Signals Before Gridlock

Privacy-preserving mobility forecasting at the urban edge

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From fragmented signals to coordinated streets

1. The forecasting gap
2. CivicPulse design
3. Evidence
4. Deployment

Citywide forecasts arrive too late for street-level decisions

- Traffic states can change within minutes after an incident, event, or downpour.

Operational mismatch

A 15-minute forecast has little value when computation and transfer consume most of that horizon.

Research question

Can intersections collaborate without exporting individual journeys?

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- Raw trajectories create privacy exposure and costly network demand.
- A useful forecast must be local, timely, and trustworthy under missing data.

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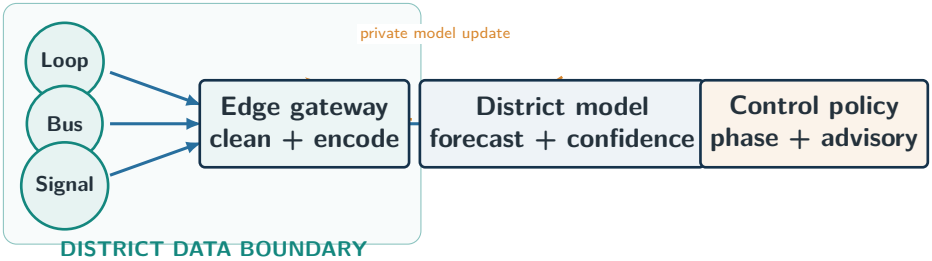
Three commitments define a deployable forecasting service

1. Learn locally	2. Act quickly	3. Fail visibly
Gateways retain raw counts and trajectories; only clipped model updates leave a district.	Inference stays on the signal-control path, independent of a cloud round trip.	Confidence falls when inputs are stale, turning uncertainty into an explicit operator signal.

Coordinate models globally; keep observations and urgent decisions local.

The real-time path ends inside each district



Aggregation improves the shared model; it never becomes a dependency for live control.

One objective balances accuracy, delay, and privacy

District k optimizes a local forecasting loss F_k; the coordinator combines updates as

$$\min_{\boldsymbol{w}} \underbrace{\sum_{k=1}^{K} p_k F_k(\boldsymbol{w})}_{\text{forecast error}} + \lambda \underbrace{\|\boldsymbol{w}\|_2^2}_{\text{stability}}, \qquad \widetilde{\boldsymbol{g}}_k = \mathrm{clip}_C(\boldsymbol{g}_k) + \mathcal{N}(\mathbf{0}, \sigma^2 C^2 \mathbf{I}).$$

- p_k: weight based on usable observations,
- C: bound on one district's influence,
- σ: calibrated privacy noise,
- λ: resistance to unstable updates.

Control contract

Publish a forecast only when latency is below 2 seconds and calibrated confidence exceeds the district threshold.

The update cycle separates urgent inference from patient learning

1. **Observe:** align recent counts, speeds, and signal states.
2. **Infer:** predict the next three 5-minute intervals locally.
3. **Protect:** clip, noise, and encrypt the scheduled update.
4. **Aggregate:** combine updates robustly across available districts.
5. **Adopt:** promote a model only after local safety checks pass.

A six-week replay tests both routine and disrupted operation

Scope	48 intersections in 6 districts
Signals	loops, transit arrivals, phase state
Horizon	5, 10, and 15 minutes
Replay	30 routine + 12 disruption days
Baselines	local ARIMA; centralized GNN
Stressors	loss, drift, and 20% sensor dropout

Primary measure

Mean absolute error for district travel time.

Guardrails

End-to-end latency, calibration error, and privacy budget.

Values in this illustrative deck are synthetic but internally consistent.

CivicPulse preserves accuracy while shrinking the decision path

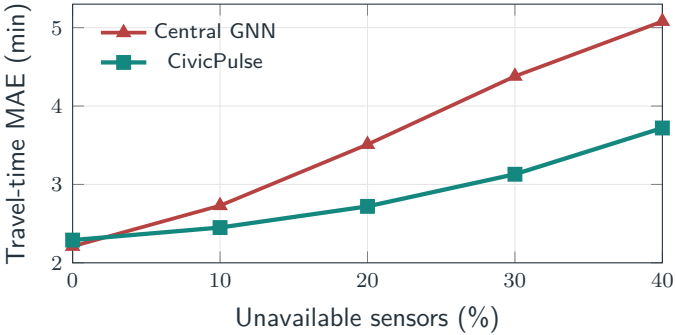
Method	MAE (min)	P95 latency	Uplink/day	Raw data leaves edge
Local ARIMA	3.84	**0.4 s**	**0.2 GB**	No
Central GNN	**2.21**	8.7 s	31.6 GB	Yes
Federated average	2.48	1.9 s	1.4 GB	No
CivicPulse	2.29	1.3 s	0.9 GB	No

40%
lower error vs. local

6.7×
faster than central

97%
less uplink data

Graceful degradation matters more than the best clean-data score



At 30% dropout

CivicPulse reduces error by **29%** and flags 94% of low-confidence forecasts.

Remaining risk

Correlated outages can remove an entire corridor's evidence; human review remains necessary.

The design earns speed by accepting explicit trade-offs

Strong fit

- recurring corridors
- constrained uplinks
- strict data boundaries

Manage carefully

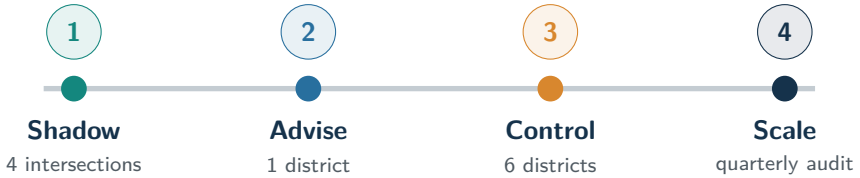
- uneven district volume
- concept drift
- model-version skew

Escalate

- mass sensor outage
- unseen event pattern
- unsafe phase proposal

Privacy does not remove accountability: every promoted model retains a signed audit trail and rollback target.

A staged rollout converts evidence into operating confidence



Promotion gate

Two weeks within accuracy, calibration, latency, and privacy thresholds.

Automatic rollback

Revert on unsafe action, budget breach, or sustained distribution shift.

Three ideas to take home

1. **Move decisions, not raw journeys.** Edge inference shortens the operational path and limits exposure.
2. **Treat uncertainty as product behavior.** Missing evidence must change confidence, escalation, and control authority.
3. **Deploy through measurable gates.** Accuracy alone is insufficient; latency, privacy, calibration, and rollback complete the contract.

Result in one sentence

CivicPulse approaches centralized accuracy with a 6.7× faster response and 97% less uplink traffic in the illustrative replay.

Questions?

Fast enough to act. Private enough to trust.

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