Modelling & Simulation

# Microscopic Simulation and Digital Twin of Traffic Flow on Porto's VCI Inner-Ring

A data-driven approach to urban motorway modelling using SUMO and real sensor data


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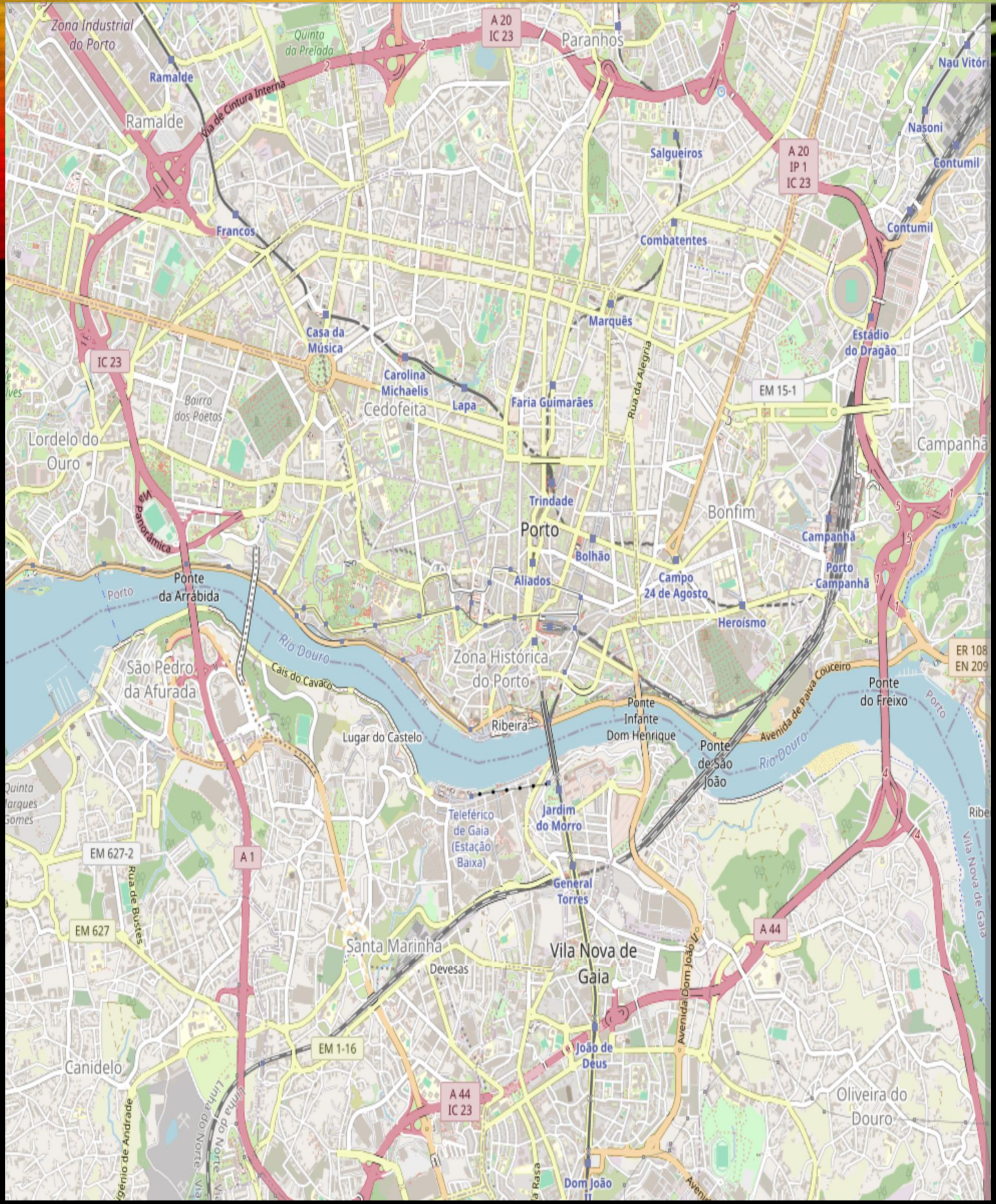



# Problem Description

The VCI (Via de Cintura Interna) is Porto's most critical urban ring motorway, facing significant operational challenges.

## Current Challenges

- Frequent congestion and unstable traffic flow patterns
- High temporal variability in demand throughout the day
- Vast inductive-loop sensor data remains underutilised
- Traffic management is predominantly reactive

## The Gap

Despite abundant sensor infrastructure, Porto lacks **predictive** and **descriptive digital twin models** capable of understanding and forecasting traffic behaviour on the VCI corridor.

# Project Objectives

01

## Build Digital Twin

Develop a microscopic simulation-based digital twin of the VCI inner-ring

02

## Integrate Real Data

Utilise inductive-loop sensor data from 2013–2015 archives

03

## Learn Behaviour

Implement data-driven vehicle behaviour learning in SUMO using a Multi-Armed Bandit Approach

04

## Validate Accuracy

Assess simulation fidelity using quantitative KPIs

05

## Enable Scalability

Deliver a descriptive simulation supporting understanding and visualization

# System Model & Data Architecture /

## Modelled Entities

**Infrastructure:** Road segments, ramps, lanes

**Vehicle classes:** Cars

**System variables:** Flow, speed, density, occupancy

## Data Source

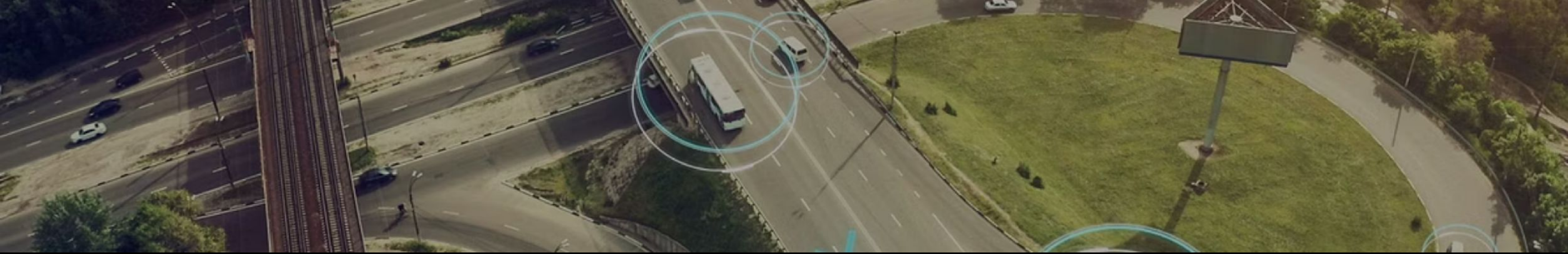
AEDL inductive-loop sensors capturing 5-minute interval measurements: volume, speed, occupancy, and vehicle class ratios.

Inductive Loop

Raw Data

Preprocessing

Simulation



# Methodology & Simulation Approach

### Data Preprocessing

Python-based cleaning and transformation of sensor data

### MAB Policy

Multi-Armed Bandit decision policy shared across entrances

### SUMO Simulation

Microscopic traffic simulation with calibrated parameters

### Evaluation

Continuous calibration to minimise real-simulated divergence

# Experimental Setup

## Temporal Scope

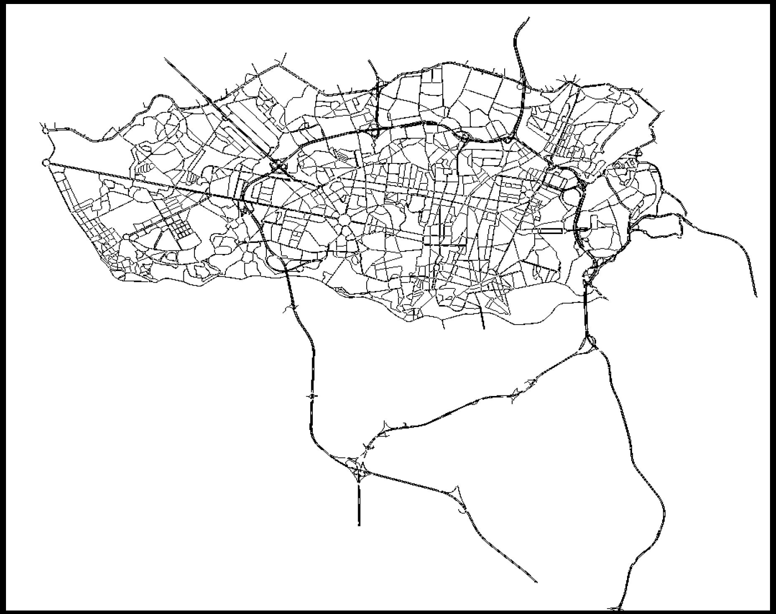
Data obtained from 2013 to 2015.

## Traffic Scenarios

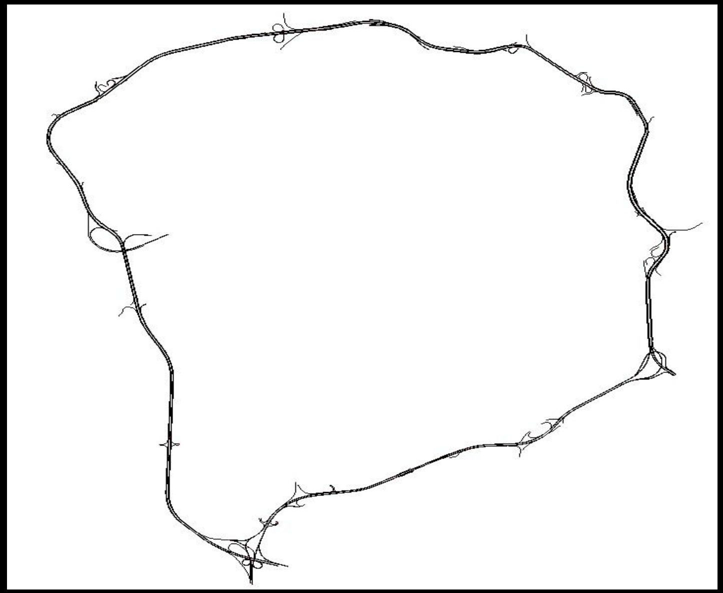
- **Baseline:** Average daily traffic conditions
- **Rush-hour:** Peak morning and evening periods

## Key Points

- Missing data addressed via temporal interpolation
- Vehicle trajectories reconstructed from sensor observations
- Distinct training and validation periods defined
- MAB Approach with 1 arm per entrance.



Original Netedit



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# Key Performance Indicators

### Traffic Metrics

- Volume (veh/h)
- Traffic density
- Daily relative error

### Statistical Accuracy

- SMAPE
- NRMSE, RMSE
- MAE

### Validation

- Real vs simulated comparison
- Temporal consistency

# Results

Data only Results:

MAE: 6.54

RMSE: 8.41

MAPE: 3.85%

The digital twin model only trained on data, successfully reproduced observed traffic patterns with strong correlation to real-world sensor measurements, while the digital twin model trained with SUMO shows a good learning behaviour

| MAE | Daily Relative Error | RMSE | SMAPE | NRMSE |
|---|---|---|---|---|
| Baseline: 115,37<br>Trained Model: 331,09 | 1.59 | 407.92 | 109% | 2.21 |
| Consistent with theoretical bandit convergence rates ($O(1/\sqrt{n})$) | Seasonal shifts not yet learned | Large errors dominate occasionally (daily traffic fluctuations) | Predictions off by the same order of magnitude | Confirms data variability dominates |

# Discussion

## Strengths

- Data-driven approach improves realism over hand-crafted models
- Scalable framework for large networks
- Effective integration of MAB learning
- Possible strong validation against real measurements

## Limitations

- Sensor sparsity constraints spatial resolution
- Trajectory reconstruction introduces uncertainty
- Simplified driver decision-making assumptions
- Historical data may not reflect current conditions
- SUMO simulation training is very computationally expensive.

# Conclusions & Future Work

## Key Achievements

- Successfully demonstrated microscopic digital twin for VCI
- Validated realism using real-world sensor data
- Supports traffic understanding and visualisation
- Established foundation for predictive systems

## Future Directions

- Real-time data streaming integration
- Predictive congestion modelling
- Prescriptive traffic control strategies
- Advanced reinforcement learning approaches