at the daily level in the pre-trial and trial periods. The mean and the standard deviation (in parentheses) are included for continuous variables and the percentage prevalence for binary variables, along with p-values derived from t-tests and chi-squared tests respectively. P-values>0.05 suggest no significant differences in the distributions between the two periods.

EC.7. Matching Methods and Results Summary

A potential endogeneity concern in our implementation study stems from non-random selection into treatment. Despite their rigorous training, some physicians may be more reluctant to adhere to the VPP protocol because of their perceived gains in treatment length. Similarly, patients with certain chief complaints may be more (or less) likely to receive the VPP for the same reason. These selection issues may bias our estimates. We address these concerns by applying matching methods to create balanced covariates between the two study periods. In this section, we provide additional information regarding the matching approaches we performed, and subsequently, we present summary tables of the resulting datasets.

EC.7.1. Methods Description

Cardinality Matching: Cardinality matching is a robust approach employed to enhance the accuracy of effect estimations in observational studies. The method, proposed by Zubizarreta et al. (2014), uses mixed integer optimization to create a balanced sample. We apply the implementation of the R package "designmatch" (Zubizarreta et al. 2018). This approach offers different types of matching including exact matching and fine balancing for categorical variables, and moment balancing for continuous variables.

Exact matching involves selecting subsets of treated and control units such that each treated unit has a corresponding control unit with identical values for all covariates of interest. This method is stringent, ensuring that the groups are perfectly balanced on all observed covariates at the expense of significantly reducing the number of units included in the final matched sample. Fine balancing balances the marginal distributions of covariates across treated and control groups. Thus, it ensures that the overall distribution of each covariate is similar between the two groups, allowing for greater flexibility in the matching process. Moment balancing seeks to ensure that the statistical moments of covariates are balanced between the treated and control groups, targeting balanced statistical properties of the covariates. For this reason, moment balancing is preferred for continuous variables. By ensuring a rigorous balance of covariates between treated and control groups, cardinality matching can isolate to some extent the impact of an intervention (e.g., implementation of the VPP protocol in our setting), providing more precise insights into their effectiveness.

To perform cardinality matching, we leverage the exact matching option of the algorithm on the ESI level, attending physician assignment, and medical shift at arrival to control for critical factors that directly influence patient treatment pathways and physician decision-making. We apply moment balancing in terms of mean and variance for the number of patients in waiting and treatment since they constitute continuous variables. We employ distributional balancing via fine balance for the number of MDs and nurses on shift, types of procedures and tests administered, and

the ED disposition of the patient. Thus, we maintain balance in key operational variables across the matched groups without significantly limiting the data size. The resulting dataset, which we refer to as "Matching on MD," is reduced to $N = 5,158$ observations.

In addition to "Matching on MD," we derive a second dataset based on the cardinality matching algorithm that will serve as sensitivity analysis for our empirical results. Specifically, we apply cardinality matching with: exact matching on the ESI level, chief complaint category expressed by the patient at the time of triage, and medical shift at arrival; moment balancing in terms of mean and variance for the number of patients in waiting and treatment; and distributional balancing via fine balance for the number of MDs and nurses on shift, types of procedures and tests administered, and the ED disposition of the patient. In comparison with the previous dataset, in the list of variables for exact matching we replace the attending physician with the chief complaint category, emphasizing more the medical condition rather than the provider. The output dataset, which we refer to as "Matching on CC," comprises $N = 5,976$ observations.

Propensity Score Matching: Propensity score matching serves as an additional supplementary sensitivity analysis for our empirical findings (Rosenbaum and Rubin 1983). To this end, we used logistic regression to estimate each patient's probability of being in the trial period based on the observed covariates. The model specification is given in Equation EC.12.

$$\log\left(\frac{\Pr(Trial_i)}{1-\Pr(Trial_i)}\right) = \alpha_0 + \boldsymbol{\beta}\mathbf{X}_i + \boldsymbol{\gamma}\mathbf{MD}_i + \boldsymbol{\delta}\mathbf{CC}_i. \tag{EC.12}$$

The vector $\mathbf{X}$ includes all variables presented in Table 2. A list of all chief complaints and MD assignments considered are available in Tables EC.11 and EC.12, respectively. Subsequently, for each patient in the trial period, we used the k-nearest neighbors algorithm to identify the most similar observation in the pre-trial period based on the computed propensity score (Fix 1985). Finally, we created matched pairs of observations using the identified neighbors ensuring balance in the likelihood of participating in the pre-trial and the trial periods. The resulting dataset includes $N = 10,926$ observations.

EC.7.2. Results Summary

Table EC.14 summarizes the covariate balance before and after cardinality matching for our primary model based on MD. We present the mean and standard deviation of the sample covariates both before and after the matching process. Before matching, t-tests (continuous variables) and χ^2 tests (binary variables) on the distribution of key variables indicated significant differences, particularly concerning physician assignment. This variation is critical as personal preferences and biases of different physicians can affect adherence to protocols and their implementation. The application

of matching was, therefore, essential to mitigate these biases and ensure a fair comparison. Post-matching, the t-tests revealed no statistically significant differences between the matched groups, with the exception of three physicians that attended less than 5% of the cases, and thus, exact matching was not possible, affirming the effectiveness of our matching process (see Table EC.14). The resulting p-values post-matching confirm that our matched sample is well-balanced, reinforcing our confidence that we have successfully generated a sample in which the probability that a patient belongs in the pre-trial or trial periods can be considered random. The standardized mean absolute difference between the pre-trial and trial groups was reduced from 0.0341 (no matching) to 0.0194 and 0.0237 when we performed cardinality matching on physician assignment and chief complaints, respectively, and to 0.0280 in the case of propensity score matching. Additional balance diagnostics and robustness checks based on chief-complaint and propensity-score matching are summarized in Tables EC.15 and EC.16, respectively. These results confirm that the matched samples remain well balanced across all specifications.

Variable	**Pre-Trial (N=2,579)**	**Trial (N=2,579)**	**p-value**
ESI 1	0.00 (0.06)	0.00 (0.06)	p>0.05
ESI 2	0.26 (0.44)	0.26 (0.44)	p>0.05
ESI 3	0.55 (0.50)	0.55 (0.50)	p>0.05
ESI 4	0.19 (0.39)	0.19 (0.39)	p>0.05
ESI 5	0.00 (0.03)	0.00 (0.03)	p>0.05
Age	58.95 (20.78)	58.55 (20.90)	p>0.05
IV	0.64 (0.48)	0.65 (0.48)	p>0.05
CT with IVcontrast	0.24 (0.43)	0.23 (0.42)	p>0.05
CT without IV contrast	0.19 (0.39)	0.19 (0.39)	p>0.05
MRI	0.02 (0.14)	0.02 (0.14)	p>0.05
Xray	0.45 (0.50)	0.45 (0.50)	p>0.05
Ultrasound	0.12 (0.32)	0.13 (0.34)	p>0.05
Nurses on shift	24.34 (6.06)	24.09 (6.08)	p>0.05
MDs on shift	5.45 (1.97)	5.50 (2.02)	p>0.05
Current waiting count	4.28 (3.48)	4.27 (3.47)	p>0.05
Current treatment count	30.94 (14.31)	30.85 (14.31)	p>0.05
Shift: 12 am-6 am	0.09 (0.29)	0.09 (0.29)	p>0.05
Shift: 12 pm-6 pm	0.35 (0.48)	0.35 (0.48)	p>0.05
Shift: 6 am-12 pm	0.32 (0.47)	0.32 (0.47)	p>0.05
Shift: 6 pm-12 am	0.24 (0.42)	0.24 (0.43)	p>0.05
ED Disposition Admit	0.19 (0.39)	0.18 (0.38)	p>0.05
ED Disposition Discharge	0.67 (0.47)	0.68 (0.47)	p>0.05
ED Disposition Hospital Observation	0.12 (0.32)	0.13 (0.34)	p>0.05
ED Disposition Left Without Being Seen/AMA	0.00 (0.06)	0.01 (0.08)	p>0.05
ED Disposition Transfer to Health Care Facility	0.01 (0.11)	0.01 (0.10)	p>0.05
MD_A	0.04 (0.20)	0.04 (0.19)	p>0.05
MD_AA	0.01 (0.11)	0.01 (0.10)	p>0.05
MD_AB	0.02 (0.13)	0.01 (0.12)	p>0.05
MD_AC	0.02 (0.16)	0.03 (0.16)	p>0.05

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Table EC.14 continued from previous page

Variable	Pre-Trial	Trial	p-value
MD_AD	0.02 (0.15)	0.01 (0.12)	p<0.01
MD_AE	0.02 (0.13)	0.03 (0.18)	p<0.001
MD_AF	0.02 (0.14)	0.03 (0.16)	p<0.05
MD_AG	0.01 (0.09)	0.01 (0.09)	p>0.05
MD_AH	0.02 (0.13)	0.01 (0.09)	p<0.01
MD_AI	0.02 (0.12)	0.01 (0.10)	p>0.05
MD_AJ	0.01 (0.11)	0.04 (0.20)	p<0.001
MD_AK	0.01 (0.08)	0.01 (0.12)	p<0.01
MD_B	0.04 (0.19)	0.04 (0.19)	p>0.05
MD_C	0.03 (0.18)	0.03 (0.18)	p>0.05
MD_D	0.03 (0.18)	0.03 (0.18)	p>0.05
MD_E	0.05 (0.21)	0.05 (0.22)	p>0.05
MD_F	0.03 (0.18)	0.03 (0.16)	p>0.05
MD_G	0.04 (0.18)	0.03 (0.18)	p>0.05
MD_H	0.03 (0.17)	0.03 (0.17)	p>0.05
MD_I	0.05 (0.21)	0.04 (0.20)	p>0.05
MD_J	0.03 (0.18)	0.03 (0.17)	p>0.05
MD_K	0.04 (0.20)	0.04 (0.20)	p>0.05
MD_L	0.05 (0.21)	0.04 (0.20)	p>0.05
MD_M	0.04 (0.19)	0.03 (0.18)	p>0.05
MD_N	0.02 (0.13)	0.02 (0.14)	p>0.05
MD_O	0.02 (0.15)	0.03 (0.16)	p>0.05
MD_P	0.02 (0.15)	0.03 (0.16)	p>0.05
MD_Q	0.04 (0.19)	0.04 (0.20)	p>0.05
MD_R	0.03 (0.16)	0.02 (0.15)	p>0.05
MD_S	0.03 (0.18)	0.03 (0.18)	p>0.05
MD_T	0.03 (0.17)	0.02 (0.14)	p<0.05
MD_U	0.02 (0.13)	0.02 (0.12)	p>0.05
MD_V	0.01 (0.10)	0.01 (0.10)	p>0.05
MD_W	0.03 (0.17)	0.03 (0.16)	p>0.05
MD_X	0.02 (0.15)	0.02 (0.14)	p>0.05
MD_Y	0.03 (0.17)	0.02 (0.15)	p>0.05
MD_Z	0.03 (0.17)	0.03 (0.18)	p>0.05
Abdominal Complaints	0.12 (0.33)	0.12 (0.32)	p>0.05
Abnormal Test Results	0.04 (0.21)	0.05 (0.22)	p>0.05
Allergic Reaction	0.01 (0.09)	0.00 (0.07)	p>0.05
Back or Flank Pain	0.06 (0.23)	0.05 (0.22)	p>0.05
Breast Complaints	0.00 (0.00)	0.00 (0.04)	p<0.05
Cardiac Arrhythmias	0.02 (0.14)	0.03 (0.16)	p>0.05
Chest Pain	0.08 (0.27)	0.07 (0.26)	p>0.05
Circulatory Issue	0.00 (0.00)	0.00 (0.03)	p>0.05
Dizziness/Lightheadedness/Syncope	0.03 (0.17)	0.04 (0.19)	p>0.05
Ear Complaints	0.01 (0.10)	0.01 (0.08)	p>0.05
Epistaxis	0.01 (0.07)	0.01 (0.08)	p>0.05
Exposures, Bites, and Envenomations	0.01 (0.07)	0.01 (0.07)	p>0.05
Extremity Complaints	0.10 (0.30)	0.11 (0.31)	p>0.05
Eye Complaints	0.02 (0.12)	0.02 (0.12)	p>0.05
Falls, Motor Vehicle Crashes, Assaults, and Trauma	0.05 (0.22)	0.05 (0.22)	p>0.05
Fatigue and Weakness	0.03 (0.18)	0.03 (0.16)	p>0.05
Fevers, Sweats or Chills	0.03 (0.17)	0.03 (0.16)	p>0.05
Foreign Body	0.00 (0.05)	0.00 (0.04)	p>0.05
Gastrointestinal Issues	0.06 (0.24)	0.06 (0.24)	p>0.05

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Table EC.14 continued from previous page

Variable	Pre-Trial	Trial	p-value
Genital Complaints	0.02 (0.12)	0.02 (0.14)	p>0.05
Medical Device or Treatment Issue	0.01 (0.11)	0.01 (0.12)	p>0.05
Medication Request	0.00 (0.02)	0.00 (0.03)	p>0.05
Neurological Issue	0.06 (0.23)	0.06 (0.24)	p>0.05
Other	0.01 (0.08)	0.01 (0.10)	p>0.05
Other Pain	0.02 (0.15)	0.02 (0.15)	p>0.05
Post-Op Issue	0.01 (0.10)	0.01 (0.09)	p>0.05
Psychiatric Complaints	0.01 (0.08)	0.01 (0.07)	p>0.05
Shortness of Breath	0.06 (0.24)	0.06 (0.24)	p>0.05
Skin Complaints	0.05 (0.22)	0.05 (0.22)	p>0.05
Substance Abuse Issues	0.00 (0.06)	0.01 (0.07)	p>0.05
Upper Respiratory Symptoms	0.05 (0.22)	0.04 (0.20)	p>0.05
Urinary Complaints	0.03 (0.16)	0.03 (0.17)	p>0.05

Table EC.14: Dataset summary after cardinality matching based on MD.

Variable	Pre-Trial (N=2,988)	Trial (N=2,988)	p-value
ESI 1	0.00 (0.05)	0.00 (0.05)	p>0.05
ESI 2	0.22 (0.41)	0.22 (0.41)	p>0.05
ESI 3	0.64 (0.48)	0.64 (0.48)	p>0.05
ESI 4	0.13 (0.34)	0.13 (0.34)	p>0.05
ESI 5	0.00 (0.03)	0.00 (0.03)	p>0.05
Age	58.56 (20.90)	58.17 (20.79)	p>0.05
IV	0.66 (0.47)	0.67 (0.47)	p>0.05
CT with IVcontrast	0.26 (0.44)	0.26 (0.44)	p>0.05
CT without IV contrast	0.20 (0.40)	0.19 (0.40)	p>0.05
MRI	0.02 (0.13)	0.02 (0.14)	p>0.05
Xray	0.44 (0.50)	0.43 (0.50)	p>0.05
ultrasound	0.12 (0.33)	0.13 (0.34)	p>0.05
Nurses on shift	24.51 (5.98)	24.24 (5.99)	p>0.05
MDs on shift	5.54 (1.96)	5.56 (1.97)	p>0.05
Current waiting count	4.40 (3.54)	4.38 (3.52)	p>0.05
Current treatment count	31.50 (14.03)	31.45 (14.01)	p>0.05
Shift: 12 am-6 am	0.07 (0.26)	0.07 (0.26)	p>0.05
Shift: 12 pm-6 pm	0.36 (0.48)	0.36 (0.48)	p>0.05
Shift: 6 am-12 pm	0.33 (0.47)	0.33 (0.47)	p>0.05
Shift: 6 pm-12 am	0.24 (0.43)	0.24 (0.43)	p>0.05
ED Disposition Admit	0.19 (0.39)	0.18 (0.39)	p>0.05
ED Disposition Discharge	0.68 (0.47)	0.68 (0.47)	p>0.05
ED Disposition Hospital Observation	0.12 (0.32)	0.12 (0.33)	p>0.05
ED Disposition Left Without Being Seen/AMA	0.00 (0.07)	0.01 (0.08)	p>0.05
ED Disposition Transfer to Health Care Facility	0.01 (0.11)	0.01 (0.10)	p>0.05
Abdominal Complaints	0.17 (0.38)	0.17 (0.38)	p>0.05
Abnormal Test Results	0.05 (0.21)	0.05 (0.21)	p>0.05
Allergic Reaction	0.01 (0.08)	0.00 (0.07)	p>0.05
Back or Flank Pain	0.06 (0.24)	0.06 (0.24)	p>0.05
Breast Complaints	0.00 (0.00)	0.00 (0.03)	p>0.05

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Table EC.15 continued from previous page

Variable	Pre-Trial	Trial	p-value
Cardiac Arrhythmias	0.02 (0.13)	0.02 (0.13)	p>0.05
Chest Pain	0.08 (0.28)	0.08 (0.28)	p>0.05
Circulatory Issue	0.00 (0.03)	0.00 (0.03)	p>0.05
Dizziness/Lightheadedness/Syncope	0.03 (0.17)	0.03 (0.17)	p>0.05
Ear Complaints	0.01 (0.10)	0.01 (0.07)	p<0.05
Epistaxis	0.00 (0.07)	0.01 (0.08)	p>0.05
Exposures, Bites, and Envenomations	0.00 (0.05)	0.01 (0.08)	p>0.05
Extremity Complaints	0.11 (0.31)	0.11 (0.31)	p>0.05
Eye Complaints	0.01 (0.09)	0.01 (0.08)	p>0.05
Falls, Motor Vehicle Crashes, Assaults, and Trauma	0.04 (0.20)	0.04 (0.20)	p>0.05
Fatigue and Weakness	0.02 (0.12)	0.02 (0.12)	p>0.05
Fevers, Sweats or Chills	0.01 (0.12)	0.01 (0.12)	p>0.05
Foreign Body	0.00 (0.04)	0.00 (0.04)	p>0.05
Gastrointestinal Issues	0.07 (0.26)	0.07 (0.26)	p>0.05
Genital Complaints	0.01 (0.10)	0.01 (0.10)	p>0.05
Medical Device or Treatment Issue	0.01 (0.09)	0.01 (0.09)	p>0.05
Medication Request	0.00 (0.02)	0.00 (0.03)	p>0.05
Neurological Issue	0.07 (0.25)	0.07 (0.25)	p>0.05
Other	0.01 (0.10)	0.01 (0.09)	p>0.05
Other Pain	0.02 (0.12)	0.01 (0.12)	p>0.05
Post-Op Issue	0.01 (0.08)	0.01 (0.08)	p>0.05
Psychiatric Complaints	0.01 (0.08)	0.01 (0.08)	p>0.05
Shortness of Breath	0.07 (0.25)	0.07 (0.25)	p>0.05
Skin Complaints	0.04 (0.20)	0.04 (0.20)	p>0.05
Substance Abuse Issues	0.00 (0.06)	0.01 (0.08)	p>0.05
Upper Respiratory Symptoms	0.04 (0.19)	0.04 (0.19)	p>0.05
Urinary Complaints	0.03 (0.17)	0.03 (0.17)	p>0.05

Table EC.15: Dataset summary after cardinality matching based on CC.

Variable	Pre-Trial (N=5,463)	Trial (N=5,463)	p-value
ESI 1	0.00 (0.07)	0.01 (0.08)	p>0.05
ESI 2	0.24 (0.43)	0.24 (0.43)	p>0.05
ESI 3	0.60 (0.49)	0.61 (0.49)	p>0.05
ESI 4	0.15 (0.35)	0.14 (0.35)	p>0.05
ESI 5	0.00 (0.07)	0.00 (0.06)	p>0.05
Age	59.02 (20.76)	58.62 (20.90)	p>0.05
IV	0.66 (0.47)	0.66 (0.47)	p>0.05
CT with IVcontrast	0.24 (0.43)	0.25 (0.43)	p>0.05
CT without IV contrast	0.21 (0.41)	0.20 (0.40)	p<0.05
MRI	0.02 (0.14)	0.02 (0.14)	p>0.05
Xray	0.44 (0.50)	0.44 (0.50)	p>0.05
ultrasound	0.13 (0.34)	0.13 (0.33)	p>0.05
Nurses on shift	24.24 (6.13)	24.29 (6.08)	p>0.05
Current waiting count	4.55 (3.86)	4.65 (3.92)	p>0.05
Current treatment count	31.16 (14.59)	31.25 (14.31)	p>0.05
Shift: 12 am-6 am	0.07 (0.26)	0.07 (0.26)	p>0.05

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Table EC.16 continued from previous page

Variable	Pre-Trial	Trial	p-value
Shift: 12 pm-6 pm	0.37 (0.48)	0.38 (0.49)	p>0.05
Shift: 6 am-12 pm	0.33 (0.47)	0.31 (0.46)	p>0.05
Shift: 6 pm-12 am	0.24 (0.43)	0.24 (0.42)	p>0.05
ED Disposition Admit	0.20 (0.40)	0.19 (0.39)	p>0.05
ED Disposition Discharge	0.66 (0.47)	0.67 (0.47)	p>0.05
ED Disposition Hospital Observation	0.13 (0.33)	0.12 (0.33)	p>0.05
ED Disposition Left Without Being Seen/AMA	0.01 (0.08)	0.01 (0.08)	p>0.05
ED Disposition Transfer to Health Care Facility	0.01 (0.09)	0.01 (0.10)	p>0.05
Abdominal Complaints	0.12 (0.33)	0.13 (0.34)	p>0.05
Abnormal Test Results	0.05 (0.22)	0.05 (0.22)	p>0.05
Allergic Reaction	0.00 (0.06)	0.00 (0.06)	p>0.05
Back or Flank Pain	0.06 (0.23)	0.05 (0.23)	p>0.05
Breast Complaints	0.00 (0.02)	0.00 (0.03)	p>0.05
Cardiac Arrhythmias	0.03 (0.17)	0.02 (0.15)	p>0.05
Chest Pain	0.07 (0.26)	0.07 (0.26)	p>0.05
Circulatory Issue	0.00 (0.03)	0.00 (0.03)	p>0.05
Dizziness/Lightheadedness/Syncope	0.04 (0.20)	0.04 (0.19)	p>0.05
Ear Complaints	0.00 (0.06)	0.00 (0.07)	p>0.05
Epistaxis	0.01 (0.08)	0.01 (0.08)	p>0.05
Exposures, Bites, and Envenomations	0.00 (0.06)	0.00 (0.07)	p>0.05
Extremity Complaints	0.09 (0.29)	0.10 (0.30)	p>0.05
Eye Complaints	0.02 (0.15)	0.02 (0.12)	p<0.05
Falls, Motor Vehicle Crashes, Assaults, and Trauma	0.06 (0.23)	0.05 (0.22)	p>0.05
Fatigue and Weakness	0.04 (0.19)	0.03 (0.17)	p>0.05
Fevers, Sweats or Chills	0.03 (0.16)	0.03 (0.16)	p>0.05
Foreign Body	0.00 (0.04)	0.00 (0.03)	p>0.05
Gastrointestinal Issues	0.07 (0.25)	0.07 (0.25)	p>0.05
Genital Complaints	0.01 (0.12)	0.01 (0.12)	p>0.05
Medical Device or Treatment Issue	0.01 (0.11)	0.01 (0.11)	p>0.05
Medication Request	0.00 (0.05)	0.00 (0.04)	p>0.05
Neurological Issue	0.06 (0.23)	0.06 (0.24)	p>0.05
Other Pain	0.02 (0.14)	0.02 (0.13)	p>0.05
Post-Op Issue	0.01 (0.09)	0.01 (0.09)	p>0.05
Psychiatric Complaints	0.00 (0.06)	0.01 (0.07)	p>0.05
Shortness of Breath	0.06 (0.25)	0.06 (0.24)	p>0.05
Skin Complaints	0.05 (0.21)	0.05 (0.21)	p>0.05
Substance Abuse Issues	0.01 (0.08)	0.01 (0.07)	p>0.05
Unknown	0.00 (0.03)	0.00 (0.00)	p<0.05
Upper Respiratory Symptoms	0.04 (0.19)	0.04 (0.19)	p>0.05
Urinary Complaints	0.03 (0.17)	0.03 (0.17)	p>0.05
Propensity score	0.54 (0.13)	0.54 (0.13)	p>0.05

Table EC.16: Dataset summary after propensity score matching.

EC.8. Empirical Models Summary

In this section, we summarize our results from the empirical models that we developed to measure the impact of the proposed VPP protocol during the implementation trial at the new Mayo ED.

Across all tables, the significance levels are denoted as follows: a p-value < 0.05 is marked with a single asterisk (*), indicating moderate evidence against the null hypothesis. A p-value < 0.01 is marked with two asterisks (**), representing strong evidence against the null hypothesis. Finally, a p-value < 0.001 is denoted by three asterisks (***), indicating very strong evidence against the null hypothesis. All p-values ≥ 0.05 are not marked.

EC.8.1. Consolidated Results for Trial Effect

	Mathing on CC			**Propensity score matching**		
Model	A	B	C	A	B	C
Trial Coef.	-0.057*** (0.013)	-0.057*** (0.013)	-0.047*** (0.013)	-0.024* (0.01)	-0.022* (0.01)	-0.022* (0.01)
Attending MD	yes	yes	no	yes	yes	no
CC Category	yes	no	no	yes	no	no
Sample size	5,976	5,976	5,976	10,926	10,926	10,926
R^2	0.419	0.405	0.336	0.438	0.42	0.344
F	48.881	70.024	132.687	95.582	134.895	250.151

Table EC.17 Supplementary empirical models summary for the dependent variable "log time from arrival to disposition." The attending MD and CC category rows indicate whether the models controlled for these variables.

	Mathing on CC			**Propensity score matching**		
Model	A	B	C	A	B	C
Trial Coef.	-0.045*** (0.009)	-0.045*** (0.009)	-0.039*** (0.01)	-0.027*** (0.007)	-0.026*** (0.007)	-0.026*** (0.007)
Attending MD	yes	yes	no	yes	yes	no
CC Category	yes	no	no	yes	no	no
Sample size	5,976	5,976	5,976	10,926	10,926	10,926
R^2	0.513	0.502	0.464	0.533	0.52	0.478
F	70.948	103.162	225.586	139.762	201.962	435.76

Table EC.18 Supplementary empirical models summary for the dependent variable "log time from arrival to ED departure." The attending MD and CC category rows indicate whether the models controlled for these variables.

	No Matching			Matching on MD		
Model	A	B	C	A	B	C
Trial Coef.	-0.002 (0.003)	-0.002 (0.003)	-0.002 (0.003)	-0.003 (0.004)	-0.002 (0.004)	-0.003 (0.004)
Attending MD	yes	yes	no	yes	yes	no
CC Category	yes	no	no	yes	no	no
Sample size	11,015	11,015	11,015	5,158	5,158	5,158
R^2	0.017	0.013	0.012	0.025	0.017	0.016
F	3.024	3.357	6.909	2.469	2.476	4.595

Table EC.19 Primary empirical models summary for the dependent variable "ED return within 72 hours (with admission)." The attending MD and CC category rows indicate whether the models controlled for these variables.

	No Matching			Matching on MD		
Model	A	B	C	A	B	C
Trial Coef.	-0.001 (0.003)	-0.0 (0.003)	-0.0 (0.003)	0.002 (0.004)	0.002 (0.004)	0.003 (0.004)
Attending MD	yes	yes	no	yes	yes	no
CC Category	yes	no	no	yes	no	no
Sample size	11,015	11,015	11,015	5,158	5,158	5,158
R^2	0.017	0.008	0.007	0.015	0.008	0.005
F	3.108	2.428	4.254	1.864	1.715	2.207

Table EC.20 Primary empirical models summary for the dependent variable "ED return within 72 hours (without admission)." The attending MD and CC category rows indicate whether the models controlled for these variables.

	Mathing on CC			Propensity score matching		
Model	A	B	C	A	B	C
Trial Coef.	0.0 (0.004)	0.0 (0.004)	-0.001 (0.004)	-0.009 (0.003)	-0.009 (0.003)	-0.009 (0.003)
Attending MD	yes	yes	no	yes	yes	no
CC Category	yes	no	no	yes	no	no
Sample size	5,976	5,976	5,976	10,926	10,926	10,926
R^2	0.022	0.012	0.012	0.026	0.022	0.017
F	2.479	2.267	4.199	4.273	5.129	9.125

Table EC.21 Supplementary empirical models summary for the dependent variable "ED return within 72 hours (with admission)." The attending MD and CC category rows indicate whether the models controlled for these variables.

	Mathing on CC			Propensity score matching		
Model	A	B	C	A	B	C
Trial Coef.	0.002 (0.004)	0.002 (0.004)	0.002 (0.004)	-0.001 (0.003)	-0.001 (0.003)	-0.001 (0.003)
Attending MD	yes	yes	no	yes	yes	no
CC Category	yes	no	no	yes	no	no
Sample size	5,976	5,976	5,976	10,926	10,926	10,926
R^2	0.014	0.01	0.006	0.019	0.012	0.009
F	1.915	1.975	2.674	3.323	3.305	5.467

Table EC.22 Supplementary empirical models summary for the dependent variable "ED return within 72 hours (without admission)." The attending MD and CC category rows indicate whether the models controlled for these variables.

EC.8.2. Comprehensive Empirical Model Results

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.577*** (0.092)	4.159*** (0.068)	0.008 (0.028)	0.023 (0.028)
ESI 1	0.2* (0.094)	0.219** (0.069)	0.037 (0.028)	0.042 (0.029)
ESI 2	0.786*** (0.071)	0.653*** (0.052)	0.031 (0.021)	0.022 (0.022)
ESI 3	0.803*** (0.071)	0.669*** (0.052)	0.022 (0.021)	0.024 (0.022)
ESI 4	0.575*** (0.071)	0.497*** (0.052)	0.015 (0.021)	0.02 (0.022)
Patient Age	0.001*** (0.0)	0.001*** (0.0)	0.0* (0.0)	-0.0 (0.0)
Trial	-0.044*** (0.01)	-0.037*** (0.007)	-0.002 (0.003)	-0.001 (0.003)
IV	0.326*** (0.013)	0.285*** (0.01)	0.016*** (0.004)	-0.001 (0.004)
CT with IVcontrast	0.363*** (0.013)	0.238*** (0.01)	-0.013*** (0.004)	-0.007. (0.004)
CT without IV contrast	0.259*** (0.013)	0.182*** (0.01)	-0.004 (0.004)	0.003 (0.004)
MRI	0.286*** (0.034)	0.248*** (0.025)	-0.028** (0.01)	0.011 (0.011)
Xray	0.187*** (0.012)	0.144*** (0.009)	-0.000036	-0.006 (0.004)
Ultrasound	0.228*** (0.015)	0.195*** (0.011)	0.001 (0.005)	-0.001 (0.005)
Nurses on shift	0.001 (0.002)	-0.000003	0.001 (0.001)	-0.0 (0.001)
MDs on shift	-0.026*** (0.006)	-0.022*** (0.004)	0.0 (0.002)	0.002 (0.002)
Current waiting count	0.004** (0.001)	0.014*** (0.001)	0.0 (0.0)	0.0 (0.0)
Current treatment count	0.004*** (0.001)	0.006*** (0.001)	-0.0 (0.0)	-0.0 (0.0)
Shift: 6 am-12 pm	0.155*** (0.025)	0.058** (0.019)	-0.013. (0.008)	-0.005 (0.008)
Shift: 12 pm-6 pm	0.019 (0.033)	-0.03 (0.024)	-0.007 (0.01)	-0.012 (0.01)
Shift: 6 pm-12 am	-0.024 (0.028)	-0.064** (0.021)	-0.01 (0.009)	-0.006 (0.009)
ED Disposition Admit	-0.195*** (0.015)	0.14*** (0.011)	0.007. (0.004)	-0.026*** (0.004)
ED Disposition Hospital Observation	-0.002 (0.016)	0.235*** (0.012)	-0.005 (0.005)	-0.019*** (0.005)
ED Disposition Left Without Being Seen/AMA	-0.027 (0.065)	-0.005217	0.161*** (0.019)	0.037. (0.02)
ED Disposition Transfer to Health Care Facility	0.124** (0.045)	0.394*** (0.033)	-0.015 (0.014)	-0.026. (0.014)
MD_A	0.148*** (0.023)	0.121*** (0.017)	-0.003 (0.007)	0.004 (0.007)
MD_AA	0.232*** (0.031)	0.264*** (0.023)	-0.011 (0.009)	-0.00019
MD_AB	0.222*** (0.034)	0.205*** (0.025)	0.006 (0.01)	-0.001 (0.01)
MD_AC	0.359*** (0.036)	0.286*** (0.027)	-0.011 (0.011)	-0.017 (0.011)
MD_AD	-0.003999	-0.054. (0.031)	0.008 (0.013)	0.005 (0.013)
MD_AE	-0.041 (0.032)	0.01 (0.023)	0.004 (0.009)	-0.006 (0.01)
MD_AF	0.003 (0.032)	0.031 (0.023)	-0.014 (0.01)	0.031** (0.01)
MD_AG	0.077* (0.038)	0.107*** (0.028)	-0.002 (0.011)	0.026* (0.012)
MD_AH	0.229*** (0.046)	0.21*** (0.033)	-0.0 (0.014)	0.0 (0.014)
MD_AI	0.285*** (0.055)	0.182*** (0.04)	0.013 (0.016)	0.025 (0.017)
MD_AJ	0.196*** (0.031)	0.165*** (0.023)	0.008 (0.009)	-0.003 (0.01)
MD_AK	0.311*** (0.053)	0.256*** (0.039)	0.011 (0.016)	0.012 (0.016)
MD_B	0.31*** (0.024)	0.249*** (0.017)	-0.007 (0.007)	-0.001 (0.007)

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Table EC.23 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MD_C	0.2*** (0.024)	0.158*** (0.018)	-0.005 (0.007)	-0.000105
MD_D	0.328*** (0.024)	0.24*** (0.018)	0.008 (0.007)	-0.004 (0.007)
MD_E	-0.161*** (0.024)	-0.016 (0.018)	-0.011 (0.007)	0.011 (0.007)
MD_F	0.015 (0.026)	0.058** (0.019)	0.003 (0.008)	0.001 (0.008)
MD_G	0.313*** (0.024)	0.251*** (0.018)	0.011 (0.007)	-0.001 (0.008)
MD_H	0.169*** (0.025)	0.15*** (0.018)	-0.002 (0.008)	-0.004 (0.008)
MD_I	-0.141*** (0.026)	-0.051** (0.019)	0.005 (0.008)	-0.01 (0.008)
MD_J	-0.185*** (0.027)	-0.034. (0.02)	0.003 (0.008)	0.007 (0.008)
MD_K	0.185*** (0.025)	0.149*** (0.018)	-0.009 (0.007)	0.0 (0.008)
MD_L	0.094*** (0.025)	0.07*** (0.018)	0.007 (0.007)	0.001 (0.008)
MD_M	0.116*** (0.025)	0.106*** (0.018)	-0.000128	-0.006 (0.008)
MD_N	0.167*** (0.028)	0.166*** (0.02)	0.007 (0.008)	-0.0 (0.009)
MD_O	0.134*** (0.026)	0.16*** (0.019)	0.001 (0.008)	-0.001 (0.008)
MD_P	0.164*** (0.027)	0.159*** (0.02)	-0.006 (0.008)	-0.001 (0.008)
MD_Q	-0.28*** (0.027)	0.002 (0.019)	0.019* (0.008)	-0.008 (0.008)
MD_R	-0.117*** (0.028)	-0.006 (0.02)	0.011 (0.008)	0.005 (0.009)
MD_S	0.214*** (0.028)	0.183*** (0.021)	-0.007 (0.008)	-0.003 (0.009)
MD_T	-0.175*** (0.033)	-0.096*** (0.024)	-0.007 (0.01)	-0.0 (0.01)
MD_U	-0.017 (0.03)	0.073** (0.022)	0.005 (0.009)	0.013 (0.009)
MD_V	0.279*** (0.032)	0.23*** (0.024)	-0.013 (0.01)	-0.0002
MD_W	0.121*** (0.029)	0.1*** (0.021)	0.012 (0.009)	0.003 (0.009)
MD_X	-0.212*** (0.03)	-0.128*** (0.022)	0.005 (0.009)	0.0 (0.009)
MD_Y	0.195*** (0.031)	0.19*** (0.022)	0.003 (0.009)	-0.008 (0.009)
MD_Z	-0.002277	0.012 (0.024)	-0.015 (0.01)	0.005 (0.01)
Abdominal Complaints	0.043 (0.058)	0.013 (0.043)	-0.017 (0.017)	-0.008 (0.018)
Abnormal Test Results	-0.07 (0.061)	-0.002 (0.044)	-0.025 (0.018)	-0.002 (0.019)
Allergic Reaction	-0.125 (0.087)	-0.113. (0.064)	-0.024 (0.026)	-0.016 (0.027)
Back or Flank Pain	0.032 (0.06)	0.028 (0.044)	0.003 (0.018)	-0.003 (0.019)
Breast Complaints	-0.12 (0.183)	-0.052 (0.134)	-0.036 (0.055)	-0.029 (0.056)
Cardiac Arrhythmias	0.054 (0.065)	0.006 (0.047)	-0.033. (0.019)	-0.015 (0.02)
Chest Pain	0.038 (0.06)	-0.006 (0.044)	-0.019 (0.018)	-0.005 (0.018)
Circulatory Issue	-0.078 (0.183)	-0.108 (0.134)	0.307*** (0.055)	-0.027 (0.056)
Dizziness, Lightheadedness, Syncope	0.041 (0.062)	0.008 (0.045)	-0.025 (0.019)	-0.02 (0.019)
Ear Complaints	-0.302*** (0.081)	-0.214*** (0.06)	-0.029 (0.024)	-0.007 (0.025)
Epistaxis	0.051 (0.086)	0.047 (0.063)	-0.037 (0.026)	0.154*** (0.027)
Exposures, Bites, and Envenomations	-0.333*** (0.094)	-0.217** (0.069)	0.019 (0.028)	-0.033 (0.029)
Extremity Complaints	-0.084 (0.059)	-0.069 (0.043)	-0.019 (0.018)	-0.009 (0.018)
Eye Complaints	-0.125. (0.069)	-0.0062	-0.015 (0.021)	-0.003 (0.021)
Falls, Motor Vehicle Crashes, Assaults, and Trauma	-0.036 (0.061)	-0.018 (0.044)	-0.026 (0.018)	0.001 (0.019)

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Table EC.23 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Fatigue and Weakness	-0.026 (0.063)	0.0 (0.046)	-0.012 (0.019)	0.001 (0.019)
Fevers, Sweats or Chills	-0.106. (0.064)	-0.063 (0.046)	-0.031 (0.019)	-0.004 (0.02)
Foreign Body	-0.04116	-0.02652	-0.022 (0.042)	-0.034 (0.043)
Gastrointestinal Issues	-0.01 (0.059)	0.015 (0.044)	-0.019 (0.018)	0.003 (0.018)
Genital Complaints	0.155* (0.068)	0.096. (0.05)	-0.025 (0.02)	-0.022 (0.021)
Medical Device or Treatment Issue	-0.052 (0.071)	0.019 (0.052)	-0.015 (0.021)	0.012 (0.022)
Medication Request	-0.522*** (0.145)	-0.026394	-0.025 (0.043)	0.043 (0.044)
Neurological Issue	-0.036 (0.06)	-0.024 (0.044)	-0.023 (0.018)	0.001 (0.018)
Other Pain	-0.088 (0.066)	-0.052 (0.048)	-0.018 (0.02)	-0.004 (0.02)
Post-Op Issue	-0.246** (0.078)	-0.218*** (0.057)	-0.003 (0.023)	-0.013 (0.024)
Psychiatric Complaints	0.241** (0.089)	0.235*** (0.065)	-0.021 (0.027)	0.008 (0.027)
Shortness of Breath	-0.036 (0.06)	-0.005 (0.044)	-0.02 (0.018)	-0.002 (0.018)
Skin Complaints	-0.218*** (0.061)	-0.156*** (0.045)	-0.018 (0.018)	-0.006 (0.019)
Substance Abuse Issues	0.146 (0.092)	0.066 (0.068)	-0.029 (0.028)	0.013 (0.028)
Unknown	-0.5445	-1.192** (0.363)	-0.042 (0.148)	0.961*** (0.152)
Upper Respiratory Symptoms	-0.106. (0.061)	-0.00432	-0.006 (0.018)	-0.012 (0.019)
Urinary Complaints	0.037 (0.063)	0.062 (0.046)	0.004 (0.019)	0.03 (0.019)
Adjusted R^2	0.427	0.527	0.017	0.017
Sample size	11,015	11,015	11,015	11,015
F value	90.504	135.005	3.024	3.108

Table EC.23: No Matching: empirical model description for category A.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.391*** (0.072)	4.026*** (0.053)	-0.006 (0.021)	0.024 (0.022)
ESI 1	0.384*** (0.091)	0.335*** (0.066)	0.028 (0.027)	0.038 (0.028)
ESI 2	0.967*** (0.067)	0.774*** (0.049)	0.026 (0.02)	0.019 (0.02)
ESI 3	0.979*** (0.066)	0.787*** (0.048)	0.02 (0.02)	0.02 (0.02)
ESI 4	0.69*** (0.067)	0.57*** (0.049)	0.015 (0.02)	0.015 (0.02)
Patient Age	0.001*** (0.0)	0.001*** (0.0)	0.0** (0.0)	-0.0 (0.0)
Trial	-0.042*** (0.01)	-0.035*** (0.007)	-0.002 (0.003)	-0.0 (0.003)
IV	0.344*** (0.013)	0.298*** (0.009)	0.017*** (0.004)	-0.002 (0.004)

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Table EC.24 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
CT with IV contrast	0.382*** (0.013)	0.244*** (0.009)	-0.013*** (0.004)	-0.000036
CT without IV contrast	0.273*** (0.012)	0.193*** (0.009)	-0.003 (0.004)	0.003 (0.004)
MRI	0.271*** (0.034)	0.234*** (0.025)	-0.027** (0.01)	0.011 (0.01)
Xray	0.185*** (0.01)	0.136*** (0.007)	-0.01*** (0.003)	-0.01** (0.003)
Ultrasound	0.239*** (0.015)	0.2*** (0.011)	0.0 (0.004)	-0.004 (0.005)
Nurses on shift	0.001 (0.002)	-0.000003	0.001 (0.001)	-0.0 (0.001)
MDs on shift	-0.027*** (0.006)	-0.023*** (0.004)	0.0 (0.002)	0.002 (0.002)
Current waiting count	0.004** (0.001)	0.014*** (0.001)	0.0 (0.0)	0.0 (0.0)
Current treatment count	0.004*** (0.001)	0.006*** (0.001)	-0.0 (0.0)	-0.0 (0.0)
Shift: 6 am-12 pm	0.148*** (0.026)	0.053** (0.019)	-0.014. (0.008)	-0.005 (0.008)
Shift: 12 pm-6 pm	0.013 (0.033)	-0.036 (0.024)	-0.009 (0.01)	-0.011 (0.01)
Shift: 6 pm-12 am	-0.034 (0.029)	-0.072*** (0.021)	-0.012 (0.009)	-0.005 (0.009)
ED Disposition Admit	-0.214*** (0.014)	0.135*** (0.011)	0.008. (0.004)	-0.024*** (0.004)
ED Disposition Hospital Observation	-0.006 (0.016)	0.232*** (0.012)	-0.006 (0.005)	-0.019*** (0.005)
ED Disposition Left Without Being Seen/AMA	-0.023 (0.065)	-0.005232	0.164*** (0.019)	0.035. (0.02)
ED Disposition Transfer to Health Care Facility	0.138** (0.045)	0.415*** (0.033)	-0.017 (0.013)	-0.023. (0.014)
MD_A	0.139*** (0.023)	0.116*** (0.017)	-0.004 (0.007)	0.003 (0.007)
MD_AA	0.227*** (0.031)	0.259*** (0.023)	-0.012 (0.009)	-0.0002
MD_AB	0.211*** (0.034)	0.198*** (0.025)	0.006 (0.01)	0.004 (0.01)
MD_AC	0.353*** (0.037)	0.281*** (0.027)	-0.012 (0.011)	-0.018 (0.011)
MD_AD	-0.004085	-0.059. (0.031)	0.008 (0.013)	0.003 (0.013)
MD_AE	-0.051 (0.032)	0.001 (0.023)	0.006 (0.009)	-0.009 (0.01)
MD_AF	-0.003 (0.032)	0.027 (0.023)	-0.015 (0.01)	0.031** (0.01)
MD_AG	0.065. (0.039)	0.1*** (0.028)	-0.003 (0.011)	0.026* (0.012)
MD_AH	0.225*** (0.046)	0.207*** (0.034)	-0.001 (0.014)	-0.001 (0.014)
MD_AI	0.274*** (0.055)	0.174*** (0.04)	0.012 (0.016)	0.026 (0.017)
MD_AJ	0.194*** (0.032)	0.163*** (0.023)	0.007 (0.009)	-0.001 (0.01)
MD_AK	0.306*** (0.053)	0.253*** (0.039)	0.009 (0.016)	0.012 (0.016)
MD_B	0.304*** (0.024)	0.246*** (0.017)	-0.007 (0.007)	-0.001 (0.007)
MD_C	0.199*** (0.024)	0.155*** (0.018)	-0.006 (0.007)	-0.000112
MD_D	0.324*** (0.024)	0.238*** (0.018)	0.008 (0.007)	-0.003 (0.007)
MD_E	-0.174*** (0.024)	-0.023 (0.018)	-0.011 (0.007)	0.012. (0.007)
MD_F	0.009 (0.026)	0.054** (0.019)	0.003 (0.008)	0.002 (0.008)
MD_G	0.314*** (0.025)	0.252*** (0.018)	0.011 (0.007)	0.0 (0.008)
MD_H	0.165*** (0.025)	0.148*** (0.019)	-0.003 (0.008)	-0.003 (0.008)
MD_I	-0.142*** (0.026)	-0.052** (0.019)	0.004 (0.008)	-0.012 (0.008)
MD_J	-0.195*** (0.028)	-0.0008	0.003 (0.008)	0.007 (0.008)
MD_K	0.185*** (0.025)	0.147*** (0.018)	-0.009 (0.007)	-0.0 (0.008)

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Table EC.24 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MD_L	0.092*** (0.025)	0.069*** (0.018)	0.007 (0.007)	0.001 (0.008)
MD_M	0.111*** (0.025)	0.103*** (0.019)	-0.000136	-0.006 (0.008)
MD_N	0.159*** (0.028)	0.164*** (0.02)	0.006 (0.008)	0.0 (0.009)
MD_O	0.134*** (0.026)	0.16*** (0.019)	0.001 (0.008)	0.0 (0.008)
MD_P	0.155*** (0.027)	0.151*** (0.02)	-0.006 (0.008)	-0.002 (0.008)
MD_Q	-0.285*** (0.027)	-0.001 (0.02)	0.018* (0.008)	-0.008 (0.008)
MD_R	-0.122*** (0.028)	-0.011 (0.021)	0.012 (0.008)	0.004 (0.009)
MD_S	0.209*** (0.029)	0.178*** (0.021)	-0.007 (0.008)	-0.005 (0.009)
MD_T	-0.181*** (0.033)	-0.102*** (0.024)	-0.006 (0.01)	-0.0 (0.01)
MD_U	-0.018 (0.03)	0.073** (0.022)	0.005 (0.009)	0.015 (0.009)
MD_V	0.279*** (0.032)	0.232*** (0.024)	-0.014 (0.01)	-0.019. (0.01)
MD_W	0.116*** (0.03)	0.095*** (0.022)	0.013 (0.009)	0.003 (0.009)
MD_X	-0.215*** (0.031)	-0.13*** (0.022)	0.004 (0.009)	0.002 (0.009)
MD_Y	0.194*** (0.031)	0.191*** (0.023)	0.002 (0.009)	-0.008 (0.009)
MD_Z	-0.00238	0.011 (0.025)	-0.016 (0.01)	0.006 (0.01)
Adjusted R^2	0.414	0.516	0.013	0.008
Sample size	11,015	11,015	11,015	11,015
F value	131.849	198.889	3.357	2.428

Table EC.24: No Matching: empirical model description for category B.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.456*** (0.077)	4.102*** (0.055)	-0.011 (0.021)	0.021 (0.022)
ESI 1	0.387*** (0.096)	0.335*** (0.069)	0.03 (0.027)	0.04 (0.028)
ESI 2	0.976*** (0.071)	0.776*** (0.051)	0.026 (0.02)	0.019 (0.02)
ESI 3	0.988*** (0.07)	0.788*** (0.05)	0.02 (0.02)	0.021 (0.02)
ESI 4	0.696*** (0.07)	0.57*** (0.051)	0.015 (0.02)	0.016 (0.02)
Patient Age	0.001*** (0.0)	0.001*** (0.0)	0.0** (0.0)	-0.0 (0.0)
Trial	-0.035*** (0.01)	-0.029*** (0.007)	-0.002 (0.003)	-0.0 (0.003)
IV	0.333*** (0.013)	0.292*** (0.01)	0.016*** (0.004)	-0.002 (0.004)
CT with IV contrast	0.4*** (0.013)	0.253*** (0.01)	-0.013*** (0.004)	-0.000032
CT without IV contrast	0.283*** (0.013)	0.198*** (0.009)	-0.003 (0.004)	0.004 (0.004)
MRI	0.281*** (0.036)	0.245*** (0.026)	-0.027** (0.01)	0.011 (0.01)
Xray	0.202*** (0.011)	0.146*** (0.008)	-0.011*** (0.003)	-0.01** (0.003)
Ultrasound	0.25*** (0.016)	0.206*** (0.011)	-0.0 (0.004)	-0.004 (0.004)
Nurses on shift	-0.001 (0.002)	-0.000003	0.001 (0.001)	-0.0 (0.001)
MDs on shift	-0.028*** (0.006)	-0.023*** (0.004)	0.001 (0.002)	0.002 (0.002)
Current waiting count	0.005** (0.002)	0.014*** (0.001)	0.0 (0.0)	0.0 (0.0)

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Table EC.25 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Current treatment count	0.005*** (0.001)	0.006*** (0.001)	-0.0 (0.0)	-0.0 (0.0)
Shift: 6 am-12 pm	0.188*** (0.024)	0.085*** (0.017)	-0.009 (0.007)	-0.006 (0.007)
Shift: 12 pm-6 pm	0.039 (0.033)	-0.015 (0.024)	-0.006 (0.009)	-0.01 (0.01)
Shift: 6 pm-12 am	-0.03 (0.029)	-0.063** (0.021)	-0.011 (0.008)	-0.003 (0.008)
ED Disposition Admit	-0.21*** (0.015)	0.138*** (0.011)	0.008. (0.004)	-0.024*** (0.004)
ED Disposition Hospital Observation	-0.001 (0.017)	0.234*** (0.012)	-0.005 (0.005)	-0.019*** (0.005)
ED Disposition Left Without Being Seen/AMA	-0.043 (0.069)	-0.005978	0.165*** (0.019)	0.035. (0.02)
ED Disposition Transfer to Health Care Facility	0.13** (0.047)	0.409*** (0.034)	-0.016 (0.013)	-0.023. (0.014)
Adjusted R^2	0.344	0.477	0.012	0.007
Sample size	11,015	11,015	11,015	11,015
F value	250.779	435.268	6.909	4.254

Table EC.25: No Matching: empirical model description for category C.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.391*** (0.072)	4.026*** (0.053)	-0.006 (0.021)	0.024 (0.022)
ESI 1	0.384*** (0.091)	0.335*** (0.066)	0.028 (0.027)	0.038 (0.028)
ESI 2	0.967*** (0.067)	0.774*** (0.049)	0.026 (0.02)	0.019 (0.02)
ESI 3	0.979*** (0.066)	0.787*** (0.048)	0.02 (0.02)	0.02 (0.02)
ESI 4	0.69*** (0.067)	0.57*** (0.049)	0.015 (0.02)	0.015 (0.02)
Patient Age	0.001*** (0.0)	0.001*** (0.0)	0.0** (0.0)	-0.0 (0.0)
Trial	-0.042*** (0.01)	-0.035*** (0.007)	-0.002 (0.003)	-0.0 (0.003)
IV	0.344*** (0.013)	0.298*** (0.009)	0.017*** (0.004)	-0.002 (0.004)
CT with IV contrast	0.382*** (0.013)	0.244*** (0.009)	-0.013*** (0.004)	-0.000036
CT without IV contrast	0.273*** (0.012)	0.193*** (0.009)	-0.003 (0.004)	0.003 (0.004)
MRI	0.271*** (0.034)	0.234*** (0.025)	-0.027** (0.01)	0.011 (0.01)
Xray	0.185*** (0.01)	0.136*** (0.007)	-0.01*** (0.003)	-0.01** (0.003)
Ultrasound	0.239*** (0.015)	0.2*** (0.011)	0.0 (0.004)	-0.004 (0.005)
Nurses on shift	0.001 (0.002)	-0.000003	0.001 (0.001)	-0.0 (0.001)
MDs on shift	-0.027*** (0.006)	-0.023*** (0.004)	0.0 (0.002)	0.002 (0.002)

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Table EC.26 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Current waiting count	0.004** (0.001)	0.014*** (0.001)	0.0 (0.0)	0.0 (0.0)
Current treatment count	0.004*** (0.001)	0.006*** (0.001)	-0.0 (0.0)	-0.0 (0.0)
Shift: 6 am-12 pm	0.148*** (0.026)	0.053** (0.019)	-0.014. (0.008)	-0.005 (0.008)
Shift: 12 pm-6 pm	0.013 (0.033)	-0.036 (0.024)	-0.009 (0.01)	-0.011 (0.01)
Shift: 6 pm-12 am	-0.034 (0.029)	-0.072*** (0.021)	-0.012 (0.009)	-0.005 (0.009)
ED Disposition Admit	-0.214*** (0.014)	0.135*** (0.011)	0.008. (0.004)	-0.024*** (0.004)
ED Disposition Hospital Observation	-0.006 (0.016)	0.232*** (0.012)	-0.006 (0.005)	-0.019*** (0.005)
ED Disposition Left Without Being Seen/AMA	-0.023 (0.065)	-0.005232	0.164*** (0.019)	0.035. (0.02)
ED Disposition Transfer to Health Care Facility	0.138** (0.045)	0.415*** (0.033)	-0.017 (0.013)	-0.023. (0.014)
MD_A	0.139*** (0.023)	0.116*** (0.017)	-0.004 (0.007)	0.003 (0.007)
MD_AA	0.227*** (0.031)	0.259*** (0.023)	-0.012 (0.009)	-0.0002
MD_AB	0.211*** (0.034)	0.198*** (0.025)	0.006 (0.01)	0.004 (0.01)
MD_AC	0.353*** (0.037)	0.281*** (0.027)	-0.012 (0.011)	-0.018 (0.011)
MD_AD	-0.004085	-0.059. (0.031)	0.008 (0.013)	0.003 (0.013)
MD_AE	-0.051 (0.032)	0.001 (0.023)	0.006 (0.009)	-0.009 (0.01)
MD_AF	-0.003 (0.032)	0.027 (0.023)	-0.015 (0.01)	0.031** (0.01)
MD_AG	0.065. (0.039)	0.1*** (0.028)	-0.003 (0.011)	0.026* (0.012)
MD_AH	0.225*** (0.046)	0.207*** (0.034)	-0.001 (0.014)	-0.001 (0.014)
MD_AI	0.274*** (0.055)	0.174*** (0.04)	0.012 (0.016)	0.026 (0.017)
MD_AJ	0.194*** (0.032)	0.163*** (0.023)	0.007 (0.009)	-0.001 (0.01)
MD_AK	0.306*** (0.053)	0.253*** (0.039)	0.009 (0.016)	0.012 (0.016)
MD_B	0.304*** (0.024)	0.246*** (0.017)	-0.007 (0.007)	-0.001 (0.007)
MD_C	0.199*** (0.024)	0.155*** (0.018)	-0.006 (0.007)	-0.000112
MD_D	0.324*** (0.024)	0.238*** (0.018)	0.008 (0.007)	-0.003 (0.007)
MD_E	-0.174*** (0.024)	-0.023 (0.018)	-0.011 (0.007)	0.012. (0.007)
MD_F	0.009 (0.026)	0.054** (0.019)	0.003 (0.008)	0.002 (0.008)
MD_G	0.314*** (0.025)	0.252*** (0.018)	0.011 (0.007)	0.0 (0.008)
MD_H	0.165*** (0.025)	0.148*** (0.019)	-0.003 (0.008)	-0.003 (0.008)
MD_I	-0.142*** (0.026)	-0.052** (0.019)	0.004 (0.008)	-0.012 (0.008)
MD_J	-0.195*** (0.028)	-0.0008	0.003 (0.008)	0.007 (0.008)
MD_K	0.185*** (0.025)	0.147*** (0.018)	-0.009 (0.007)	-0.0 (0.008)
MD_L	0.092*** (0.025)	0.069*** (0.018)	0.007 (0.007)	0.001 (0.008)
MD_M	0.111*** (0.025)	0.103*** (0.019)	-0.000136	-0.006 (0.008)
MD_N	0.159*** (0.028)	0.164*** (0.02)	0.006 (0.008)	0.0 (0.009)
MD_O	0.134*** (0.026)	0.16*** (0.019)	0.001 (0.008)	0.0 (0.008)
MD_P	0.155*** (0.027)	0.151*** (0.02)	-0.006 (0.008)	-0.002 (0.008)
MD_Q	-0.285*** (0.027)	-0.001 (0.02)	0.018* (0.008)	-0.008 (0.008)
MD_R	-0.122*** (0.028)	-0.011 (0.021)	0.012 (0.008)	0.004 (0.009)
MD_S	0.209*** (0.029)	0.178*** (0.021)	-0.007 (0.008)	-0.005 (0.009)
MD_T	-0.181*** (0.033)	-0.102*** (0.024)	-0.006 (0.01)	-0.0 (0.01)

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Table EC.26 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MD_U	-0.018 (0.03)	0.073** (0.022)	0.005 (0.009)	0.015 (0.009)
MD_V	0.279*** (0.032)	0.232*** (0.024)	-0.014 (0.01)	-0.019. (0.01)
MD_W	0.116*** (0.03)	0.095*** (0.022)	0.013 (0.009)	0.003 (0.009)
MD_X	-0.215*** (0.031)	-0.13*** (0.022)	0.004 (0.009)	0.002 (0.009)
MD_Y	0.194*** (0.031)	0.191*** (0.023)	0.002 (0.009)	-0.008 (0.009)
MD_Z	-0.00238	0.011 (0.025)	-0.016 (0.01)	0.006 (0.01)
Adjusted R^2	0.414	0.516	0.013	0.008
Sample size	11,015	11,015	11,015	11,015
F value	131.849	198.889	3.357	2.428

Table EC.26: No Matching: empirical model description for category B.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.338*** (0.216)	4.138*** (0.157)	0.018 (0.061)	0.012 (0.067)
ESI 1	0.258 (0.238)	0.126 (0.173)	0.012 (0.067)	0.038 (0.074)
ESI 2	1.044*** (0.206)	0.672*** (0.15)	0.036 (0.058)	0.037 (0.064)
ESI 3	1.041*** (0.205)	0.659*** (0.15)	0.026 (0.058)	0.037 (0.064)
ESI 4	0.826*** (0.205)	0.493*** (0.15)	0.019 (0.058)	0.035 (0.064)
Patient Age	0.002*** (0.0)	0.001*** (0.0)	0.0 (0.0)	0.0 (0.0)
Trial	-0.057*** (0.014)	-0.047*** (0.01)	-0.003 (0.004)	0.002 (0.004)
IV	0.336*** (0.02)	0.292*** (0.015)	0.003 (0.006)	-0.01 (0.006)
CT with IV contrast	0.351*** (0.02)	0.228*** (0.014)	0.001 (0.006)	-0.001 (0.006)
CT without IV contrast	0.268*** (0.02)	0.186*** (0.015)	-0.0 (0.006)	0.004 (0.006)
MRI	0.255*** (0.051)	0.233*** (0.037)	-0.023 (0.015)	0.008 (0.016)
Xray	0.198*** (0.018)	0.155*** (0.013)	-0.013** (0.005)	0.003 (0.005)
Ultrasound	0.228*** (0.023)	0.203*** (0.016)	0.004 (0.006)	-0.007 (0.007)
Nurses on shift	-0.001 (0.003)	-0.003. (0.002)	0.002* (0.001)	-0.0 (0.001)
MDs on shift	-0.029*** (0.009)	-0.023*** (0.006)	-0.002 (0.002)	0.004 (0.003)
Current waiting count	0.005* (0.002)	0.015*** (0.002)	-0.0 (0.001)	0.001 (0.001)
Current treatment count	0.004*** (0.001)	0.005*** (0.001)	-0.001. (0.0)	-0.0 (0.0)
Shift: 12 pm-6 pm	0.03 (0.048)	-0.021 (0.035)	-0.001 (0.014)	-0.028. (0.015)
Shift: 6 am-12 pm	0.119** (0.037)	0.04 (0.027)	0.001 (0.011)	-0.019 (0.012)
Shift: 6 pm-12 am	-0.022 (0.041)	-0.00201	-0.003 (0.012)	-0.011 (0.013)
ED Disposition Admit	-0.209*** (0.022)	0.135*** (0.016)	0.013* (0.006)	-0.028*** (0.007)

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Table EC.27 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
ED Disposition Hospital Observation	-0.023 (0.024)	0.227*** (0.017)	0.004 (0.007)	-0.000112
ED Disposition Left Without Being Seen/AMA	-0.109 (0.1)	-0.013432	0.224*** (0.028)	0.043 (0.031)
ED Disposition Transfer to Health Care Facility	0.062 (0.067)	0.35*** (0.049)	-0.018 (0.019)	-0.035. (0.021)
MD_A	0.16*** (0.036)	0.132*** (0.026)	0.006 (0.01)	-0.003 (0.011)
MD_AA	0.128. (0.066)	0.218*** (0.048)	-0.011 (0.019)	-0.03 (0.021)
MD_AB	0.25*** (0.054)	0.207*** (0.04)	0.005 (0.015)	-0.001 (0.017)
MD_AC	0.314*** (0.049)	0.245*** (0.035)	-0.0 (0.014)	-0.016 (0.015)
MD_AD	-0.054 (0.053)	-0.02 (0.038)	0.017 (0.015)	0.01 (0.016)
MD_AE	-0.06 (0.044)	-0.002 (0.032)	0.005 (0.012)	-0.006 (0.014)
MD_AF	-0.043 (0.045)	-0.005 (0.033)	-0.025. (0.013)	0.042** (0.014)
MD_AG	0.055 (0.074)	0.088 (0.054)	0.006 (0.021)	0.025 (0.023)
MD_AH	0.258*** (0.063)	0.223*** (0.046)	-0.015 (0.018)	0.01 (0.02)
MD_AI	0.252*** (0.063)	0.158*** (0.046)	0.014 (0.018)	0.028 (0.02)
MD_AJ	0.18*** (0.043)	0.156*** (0.031)	0.008 (0.012)	-0.01 (0.013)
MD_AK	0.322*** (0.066)	0.273*** (0.048)	-0.004 (0.019)	0.029 (0.02)
MD_B	0.339*** (0.036)	0.27*** (0.026)	-0.008 (0.01)	0.007 (0.011)
MD_C	0.154*** (0.039)	0.137*** (0.028)	-0.002 (0.011)	-0.00036
MD_D	0.368*** (0.039)	0.258*** (0.028)	0.008 (0.011)	-0.013 (0.012)
MD_E	-0.153*** (0.033)	-0.013 (0.024)	-0.00018	0.027** (0.01)
MD_F	0.015 (0.042)	0.043 (0.03)	-0.005 (0.012)	-0.015 (0.013)
MD_G	0.311*** (0.038)	0.241*** (0.028)	0.005 (0.011)	-0.005 (0.012)
MD_H	0.154*** (0.041)	0.158*** (0.03)	0.016 (0.011)	0.009 (0.013)
MD_I	-0.105** (0.033)	-0.006 (0.024)	0.012 (0.009)	-0.009 (0.01)
MD_J	-0.183*** (0.04)	-0.035 (0.029)	-0.001 (0.011)	0.002 (0.012)
MD_K	0.184*** (0.035)	0.161*** (0.026)	-0.006 (0.01)	-0.003 (0.011)
MD_L	0.088** (0.034)	0.085*** (0.025)	0.014 (0.01)	-0.007 (0.011)
MD_M	0.134*** (0.037)	0.127*** (0.027)	-0.00021	-0.001 (0.011)
MD_N	0.204*** (0.052)	0.2*** (0.038)	-0.002 (0.015)	0.001 (0.016)
MD_O	0.206*** (0.044)	0.18*** (0.032)	-0.007 (0.012)	-0.016 (0.014)
MD_P	0.195*** (0.044)	0.179*** (0.032)	-0.009 (0.013)	-0.01 (0.014)
MD_Q	-0.303*** (0.036)	-0.001 (0.026)	0.019. (0.01)	-0.001 (0.011)
MD_R	-0.138** (0.044)	-0.032 (0.032)	-0.006 (0.013)	0.033* (0.014)
MD_S	0.196*** (0.039)	0.183*** (0.029)	0.0 (0.011)	-0.008 (0.012)
MD_T	-0.259*** (0.047)	-0.145*** (0.035)	0.017 (0.013)	-0.015 (0.015)
MD_U	-0.089 (0.055)	0.037 (0.04)	0.033* (0.015)	0.016 (0.017)
MD_V	0.39*** (0.068)	0.297*** (0.05)	-0.013 (0.019)	-0.014 (0.021)
MD_W	0.099* (0.041)	0.103*** (0.03)	0.015 (0.011)	-0.012 (0.013)
MD_X	-0.251*** (0.047)	-0.11** (0.034)	-0.008 (0.013)	0.01 (0.015)
MD_Y	0.168*** (0.044)	0.182*** (0.032)	-0.005 (0.012)	-0.008 (0.014)
MD_Z	-0.148*** (0.045)	-0.032 (0.033)	-0.016 (0.013)	-0.003 (0.014)
Abdominal Complaints	0.123 (0.082)	0.088 (0.06)	-0.001288	0.002 (0.025)

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Table EC.27 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Abnormal Test Results	-0.037 (0.085)	0.046 (0.062)	-0.068** (0.024)	-0.006 (0.027)
Allergic Reaction	-0.103 (0.12)	-0.129 (0.087)	-0.037 (0.034)	-0.005 (0.037)
Back or Flank Pain	0.074 (0.085)	0.072 (0.062)	-0.03 (0.024)	-0.01 (0.027)
Breast Complaints	-0.169 (0.261)	-0.151 (0.19)	-0.069 (0.074)	-0.039 (0.081)
Cardiac Arrhythmias	0.089 (0.092)	0.064 (0.067)	-0.068** (0.026)	-0.013 (0.029)
Chest Pain	0.084 (0.084)	0.035 (0.061)	-0.044. (0.024)	-0.014 (0.026)
Circulatory Issue	0.22 (0.361)	0.073 (0.263)	0.429*** (0.102)	-0.032 (0.112)
Dizziness/Lightheadedness/Syncope	0.111 (0.088)	0.073 (0.064)	-0.001575	-0.011 (0.027)
Ear Complaints	-0.028971	-0.015633	-0.002046	-0.015 (0.035)
Epistaxis	0.218. (0.121)	0.186* (0.088)	-0.00255	0.165*** (0.038)
Exposures, Bites, and Envenomations	-0.034125	-0.127 (0.091)	-0.063. (0.035)	-0.036 (0.039)
Extremity Complaints	-0.03 (0.083)	-0.016 (0.06)	-0.001173	-0.016 (0.026)
Eye Complaints	-0.109 (0.098)	-0.102 (0.071)	-0.001624	-0.009 (0.03)
Falls, Motor Vehicle Crashes, Assaults, and Trauma	0.063 (0.086)	0.061 (0.062)	-0.001368	-0.002 (0.027)
Fatigue and Weakness	-0.012 (0.089)	0.016 (0.065)	-0.042. (0.025)	0.002 (0.028)
Fevers, Sweats or Chills	-0.03 (0.09)	-0.001 (0.065)	-0.076** (0.025)	-0.013 (0.028)
Foreign Body	-0.19 (0.177)	-0.159 (0.129)	-0.06 (0.05)	-0.032 (0.055)
Gastrointestinal Issues	0.057 (0.084)	0.085 (0.061)	-0.001368	0.014 (0.026)
Genital Complaints	0.251** (0.095)	0.171* (0.069)	-0.001755	-0.018 (0.03)
Medical Device or Treatment Issue	0.077 (0.099)	0.143* (0.072)	-0.04 (0.028)	0.031 (0.031)
Medication Request	0.049 (0.3)	-0.055 (0.219)	-0.077 (0.085)	-0.052 (0.094)
Neurological Issue	0.01 (0.085)	0.035 (0.062)	-0.062** (0.024)	-0.009 (0.026)
Other Pain	-0.078 (0.091)	-0.031 (0.067)	-0.068** (0.026)	-0.009 (0.028)
Post-Op Issue	-0.108 (0.109)	-0.077 (0.079)	-0.002325	-0.029 (0.034)
Psychiatric Complaints	0.221. (0.123)	0.258** (0.09)	-0.062. (0.035)	0.003 (0.038)
Shortness of Breath	0.026 (0.084)	0.044 (0.062)	-0.037 (0.024)	0.004 (0.026)
Skin Complaints	-0.01547	-0.113. (0.062)	-0.0012	0.002 (0.027)
Substance Abuse Issues	0.072 (0.133)	0.001 (0.097)	-0.037 (0.038)	0.058 (0.041)
Upper Respiratory Symptoms	-0.064 (0.086)	-0.061 (0.063)	-0.041. (0.024)	-0.017 (0.027)
Urinary Complaints	0.078 (0.089)	0.13* (0.065)	-0.008 (0.025)	0.031 (0.028)
Adjusted R^2	0.436	0.533	0.025	0.015
Sample size	5158	5158	5158	5158

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Table EC.27 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
F value	45.329	66.48	2.469	1.864

Table EC.27: Matching on MD: empirical model description for category A.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.297*** (0.207)	4.108*** (0.151)	-0.033 (0.058)	0.003 (0.064)
ESI 1	0.326 (0.238)	0.173 (0.174)	0.003 (0.067)	0.036 (0.074)
ESI 2	1.124*** (0.207)	0.741*** (0.151)	0.031 (0.058)	0.043 (0.064)
ESI 3	1.124*** (0.206)	0.73*** (0.151)	0.023 (0.058)	0.043 (0.064)
ESI 4	0.846*** (0.206)	0.516*** (0.151)	0.017 (0.058)	0.038 (0.064)
Patient Age	0.002*** (0.0)	0.001*** (0.0)	0.0. (0.0)	0.0 (0.0)
Trial	-0.053*** (0.014)	-0.043*** (0.01)	-0.002 (0.004)	0.002 (0.004)
IV	0.352*** (0.02)	0.305*** (0.014)	0.004 (0.005)	-0.009 (0.006)
CT with IV contrast	0.382*** (0.019)	0.243*** (0.014)	0.0 (0.005)	-0.001 (0.006)
CT without IV contrast	0.287*** (0.019)	0.201*** (0.014)	-0.001 (0.005)	0.002 (0.006)
MRI	0.233*** (0.051)	0.218*** (0.037)	-0.026. (0.014)	0.002 (0.016)
Xray	0.196*** (0.015)	0.141*** (0.011)	-0.012** (0.004)	-0.005 (0.005)
Ultrasound	0.245*** (0.022)	0.213*** (0.016)	0.003 (0.006)	-0.011 (0.007)
Nurses on shift	-0.001 (0.003)	-0.003 (0.002)	0.002** (0.001)	-0.0 (0.001)
MDs on shift	-0.03*** (0.009)	-0.024*** (0.006)	-0.002 (0.002)	0.004 (0.003)
Current waiting count	0.005* (0.003)	0.015*** (0.002)	-0.0 (0.001)	0.001 (0.001)
Current treatment count	0.004** (0.001)	0.005*** (0.001)	-0.001. (0.0)	-0.0 (0.0)
Shift: 12 pm-6 pm	0.027 (0.048)	-0.025 (0.035)	-0.002 (0.014)	-0.026. (0.015)
Shift: 6 am-12 pm	0.111** (0.038)	0.033 (0.028)	0.001 (0.011)	-0.019 (0.012)
Shift: 6 pm-12 am	-0.03 (0.042)	-0.00228	-0.004 (0.012)	-0.01 (0.013)
ED Disposition Admit	-0.228*** (0.022)	0.129*** (0.016)	0.014* (0.006)	-0.025*** (0.007)
ED Disposition Hospital Observation	-0.026 (0.024)	0.225*** (0.017)	0.003 (0.007)	-0.000119
ED Disposition Left Without Being Seen/AMA	-0.103 (0.101)	-0.013838	0.219*** (0.028)	0.041 (0.031)
ED Disposition Transfer to Health Care Facility	0.085 (0.067)	0.377*** (0.049)	-0.018 (0.019)	-0.029 (0.021)
MD_A	0.155*** (0.036)	0.127*** (0.026)	0.004 (0.01)	-0.003 (0.011)
MD_AA	0.141* (0.067)	0.225*** (0.049)	-0.014 (0.019)	-0.03 (0.021)

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Table EC.28 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MD_AB	0.241*** (0.055)	0.205*** (0.04)	0.003 (0.015)	-0.002 (0.017)
MD_AC	0.305*** (0.049)	0.233*** (0.036)	-0.003 (0.014)	-0.019 (0.015)
MD_AD	-0.062 (0.053)	-0.031 (0.039)	0.018 (0.015)	0.007 (0.016)
MD_AE	-0.067 (0.044)	-0.009 (0.032)	0.008 (0.012)	-0.008 (0.014)
MD_AF	-0.052 (0.045)	-0.01 (0.033)	-0.025. (0.013)	0.041** (0.014)
MD_AG	0.036 (0.075)	0.075 (0.055)	0.002 (0.021)	0.024 (0.023)
MD_AH	0.257*** (0.064)	0.223*** (0.047)	-0.02 (0.018)	0.008 (0.02)
MD_AI	0.248*** (0.063)	0.153*** (0.046)	0.013 (0.018)	0.03 (0.02)
MD_AJ	0.185*** (0.043)	0.161*** (0.032)	0.006 (0.012)	-0.007 (0.013)
MD_AK	0.314*** (0.066)	0.27*** (0.048)	-0.004 (0.019)	0.03 (0.021)
MD_B	0.337*** (0.036)	0.269*** (0.027)	-0.01 (0.01)	0.006 (0.011)
MD_C	0.157*** (0.039)	0.136*** (0.028)	-0.004 (0.011)	-0.00036
MD_D	0.361*** (0.039)	0.255*** (0.028)	0.006 (0.011)	-0.012 (0.012)
MD_E	-0.167*** (0.033)	-0.022 (0.024)	-0.000189	0.027** (0.01)
MD_F	0.024 (0.042)	0.051. (0.031)	-0.006 (0.012)	-0.013 (0.013)
MD_G	0.316*** (0.039)	0.245*** (0.028)	0.004 (0.011)	-0.004 (0.012)
MD_H	0.159*** (0.041)	0.161*** (0.03)	0.014 (0.011)	0.008 (0.013)
MD_I	-0.102** (0.034)	-0.008 (0.024)	0.008 (0.009)	-0.012 (0.01)
MD_J	-0.186*** (0.04)	-0.035 (0.029)	-0.002 (0.011)	0.0 (0.012)
MD_K	0.183*** (0.035)	0.158*** (0.026)	-0.006 (0.01)	-0.003 (0.011)
MD_L	0.089** (0.034)	0.084*** (0.025)	0.012 (0.01)	-0.008 (0.011)
MD_M	0.137*** (0.037)	0.131*** (0.027)	-0.00021	-0.001 (0.011)
MD_N	0.197*** (0.053)	0.199*** (0.038)	-0.003 (0.015)	0.005 (0.016)
MD_O	0.205*** (0.044)	0.183*** (0.032)	-0.01 (0.012)	-0.016 (0.014)
MD_P	0.202*** (0.045)	0.187*** (0.033)	-0.011 (0.013)	-0.011 (0.014)
MD_Q	-0.305*** (0.036)	-0.001 (0.026)	0.017. (0.01)	-0.001 (0.011)
MD_R	-0.132** (0.045)	-0.033 (0.033)	-0.004 (0.013)	0.033* (0.014)
MD_S	0.195*** (0.039)	0.179*** (0.029)	-0.001 (0.011)	-0.011 (0.012)
MD_T	-0.261*** (0.048)	-0.152*** (0.035)	0.019 (0.013)	-0.016 (0.015)
MD_U	-0.087 (0.055)	0.035 (0.04)	0.03* (0.015)	0.018 (0.017)
MD_V	0.4*** (0.069)	0.317*** (0.05)	-0.013 (0.019)	-0.012 (0.021)
MD_W	0.096* (0.041)	0.1*** (0.03)	0.016 (0.011)	-0.014 (0.013)
MD_X	-0.243*** (0.048)	-0.104** (0.035)	-0.012 (0.013)	0.012 (0.015)
MD_Y	0.173*** (0.044)	0.189*** (0.032)	-0.007 (0.012)	-0.008 (0.014)
MD_Z	-0.154*** (0.045)	-0.037 (0.033)	-0.016 (0.013)	-0.003 (0.014)
Adjusted R^2	0.423	0.521	0.017	0.008
Sample size	5158	5158	5158	5158
F value	64.962	95.966	2.476	1.715

Table EC.28: Matching on MD: empirical model description for category B.

Variable	**Log Time from Arrival to Disposition**	**Log Time from Arrival to ED Departure**	**ED Return within 72 Hours (with admission)**	**ED Return within 72 Hours (without admission)**
Intercept	3.205*** (0.224)	4.086*** (0.16)	-0.024 (0.059)	0.005 (0.065)
ESI 1	0.486. (0.253)	0.258 (0.181)	0.001 (0.067)	0.021 (0.074)
ESI 2	1.202*** (0.22)	0.779*** (0.157)	0.03 (0.058)	0.037 (0.064)
ESI 3	1.237*** (0.219)	0.79*** (0.156)	0.021 (0.058)	0.035 (0.064)
ESI 4	0.943*** (0.219)	0.572*** (0.156)	0.014 (0.058)	0.03 (0.064)
Patient Age	0.002*** (0.0)	0.001*** (0.0)	0.0* (0.0)	0.0 (0.0)
Trial	-0.053*** (0.015)	-0.041*** (0.011)	-0.003 (0.004)	0.003 (0.004)
IV	0.342*** (0.02)	0.302*** (0.015)	0.003 (0.005)	-0.007 (0.006)
CT with IV contrast	0.401*** (0.02)	0.251*** (0.014)	0.0 (0.005)	-0.002 (0.006)
CT without IV contrast	0.302*** (0.02)	0.208*** (0.014)	-0.001 (0.005)	0.002 (0.006)
MRI	0.237*** (0.054)	0.224*** (0.038)	-0.026. (0.014)	0.003 (0.016)
Xray	0.213*** (0.016)	0.15*** (0.011)	-0.013** (0.004)	-0.005 (0.005)
Ultrasound	0.25*** (0.023)	0.214*** (0.016)	0.003 (0.006)	-0.009 (0.007)
Nurses on shift	-0.002 (0.003)	-0.003 (0.002)	0.002* (0.001)	-0.0 (0.001)
MDs on shift	-0.03** (0.009)	-0.024*** (0.007)	-0.002 (0.002)	0.003 (0.003)
Current waiting count	0.004. (0.003)	0.015*** (0.002)	0.0 (0.001)	0.001 (0.001)
Current treatment count	0.005*** (0.001)	0.005*** (0.001)	-0.001. (0.0)	-0.0 (0.0)
Shift: 12 pm-6 pm	0.07 (0.048)	0.013 (0.034)	-0.003 (0.013)	-0.024. (0.014)
Shift: 6 am-12 pm	0.185*** (0.033)	0.092*** (0.023)	-0.001 (0.009)	-0.00019
Shift: 6 pm-12 am	-0.006 (0.042)	-0.051. (0.03)	-0.007 (0.011)	-0.006 (0.012)
ED Disposition Admit	-0.218*** (0.023)	0.135*** (0.016)	0.014* (0.006)	-0.025*** (0.007)
ED Disposition Hospital Observation	-0.017 (0.025)	0.228*** (0.018)	0.003 (0.007)	-0.000126
ED Disposition Left Without Being Seen/AMA	-0.119 (0.107)	-0.015092	0.223*** (0.028)	0.045 (0.031)
ED Disposition Transfer to Health Care Facility	0.058 (0.071)	0.361*** (0.05)	-0.017 (0.019)	-0.03 (0.021)
Adjusted R^2	0.345	0.481	0.016	0.005
Sample size	5158	5158	5158	5158
F value	119.053	208.81	4.595	2.207

Table EC.29: Matching on MD: empirical model description for category C.

Variable	**Log Time from Arrival to Disposition**	**Log Time from Arrival to ED Departure**	**ED Return within 72 Hours (with admission)**	**ED Return within 72 Hours (without admission)**
Intercept	3.345*** (0.206)	4.13*** (0.152)	-0.004 (0.062)	-0.0 (0.068)
ESI 1	0.251 (0.231)	0.107 (0.17)	-0.004 (0.069)	0.036 (0.076)
ESI 2	1.039*** (0.2)	0.659*** (0.147)	0.024 (0.06)	0.044 (0.066)
ESI 3	1.069*** (0.2)	0.672*** (0.147)	0.012 (0.06)	0.046 (0.065)
ESI 4	0.846*** (0.2)	0.513*** (0.147)	0.007 (0.06)	0.037 (0.065)
Patient Age	0.002*** (0.0)	0.002*** (0.0)	0.0* (0.0)	0.0 (0.0)
Trial	-0.057*** (0.013)	-0.045*** (0.009)	0.0 (0.004)	0.002 (0.004)
IV	0.321*** (0.018)	0.284*** (0.013)	0.018*** (0.005)	-0.005 (0.006)
CT with IV contrast	0.361*** (0.017)	0.235*** (0.013)	-0.000065	-0.006 (0.006)
CT without IV contrast	0.244*** (0.018)	0.174*** (0.013)	0.0 (0.005)	0.007 (0.006)
MRI	0.282*** (0.048)	0.253*** (0.035)	-0.000448	0.012 (0.016)
Xray	0.196*** (0.016)	0.159*** (0.012)	-0.000055	-0.009. (0.005)
Ultrasound	0.223*** (0.02)	0.199*** (0.015)	-0.006 (0.006)	-0.002 (0.007)
Nurses on shift	0.003 (0.002)	-0.002 (0.002)	0.001 (0.001)	-0.0 (0.001)
MDs on shift	-0.035*** (0.008)	-0.025*** (0.006)	0.001 (0.002)	0.001 (0.003)
Current waiting count	0.001 (0.002)	0.013*** (0.002)	0.0 (0.001)	0.0 (0.001)
Current treatment count	0.004*** (0.001)	0.005*** (0.001)	-0.001. (0.0)	-0.0 (0.0)
Shift: 12 pm-6 pm	0.029 (0.043)	-0.018 (0.032)	-0.006 (0.013)	-0.007 (0.014)
Shift: 6 am-12 pm	0.143*** (0.033)	0.056* (0.024)	-0.014 (0.01)	-0.003 (0.011)
Shift: 6 pm-12 am	-0.02 (0.037)	-0.047. (0.027)	-0.007 (0.011)	-0.002 (0.012)
ED Disposition Admit	-0.201*** (0.019)	0.128*** (0.014)	0.013* (0.006)	-0.028*** (0.006)
ED Disposition Hospital Observation	-0.009 (0.021)	0.233*** (0.016)	-0.002 (0.006)	-0.022** (0.007)
ED Disposition Left Without Being Seen/AMA	-0.15. (0.088)	-0.226*** (0.064)	0.143*** (0.026)	0.031 (0.029)
ED Disposition Transfer to Health Care Facility	0.112. (0.061)	0.416*** (0.045)	-0.023 (0.018)	-0.035. (0.02)
MD_A	0.165*** (0.031)	0.137*** (0.023)	-0.007 (0.009)	0.015 (0.01)
MD_AA	0.268*** (0.041)	0.287*** (0.03)	-0.014 (0.012)	-0.026. (0.014)
MD_AB	0.238*** (0.043)	0.222*** (0.032)	-0.0 (0.013)	0.014 (0.014)
MD_AC	0.317*** (0.048)	0.28*** (0.035)	-0.008 (0.014)	-0.000496
MD_AD	-0.008083	-0.066 (0.043)	0.025 (0.018)	-0.002 (0.019)
MD_AE	-0.051 (0.041)	-0.007 (0.03)	0.003 (0.012)	-0.011 (0.013)
MD_AF	-0.053 (0.04)	0.002 (0.029)	-0.017 (0.012)	0.041** (0.013)
MD_AG	0.06 (0.05)	0.101** (0.037)	0.002 (0.015)	0.027. (0.016)
MD_AH	0.215*** (0.062)	0.183*** (0.046)	-0.014 (0.019)	0.021 (0.02)
MD_AI	0.296*** (0.066)	0.201*** (0.048)	-0.008 (0.02)	0.028 (0.022)
MD_AJ	0.189*** (0.042)	0.144*** (0.031)	-0.017 (0.013)	0.001 (0.014)
MD_AK	0.312*** (0.07)	0.246*** (0.052)	0.038. (0.021)	0.014 (0.023)
MD_B	0.278*** (0.032)	0.212*** (0.024)	-0.011 (0.01)	-0.008 (0.011)
MD_C	0.183*** (0.032)	0.147*** (0.024)	-0.006 (0.01)	-0.02. (0.011)

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Table EC.30 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MD_D	0.288*** (0.032)	0.213*** (0.024)	-0.0 (0.01)	-0.016 (0.011)
MD_E	-0.18*** (0.032)	-0.03 (0.024)	-0.01 (0.01)	0.013 (0.011)
MD_F	-0.002 (0.034)	0.068** (0.025)	0.008 (0.01)	0.003 (0.011)
MD_G	0.285*** (0.032)	0.239*** (0.023)	-0.004 (0.01)	-0.007 (0.01)
MD_H	0.171*** (0.035)	0.175*** (0.026)	-0.005 (0.011)	-0.002 (0.012)
MD_I	-0.124*** (0.035)	-0.046. (0.025)	0.023* (0.01)	-0.016 (0.011)
MD_J	-0.183*** (0.038)	-0.023 (0.028)	0.008 (0.011)	0.002 (0.012)
MD_K	0.201*** (0.034)	0.169*** (0.025)	-0.018. (0.01)	-0.004 (0.011)
MD_L	0.079* (0.034)	0.04 (0.025)	0.009 (0.01)	0.005 (0.011)
MD_M	0.075* (0.034)	0.078** (0.025)	-0.014 (0.01)	0.001 (0.011)
MD_N	0.19*** (0.039)	0.18*** (0.029)	0.007 (0.012)	-0.01 (0.013)
MD_O	0.133*** (0.034)	0.154*** (0.025)	-0.007 (0.01)	0.005 (0.011)
MD_P	0.181*** (0.037)	0.172*** (0.027)	0.0 (0.011)	-0.012 (0.012)
MD_Q	-0.337*** (0.036)	-0.033 (0.026)	0.012 (0.011)	-0.019 (0.012)
MD_R	-0.123*** (0.037)	-0.021 (0.027)	0.017 (0.011)	0.011 (0.012)
MD_S	0.19*** (0.038)	0.178*** (0.028)	-0.003 (0.011)	-0.013 (0.012)
MD_T	-0.129** (0.046)	-0.061. (0.034)	-0.0 (0.014)	-0.012 (0.015)
MD_U	-0.029 (0.04)	0.075* (0.029)	0.007 (0.012)	0.025. (0.013)
MD_V	0.271*** (0.048)	0.238*** (0.035)	-0.024. (0.014)	-0.016 (0.016)
MD_W	0.123** (0.039)	0.12*** (0.028)	0.015 (0.012)	-0.004 (0.013)
MD_X	-0.148*** (0.044)	-0.002432	0.022. (0.013)	0.009 (0.014)
MD_Y	0.208*** (0.041)	0.226*** (0.03)	0.0 (0.012)	-0.012 (0.014)
MD_Z	-0.074. (0.043)	0.005 (0.032)	-0.015 (0.013)	0.006 (0.014)
Abdominal Complaints	-0.009 (0.069)	-0.003 (0.051)	0.004 (0.021)	-0.0 (0.023)
Abnormal Test Results	-0.122. (0.074)	-0.034 (0.054)	-0.021 (0.022)	0.007 (0.024)
Allergic Reaction	-0.203. (0.107)	-0.012168	0.003 (0.032)	-0.001 (0.035)
Back or Flank Pain	-0.03 (0.073)	-0.0 (0.053)	0.03 (0.022)	-0.009 (0.024)
Breast Complaints	-0.12 (0.287)	-0.074 (0.212)	-0.012 (0.086)	-0.042 (0.094)
Cardiac Arrhythmias	0.03 (0.084)	0.017 (0.062)	-0.022 (0.025)	0.01 (0.027)
Chest Pain	-0.002 (0.071)	-0.026 (0.053)	0.002 (0.021)	0.0 (0.023)
Circulatory Issue	-0.274 (0.252)	-0.11 (0.185)	0.484*** (0.076)	-0.018 (0.082)
Dizziness/Lightheadedness/Syncope	-0.095 (0.077)	-0.033 (0.057)	-0.016 (0.023)	-0.025 (0.025)
Ear Complaints	-0.395*** (0.099)	-0.247*** (0.073)	-0.008 (0.03)	-0.01 (0.032)
Epistaxis	0.059 (0.11)	0.079 (0.081)	-0.019 (0.033)	0.146*** (0.036)
Exposures, Bites, and Envenomations	-0.42*** (0.118)	-0.229** (0.087)	0.026 (0.036)	-0.027 (0.039)
Extremity Complaints	-0.010792	-0.005668	-0.0 (0.021)	0.001 (0.023)
Eye Complaints	0.017 (0.099)	0.015 (0.073)	-0.018 (0.03)	-0.008 (0.032)
Falls, Motor Vehicle Crashes, Assaults, and Trauma	-0.065 (0.075)	-0.036 (0.055)	-0.004 (0.022)	0.006 (0.024)
Fatigue and Weakness	-0.1 (0.085)	-0.074 (0.062)	-0.014 (0.025)	-0.004 (0.028)

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Table EC.30 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Fevers, Sweats or Chills	-0.129 (0.085)	-0.082 (0.063)	-0.017 (0.026)	-0.001 (0.028)
Foreign Body	-0.459** (0.168)	-0.331** (0.124)	-0.001 (0.051)	-0.023 (0.055)
Gastrointestinal Issues	-0.059 (0.071)	0.004 (0.053)	-0.007 (0.021)	0.015 (0.023)
Genital Complaints	0.067 (0.091)	0.039 (0.067)	0.003 (0.027)	-0.031 (0.03)
Medical Device or Treatment Issue	-0.113 (0.097)	-0.018 (0.072)	0.047 (0.029)	0.04 (0.032)
Medication Request	-0.447. (0.252)	-0.082398	-0.01 (0.076)	-0.045 (0.083)
Neurological Issue	-0.073 (0.072)	-0.036 (0.053)	-0.001 (0.022)	0.004 (0.024)
Other Pain	-0.154. (0.086)	-0.113. (0.063)	0.007 (0.026)	0.017 (0.028)
Post-Op Issue	-0.021715	-0.132. (0.075)	0.001 (0.03)	0.003 (0.033)
Psychiatric Complaints	0.322** (0.109)	0.285*** (0.08)	-0.016 (0.033)	0.002 (0.036)
Shortness of Breath	-0.073 (0.072)	-0.019 (0.053)	-0.001 (0.022)	0.002 (0.024)
Skin Complaints	-0.263*** (0.075)	-0.158** (0.055)	-0.002 (0.022)	0.006 (0.024)
Substance Abuse Issues	0.073 (0.109)	0.01 (0.08)	-0.008 (0.033)	0.032 (0.036)
Upper Respiratory Symptoms	-0.0129	-0.007535	0.008 (0.023)	-0.014 (0.025)
Urinary Complaints	0.017 (0.077)	0.062 (0.057)	0.029 (0.023)	0.035 (0.025)
Adjusted R^2	0.419	0.513	0.022	0.014
Sample size	5976	5976	5976	5976
F value	48.881	70.948	2.479	1.915

Table EC.30: Matching on CC: empirical model description for category A.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.212*** (0.2)	4.046*** (0.147)	-0.003 (0.06)	-0.005 (0.065)
ESI 1	0.347 (0.232)	0.163 (0.17)	-0.009 (0.069)	0.04 (0.075)
ESI 2	1.136*** (0.201)	0.726*** (0.148)	0.022 (0.06)	0.051 (0.065)
ESI 3	1.152*** (0.2)	0.73*** (0.147)	0.014 (0.06)	0.051 (0.065)
ESI 4	0.856*** (0.201)	0.52*** (0.148)	0.011 (0.06)	0.043 (0.065)
Patient Age	0.002*** (0.0)	0.002*** (0.0)	0.0* (0.0)	0.0 (0.0)
Trial	-0.057*** (0.013)	-0.045*** (0.009)	0.0 (0.004)	0.002 (0.004)
IV	0.335*** (0.017)	0.296*** (0.013)	0.02*** (0.005)	-0.006 (0.006)
CT with IV contrast	0.384*** (0.017)	0.245*** (0.012)	-0.00006	-0.009 (0.005)
CT without IV contrast	0.257*** (0.017)	0.183*** (0.012)	0.002 (0.005)	0.004 (0.005)

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Table EC.31 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MRI	0.266*** (0.048)	0.24*** (0.035)	-0.028. (0.014)	0.01 (0.015)
Xray	0.188*** (0.014)	0.141*** (0.01)	-0.014*** (0.004)	-0.013** (0.004)
Ultrasound	0.224*** (0.019)	0.195*** (0.014)	-0.005 (0.006)	-0.005 (0.006)
Nurses on shift	0.003 (0.002)	-0.002 (0.002)	0.001 (0.001)	-0.0 (0.001)
MDs on shift	-0.035*** (0.008)	-0.026*** (0.006)	0.001 (0.002)	0.0 (0.003)
Current waiting count	0.002 (0.002)	0.014*** (0.002)	0.0 (0.001)	0.0 (0.001)
Current treatment count	0.004*** (0.001)	0.005*** (0.001)	-0.001 (0.0)	-0.0 (0.0)
Shift: 12 pm-6 pm	0.028 (0.044)	-0.02 (0.032)	-0.008 (0.013)	-0.007 (0.014)
Shift: 6 am-12 pm	0.139*** (0.034)	0.053* (0.025)	-0.016 (0.01)	-0.003 (0.011)
Shift: 6 pm-12 am	-0.02 (0.038)	-0.049. (0.028)	-0.01 (0.011)	-0.002 (0.012)
ED Disposition Admit	-0.216*** (0.019)	0.125*** (0.014)	0.011. (0.006)	-0.027*** (0.006)
ED Disposition Hospital Observation	-0.013 (0.022)	0.229*** (0.016)	-0.002 (0.006)	-0.022** (0.007)
ED Disposition Left Without Being Seen/AMA	-0.156. (0.088)	-0.23*** (0.065)	0.138*** (0.026)	0.031 (0.029)
ED Disposition Transfer to Health Care Facility	0.146* (0.061)	0.449*** (0.045)	-0.025 (0.018)	-0.034. (0.02)
MD_A	0.159*** (0.031)	0.131*** (0.023)	-0.008 (0.009)	0.012 (0.01)
MD_AA	0.261*** (0.042)	0.28*** (0.031)	-0.013 (0.012)	-0.000406
MD_AB	0.234*** (0.044)	0.222*** (0.032)	0.001 (0.013)	0.013 (0.014)
MD_AC	0.313*** (0.048)	0.277*** (0.035)	-0.009 (0.014)	-0.000496
MD_AD	-0.008909	-0.072. (0.044)	0.026 (0.018)	-0.002 (0.019)
MD_AE	-0.058 (0.041)	-0.016 (0.03)	0.005 (0.012)	-0.015 (0.013)
MD_AF	-0.064 (0.04)	-0.005 (0.029)	-0.016 (0.012)	0.04** (0.013)
MD_AG	0.041 (0.05)	0.089* (0.037)	0.002 (0.015)	0.027 (0.016)
MD_AH	0.215*** (0.063)	0.183*** (0.046)	-0.017 (0.019)	0.021 (0.02)
MD_AI	0.292*** (0.066)	0.196*** (0.049)	-0.009 (0.02)	0.03 (0.022)
MD_AJ	0.198*** (0.042)	0.15*** (0.031)	-0.015 (0.013)	0.004 (0.014)
MD_AK	0.308*** (0.071)	0.25*** (0.052)	0.037. (0.021)	0.016 (0.023)
MD_B	0.275*** (0.033)	0.212*** (0.024)	-0.009 (0.01)	-0.008 (0.011)
MD_C	0.18*** (0.033)	0.142*** (0.024)	-0.007 (0.01)	-0.000231
MD_D	0.287*** (0.032)	0.216*** (0.024)	0.0 (0.01)	-0.016 (0.011)
MD_E	-0.188*** (0.032)	-0.033 (0.024)	-0.009 (0.01)	0.015 (0.011)
MD_F	-0.005 (0.034)	0.065** (0.025)	0.008 (0.01)	0.003 (0.011)
MD_G	0.282*** (0.032)	0.238*** (0.024)	-0.004 (0.01)	-0.006 (0.01)
MD_H	0.165*** (0.035)	0.171*** (0.026)	-0.006 (0.011)	-0.002 (0.012)
MD_I	-0.126*** (0.035)	-0.047. (0.026)	0.022* (0.01)	-0.017 (0.011)
MD_J	-0.189*** (0.038)	-0.026 (0.028)	0.008 (0.011)	0.002 (0.012)
MD_K	0.2*** (0.034)	0.166*** (0.025)	-0.015 (0.01)	-0.006 (0.011)
MD_L	0.074* (0.035)	0.037 (0.025)	0.01 (0.01)	0.005 (0.011)
MD_M	0.074* (0.035)	0.078** (0.025)	-0.013 (0.01)	0.001 (0.011)
MD_N	0.183*** (0.039)	0.178*** (0.029)	0.005 (0.012)	-0.01 (0.013)
MD_O	0.132*** (0.034)	0.156*** (0.025)	-0.008 (0.01)	0.007 (0.011)

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Table EC.31 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MD_P	0.177*** (0.038)	0.17*** (0.028)	-0.0 (0.011)	-0.013 (0.012)
MD_Q	-0.342*** (0.036)	-0.038 (0.027)	0.01 (0.011)	-0.019. (0.012)
MD_R	-0.128*** (0.037)	-0.025 (0.027)	0.017 (0.011)	0.011 (0.012)
MD_S	0.185*** (0.038)	0.171*** (0.028)	-0.001 (0.011)	-0.016 (0.012)
MD_T	-0.134** (0.046)	-0.002312	0.002 (0.014)	-0.013 (0.015)
MD_U	-0.017 (0.04)	0.08** (0.029)	0.007 (0.012)	0.027* (0.013)
MD_V	0.259*** (0.049)	0.232*** (0.036)	-0.024. (0.014)	-0.017 (0.016)
MD_W	0.113** (0.039)	0.113*** (0.029)	0.016 (0.012)	-0.005 (0.013)
MD_X	-0.137** (0.044)	-0.002277	0.02 (0.013)	0.011 (0.014)
MD_Y	0.21*** (0.042)	0.229*** (0.031)	-0.001 (0.012)	-0.013 (0.014)
MD_Z	-0.065 (0.043)	0.012 (0.032)	-0.015 (0.013)	0.007 (0.014)
Adjusted R^2	0.405	0.502	0.012	0.01
Sample size	5976	5976	5976	5976
F value	70.024	103.162	2.267	1.975

Table EC.31: Matching on CC: empirical model description for category B.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	3.158*** (0.215)	4.059*** (0.156)	-0.003 (0.061)	-0.004 (0.066)
ESI 1	0.491* (0.244)	0.236 (0.176)	-0.009 (0.069)	0.03 (0.075)
ESI 2	1.253*** (0.212)	0.791*** (0.153)	0.022 (0.06)	0.045 (0.065)
ESI 3	1.269*** (0.211)	0.795*** (0.153)	0.014 (0.06)	0.045 (0.065)
ESI 4	0.972*** (0.212)	0.586*** (0.153)	0.011 (0.06)	0.037 (0.065)
Patient Age	0.002*** (0.0)	0.002*** (0.0)	0.0* (0.0)	0.0 (0.0)
Trial	-0.047*** (0.013)	-0.039*** (0.01)	-0.001 (0.004)	0.002 (0.004)
IV	0.332*** (0.018)	0.295*** (0.013)	0.018*** (0.005)	-0.006 (0.006)
CT with IV contrast	0.401*** (0.017)	0.254*** (0.013)	-0.013** (0.005)	-0.008 (0.005)
CT without IV contrast	0.269*** (0.018)	0.188*** (0.013)	0.001 (0.005)	0.005 (0.005)
MRI	0.267*** (0.05)	0.247*** (0.036)	-0.000392	0.011 (0.015)
Xray	0.201*** (0.014)	0.148*** (0.01)	-0.015*** (0.004)	-0.012** (0.004)
Ultrasound	0.225*** (0.02)	0.196*** (0.015)	-0.006 (0.006)	-0.004 (0.006)
Nurses on shift	0.001 (0.003)	-0.003 (0.002)	0.001 (0.001)	0.0 (0.001)
MDs on shift	-0.032*** (0.008)	-0.024*** (0.006)	0.001 (0.002)	0.001 (0.003)
Current waiting count	0.003 (0.002)	0.014*** (0.002)	0.0 (0.001)	0.0 (0.001)
Current treatment count	0.004*** (0.001)	0.005*** (0.001)	-0.001. (0.0)	-0.0 (0.0)
Shift: 12 pm-6 pm	0.05 (0.044)	-0.001 (0.032)	-0.009 (0.013)	-0.004 (0.014)
Shift: 6 am-12 pm	0.177*** (0.031)	0.082*** (0.023)	-0.014 (0.009)	-0.003 (0.01)

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Table EC.32 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Shift: 6 pm-12 am	-0.013 (0.039)	-0.038 (0.028)	-0.011 (0.011)	0.002 (0.012)
ED Disposition Admit	-0.208*** (0.02)	0.131*** (0.015)	0.011. (0.006)	-0.026*** (0.006)
ED Disposition Hospital Observation	-0.009 (0.023)	0.232*** (0.016)	-0.002 (0.006)	-0.021** (0.007)
ED Disposition Left Without Being Seen/AMA	-0.158. (0.093)	-0.229*** (0.067)	0.14*** (0.026)	0.029 (0.029)
ED Disposition Transfer to Health Care Facility	0.114. (0.064)	0.43*** (0.046)	-0.022 (0.018)	-0.033. (0.02)
Adjusted R^2	0.336	0.464	0.012	0.006
Sample size	5976	5976	5976	5976
F value	132.687	225.586	4.199	2.674

Table EC.32: Matching on CC: empirical model description for category C.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	2.944*** (0.081)	3.544*** (0.059)	0.029 (0.026)	0.084*** (0.025)
ESI 1	0.212* (0.104)	0.229** (0.075)	0.081* (0.033)	-0.027 (0.032)
ESI 2	0.78*** (0.079)	0.686*** (0.057)	0.031 (0.025)	-0.014 (0.024)
ESI 3	0.764*** (0.078)	0.682*** (0.057)	0.015 (0.025)	-0.015 (0.024)
ESI 4	0.516*** (0.079)	0.496*** (0.057)	0.01 (0.025)	-0.017 (0.024)
Patient Age	0.002*** (0.0)	0.002*** (0.0)	0.0 (0.0)	0
Trial	-0.00024 (0.0)	-0.027*** (0.007)	-0.009 (0.003)	-0.001 (0.003)
IV	0.322*** (0.013)	0.28*** (0.01)	0.027*** (0.004)	-0.002 (0.004)
CT with IV contrast	0.356*** (0.013)	0.227*** (0.01)	-0.02*** (0.004)	-0.011** (0.004)
CT without IV contrast	0.261*** (0.014)	0.177*** (0.01)	-0.00004	-0.008. (0.004)
MRI	0.315*** (0.035)	0.269*** (0.026)	-0.000297	-0.006 (0.011)
Xray	0.187*** (0.012)	0.145*** (0.009)	-0.01** (0.004)	-0.007. (0.004)
Ultrasound	0.196*** (0.015)	0.17*** (0.011)	-0.003 (0.005)	0.005 (0.005)
Nurses on shift	0.001 (0.002)	-0.000003	0.0 (0.001)	-0.001. (0.001)
MDs on shift	-0.023*** (0.006)	-0.018*** (0.004)	0.002 (0.002)	0.004* (0.002)
Current waiting count	0.003* (0.002)	0.013*** (0.001)	0.0 (0.0)	0.001 (0.0)
Current treatment count	0.004*** (0.001)	0.005*** (0.001)	-0.0 (0.0)	-0.0. (0.0)
Shift: 12 pm-6 pm	0.019 (0.033)	-0.032 (0.024)	-0.003 (0.011)	0.004 (0.01)

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Table EC.33 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Shift: 6 am-12 pm	0.152*** (0.025)	0.063*** (0.018)	-0.014. (0.008)	0.001 (0.008)
Shift: 6 pm-12 am	-0.037 (0.029)	-0.059** (0.021)	-0.017. (0.009)	0.015. (0.009)
ED Disposition Admit	0.393*** (0.024)	0.696*** (0.017)	-0.014. (0.008)	0.007 (0.007)
ED Disposition Discharge	0.593*** (0.022)	0.559*** (0.016)	-0.000119	0.028*** (0.007)
ED Disposition Hospital Observation	0.585*** (0.024)	0.807*** (0.018)	-0.029*** (0.008)	0.016* (0.008)
ED Disposition Left Without Being Seen/AMA	0.662*** (0.054)	0.536*** (0.039)	0.135*** (0.017)	0.039* (0.017)
ED Disposition Transfer to Health Care Facility	0.711*** (0.046)	0.946*** (0.034)	-0.046** (0.015)	-0.006 (0.014)
MD_A	0.164*** (0.025)	0.134*** (0.018)	-0.014. (0.008)	0.02* (0.008)
MD_AA	0.236*** (0.03)	0.242*** (0.022)	-0.015 (0.01)	-0.017. (0.009)
MD_AB	0.211*** (0.034)	0.17*** (0.024)	-0.004 (0.011)	0.009 (0.01)
MD_AC	0.375*** (0.037)	0.285*** (0.027)	-0.013 (0.012)	-0.000253
MD_AD	-0.006318	-0.054 (0.039)	-0.004 (0.017)	-0.021 (0.017)
MD_AE	-0.087** (0.029)	-0.036. (0.021)	0.0 (0.009)	-0.004 (0.009)
MD_AF	0.004 (0.03)	0.008 (0.021)	-0.017. (0.009)	0.03** (0.009)
MD_AG	0.031 (0.04)	0.074* (0.029)	0.025* (0.013)	0.001 (0.012)
MD_AH	0.25*** (0.059)	0.248*** (0.043)	-0.02 (0.019)	-0.011 (0.018)
MD_AI	0.27*** (0.065)	0.192*** (0.047)	0.027 (0.021)	0.032 (0.02)
MD_AJ	0.171*** (0.025)	0.136*** (0.018)	0.041*** (0.008)	-0.007 (0.008)
MD_AK	0.408*** (0.048)	0.311*** (0.034)	0.02 (0.015)	-0.001 (0.015)
MD_B	0.298*** (0.024)	0.228*** (0.017)	0.011 (0.008)	-0.002 (0.007)
MD_C	0.199*** (0.025)	0.158*** (0.018)	-0.011 (0.008)	-0.011 (0.008)
MD_D	0.327*** (0.024)	0.231*** (0.018)	0.002 (0.008)	-0.006 (0.008)
MD_E	-0.181*** (0.023)	-0.000629	-0.000105	0.014. (0.007)
MD_F	0.04 (0.028)	0.067*** (0.02)	0.015. (0.009)	0.004 (0.009)
MD_G	0.306*** (0.024)	0.235*** (0.017)	0.016* (0.008)	0.006 (0.007)
MD_H	0.133*** (0.025)	0.117*** (0.018)	0.007 (0.008)	0.014. (0.008)
MD_I	-0.172*** (0.028)	-0.062** (0.02)	0.013 (0.009)	-0.009 (0.009)
MD_J	-0.206*** (0.03)	-0.064** (0.022)	-0.003 (0.01)	0.01 (0.009)
MD_K	0.156*** (0.025)	0.121*** (0.018)	0.001 (0.008)	0.007 (0.008)
MD_L	0.073** (0.026)	0.041* (0.019)	0.002 (0.008)	0.017* (0.008)
MD_M	0.082*** (0.025)	0.092*** (0.018)	-0.013 (0.008)	-0.003 (0.008)
MD_N	0.122*** (0.031)	0.14*** (0.022)	0.018. (0.01)	0.003 (0.01)
MD_O	0.144*** (0.025)	0.159*** (0.018)	-0.01 (0.008)	-0.002 (0.008)
MD_P	0.107*** (0.027)	0.117*** (0.019)	-0.011 (0.009)	-0.006 (0.008)
MD_Q	-0.298*** (0.026)	-0.012 (0.019)	0.004 (0.008)	0.028*** (0.008)
MD_R	-0.145*** (0.029)	-0.003 (0.021)	0.003 (0.009)	0.012 (0.009)
MD_S	0.201*** (0.029)	0.158*** (0.021)	-0.008 (0.009)	-0.006 (0.009)
MD_T	-0.208*** (0.042)	-0.128*** (0.03)	-0.021 (0.013)	-0.004 (0.013)
MD_U	-0.0021	0.036 (0.022)	0.0 (0.01)	0.012 (0.009)
MD_V	0.251*** (0.036)	0.205*** (0.026)	-0.03** (0.011)	-0.013 (0.011)
MD_W	0.102*** (0.029)	0.09*** (0.021)	0.021* (0.009)	0.016. (0.009)

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Table EC.33 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
MD_X	-0.286*** (0.03)	-0.196*** (0.022)	-0.002 (0.01)	-0.008 (0.009)
MD_Y	0.151*** (0.03)	0.145*** (0.022)	0.001 (0.01)	-0.008 (0.009)
MD_Z	-0.101** (0.033)	-0.004 (0.024)	0.012 (0.01)	0.009 (0.01)
Abdominal Complaints	0.088 (0.054)	0.046 (0.039)	0.001 (0.017)	-0.047** (0.017)
Abnormal Test Results	-0.057 (0.057)	0.022 (0.041)	-0.017 (0.018)	-0.048** (0.018)
Allergic Reaction	-0.09 (0.091)	-0.098 (0.066)	-0.019 (0.029)	-0.088** (0.028)
Back or Flank Pain	0.121* (0.057)	0.073. (0.041)	0.004 (0.018)	-0.055** (0.018)
Breast Complaints	-0.143 (0.183)	-0.069 (0.133)	-0.028 (0.058)	-0.075 (0.057)
Cardiac Arrhythmias	-0.012 (0.061)	-0.055 (0.044)	-0.036. (0.019)	-0.064*** (0.019)
Chest Pain	0.085 (0.056)	0.023 (0.041)	0.008 (0.018)	-0.053** (0.017)
Circulatory Issue	-0.038 (0.175)	-0.141 (0.127)	-0.001 (0.056)	-0.071 (0.054)
Dizziness/ Lightheadedness/ Syncope	0.126* (0.058)	0.053 (0.042)	-0.027 (0.018)	-0.064*** (0.018)
Ear Complaints	-0.376*** (0.091)	-0.275*** (0.066)	-0.03 (0.029)	-0.001764
Epistaxis	0.061 (0.081)	0.038 (0.059)	-0.035 (0.026)	0.066** (0.025)
Exposures, Bites, and Envenomations	-0.313*** (0.092)	-0.234*** (0.067)	0.025 (0.029)	-0.086** (0.029)
Extremity Complaints	-0.036 (0.055)	-0.039 (0.04)	-0.015 (0.018)	-0.055** (0.017)
Eye Complaints	-0.235*** (0.063)	-0.167*** (0.046)	-0.025 (0.02)	-0.0008
Falls, Motor Vehicle Crashes, Assaults, and Trauma	0.004 (0.057)	-0.002 (0.041)	-0.014 (0.018)	-0.029. (0.018)
Fatigue and Weakness	0.01 (0.059)	0.007 (0.043)	-0.006 (0.019)	-0.049** (0.018)
Fevers, Sweats or Chills	-0.093 (0.06)	-0.058 (0.044)	-0.031 (0.019)	-0.064*** (0.019)
Foreign Body	-0.27. (0.139)	-0.024442	-0.015 (0.044)	-0.081. (0.043)
Gastrointestinal Issues	0.032 (0.056)	0.046 (0.04)	-0.017 (0.018)	-0.048** (0.017)
Genital Complaints	0.225*** (0.066)	0.135** (0.048)	-0.031 (0.021)	-0.00092
Medical Device or Treatment Issue	0.057 (0.068)	0.075 (0.049)	-0.002 (0.022)	-0.028 (0.021)
Medication Request	-0.853*** (0.125)	-0.308*** (0.09)	-0.026 (0.04)	0.041 (0.039)
Neurological Issue	0.0 (0.057)	0.004 (0.041)	-0.024 (0.018)	-0.031. (0.017)
Other Pain	-0.029 (0.063)	0.004 (0.046)	-0.012 (0.02)	-0.06** (0.02)
Post-Op Issue	-0.117 (0.076)	-0.00781	-0.008 (0.024)	-0.077** (0.024)
Psychiatric Complaints	0.303*** (0.088)	0.24*** (0.064)	-0.013 (0.028)	-0.039 (0.027)
Shortness of Breath	-0.006 (0.056)	0.01 (0.041)	-0.021 (0.018)	-0.056** (0.017)
Skin Complaints	-0.165** (0.057)	-0.132** (0.041)	-0.014 (0.018)	-0.048** (0.018)
Substance Abuse Issues	0.13 (0.083)	0.023 (0.06)	-0.001378	-0.046. (0.026)

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Table EC.33 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Upper Respiratory Symptoms	-0.066 (0.058)	-0.074. (0.042)	-0.004 (0.019)	-0.06*** (0.018)
Urinary Complaints	0.046 (0.06)	0.073. (0.043)	0.027 (0.019)	-0.029 (0.018)
Adjusted R^2	0.438	0.533	0.026	0.019
Sample size	10926	10926	10926	10926
F value	95.582	139.762	4.273	3.323

Table EC.33: Propensity Score Matching: empirical model description for category A.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	2.766*** (0.068)	3.44*** (0.049)	0.02 (0.021)	0.05* (0.021)
ESI 1	0.464*** (0.101)	0.364*** (0.073)	0.073* (0.032)	-0.028 (0.031)
ESI 2	1.034*** (0.075)	0.827*** (0.054)	0.03 (0.024)	-0.021 (0.023)
ESI 3	1.022*** (0.074)	0.827*** (0.054)	0.019 (0.023)	-0.022 (0.023)
ESI 4	0.72*** (0.075)	0.601*** (0.054)	0.012 (0.023)	-0.025 (0.023)
Patient Age	0.002*** (0.0)	0.002*** (0.0)	0.0 (0.0)	0
Trial	-0.00022 (0.0)	-0.026*** (0.007)	-0.009 (0.003)	-0.001 (0.003)
IV	0.342*** (0.013)	0.294*** (0.009)	0.027*** (0.004)	-0.004 (0.004)
CT with IV contrast	0.383*** (0.013)	0.241*** (0.009)	-0.016*** (0.004)	-0.011** (0.004)
CT without IV contrast	0.289*** (0.013)	0.197*** (0.009)	-0.000036	-0.004 (0.004)
MRI	0.297*** (0.035)	0.253*** (0.025)	-0.031** (0.011)	-0.003 (0.011)
Xray	0.185*** (0.01)	0.135*** (0.007)	-0.011** (0.003)	-0.012*** (0.003)
Ultrasound	0.211*** (0.015)	0.179*** (0.011)	-0.004 (0.005)	0.003 (0.004)
Nurses on shift	-0.0 (0.002)	-0.000003	0.0 (0.001)	-0.001 (0.001)
MDs on shift	-0.025*** (0.006)	-0.019*** (0.004)	0.002 (0.002)	0.004* (0.002)
Current waiting count	0.003* (0.002)	0.013*** (0.001)	-0.0 (0.0)	0.001 (0.0)
Current treatment count	0.005*** (0.001)	0.005*** (0.001)	-0.0 (0.0)	-0.0. (0.0)
Shift: 12 pm-6 pm	0.009 (0.034)	-0.041. (0.024)	-0.005 (0.011)	0.005 (0.01)
Shift: 6 am-12 pm	0.139*** (0.025)	0.054** (0.018)	-0.000128	0.003 (0.008)
Shift: 6 pm-12 am	-0.054. (0.029)	-0.072*** (0.021)	-0.000162	0.015. (0.009)
ED Disposition Admit	0.334*** (0.022)	0.667*** (0.016)	-0.000112	0.0 (0.007)
ED Disposition Discharge	0.556*** (0.02)	0.535*** (0.014)	-0.018** (0.006)	0.021*** (0.006)

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Table EC.34 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
ED Disposition Hospital Observation	0.546*** (0.023)	0.782*** (0.016)	-0.031*** (0.007)	0.008 (0.007)
ED Disposition Left Without Being Seen/AMA	0.644*** (0.054)	0.518*** (0.039)	0.134*** (0.017)	0.029. (0.016)
ED Disposition Transfer to Health Care Facility	0.687*** (0.046)	0.937*** (0.033)	-0.05*** (0.014)	-0.009 (0.014)
MD_A	0.16*** (0.026)	0.134*** (0.019)	-0.015. (0.008)	0.019* (0.008)
MD_AA	0.233*** (0.03)	0.24*** (0.022)	-0.016. (0.01)	-0.000171
MD_AB	0.211*** (0.034)	0.176*** (0.025)	-0.003 (0.011)	0.01 (0.01)
MD_AC	0.36*** (0.038)	0.272*** (0.027)	-0.015 (0.012)	-0.000276
MD_AD	-0.00638	-0.057 (0.04)	-0.003 (0.017)	-0.023 (0.017)
MD_AE	-0.104*** (0.029)	-0.001008	-0.0 (0.009)	-0.007 (0.009)
MD_AF	-0.006 (0.03)	0.005 (0.022)	-0.000171	0.029** (0.009)
MD_AG	0.026 (0.041)	0.071* (0.029)	0.024. (0.013)	0.001 (0.012)
MD_AH	0.254*** (0.06)	0.252*** (0.043)	-0.021 (0.019)	-0.011 (0.018)
MD_AI	0.269*** (0.065)	0.187*** (0.047)	0.03 (0.021)	0.03 (0.02)
MD_AJ	0.17*** (0.025)	0.133*** (0.018)	0.041*** (0.008)	-0.006 (0.008)
MD_AK	0.407*** (0.048)	0.308*** (0.035)	0.019 (0.015)	-0.003 (0.015)
MD_B	0.299*** (0.024)	0.23*** (0.017)	0.011 (0.008)	-0.002 (0.007)
MD_C	0.195*** (0.025)	0.154*** (0.018)	-0.012 (0.008)	-0.013 (0.008)
MD_D	0.322*** (0.025)	0.232*** (0.018)	0.003 (0.008)	-0.005 (0.008)
MD_E	-0.208*** (0.024)	-0.05** (0.017)	-0.000105	0.015* (0.007)
MD_F	0.043 (0.028)	0.068*** (0.02)	0.016. (0.009)	0.002 (0.009)
MD_G	0.302*** (0.024)	0.234*** (0.017)	0.016* (0.008)	0.005 (0.007)
MD_H	0.134*** (0.025)	0.117*** (0.018)	0.005 (0.008)	0.014. (0.008)
MD_I	-0.176*** (0.028)	-0.061** (0.02)	0.012 (0.009)	-0.012 (0.009)
MD_J	-0.219*** (0.03)	-0.07** (0.022)	-0.004 (0.01)	0.009 (0.009)
MD_K	0.16*** (0.025)	0.122*** (0.018)	0.002 (0.008)	0.004 (0.008)
MD_L	0.065* (0.026)	0.037. (0.019)	0.003 (0.008)	0.016* (0.008)
MD_M	0.073** (0.025)	0.085*** (0.018)	-0.013. (0.008)	-0.004 (0.008)
MD_N	0.116*** (0.031)	0.14*** (0.023)	0.017. (0.01)	0.004 (0.01)
MD_O	0.13*** (0.025)	0.151*** (0.018)	-0.01 (0.008)	-0.001 (0.008)
MD_P	0.102*** (0.027)	0.113*** (0.02)	-0.012 (0.009)	-0.006 (0.008)
MD_Q	-0.308*** (0.027)	-0.016 (0.019)	0.004 (0.008)	0.028*** (0.008)
MD_R	-0.154*** (0.029)	-0.012 (0.021)	0.002 (0.009)	0.008 (0.009)
MD_S	0.194*** (0.029)	0.149*** (0.021)	-0.006 (0.009)	-0.009 (0.009)
MD_T	-0.216*** (0.042)	-0.136*** (0.03)	-0.019 (0.013)	-0.006 (0.013)
MD_U	-0.00222	0.035 (0.022)	-0.0 (0.009)	0.012 (0.009)
MD_V	0.268*** (0.036)	0.218*** (0.026)	-0.031** (0.011)	-0.013 (0.011)
MD_W	0.09** (0.029)	0.082*** (0.021)	0.022* (0.009)	0.014 (0.009)
MD_X	-0.286*** (0.031)	-0.198*** (0.022)	-0.005 (0.01)	-0.008 (0.009)
MD_Y	0.161*** (0.031)	0.153*** (0.022)	0.002 (0.01)	-0.008 (0.009)
MD_Z	-0.11*** (0.033)	-0.012 (0.024)	0.01 (0.01)	0.009 (0.01)
Adjusted R^2	0.42	0.52	0.022	0.012
Sample size	10926	10926	10926	10926

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Table EC.34 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
F value	134.895	201.962	5.129	3.305

Table EC.34: Propensity Score Matching: empirical model description for category B.

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
Intercept	2.822*** (0.072)	3.497*** (0.051)	0.019 (0.021)	0.045* (0.021)
ESI 1	0.467*** (0.107)	0.373*** (0.076)	0.074* (0.032)	-0.026 (0.031)
ESI 2	1.032*** (0.08)	0.831*** (0.057)	0.031 (0.024)	-0.022 (0.023)
ESI 3	1.019*** (0.079)	0.831*** (0.056)	0.02 (0.023)	-0.022 (0.023)
ESI 4	0.725*** (0.079)	0.607*** (0.056)	0.014 (0.023)	-0.024 (0.023)
Patient Age	0.002*** (0.0)	0.001*** (0.0)	0.0 (0.0)	0
Trial	-0.00022 (0.0)	-0.026*** (0.007)	-0.009 (0.003)	-0.001 (0.003)
IV	0.33*** (0.014)	0.286*** (0.01)	0.026*** (0.004)	-0.004 (0.004)
CT with IV contrast	0.401*** (0.014)	0.25*** (0.01)	-0.015*** (0.004)	-0.011** (0.004)
CT without IV contrast	0.303*** (0.013)	0.203*** (0.009)	-0.007. (0.004)	-0.004 (0.004)
MRI	0.286*** (0.037)	0.258*** (0.026)	-0.033** (0.011)	-0.003 (0.011)
Xray	0.206*** (0.011)	0.146*** (0.008)	-0.012*** (0.003)	-0.012*** (0.003)
Ultrasound	0.221*** (0.016)	0.186*** (0.011)	-0.003 (0.005)	0.003 (0.004)
Nurses on shift	-0.002 (0.002)	-0.004** (0.001)	0.0 (0.001)	-0.001 (0.001)
MDs on shift	-0.025*** (0.006)	-0.018*** (0.005)	0.002 (0.002)	0.004* (0.002)
Current waiting count	0.004* (0.002)	0.013*** (0.001)	-0.0 (0.0)	0.001 (0.0)
Current treatment count	0.005*** (0.001)	0.006*** (0.001)	-0.0 (0.0)	0
Shift: 12 pm-6 pm	0.035 (0.035)	-0.026 (0.024)	-0.004 (0.01)	0.007 (0.01)
Shift: 6 am-12 pm	0.184*** (0.024)	0.082*** (0.017)	-0.012. (0.007)	0.004 (0.007)
Shift: 6 pm-12 am	-0.052. (0.03)	-0.067** (0.021)	-0.00018	0.017* (0.009)
ED Disposition Admit	0.348*** (0.023)	0.682*** (0.016)	-0.000112	-0.002 (0.007)
ED Disposition Discharge	0.562*** (0.021)	0.545*** (0.015)	-0.019** (0.006)	0.02*** (0.006)
ED Disposition Hospital Observation	0.566*** (0.024)	0.799*** (0.017)	-0.029*** (0.007)	0.007 (0.007)
ED Disposition Left Without Being Seen/AMA	0.653*** (0.057)	0.53*** (0.04)	0.133*** (0.017)	0.028. (0.016)

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Table EC.35 continued from previous page

Variable	Log Time from Arrival to Disposition	Log Time from Arrival to ED Departure	ED Return within 72 Hours (with admission)	ED Return within 72 Hours (without admission)
ED Disposition Transfer to Health Care Facility	0.692*** (0.048)	0.941*** (0.034)	-0.05*** (0.014)	-0.008 (0.014)
Adjusted R^2	0.344	0.478	0.017	0.009
Sample size	10926	10926	10926	10926
F value	250.151	435.76	9.125	5.467

Table EC.35: Propensity Score Matching: empirical model description for category C.

EC.8.3. Bonferroni Correction

We evaluated the robustness of our findings concerning the independence of our outcome variables. A violation of this assumption could lead to an increased likelihood of Type I errors, where null hypotheses are incorrectly rejected. This risk is heightened when multiple comparisons are made across different outcomes. To address this potential issue, we initially conducted a correlation analysis to examine the interdependence among our outcome variables. We found a significant correlation between time from arrival to disposition and time from arrival to ED departure, which is expected since time from arrival to disposition is always part of the total time a patient spends in the ED.

To further ensure the robustness of our results against potential correlations among all outcome variables, we employed a highly conservative approach using the Bonferroni correction. This adjustment modifies the significance threshold, requiring p-values to be less than 0.025 (0.05 divided by 2 outcome variables) to be considered significant. Applying this stringent criterion, we continued to observe significant results across all models presented in Table 3 and Tables EC.17-EC.18 with the exception of the models pertaining to propensity score matching for the outcome variable "log time from arrival to disposition." These additional analyses reinforce the validity of our empirical findings.

EC.9. LOS Analysis for VPP Eligible Patients

In this Section, we present an expanded empirical validation of key modeling assumptions underlying our VPP protocol. Our analytical framework assumes that (1) VPP-eligible patients experience shorter LOS when routed through the VPP compared to when routed to the main ED, and (2) VPP-eligible patients routed to the main ED incur a LOS comparable to the overall main ED average. To empirically validate both assumptions, we conduct two complementary regression analyses based on patient-level data from the VPP implementation trial.

EC.9.1. LOS Advantage for VPP Routing

First, we test the hypothesis that VPP eligible patients routed through the vertical pathway experience shorter LOS compared to similar patients routed directly to the main ED. This analysis aims to empirically validate to ensure robustness and credibility of our analytical framework in practice.

To this end, we utilize patient-level observational data collected during the VPP implementation trial. The scope of this analysis is explicitly restricted to the 850 patient visits that were eligible for the VPP pathway (i.e., patients categorized as ESI levels 4, 5, or level 3 with urinary, skin, or eye complaints) during the trial period who were discharged from the hospital at the end of their ED stay without the use of IV. Following the data and model specification presented in Sections 7.2–7.3, we use regression analyses to empirically examine whether VPP-routing leads to statistically significant differences in LOS outcomes, while controlling for patient clinical characteristics, ED operational conditions, physician practice variability, and the nature of patient complaints.

We estimate the following regression models:

$$\text{LOS}i = \alpha_0 + \alpha_1 \text{VPP}i + \boldsymbol{\beta}\mathbf{X}_i + \boldsymbol{\gamma}\text{MD}_i + \boldsymbol{\delta}\text{CC}i + \epsilon i,$$
$$\log(\text{LOS}i) = \alpha_0 + \alpha_1 \text{VPP}i + \boldsymbol{\beta}\mathbf{X}_i + \boldsymbol{\gamma}\text{MD}_i + \boldsymbol{\delta}\text{CC}i + \epsilon i,$$

where LOSi denotes the length of stay for patient i, and VPPi is a binary variable indicating if the patient was first routed through the VPP (coded as 1) or directly admitted to the main ED (coded as 0). Patient-specific characteristics, including vital signs at triage, are captured in the vector $\mathbf{X}i$. Additionally, we include physician fixed effects (MDi) and chief complaint categories (CC_i) to rigorously control for variations attributable to specific physicians and patient clinical condition. We summarize our findings in Table EC.36.

Variable	**Time from Arrival to ED Departure**	**Log Time from Arrival to ED Departure**
Intercept	55.295 (317.517)	4.69* (2.323)
VPP assignment	-19.435*** (5.334)	-0.163*** (0.039)
Baseline Patient Characteristics		
ESI 3.5	31.561 (106.274)	1.716* (0.777)
ESI 4	20.808 (105.867)	1.627* (0.774)
ESI 5	2.925 (106.444)	1.347. (0.779)
Patient Age	-0.015 (0.129)	-0.0 (0.001)
Procedures and Diagnostic Tests		

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Table EC.36 continued from previous page

Variable	Time from Arrival to ED Departure	Log Time from Arrival to ED Departure
CT with IVcontrast	0.0 (0.0)	0.0* (0.0)
CT without IV contrast	74.135*** (9.464)	0.553*** (0.069)
MRI	-8904.13923	-0.748 (0.467)
Xray	41.0*** (6.29)	0.37*** (0.046)
Ultrasound	76.145*** (9.847)	0.524*** (0.072)
ED Operational Characteristics		
Nurses on shift	-1.106 (0.919)	-0.007 (0.007)
MDs on shift	-17.935104	-0.000966
Current waiting count	2.704*** (0.769)	0.019*** (0.006)
Current treatment count	1.017** (0.37)	0.007** (0.003)
Shift: 6 am-12 pm	-21.499 (14.341)	-0.085 (0.105)
Shift: 12 pm-6 pm	-22.195 (16.671)	-0.099 (0.122)
Shift: 6 pm-12 am	-24.065 (15.143)	-0.078 (0.111)
Physician Assignment		
MD_A	0.668 (13.897)	0.124 (0.102)
MD_AA	18.213 (15.842)	0.258* (0.116)
MD_AB	12.368 (17.844)	0.201 (0.131)
MD_AC	-5.154 (22.738)	0.151 (0.166)
MD_AD	-48.867 (42.253)	-0.364 (0.309)
MD_AE	-13.237 (15.09)	0.009 (0.11)
MD_AF	-19.096 (18.79)	0.032 (0.137)
MD_AG	-1.781 (22.72)	0.091 (0.166)
MD_AH	61.789* (26.991)	0.483* (0.197)
MD_AI	-16.657 (30.447)	0.057 (0.223)
MD_AJ	13.696 (15.631)	0.243* (0.114)
MD_AK	-6.661 (30.724)	0.089 (0.225)
MD_B	34.557* (16.215)	0.425*** (0.119)
MD_C	-3.398 (13.808)	0.139 (0.101)
MD_D	25.275. (14.717)	0.384*** (0.108)
MD_E	-15.364 (13.814)	-0.008 (0.101)
MD_F	-18.72 (15.441)	-0.006 (0.113)
MD_G	37.429* (16.039)	0.324** (0.117)
MD_H	13.817 (14.268)	0.268* (0.104)
MD_I	-12.412 (14.405)	0.033 (0.105)
MD_J	-15.384 (16.105)	-0.046 (0.118)
MD_K	6.927 (16.769)	0.256* (0.123)
MD_L	11.946 (15.791)	0.179 (0.116)
MD_M	1.607 (15.942)	0.193. (0.117)
MD_N	7.424 (17.585)	0.147 (0.129)
MD_O	35.106* (15.947)	0.344** (0.117)
MD_P	26.938. (14.536)	0.411*** (0.106)
MD_Q	-14.353 (14.97)	0.025 (0.109)
MD_R	-13.138 (16.769)	0.028 (0.123)
MD_S	12.118 (14.562)	0.234* (0.107)
MD_T	-55.166** (18.419)	-0.045495
MD_U	-8.39 (18.291)	-0.01 (0.134)
MD_V	78.184*** (20.716)	0.553*** (0.152)
MD_W	-6.314 (14.483)	-0.015 (0.106)

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Table EC.36 continued from previous page

Variable	Time from Arrival to ED Departure	Log Time from Arrival to ED Departure
MD_X	-544.654208	-0.03696
MD_Y	-2.161 (15.963)	0.138 (0.117)
MD_Z	-33.363. (18.334)	-0.036 (0.134)
Chief Complaint Category		
Abdominal Complaints	-65.633 (66.261)	-0.536 (0.485)
Abnormal Test Results	-62.266 (45.798)	-0.329 (0.335)
Allergic Reaction	-54.94 (67.353)	-0.307 (0.493)
Back or Flank Pain	-37.527 (31.534)	-0.17 (0.231)
Cardiac Arrhythmias	24.085 (66.578)	0.432 (0.487)
Chest Pain	-61.464 (40.622)	-0.225 (0.297)
Ear Complaints	-55.146. (32.779)	-0.347 (0.24)
Epistaxis	-12.599 (34.023)	0.064 (0.249)
Exposures, Bites, and Envenomations	-63.633. (34.511)	-0.365 (0.252)
Extremity Complaints	-50.79. (30.771)	-0.272 (0.225)
Eye Complaints	-53.884. (31.506)	-0.283 (0.23)
Falls, Motor Vehicle Crashes, Assaults, and Trauma	-58.952. (31.43)	-0.307 (0.23)
Fevers, Sweats or Chills	-15.895 (39.256)	0.085 (0.287)
Foreign Body	-54.189 (40.561)	-0.332 (0.297)
Gastrointestinal Issues	9.759 (42.474)	0.23 (0.311)
Genital Complaints	76.023 (67.338)	0.898. (0.493)
Medical Device or Treatment Issue	-3.104 (33.709)	-0.08 (0.247)
Medication Request	-53.595 (36.815)	-0.435 (0.269)
Neurological Issue	0.918 (36.848)	-0.045 (0.27)
Other Pain	-2432.90073	-0.463. (0.247)
Post-Op Issue	-77.222. (39.831)	-0.167616
Psychiatric Complaints	-10.061 (67.696)	0.165 (0.495)
Shortness of Breath	-20.092 (43.313)	0.002 (0.317)
Skin Complaints	-47.173 (30.584)	-0.249 (0.224)
Upper Respiratory Symptoms	-36.222 (31.554)	-0.106 (0.231)
Urinary Complaints	6.696 (32.584)	0.126 (0.238)
Patient Vitals at Triage		
Triage Systolic Blood Pressure	0.261 (0.159)	0.002 (0.001)
Triage Diastolic Blood Pressure	-0.170078	-0.003 (0.002)
Triage Heart Rate	0.072 (0.174)	0.0 (0.001)
Triage Resp Rate	-0.439 (1.171)	-0.002 (0.009)
Triage Temp (F)	3.622 (4.147)	-0.004 (0.03)
Triage SPO2 %	-2.239 (1.393)	-0.01 (0.01)
Model Evaluation		
Adjusted R-squared	0.376	0.421
Number of Observations	702	702
F value	6.084	7.136

Table EC.36: Summary of regression model results for assumption (1). We report the regression coefficient and the standard errors in parentheses. Significance levels are denoted similarly to Section EC.8.

The results from both regression models indicate that the coefficient associated with VPP routing is negative and statistically significant, supporting the hypothesized assumption. The derived empirical models from the trial period suggest that patients routed through the VPP are more likely have shorter LOS compared to similar patients routed directly to the main ED, even after comprehensive control for potential confounders. This analysis thus reinforces our model's foundational assumptions, highlighting the operational efficacy of the VPP pathway and justifying its use as a strategy for ED throughput improvement.

EC.9.2. LOS Comparison for VPP-Eligible Patients Routed to Main ED

Next, we examine whether VPP-eligible patients who are routed to the main ED experience similar LOS to other patients treated in the main ED. This analysis is motivated by a second modeling assumption in our analytical framework, which posits that the LOS incurred by VPP-eligible patients routed to the main ED is representative of the average LOS observed among main ED patients. While VPP-eligible patients typically present with less complex conditions, in this section we conduct empirical validation to test whether their relative efficiency translates into shorter LOS when they are managed through the main ED rather than the VPP.

To address this, similarly to Section EC.9.1, we use the full patient cohort from the VPP trial period and estimate the following regression models:

$$\begin{aligned}\text{LOS}_i =& \alpha_0 + \alpha_1 \text{MainED}_i + + \alpha_2 \text{VPPEligible}_i + \alpha_3 (\text{MainED}_i \times \text{VPPEligible}_i) + \\ & \boldsymbol{\beta} \mathbf{X}_i + \boldsymbol{\gamma} \text{MD}_i + \boldsymbol{\delta} \text{CC} i + \epsilon i \\ \log(\text{LOS})_i =& \alpha_0 + \alpha_1 \text{MainED}_i + + \alpha_2 \text{VPPEligible}_i + \alpha_3 (\text{MainED}_i \times \text{VPPEligible}_i) + \\ & \boldsymbol{\beta} \mathbf{X}_i + \boldsymbol{\gamma} \text{MD}_i + \boldsymbol{\delta} \text{CC} i + \epsilon i\end{aligned}$$

The indicator variable MainED_i captures whether patient i was initially routed to the main ED. VPPEligible_i identifies patients meeting VPP eligibility criteria. The interaction term $\text{MainED}_i \times \text{VPPEligible}_i$ is included to test whether VPP-eligible patients who are routed to the main ED experience systematically different LOS compared to the overall main ED patient population. Control variables include patient demographics, triage vitals, chief complaints, ED operational conditions (e.g., staffing levels and patient load), and physician fixed effects.

The regression results are presented in Table EC.37.

Variable	**Time from Arrival to ED Departure**	**Log Time from Arrival to ED Departure**
Intercept	135.859 (98.378)	4.356*** (0.429)
VPP Eligibility	-57.009*** (6.252)	-0.372*** (0.027)
Main ED VPP interaction	6.753 (6.699)	0.042 (0.029)
Main ED	32.43*** (5.796)	0.207*** (0.025)
Baseline Patient Characteristics		
ESI 1	-1559.3757	-0.016 (0.114)
ESI 2	21.472 (21.32)	0.386*** (0.093)
ESI 3	23.76 (21.093)	0.399*** (0.092)
ESI 4	30.116 (20.251)	0.444*** (0.088)
Patient Age	0.215** (0.068)	0.001*** (0.0)
Procedures and Diagnostic Tests		
CT with IVcontrast	73.544*** (3.071)	0.301*** (0.013)
CT without IV contrast	38.389*** (3.307)	0.185*** (0.014)
MRI	70.774*** (8.428)	0.241*** (0.037)
Xray	28.169*** (2.85)	0.154*** (0.012)
Ultrasound	44.703*** (3.735)	0.198*** (0.016)
ED Operational Characteristics		
Nurses on shift	-1.385** (0.453)	-0.005** (0.002)
MDs on shift	-3.999** (1.436)	-0.017** (0.006)
Current waiting count	3.117*** (0.372)	0.014*** (0.002)
Current treatment count	1.402*** (0.18)	0.006*** (0.001)
Shift: 6 am-12 pm	14.202* (6.205)	0.069* (0.027)
Shift: 12 pm-6 pm	-10.331 (7.91)	-0.03 (0.035)
Shift: 6 pm-12 am	-119.99761	-0.055. (0.03)
ED Disposition Admit	51.447*** (3.59)	0.183*** (0.016)
ED Disposition Hospital Observation	69.414*** (3.848)	0.262*** (0.017)
ED Disposition Left Without Being Seen/AMA	-4.582 (14.493)	-0.171** (0.063)
ED Disposition Transfer to Health Care Facility	128.544*** (11.698)	0.421*** (0.051)
Physician Assignment		
MD_A	2.432 (6.5)	0.116*** (0.028)
MD_AA	45.906*** (7.653)	0.292*** (0.033)
MD_AB	31.903*** (8.806)	0.251*** (0.038)
MD_AC	36.764*** (9.08)	0.274*** (0.04)
MD_AD	-355.93925	-0.048 (0.057)
MD_AE	-5.489 (7.429)	0.056. (0.032)
MD_AF	-11.142 (7.553)	0.021 (0.033)
MD_AG	-10.456 (9.983)	0.064 (0.044)
MD_AH	46.461*** (13.285)	0.283*** (0.058)
MD_AI	6.45 (16.136)	0.128. (0.07)
MD_AJ	14.198* (6.485)	0.172*** (0.028)
MD_AK	31.923** (11.639)	0.244*** (0.051)
MD_B	44.519*** (6.448)	0.309*** (0.028)
MD_C	19.393** (6.671)	0.173*** (0.029)
MD_D	28.631*** (6.471)	0.233*** (0.028)

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Table EC.37 continued from previous page

Variable	Time from Arrival to ED Departure	Log Time from Arrival to ED Departure
MD_E	-22.139*** (6.303)	0.02 (0.027)
MD_F	-18.748** (7.091)	0.048 (0.031)
MD_G	33.532*** (6.448)	0.247*** (0.028)
MD_H	8.337 (6.8)	0.158*** (0.03)
MD_I	-29.163*** (7.065)	-0.043 (0.031)
MD_J	-27.605*** (7.944)	-0.048 (0.035)
MD_K	17.21** (6.531)	0.199*** (0.028)
MD_L	-11.937. (6.57)	0.076** (0.029)
MD_M	-3.263 (6.489)	0.098*** (0.028)
MD_N	9.895 (7.545)	0.14*** (0.033)
MD_O	10.569 (6.751)	0.173*** (0.029)
MD_P	17.063* (7.072)	0.218*** (0.031)
MD_Q	-23.42*** (6.83)	-0.008 (0.03)
MD_R	-19.548** (7.368)	0.009 (0.032)
MD_S	16.991* (7.664)	0.191*** (0.033)
MD_T	-31.318** (10.075)	-0.004708
MD_U	-15.108. (7.776)	0.053 (0.034)
MD_V	23.223** (8.919)	0.232*** (0.039)
MD_W	-1.807 (7.469)	0.094** (0.033)
MD_X	-43.378*** (7.956)	-0.155*** (0.035)
MD_Y	7.892 (7.968)	0.146*** (0.035)
MD_Z	-15.591. (8.325)	0.048 (0.036)
Chief Complaint Category		
Abdominal Complaints	1.907 (14.396)	0.054 (0.063)
Abnormal Test Results	-1.391 (14.975)	-0.005 (0.065)
Allergic Reaction	-24.037 (22.962)	-0.187. (0.1)
Back or Flank Pain	7.523 (14.896)	0.062 (0.065)
Breast Complaints	-33.039 (37.333)	-0.173 (0.163)
Cardiac Arrhythmias	6.04 (16.022)	0.057 (0.07)
Chest Pain	-7.556 (14.787)	-0.016 (0.065)
Circulatory Issue	-31.362 (44.734)	-0.013 (0.195)
Dizziness/Lightheadedness/Syncope	9.42 (15.222)	0.063 (0.066)
Ear Complaints	-26.926 (22.008)	-0.020928
Epistaxis	2.624 (20.313)	0.008 (0.089)
Exposures, Bites, and Envenomations	-26.176 (22.154)	-0.173. (0.097)
Extremity Complaints	-13.872 (14.544)	-0.054 (0.063)
Eye Complaints	-13.026 (16.985)	-0.105 (0.074)
Falls, Motor Vehicle Crashes, Assaults, and Trauma	-7.555 (15.009)	-0.022 (0.065)
Fatigue and Weakness	13.12 (15.54)	0.06 (0.068)
Fevers, Sweats or Chills	-11.591 (15.773)	-0.013 (0.069)
Foreign Body	-7.964 (37.505)	-0.1 (0.164)
Gastrointestinal Issues	10.629 (14.709)	0.066 (0.064)
Genital Complaints	5.054 (16.98)	0.059 (0.074)
Medical Device or Treatment Issue	17.157 (17.545)	0.021 (0.077)
Medication Request	-22.137 (34.147)	-0.052895
Neurological Issue	-1.341 (14.843)	0.011 (0.065)
Other Pain	-4.729 (16.465)	-0.04 (0.072)

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Table EC.37 continued from previous page

Variable	Time from Arrival to ED Departure	Log Time from Arrival to ED Departure
Post-Op Issue	-11.439 (19.485)	-0.044 (0.085)
Psychiatric Complaints	15.904 (21.424)	0.067 (0.093)
Shortness of Breath	-3.287 (14.912)	0.004 (0.065)
Skin Complaints	-10.182 (15.127)	-0.067 (0.066)
Substance Abuse Issues	8.878 (21.448)	0.008 (0.094)
Upper Respiratory Symptoms	-23.77 (15.257)	-0.081 (0.067)
Urinary Complaints	27.147. (15.966)	0.153* (0.07)
Patient Vitals at Triage		
Triage Systolic Blood Pressure	-0.061 (0.068)	-0.0 (0.0)
Triage Diastolic Blood Pressure	-0.02 (0.12)	-0.0 (0.001)
Triage Heart Rate	0.068 (0.072)	0.0 (0.0)
Triage Resp Rate	0.576 (0.494)	0.002 (0.002)
Triage Temp (F)	-0.456 (0.829)	-0.003 (0.004)
Triage SPO2 %	0.288 (0.485)	0.002 (0.002)
Model Evaluation		
Adjusted R-squared	0.466	0.515
Number of Observations	5463	5463
F value	50.068	60.766

Table EC.37: Summary of regression model results for assumption (2). We report the regression coefficient and the standard errors in parentheses. Significance levels are denoted similarly to Section EC.8.

The results from both regression models indicate that the coefficient associated with *MainED* is positive and statistically significant, confirming that routing to the main ED is associated with increased LOS relative to alternative routing options. The coefficient for *VPPEligible* is negative and statistically significant, indicating that VPP-eligible patients, in general, have shorter LOS compared to non-eligible patients. The interaction term *MainED* $\times$ *VPPEligible* is positive but not statistically significant. There results suggest that VPP-eligible patients routed to the main ED do not experience statistically significant shorter LOS compared to the general main ED population.

These results empirically support the assumption used in our modeling framework: VPP-eligible patients routed to the main ED do not retain their LOS advantage and instead experience durations of stay comparable to those of the general main ED cohort. This finding further validates the design of the VPP protocol as a mechanism to preserve efficiency gains for eligible patients.

EC.10. VPP Impact Analysis for Typical Urban EDs

In this section, we extend our analysis to estimate system-wide impacts across three ED volume categories based on Centers for Disease Control and Prevention and National Center for Health Statistics classifications (McCaig et al. 2007). We consider small EDs with 20,000 annual visits,

medium EDs with 40,000 visits, and large urban EDs with 60,000 visits, representing the spectrum of facilities where VPP implementation would be applicable across the US. We conduct a simulation that incorporates both observed parameters from our study and evidence-based estimates from the literature. The computational approach employs 10,000 Monte Carlo iterations for each ED size category to generate robust confidence intervals. For each iteration, we sample from probability distributions representing key operational parameters, with the goal of estimating the expected downstream impact at the healthcare system level.

The simulation process begins by sampling the VPP eligibility rate from a normal distribution centered at our observed value of 19.85% with a coefficient of variation of 15%, reflecting natural variation in patient mix across days and seasons.

Since the observed system-wide reduction in ED LOS was 11 minutes at e_0=0.1985, we calibrate the mean per-visit effect for alternative eligibility e via $\Delta(e) = 11 \times \left(\frac{e}{0.1985}\right)^{\beta}$, which allows the system-wide impact to attenuate if the VPP-eligible share is smaller than at our site. We set β=0.5 in the baseline (capturing congestion spillovers that make the effect decline sub-linearly with e), and report a conservative linear sensitivity with β=1. The per-visit LOS reduction used in the simulation is drawn as $\Delta \sim \text{Truncated Normal}\big(\mu = \Delta(e),\, \sigma = 3;\, 5,\, 20\big)$ minutes. The distribution is bounded between 5 and 20 minutes to represent plausible operational limits.

Implementation efficiency is modeled as a truncated normal distribution (sd=10%, bounds [0,1]) with phase-specific means: 70% (Year 1, ramp-up), 85% (Year 2, consolidation), and 100% (Steady State). This efficiency factor multiplies the theoretical LOS reduction to yield the effective reduction realized in practice. This efficiency factor is applied once to the per-visit LOS reduction to yield the effective reduction realized in practice. Total time saved (bed-hours) is then computed as the product of annual ED visits with the effective per-visit reduction in minutes.

To translate bed-hours saved into additional patient capacity, we divide by the ED LOS. We model the latter using log-normal distributions calibrated by facility type: small community EDs (mean=180 minutes), medium EDs (mean=220 minutes), and large academic centers (mean=280 minutes), consistent with documented correlations between ED volume, acuity, and processing times (Emergency Department Benchmarking Alliance 2024, Augustine 2023). This parametrization captures both typical patient experiences and the long tail of prolonged stays while allowing appropriate variation across ED settings.

To estimate the annual system-wide financial impact of VPP implementation, we calculate the total reimbursements that would be paid by insurers and other payers for the additional ED visits enabled by improved throughput. Note that these figures represent total payments in the healthcare system, not the net revenue or profit captured by EDs, which typically receive only a fraction of these reimbursements. To this end, we approximate ED reimbursements using national

payer mix and published benchmarks. In 2021, ED visits were distributed as 32.3% commercial, 37.3% Medicaid, 19.9% Medicare, and 6.7% uninsured (Cairns et al. 2023). Commercial insurers typically reimburse 180–250% of Medicare rates (Cooper et al. 2019), while Medicaid averages about 70% of Medicare (Medicaid and CHIP Payment and Access Commission 2023). Based on the 2024–2025 Medicare Physician Fee Schedule final rules and fee schedule search tool (Centers for Medicare & Medicaid Services 2023, 2024a,b), combined professional and facility payments range from roughly $280 for low-acuity (CPT 99281) to $1,500–$1,800 for high-acuity (CPT 99285) visits. Adjusting for payer mix and regional variation using Health Care Cost Institute and EDBA benchmarks (Health Care Cost Institute 2023, Emergency Department Benchmarking Alliance 2023), we model reimbursement as a normal distribution with mean $1,500 and standard deviation $400, which conservatively captures variation in payer mix across patients and uncertainty in actual reimbursement rates.

(a) Annual Impact on Bed-Hours and Patient Served.

ED Type	Annual Volume	VPP Rate	Bed-Hours Saved	Additional Patients Served
Small (Rural/ Community)	20,000	15.00%	3,049 (1,667, 4,886)	1,068 (479, 1,979)
		19.90%	3,409 (1,776, 5,296)	1,191 (517, 2,141)
		25.00%	3,769 (2,000, 5,626)	1,321 (596, 2,345)
Medium (Suburban)	40,000	15.00%	6,092 (3,323, 9,719)	1,760 (780, 3,298)
		19.90%	6,849 (3,584, 10,535)	1,979 (866, 3,653)
		25.00%	7,518 (3,925, 11,210)	2,176 (953, 3,964)
Large (Urban)	60,000	15.00%	9,142 (4,986, 14,557)	2,085 (914, 3,988)
		19.90%	10,222 (5,320, 15,865)	2,329 (1,017, 4,385)
		25.00%	11,355 (5,975, 17,035)	2,587 (1,130, 4,697)

(b) Annual Impact on Financial and Capacity Outcomes.

ED Type	Annual Volume	VPP Rate	Added Visit Reimbursements	Capacity Improvement
Small (Rural/ Community)	20,000	15.00%	$1,604,790 ($567,903, $3,350,506)	5.34% (2.40, 9.89)
		19.90%	$1,783,623 ($615,610, $3,697,440)	5.96% (2.59, 10.70)
		25.00%	$1,980,327 ($678,490, $4,096,522)	6.60% (2.98, 11.72)
Medium (Suburban)	40,000	15.00%	$2,651,438 ($881,308, $5,722,642)	4.40% (1.95, 8.24)
		19.90%	$2,959,880 ($976,968, $6,309,426)	4.95% (2.16, 9.13)
		25.00%	$3,258,763 ($1,134,677, $6,739,404)	5.44% (2.38, 9.91)
Large (Urban)	60,000	15.00%	$3,130,879 ($1,000,498, $6,746,201)	3.47% (1.52, 6.65)
		19.90%	$3,494,602 ($1,171,788, $7,405,725)	3.88% (1.70, 7.31)
		25.00%	$3,871,339 ($1,285,473, $8,020,169)	4.31% (1.88, 7.83)

Table EC.38 Summary of operational and financial impact analysis for the VPP design across typical urban ED types.

The results of our analysis are summarized in Table EC.38. Across ED sizes, the VPP protocol yields sizable absolute gains that increase with both annual volume and the VPP rate. Using the Mayo-like rate (19.9%), for an individual ED of each size category, the median annual bed-hours

saved are 3,409 (small), 6,849 (medium), and 10,222 (large), translating into 1,191, 1,979, and 2,329 additional completed visits, respectively. Median additional payer reimbursements per hospital at this rate range from \$1.78M (small) to \$3.49M (large), while capacity improves by roughly 4–6% (5.96% small; 4.95% medium; 3.88% large). Even under a conservative 15% VPP rate, effects remain substantial (e.g., small: 3,049 hours, 1,068 visits; large: 9,142 hours, 2,085 visits), and under 25% rates they become more profound (e.g., large: 11,355 hours, 2,587 visits; \$3.87M; 4.31%). The 95% intervals reflect the high levels of modeled heterogeneity in expected LOS, adherence, and reimbursement. Notably, relative capacity gains taper modestly with ED size because longer baseline LOS in larger centers dilutes the conversion of saved hours into completed visits. Overall, these results indicate clinically and operationally meaningful throughput improvements with significant corresponding financial gains across all sizes of EDs considered.

EC.11. Alternative Objective Function

To address potential concerns regarding the sensitivity of our findings to the specific choice of objective function, in this Section, we analyze an alternative formulation. The primary objective presented in Section 4.3 captures the direct additional LOS experienced by misrouted patients under the assumption that individual routing decisions have infinitesimal impact on queue lengths. In contrast, the alternative formulation explicitly minimizes the total expected LOS across all patients in the system:

$$\tau^* = \underset{\tau\in[0,1]}{\arg\min}\, \tau L_\nu|_{\lambda_\nu=\tau\lambda} + PL_E|_{\lambda_E=P\lambda}, \quad \text{where} \quad P = 1-\tau+p(\tau)\tau.$$

The primary objective can be understood as approximating the derivative of this total LOS function with respect to τ, treating congestion feedback effects as second-order. The motivation behind introducing and analyzing this alternative formulation is twofold. First, it allows us to verify the theoretical robustness and generalizability of the insights and policies derived from our primary analytical model. By rigorously comparing both objective functions, we aim to establish whether key structural properties, such as the form and conditions of the optimal threshold policies, remain consistent across different but related modeling paradigms. Second, this analysis enhances the practical relevance of our research by demonstrating whether operational policy recommendations derived from our primary formulation hold true under slightly modified modeling assumptions.

In Section EC.11.1, we conduct a theoretical analysis of the optimal policy for the alternative objective function and compare its structure with the primary cost function introduced in Sections 4–5. Subsequently, in Section EC.11.3 we verify our findings with computational experiments across a range of parameter settings encountered in real-world EDs.

EC.11.1. Theoretical Analysis and Comparison with Primary Objective Function

In this formulation, we aim to capture the expected total length of stay of patients in the system:

$$C(\tau;\mu,\lambda,\alpha,k_1) = \frac{\tau}{\mu} + \frac{(1-\tau+p(\tau)\tau)}{1-\lambda((1-\tau)+p(\tau)\tau)} - \frac{(1-\tau+p(\tau)\tau)}{\mu} \tag{EC.13}$$

EC.11.2. Characterizing the Optimal Policy Across Domains

Due to the functional dependence of $p(\tau)$ on τ relative to the threshold α, the objective function naturally splits into two regimes:

- For $\tau \le \alpha$, the objective function becomes $C_1(\tau;\mu,\lambda,\alpha,k_1)$;
- For $\tau > \alpha$, the objective function becomes $C_2(\tau;\mu,\lambda,\alpha,k_1)$.

Substituting the expressions for $p(\tau)$ and $q(\tau)$ from Equations (7) and (8), the cost function becomes:

$$C_1(\tau;\mu,\lambda,\alpha,k_1) = -\frac{1+(-2+k_1)\tau}{\mu} + \frac{1}{-\lambda+\frac{1}{1+(-1+k_1)\tau}}, \quad \text{for } \tau \le \alpha \tag{EC.14}$$

$$C_2(\tau;\mu,\lambda,\alpha,k_1) = \frac{-1+2\tau-\alpha k_1-(1-\frac{\alpha k_1}{1-\alpha})(\tau-\alpha)}{\mu} + \frac{1}{-\lambda+\frac{1}{1-\tau+(\alpha k_1+(1-\frac{\alpha k_1}{1-\alpha})(\tau-\alpha))}}, \quad \text{for } \tau > \alpha \tag{EC.15}$$

The overall domain of the function is:

$$0<\alpha<\tfrac{1}{2}, \quad 0<k_1<1-\alpha, \quad 2<\mu, \quad 0<\lambda<1.$$

We can show by taking the second derivative of both functions C_1, C_2 that they are convex. Next, we evaluate each separately to find the optimal solution τ^* across its domain.

The Case of $\tau \le \alpha$

We first look at the points where the first derivative $\frac{\partial C_1}{\partial \tau} = 0$. We find that it is equal to zero for the region:

$$0<\alpha<\tfrac{1}{2}, \quad 0<k_1<1-\alpha, \quad 2<\mu<\mu_1=\frac{-2+k_1}{-1+k_1}, \quad \lambda_1<\lambda<\lambda_2$$

where

$$\begin{aligned}
\mu_1 &= \frac{-2+k_1}{-1+k_1},\\
\lambda_1 &= 1-\frac{\sqrt{(-1+k_1)\mu}}{1+\alpha(k_1-1)},\\
\lambda_2 &= \frac{1}{1+\alpha(k_1-1)} - \sqrt{\frac{(-1+k_1)\mu}{(1+\alpha(k_1-1))^2(-2+k_1)}},\\
\tau_1^* &= \frac{1-\lambda}{(k_1-1)\lambda} + \sqrt{\frac{\mu}{(k_1-2)(k_1-1)\lambda^2}}
\end{aligned}$$

In the regions that fall outside this interval, we need to check if the derivative is positive or negative. Due to the complexity of the function it is not possible to solve analytically the equation for these regions. However, leveraging the Intermediate Value Theorem, we can simply evaluate across a wide range of combinations.

1. If $\mu > \mu_1$, then $\tau^* = \alpha$
2. If $\lambda < \lambda_1$, the function is strictly increasing $\Rightarrow \tau^* = 0$
3. If $\lambda > \lambda_2$, then $\tau^* = \alpha$

Comparison with Original Objective Function

Let's compare these findings with the original optimal $\hat{\tau}_1$:

$$\hat{\tau}_1 = \frac{1-\lambda}{(k_1-1)\lambda} + \sqrt{\frac{(-1+\lambda-\alpha\lambda)^2\mu}{(k_1-1)\lambda^2}} \tag{EC.16}$$

So compared to our original $\hat{\tau}_1$, τ_1^*, in the square root there is one additional term $\frac{1}{(k_1-2)}$ compared to $(-1+\lambda-\alpha\lambda)^2$.

The Case of $\tau > \alpha$

Next, we evaluate the regime in which $\tau > \alpha$. We equate the first derivative to zero: $\frac{\partial C_2(\tau;\mu,\lambda,\alpha,k_1)}{\partial \tau} = 0$ and find the following regions in which $\tau^* = \tau_2$.

$$\begin{aligned}
&\textbf{(1)} \quad 0<\alpha<\alpha_1, \quad 0<k_1<k_{11}(\alpha), \quad \mu_2<\mu<\mu_3, \quad \lambda_3<\lambda<1\\
&\textbf{(2)} \quad 0<\alpha<\alpha_1, \quad 0<k_1<k_{11}(\alpha), \quad \mu_3<\mu<\mu_4, \quad \lambda_3<\lambda<\lambda_4\\
&\textbf{(3)} \quad 0<\alpha<\alpha_1, \quad k_{11}(\alpha)<k_1<k_{12}(\alpha), \quad 2<\mu<\mu_3, \quad \lambda_3<\lambda<1\\
&\textbf{(4)} \quad 0<\alpha<\alpha_1, \quad k_{11}(\alpha)<k_1<k_{12}(\alpha), \quad \mu_3<\mu<\mu_4, \quad \lambda_3<\lambda<\lambda_4\\
&\textbf{(5)} \quad 0<\alpha<\alpha_1, \quad k_{12}<k_1(\alpha)<1-\alpha, \quad 2<\mu<\mu_4, \quad \lambda_3<\lambda<\lambda_4\\
&\textbf{(6)} \quad \alpha_1<\alpha<0.5, \quad 0<k_1<k_{11}(\alpha), \quad \mu_2<\mu<\mu_3, \quad \lambda_3<\lambda<1\\
&\textbf{(7)} \quad \alpha_1<\alpha<0.5, \quad 0<k_1<k_{11}(\alpha), \quad \mu_3<\mu<\mu_4, \quad \lambda_3<\lambda<\lambda_4\\
&\textbf{(8)} \quad \alpha_1<\alpha<0.5, \quad k_{11}(\alpha)<k_1<k_{12}(\alpha), \quad 2<\mu<\mu_3, \quad \lambda_3<\lambda<1\\
&\textbf{(9)} \quad \alpha_1<\alpha<0.5, \quad k_{11}(\alpha)<k_1<k_{12}(\alpha), \quad \mu_3<\mu<\mu_4, \quad \lambda_3<\lambda<\lambda_4\\
&\textbf{(10)} \quad \alpha_1<\alpha<0.5, \quad k_{12}<k_1(\alpha)<1-\alpha, \quad 2<\mu<\mu_4, \quad \lambda_3<\lambda<\lambda_4,
\end{aligned}$$

where

$$\tau_2^* = \frac{-1+\alpha+\lambda-2\alpha\lambda+\alpha^2\lambda+\alpha k_1\lambda}{\alpha k_1\lambda} + \sqrt{\frac{\mu(1-2\alpha+\alpha^2)}{\alpha k_1(1-\alpha+\alpha k_1)\lambda^2}}.$$

Comparison with Original Objective Function

Similarly to the case of τ_1^*, we compare the function for the with the respective solution of the original objective function $\hat{\tau}_2$.

$$\hat{\tau}_2 = \frac{-1+\alpha+\lambda-2\alpha\lambda+\alpha^2\lambda+\alpha k_1\lambda}{\alpha k_1\lambda} + \sqrt{\frac{-(1-\alpha)(1+(\alpha-1)\lambda)\mu}{\alpha k_1\lambda^2}}$$

The first terms of τ_2^* and $\hat{\tau}_2$ are identical. We only see the difference in the square root terms where the component μ is multiplied with:

- $\frac{1-2\alpha+\alpha^2}{1-\alpha+\alpha k_1}$ for τ_2^*;
- $-(1-\alpha)(1+(\alpha-1)\lambda)$ for $\hat{\tau}_2$.

Defining Region Boundaries

Next we define the parameters of the condition:

$$\alpha_1 = \text{Root}\left(8-54x+103x^2-60x^3+4x^4, 1\right)$$

We let

$$\begin{aligned} k_{11}(\alpha) &= \text{second real root of } f_1(x,\alpha), \\ f_{11}(x;a) &= \left(\alpha-\alpha^2+(-2-2\alpha+3\alpha^2)x+(\alpha-3\alpha^2)x^2+\alpha^2x^3, 2\right), \\ k_{12}(\alpha) &= \frac{-\alpha+\alpha^2}{-2+\alpha^2}. \end{aligned}$$

Thresholds $\mu_2, \mu_3, \mu_4,\ \lambda_3, \lambda_4$ are defined below:

$$\begin{aligned} \mu_2 &= \frac{\alpha-\alpha^2-2\alpha k_1+3\alpha^2k_1+\alpha k_1^2-3\alpha^2k_1^2+\alpha^2k_1^3}{k_1} \\ \mu_3 &= \frac{\alpha-\alpha^2+\alpha^2k_1}{k_1} \\ \mu_4 &= \frac{1-\alpha+\alpha k_1}{\alpha k_1} \\ \lambda_3 &= \frac{1}{1-\alpha+\alpha k_1} - \sqrt{\frac{\alpha k_1\mu}{(1-\alpha+\alpha k_1)^3}} \\ \lambda_4 &= \frac{1}{1-\alpha} - \sqrt{\frac{\alpha k_1\mu}{(1-\alpha)^2(1-\alpha+\alpha k_1)}} \end{aligned}$$

Notice that when we substitute $\mu = \mu_4(\alpha, k_1)$:

$$\lambda_3\left(\alpha, k_1, \mu_4\right) = \frac{1}{1-\alpha+\alpha k_1} - \sqrt{\frac{\alpha k_1 \dfrac{1-\alpha+\alpha k_1}{\alpha k_1}}{\left(1-\alpha+\alpha k_1\right)^3}} = \frac{1}{1-\alpha+\alpha k_1} - \sqrt{\frac{1}{\left(1-\alpha+\alpha k_1\right)^2}} = 0.$$

We now need to consider what is the value of τ^* by looking at all the regions in which $\frac{\partial C_2}{\partial \tau} \neq 0$. We cannot solve this analytically, thus we resort to a computational solution in which we compare the value of C_2 for $\tau = \alpha$ and $\tau = 1$.

We enumerate all the remaining regions in which the first derivative is not zero and associate with them the optimal value of τ^* based on comprehensive numerical experiments that evaluate the cost function at the extrema of the τ domain, namely $\tau = \alpha$ and $\tau = 1$. In Table EC.39 we summarize our findings across the parameter space. The entries where we indicate $\tau^* =$n/a correspond to infeasible regions due to the definition of the parameter ranges. We observe that the optimal value τ^* is symmetric across the two regions of parameter α.

Table EC.39: Parameter region characterization summary for $\tau \geq \alpha$.

α	k	μ	λ	τ^*
$0 < \alpha < \alpha_1$	$0 < k_1 < k_{11}(\alpha)$	$2 < \mu < \mu_2$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	n/a
		$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	α
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	τ_2^*
		$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	α
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	1
		$\mu_4 < \mu$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	1
	$k_{11}(\alpha) < k_1 < k_{12}(\alpha)$	$2 < \mu < \mu_2$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	τ_2^*
		$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	τ_2^*
		$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	α
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	1
		$\mu_4 < \mu$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	1
	$k_{12}(\alpha) < k_1 < 1 - \alpha$	$2 < \mu < \mu_2$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	n/a
		$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	n/a
		$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	1
		$\mu_4 < \mu$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	1

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α	k	μ	λ	τ^*
$\alpha_1 < \alpha < 0.5$	$0 < k_1 < k_{11}(\alpha)$	$2 < \mu < \mu_2$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	n/a
		$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	α
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	τ_2^*
		$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	α
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	1
		$\mu_4 < \mu$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	1
	$k_{11}(\alpha) < k_1 < k_{12}(\alpha)$	$2 < \mu < \mu_2$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	τ_2^*
		$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	τ_2^*
		$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	α
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	1
		$\mu_4 < \mu$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	1
	$k_{12}(\alpha) < k_1 < 1 - \alpha$	$2 < \mu < \mu_2$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	n/a
		$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	n/a
		$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	$\alpha(0)$
			$\lambda_3 < \lambda < \lambda_4$	τ_2^*
			$\lambda_4 < \lambda < 1$	1
		$\mu_4 < \mu$	$0 < \lambda < \lambda_3$	n/a
			$\lambda_3 < \lambda < \lambda_4$	n/a
			$\lambda_4 < \lambda < 1$	1

Optimal Solution Characterization Across Regions

The structure of the optimal solution τ^* depends fundamentally on the relationship between the system parameters μ, λ, α, and k_1. In particular, thresholds such as $\mu_1, \mu_2, \mu_3, \mu_4, \lambda_1, \lambda_2, \lambda_3$, and λ_4 govern the regime boundaries for the decision on whether to set τ^* at zero, α, an interior optimum τ_1^* or τ_2^*, or at the upper bound 1.

The values of these thresholds are determined explicitly as functions of α and k_1 and are derived from the behavior of the first derivative of the cost function in each subdomain (for $\tau \leq \alpha$ and $\tau > \alpha$). Depending on the ordering of these thresholds, the domain (μ, λ) is partitioned differently into regions where different forms of τ^* are optimal.

Table EC.40 presents the identified regions for both areas of the domain $\tau \leq \alpha$ and $\tau > \alpha$.

Table EC.40: Optimal policy per domain region.

k	μ	λ	τ^*
	$\tau \leq \alpha$		
$0 < k_1 < 1-\alpha$	$2 < \mu < \mu_1$	$0 < \lambda < \lambda_1$	0
		$\lambda_1 < \lambda < \lambda_2$	τ_1^*
		$\lambda_2 < \lambda < 1$	α
	$\mu_1 < \mu$	$0 < \lambda < 1$	α
	$\tau \leq \alpha$		
$0 < k_1 < k_{11}$	$2 < \mu < \mu_2$	$0 < \lambda < \lambda_3$	α
	$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < 1$	τ_2^*
	$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2^*
		$\lambda_4 < \lambda < 1$	1
	$\mu_4 < \mu$	$\lambda_4 < \lambda < 1$	1
$k_{11} < k_1 < k_{12}$	$2 < \mu < \mu_2$	$\lambda_3 < \lambda < 1$	τ_2^*
	$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < 1$	τ_2^*
	$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2^*
		$\lambda_4 < \lambda < 1$	1
	$\mu_4 < \mu$	$\lambda_4 < \lambda < 1$	1
$k_{12} < k_1 < 1-\alpha$	$2 < \mu < \mu_2$	$\lambda_3 < \lambda < \lambda_4$	τ_2^*
	$\mu_2 < \mu < \mu_3$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2^*
	$\mu_3 < \mu < \mu_4$	$0 < \lambda < \lambda_3$	α
		$\lambda_3 < \lambda < \lambda_4$	τ_2^*
		$\lambda_4 < \lambda < 1$	1
	$\mu_4 < \mu$	$\lambda_4 < \lambda < 1$	1

To provide a full and unified characterization of the optimal solution, it is necessary to consolidate the results from both regimes. The consolidation process involves systematically determining, for each parameter combination, which regime yields the lower cost and hence the globally optimal τ^*.

The case of $\mu_1 < \mu_2$ and $\lambda_2 < \lambda_3$ for $0 < k_1 < 1-\alpha$: In what follows, we provide a complete characterization of the optimal policy under the regime of $0 < k_1 < 1-\alpha$, assuming the ordering $\mu_1 < \mu_2$ and $\lambda_2 < \lambda_3$. We analytically characterize the global minimizer τ^* across the parameter space. For $\mu < \mu_1$, the optimal solution lies within the regime $\tau \leq \alpha$, with τ^* determined by the behavior of $C_1(\tau; \mu, \lambda, \alpha, k_1)$. We find that for $\mu_1 < \mu < \mu_2$, a comparison between regimes is required. Similarly, for $\mu > \mu_2$, the optimal solution arises from the $\tau > \alpha$ regime. The consolidated policy, summarized in Table EC.41, bears the equivalent structure as the primary optimal policy described in Table EC.1.

Our analysis reveals that the threshold parameters μ_i and λ_i vary nonlinearly with the slope parameter k_1, which governs the sensitivity of patient redirection to predictive confidence. As k_1 changes, the functional form of the redirection probability $p(\tau)$ shifts, altering the structure of

Table EC.41 **The case of $\mu_1 < \mu_2$ and $\lambda_2 < \lambda_3$: summary of optimal policy τ^* across (μ, λ) regimes when $0 < k_1 < 1 - \alpha$.**

μ	λ	τ^*
$\mu < \mu_1$	$\lambda < \lambda_1$	0
	$\lambda_1 < \lambda < \lambda_2$	τ_1^*
	$\lambda > \lambda_2$	α
$\mu_1 < \mu < \mu_2$	$\lambda < \lambda_3$	α
	$\lambda_3 < \lambda < \lambda_4$	τ_2^*
	$\lambda > \lambda_4$	1
$\mu > \mu_2$	$\lambda < \lambda_3$	α
	$\lambda_3 < \lambda < \lambda_4$	τ_2^*
	$\lambda > \lambda_4$	1

the cost functions and the corresponding optimal policy boundaries. This potential reversal in the relative ordering of thresholds as a function of k_1 fundamentally changes the partitioning of the parameter space as it is no longer monotonic. Thus, one must carefully evaluate the ordering of the thresholds for each specific combination of α and k_1. As such, the determination of the optimal policy τ^* under the alternative objective function becomes inherently case-specific, requiring separate characterization depending on whether k_1 falls below, within, or above the critical interval $[k_{11}(\alpha), k_{12}(\alpha)]$. This added complexity leads to a non-uniform decision boundary across the parameter space and limits the generalizability of closed-form expressions for τ^*.

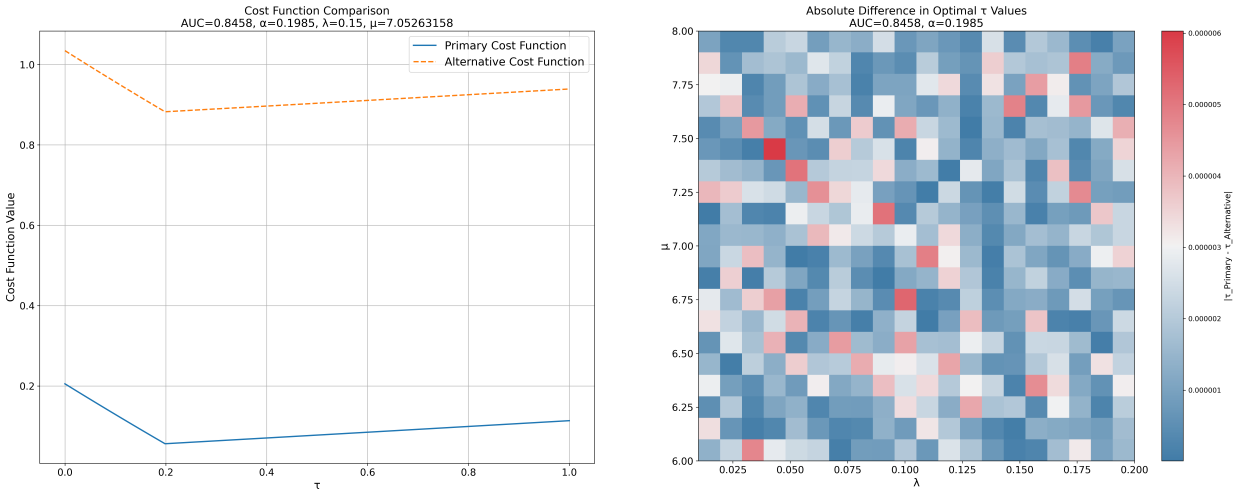
By contrast, the primary objective function admits a simpler structure with more stable threshold ordering across the parameter range. The characterization of the optimal policy is more uniform and admits a globally consistent interpretation of the decision logic, making it better suited for practical implementation. In operational settings where interpretable and robust policy guidelines are essential, this comparative simplicity may offer a significant advantage, even if the alternative objective captures a more nuanced representation of system-wide patient cost.

EC.11.3. Numerical Comparison Against the Primary Objective Function

To further assess the practical implications of adopting the alternative objective, we conduct numerical experiments comparing the optimal τ values obtained under the primary and alternative cost functions across a range of μ, α, and AUC values (equivalent to the model parameter k_1). Figures EC.12 and EC.11 illustrate these comparisons.

In Figure EC.11, we present a detailed analysis for the parameter values that correspond to the most prevalent conditions of the Mayo Clinic ED (AUC $= 0.8458$, $\alpha = 0.1985$, $\lambda = 0.15$, $\mu = 7.05$), comparing the alternative and original objective functions across the τ range. Figure EC.11a demonstrates that both objective functions yield very similar cost structures across the decision threshold τ domain, minimized at the same point $\tau = \alpha$. Figure EC.11b reinforces this observation

by providing a heatmap of absolute differences between optimal τ values for varying arrival rates and service rates across the ranges observed in real-world EDs, such as the Mayo Clinic and the BMC. Our results highlight that even across a range of λ and μ values the differences in the optimal policy across the two objective functions are exceedingly small, on the order of 10^{-6}. These results indicate robust alignment and the equivalence between the two objective functions across realistic parameter settings that reflect real-world ED conditions, further validating the practical applicability and theoretical robustness of our original modeling assumptions.



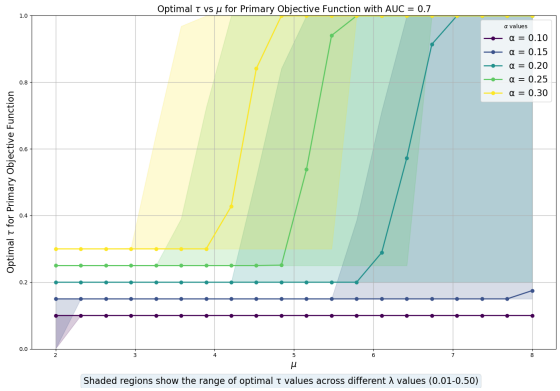
(a) Cost function values across τ for both objective functions.

(b) Absolute difference in optimal τ values across λ and μ.

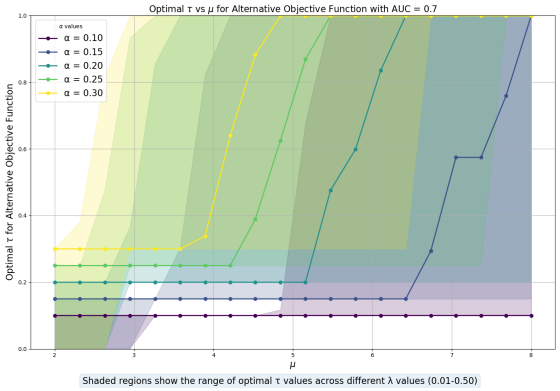
Figure EC.11 Detailed comparison between the primary and alternative objective functions at AUC = 0.8458 and α = 0.1985. Left: Cost values over τ. Right: Heatmap of absolute differences in optimal τ values.

In Figure EC.12, we plot the optimal τ as a function of μ for several fixed α values under three different classifier performance levels (AUC = 0.70, 0.85, and 0.95). Each parameter combination is evaluated for a range of $\lambda \in (0.01, 0.5)$. The line reflects the median τ^*, while the shaded regions represent the range between the minimum and the maximum value of the optimal policy. Each subplot compares the primary and alternative objective function results side-by-side, highlighting how classifier performance influences the stability and variability of the optimal threshold policy.

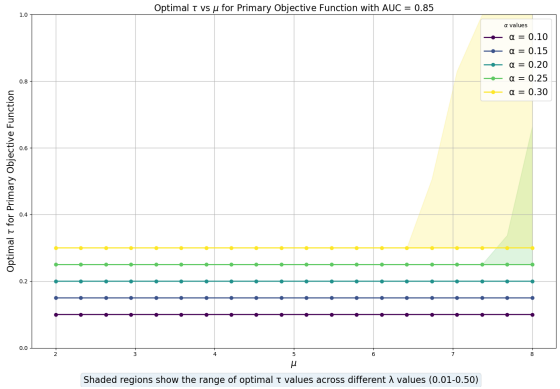
For both objective functions, the structural form of the optimal policies remains consistent, aligning closely with our analytical findings in Section EC.11.1. At low levels of service capacity and patient arrival rates, the optimal policy sets $\tau^* = 0$, effectively routing nearly all patients to the main ED. As ED capacity and arrival rates reach moderate levels, the optimal threshold stabilizes precisely at $\tau^* = \alpha$, signifying the regime in which the VPP is utilized primarily for patients predicted as low acuity by the ML model. The region where τ^* equals α expands with improved ML classification accuracy (increased AUC), indicating that better predictive performance increases the



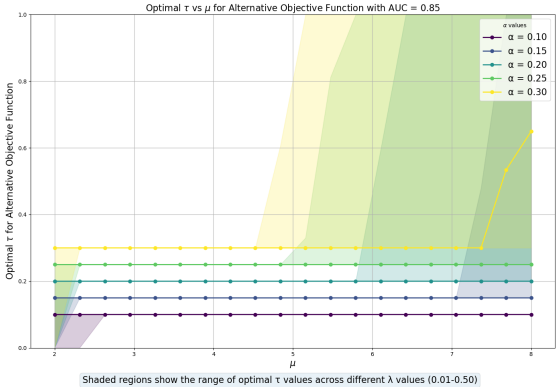
(a) Primary Objective, AUC = 0.70



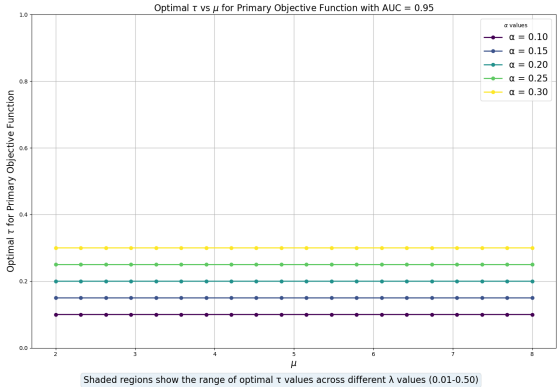
(b) Alternative Objective, AUC = 0.70



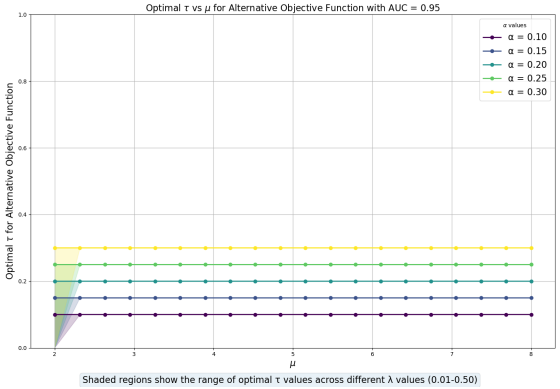
(c) Primary Objective, AUC = 0.85



(d) Alternative Objective, AUC = 0.85



(e) Primary Objective, AUC = 0.95



(f) Alternative Objective, AUC = 0.95

Figure EC.12 Comparison of optimal τ values across μ and α for three AUC levels under two objective functions.

robustness of the optimal policy against variations in ED conditions. Notably, under conditions of severe ED congestion—characterized by high patient arrival rates and limited service capacity—the optimal policy transitions to $\tau^* = 1$, where all patients become eligible for the VPP, demonstrating the VPP's crucial role as an overflow mechanism under high-stress scenarios.

The computational experiments and analytical results further highlight the similarity between the function structure of (τ_1^* and τ_2^*) and their counterparts in the original objective. While there is a broader range of conditions in the alternative objective function under which the optimal policy reduces to τ_1^* or τ_2^* (i.e., lower service rates), the differences between the two policies are small, underscoring the robust alignment between the original and alternative objective functions.

However, despite these structural consistencies and similarities, we observe differences in sensitivity between the two objective functions. Specifically, the alternative objective function exhibits higher sensitivity to changes in ED conditions, reflected in greater variability of optimal threshold values, particularly at lower classification performance (AUC = 0.70). This increased variability indicates that the alternative formulation is more responsive to operational changes, suggesting a potentially more dynamic but less stable policies. Conversely, the primary objective demonstrates greater stability in its optimal policy across a wide range of realistic operational scenarios, facilitating ease of deployment and highlighting its suitability and practical advantages for consistent decision-making in ED settings.

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