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

Group 13

António Santos

Gonçalo Dias

Paulo Silva

U.PORTO FEUP FACULDADE DE ENGENHARIA UNIVERSIDADE DO PORTO

U.PORTO FC FACULDADE DE CIÊNCIAS UNIVERSIDADE DO PORTO

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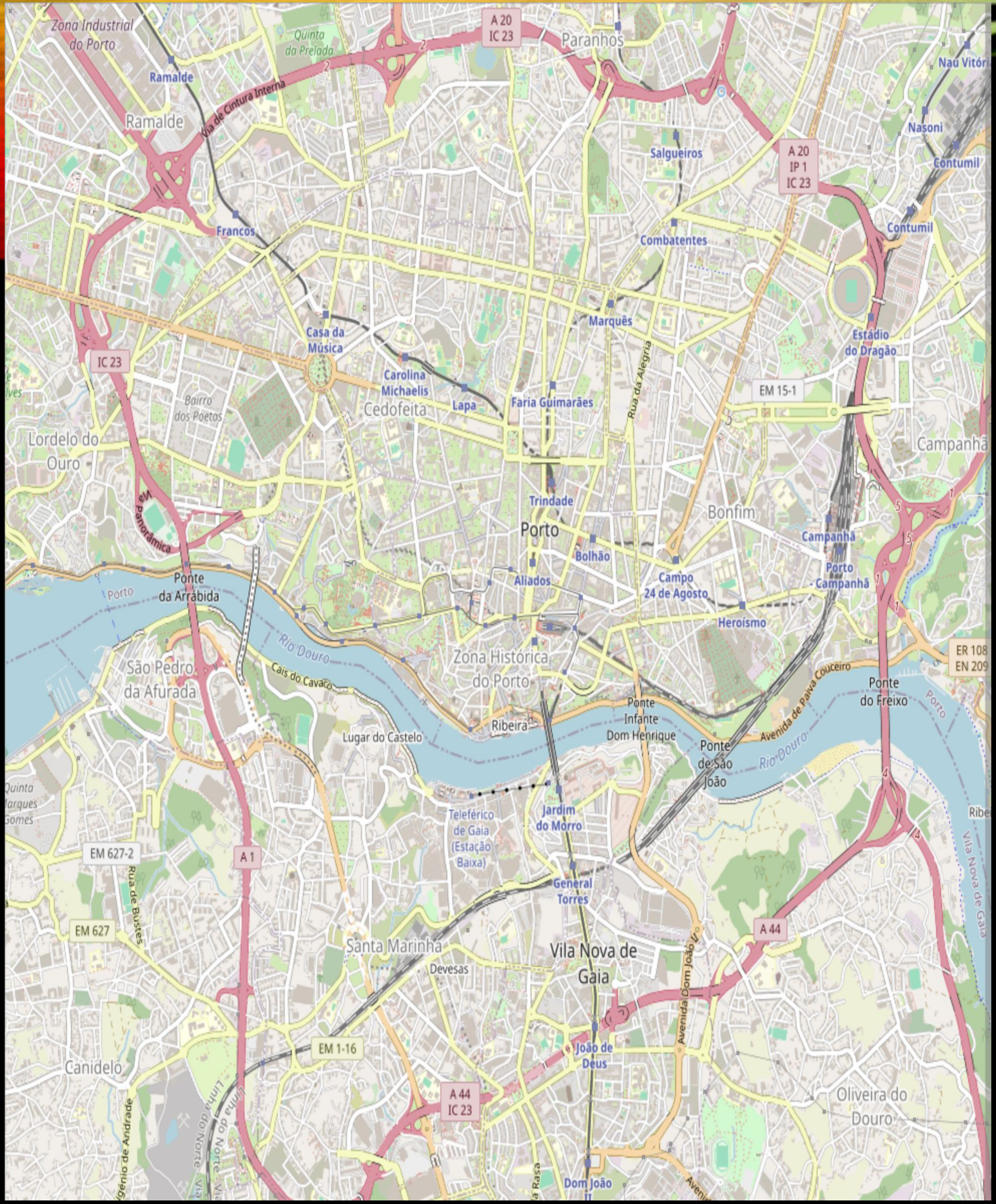


Problem Description

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

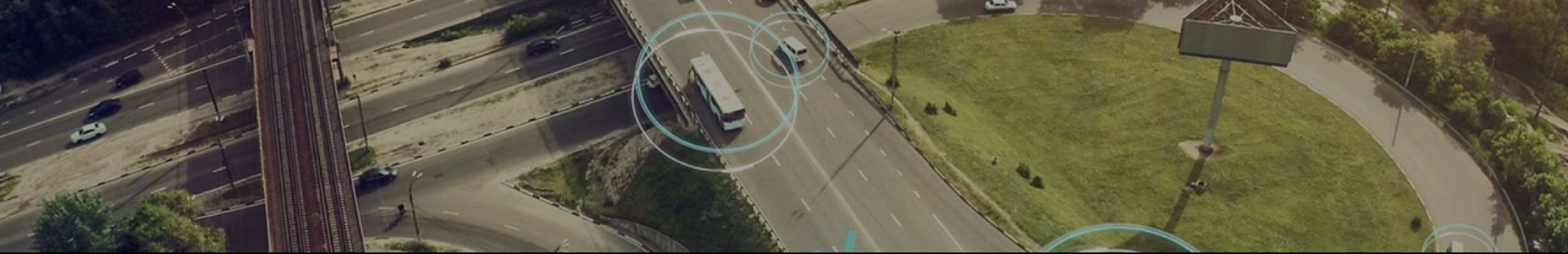
AEDL inductive-loop sensors capturing 5-minute interval measurements: volume, speed, occupancy, and vehicle class ratios.

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

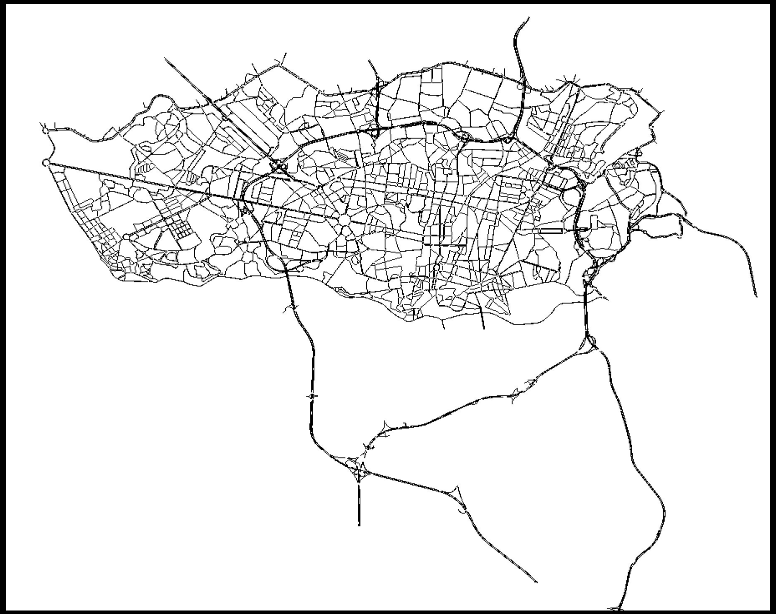
Data obtained from 2013 to 2015.

Traffic Scenarios

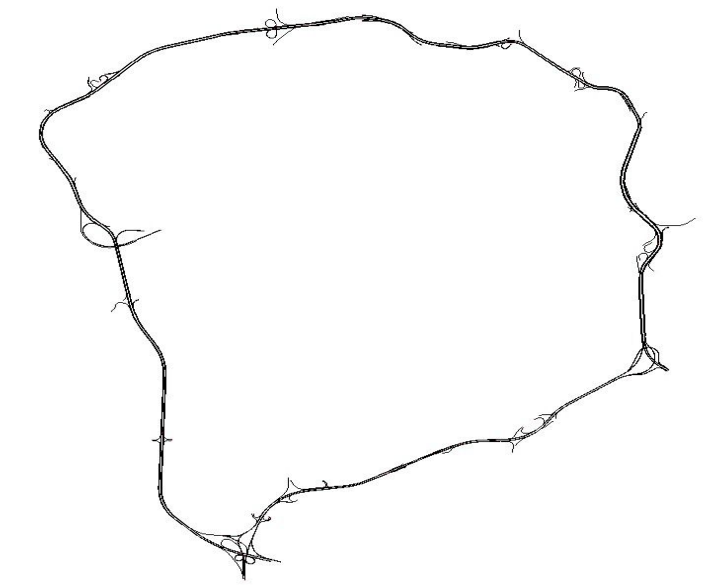
- **Baseline:** Average daily traffic conditions
- **Rush-hour:** Peak morning and evening periods

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



Final Netedit

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: 6.46

RMSE: 8.26

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 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