

## The Problem: Equity Fails Under Pressure

- ▶ A credible M7.7 Shelby County (Memphis, TN) earthquake produces **3,618 casualties** across 201 zones with only 8 functional hospitals.
- ▶ Proximity-based dispatch — the real-world default — leaves **79 of 201 zones** with essentially zero service, abandoning peripheral communities entirely.
- ▶ Existing disaster logistics models treat equity as a **soft penalty**, not a hard guarantee.

**Can a hard equity floor protect every zone without sacrificing life-saving throughput?**

## Equity-Aware LP: One Structural Addition

**Objective** — maximize survival-weighted transport:

$$\max_{t,z,h,k} \sum w_{kt} \cdot y_{tzhk} \quad w_{kt} = \theta_k \cdot e^{-\delta_k t_{mid}/60}$$

**Max-min equity floor** (the key new constraint):

$$\frac{\sum_{t,h,k} y_{tzhk}}{D_z} \geq \varepsilon \quad \forall z \in \mathcal{Z}$$

**Ambulance-time budget** per period  $t$ :

$$\sum_{z,h,k} \tau_{zh} \cdot y_{tzhk} \leq A \cdot \rho \cdot \Delta$$

≈44,000 variables · ≈6,700 constraints · **solves in seconds**

## Case Study: Shelby County, Tennessee

Earthquake scenario	M7.7 New Madrid Seismic Zone
Geographic zones	201 (census-tract level)
Hospitals	8 post-earthquake operational
Total casualties	3,618 (4 triage categories)
Planning horizon	6 periods × 120 min
Robustness check	20 independent MC replicates

## Broader Applicability

- ▶ **Hazard-agnostic**: directly transferable to hurricanes, floods, and mass-casualty events using local casualty and road-network inputs.
- ▶ **EOC-ready**: county-scale instances solve in seconds, enabling real-time scenario analysis inside an Emergency Operations Center.
- ▶ **Transferable framework**: one parameter ( $\varepsilon$ ) controls the equity-efficiency trade-off; planners choose the level that fits their resource context.

## Four Headline Results

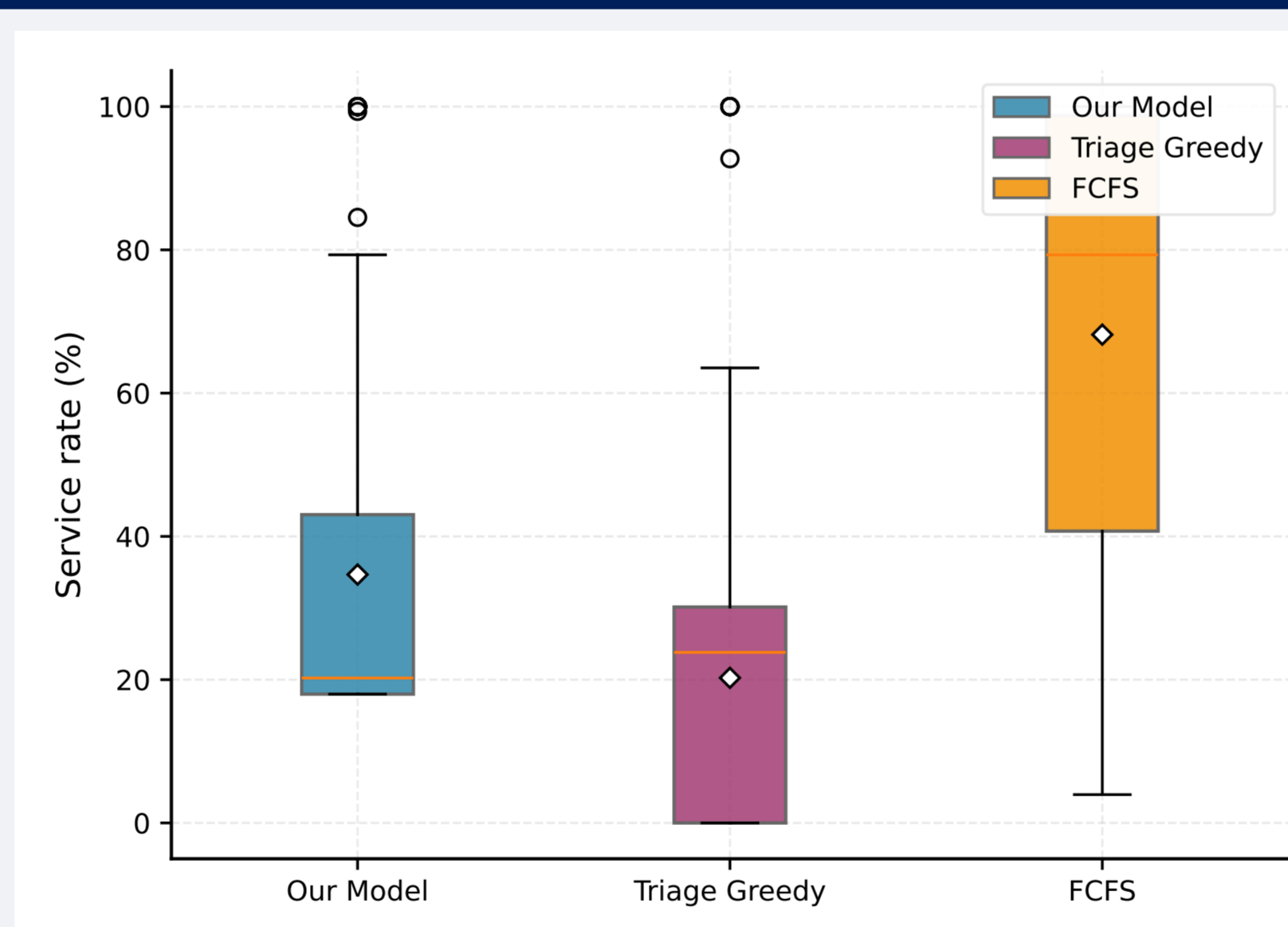
<b>79 → 0</b>	<b>+17.4points</b>
Zones with <1% service eliminated entirely	Worst-zone service rate vs. proximity dispatch
<b>-38%</b>	<b>+2.0%</b>
Zone-level inequality (Gini) reduced	Survival score per patient equity improves survival

## Performance vs. Baselines

Metric	Ours	Greedy	FCFS
Treatment rate (%)	29.4	28.3	28.8
Min. service rate (%)	<b>17.4</b>	0.01	4.4
Guaranteed floor (%)	<b>18.0</b>	—	—
Zone Gini	<b>0.337</b>	0.539	0.259
Survival score / patient	<b>5.09</b>	5.03	3.77

*Greedy = proximity-based; FCFS = first-come-first-served. Only our model guarantees every zone a minimum service floor.*

## Zone-Level Service Distribution



Proximity dispatch creates a **left tail of near-zero-service zones**. The equity-aware model **compresses the distribution upward** while preserving aggregate throughput.

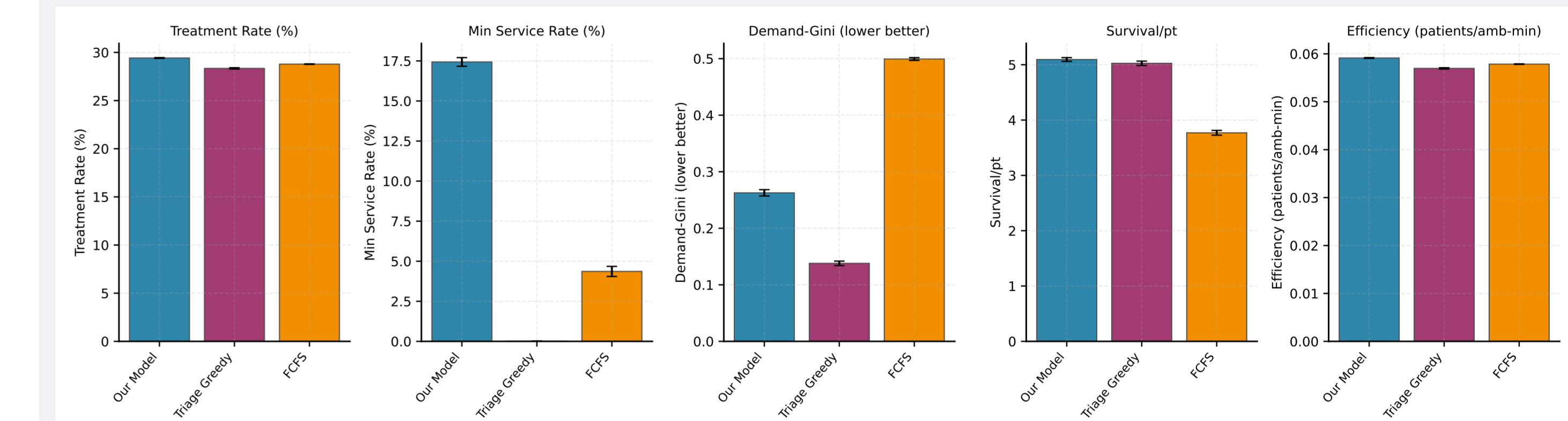
## Key Insight: Equity and Efficacy Are Compatible

- ▶ The  $\varepsilon$ -floor redirects ambulances toward peripheral zones that contain **high-acuity casualties** proximity dispatch ignores.
- ▶ Enforcing equity **simultaneously raises survival-weighted outcomes**: the constraint and the objective reinforce each other.
- ▶ The conventional assumption that *equity costs efficiency* is **not supported** in this setting.

## Acknowledgments

Scenario data: Sediek, A., El-Tawil, S., & McCormick, J. (Univ. Michigan, 2021–22). Manuscript under review at *Safety Science*.  
Open code and data: Zenodo DOI 10.5281/zenodo.18708120. Solver: Gurobi 13.0

## Robustness: 20 Independent Replicates



Mean realized min. service rate: **16.44%** (95% CI: ±0.8 pp) across 20 independent Monte Carlo draws. Performance is stable under scenario uncertainty — equity guarantees are not artifacts of a single realization.

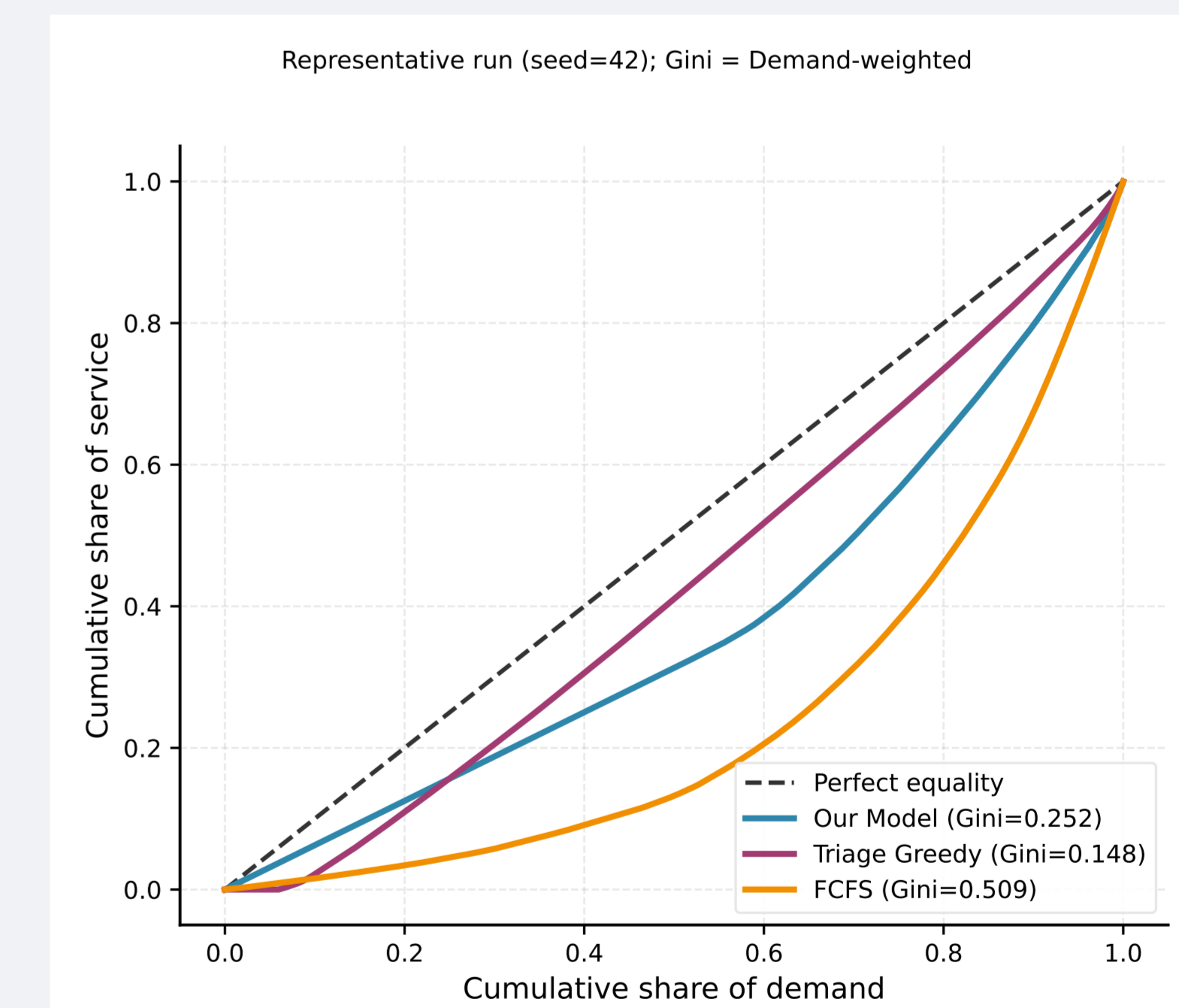
## Vulnerability: Who Gets Left Behind?

Threshold	Greedy	Ours
Zones with <1% service	<b>79 (39%)</b>	<b>0</b>
Zones with <20% service	95 (47%)	100 <sup>†</sup>

<sup>†</sup>All zones at or near the guaranteed floor  $\varepsilon = 17.98\%$ .

Under proximity dispatch **4 in 10 zones** receive effectively no care. The equity-aware model eliminates this class of neglect entirely.

## Equity-Efficiency Frontier



Lorenz curves show how equity-aware optimization raises the lower tail of service coverage. The key operational gain is worst-zone protection: the model eliminates near-zero-service zones while preserving aggregate throughput.

**Equity can be engineered, not just aspired to.**

One parameter ( $\varepsilon$ ) in a linear program eliminates near-zero-service zones, guarantees every community a minimum, and improves survival — solving in seconds.