Projeto de Formatura – 2025

PCS - Departamento de Engenharia de Computação e Sistemas Digitais

Engenharia de Computação

Tema:

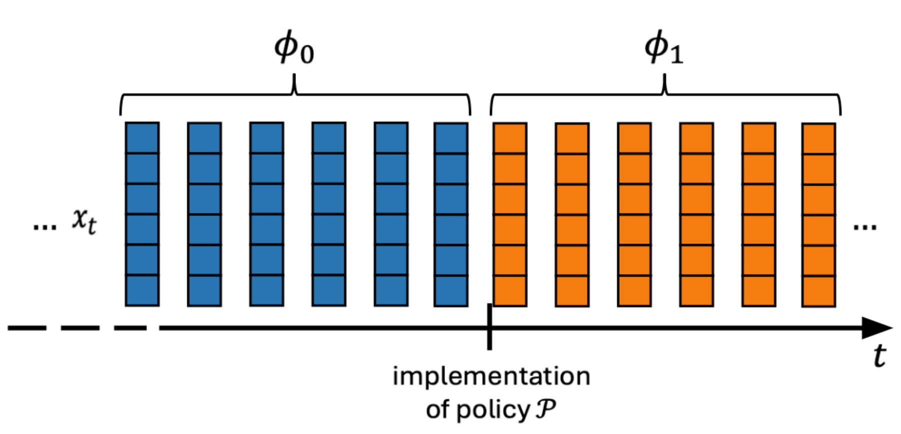
Assessing Mobility Policies A Priori: A Change Detection Methodology Using Traffic Simulation

Introduction

- **Traffic management is needed** to mitigate congestion and pollution in large cities, especially near **logistics hubs such as ports.**
- City authorities can enforce **mobility policies. However,** real-world trials are **costly, disruptive and slow. Also,** impacts can be **subtle or demand-dependent**, requiring **statistically robust analysis** beyond simple before/after averages.
- This raises two key questions **before** deployment:
  - **(Q1)** Does a candidate policy actually change traffic conditions in a statistically significant way?
  - **(Q2)** How many days of monitoring are needed to reliably detect this change?
- In this work, **we present a new framework** that combines **microscopic traffic simulation** with **sequential, multivariate change detection** to provide a **statistically robust assessment** of policy effectiveness and time-to-detection before **real-world deployment**.

Problem Formulation

- At selected **road segments** we observe **daily multivariate traffic vectors** $x_t \in \mathbb{R}^d$ (counts, speeds and flows by vehicle class). Under **normal conditions** (no policy) x_t follows an **unknown baseline distribution** ϕ_0. **After policy** P is enforced, the **distribution** may **shift** to ϕ_1, with $H_0 : \phi_1 = \phi_0$ vs. $H_1 : \phi_1 \neq \phi_0$.

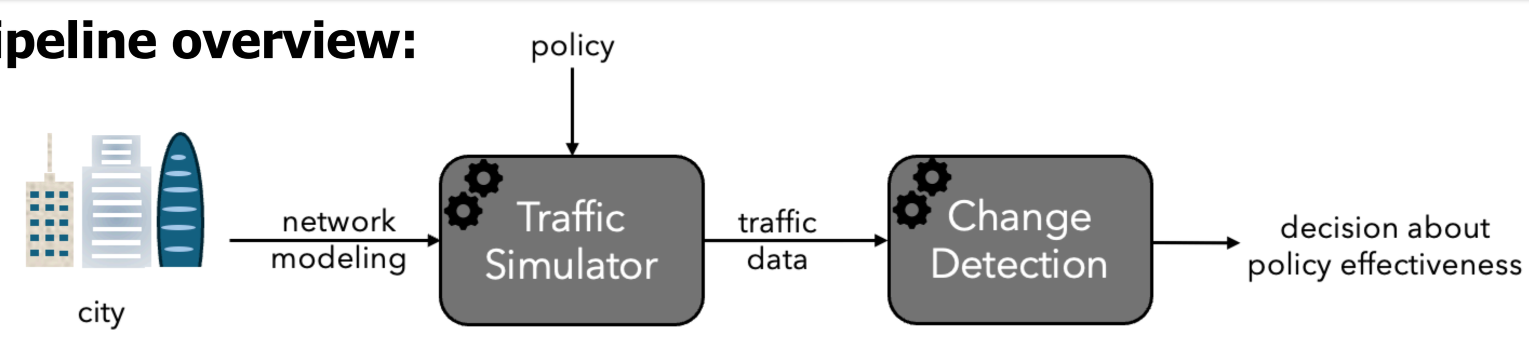


- We treat policy assessment as a **sequential change detection** problem: as days $x_1, x_2, \ldots$ arrive, a detector decides when to stop and signal that the distribution has changed.

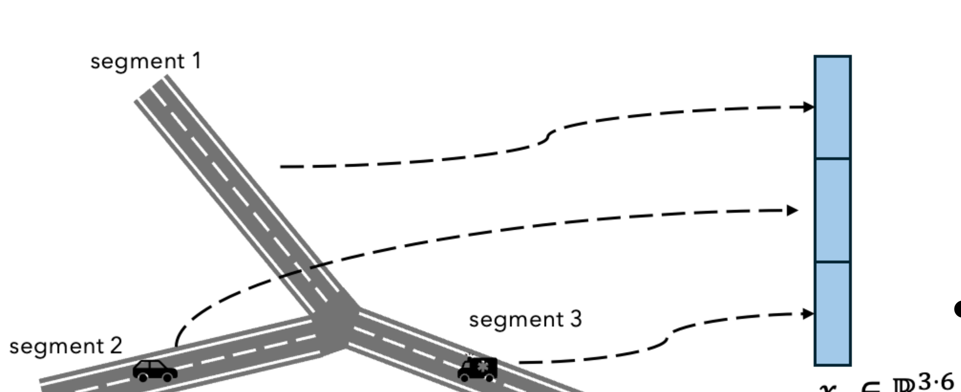
- Two key performance metrics guide the design:
  - **In-control ARL$_0$:** expected number of days until a **false alarm** when no policy effect is present.
  - **Detection delay:** expected number of days from policy activation until the change is **reliably detected**.

Methodology

Pipeline overview:



Traffic simulator:

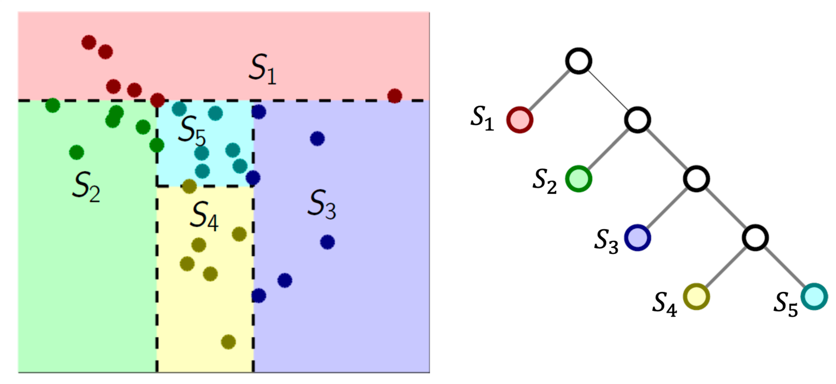


- **Microscopic simulation** (SUMO) generates synthetic "days" of traffic x_t under: baseline (no policy) and each candidate policy P
- For each segment, we monitor **6 traffic variables**:
  - speed, number, flow for both cars and trucks.

Change Detection:

We adopt the QuantTree Exponentially Weighted Moving Average [2].

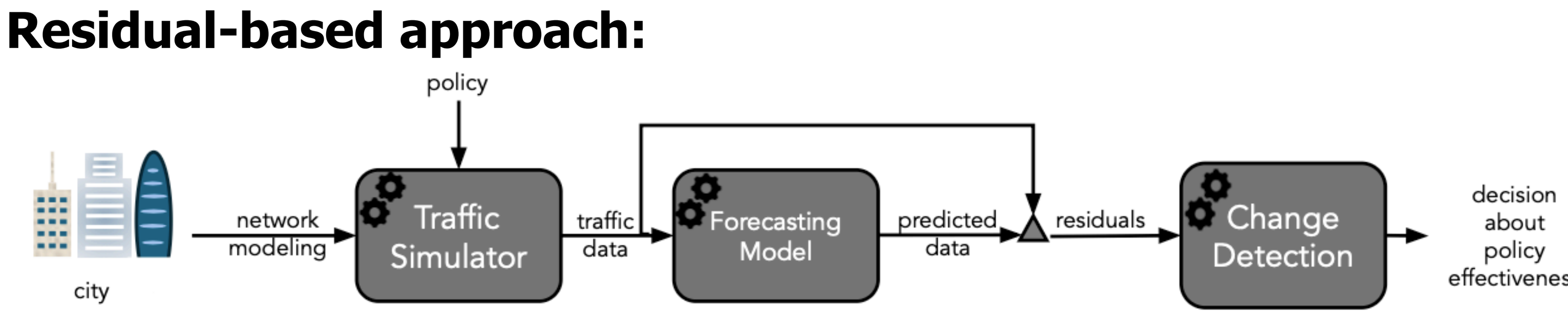
QT-EWMA is **unsupervised**, **nonparametric**, **multivariate** and a **sequential** change detection test —> ideal for realistic policy assessment by monitoring traffic data sequentially.



During **training**, QT-EWMA constructs a **QuantTree** [1] **histogram** by partitioning the data space according to empirical quantiles (adaptive bins with equal probability) -> estimates $\hat{\phi}_0$.

During **sequential monitoring**, after each new day x_t arrives, we update EWMA-based empirical bin probabilities and declare a change as soon as their deviation from the baseline exceeds a calibrated threshold, providing enough evidence to accept H_1 ($\hat{\phi}_1 \neq \hat{\phi}_0$).

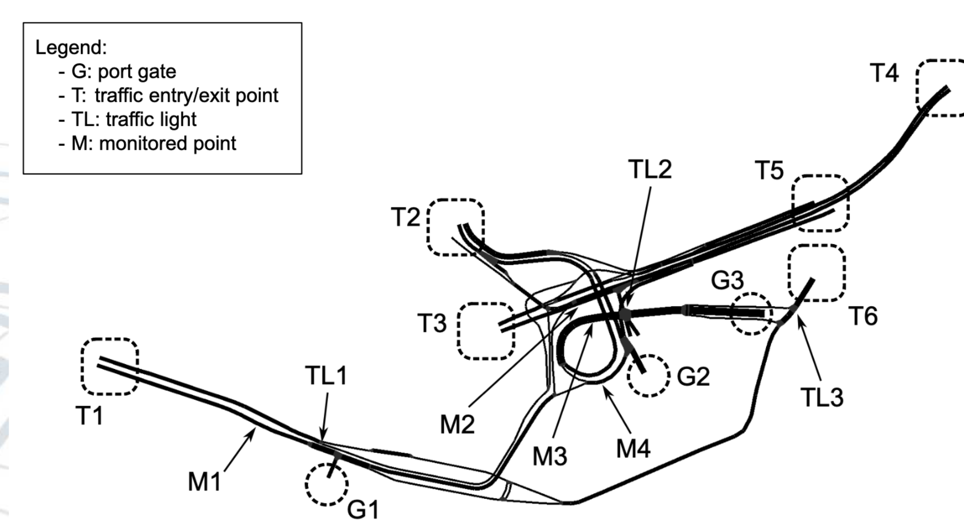
Residual-based approach:



Goal: isolate changes from policy interventions and filter out variability.

Experiments & Results

Genova port-city case study:



Experimental setup:

- **4** monitored **segments**;
- **3** demand **regimes**:
  - **A** weekdays (congested),
  - **B** weekends (low demand),
  - **AB** mixed 70%/30%;
- **3 policies:**
  - **P1** minor retiming TL2,
  - **P2** timing all 3 TLs,
  - **P3** adaptive control.

Evaluation: For each setup, **1000 Monte Carlo runs** estimate empirical ARL$_0$ and detection delay, with thresholds calibrated to **ARL$_0$ = 500 and 1000 days**, and the empirical ARL$_0$ from simulations staying close to these targets.

Table 1 - Network-level average detection delay (days) for QT-EWMA on **raw traffic data** ($N = 256$ baseline days). Each cell reports the delay for $\mathrm{ARL}_0 = 500/1000$.

Scenario	P1	P2	P3
A – Weekdays (congested)	130.7 / 186.1	22.7 / 27.7	6.4 / 6.9
B – Weekends (low demand)	512.0 / 923.6	290.2 / 535.0	83.0 / 126.8
AB – Mixed (70% A, 30% B)	256.1 / 436.1	61.0 / 87.4	12.1 / 14.0

Table 2 - Scenario A, network-level average detection delay (days) for QT-EWMA on **raw traffic** data **versus** the **residual-based** approach ($N = 256$, $\mathrm{ARL}_0 = 500$).

Policy	Raw QT-EWMA	Residual-approach
P1	130.7	177.3
P2	22.7	29.7
P3	6.4	8.6

Conclusions

- We proposed a new **framework** that combines microscopic traffic simulation with **QT-EWMA** to assess mobility policies **before deployment**.
- In the Genova port–city case study, **stronger policies (P2, P3)** are detected within **few days** in congested regimes, while **mild tweaks (P1)** often remain hard to detect or require very long monitoring.
- The **residual-based approach** preserves ARL$_0$ control and shows **only modest gains** over the raw detector, acting mainly as a **conservative alternative**.

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- **Presented at:** EANN/EAAAI 2025 conference.
- **Published in:** Springer LNCS–CCIS [3].
- **Funding:** European Union Next Generation EU – PRIN 2022 PNNR.

References

[1] G. Boracchi et al., "QuantTree: Histograms for change detection in multivariate data streams", ICML, 2018.

[2] L. Frittoli, D. Carrera, G. Boracchi, "Nonparametric and online change detection in multivariate datastreams using QuantTree", IEEE TKDE, 2023.

[3] F. Bagni et al., "Assessing mobility policies by traffic simulation and change detection", EANN/EAAAI, Springer, 2025.

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