Evaluating and Forecasting the Operational Performance of Road Intersections

Supervisor: Manos Papagelis

M.SC. THESIS OF ALI NEMATICHARI

LASSONDE SCHOOL OF ENGINEERING | YORK U

Motivation

Traffic Congestion Consequences

Slow Speeds

Long Trips

Vehicle Queues

Environmental Costs

Anxiety

Car Wear

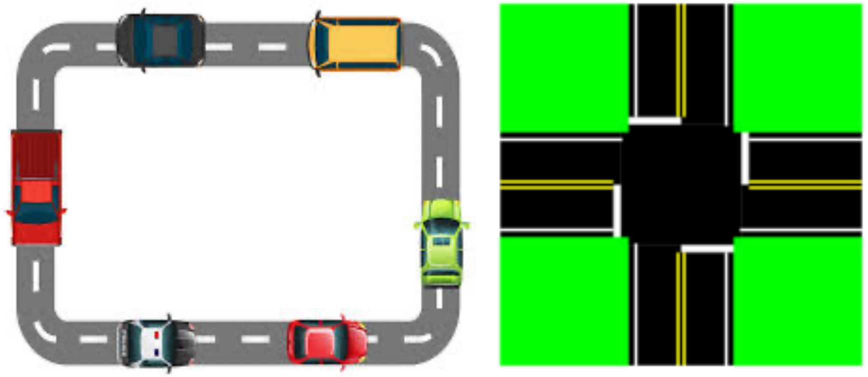
Road Intersection Effect on Traffic Management

Complex Configurations

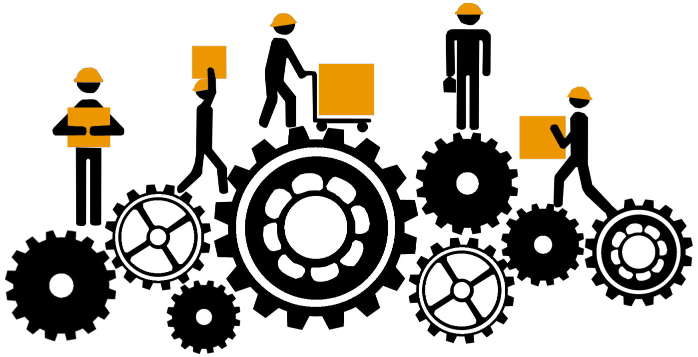
Great Part of Travel Times

High Percentage of Accidents

Limitations of Current Approaches



Limited Focus on Road Intersection Performance



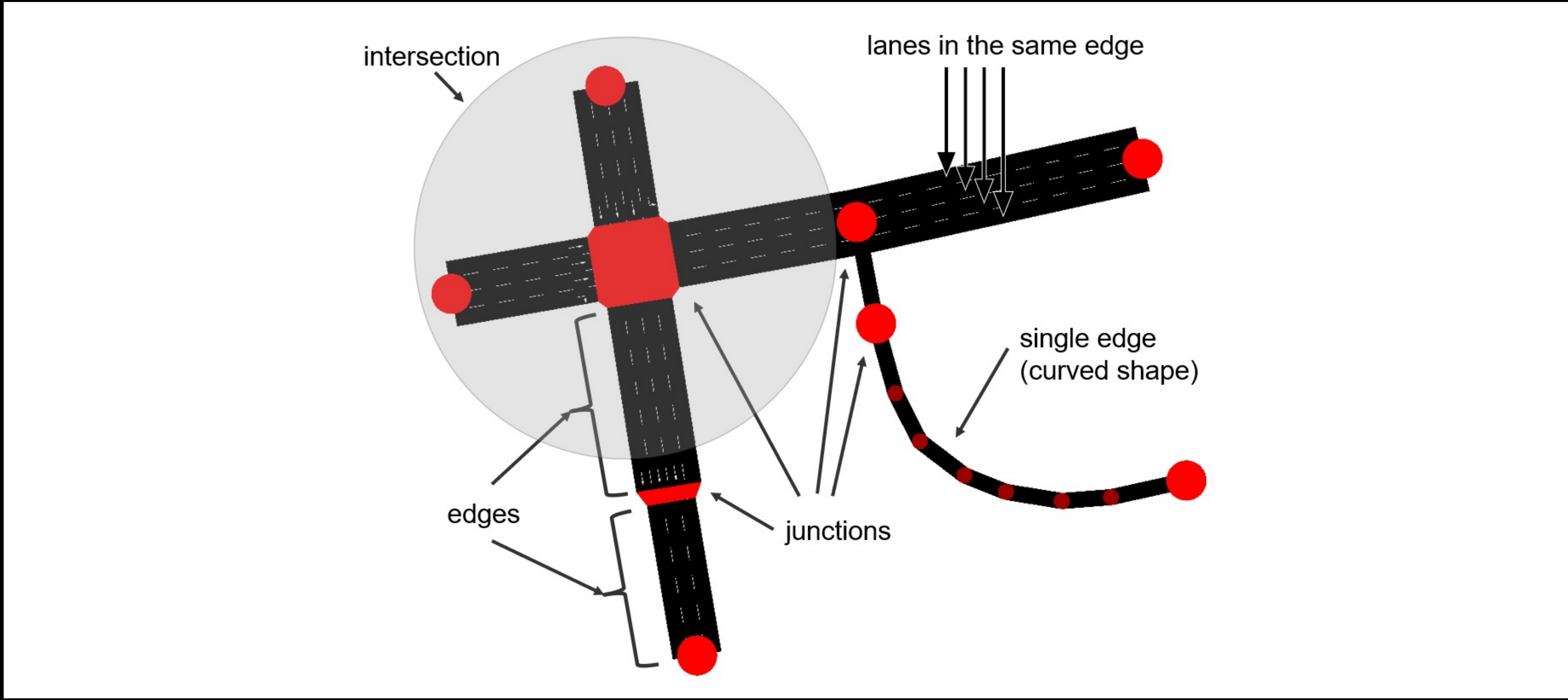
Industry Standards

Measures of Effectiveness (MOEs)

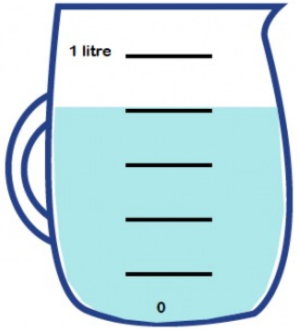
How can we compute the road operational performance using the MOEs?

Problem Definition

Road Network and Intersection Definition



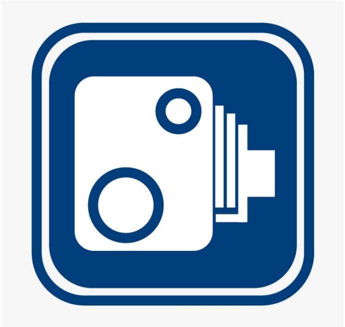
Measures of Effectiveness (MOEs)



Capacity
(#vehicle)

Throughput
(#Vehicle/sec)

Delay
(sec)



Mean System Speed
(meters/sec)

Travel Time Index (TTI)

Problem

Definitions:

- Road network G := (V, E, s, t)
- Observation time period [0, T]
- Set of trajectories τ = {Ci}
- Registry of vehicles Ci = {(ti, e)}

Problem 1 (Real time analysis)

Given a road intersection v ∊ V of the road network G and τ, **we want to compute the TTI of the intersection during [0, T]**

Problem 2 (Time series forecasting)

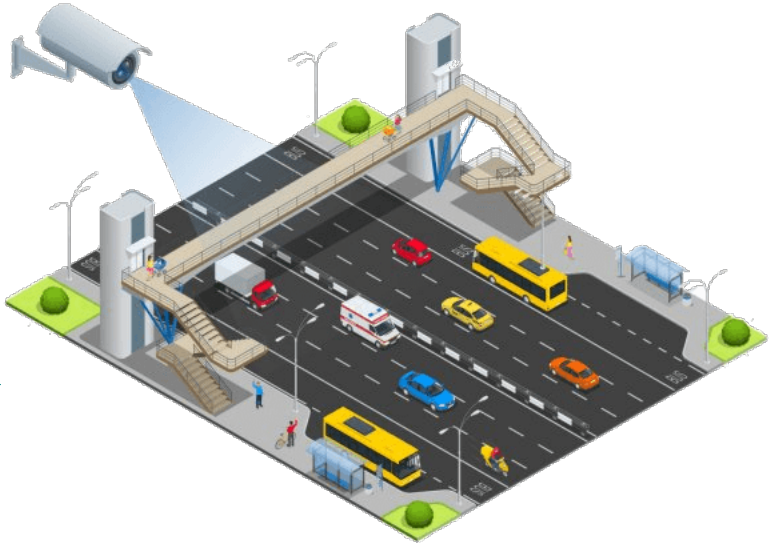
Given a road intersection v ∊ V of the road network G and τ, **we want to forecast the TTI of the intersection for the period [T, T + Δ], where Δ > 0**

Methodology

Data Representation

Road Network

Traffic Data



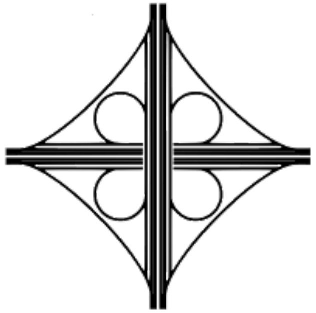
Traffic Flow

Graph Representation of a Road Network

Problem 1

System Abstractions

micro-level



meso-level

macro-level

Road Network MOEs Evaluation

- RoadNetworkModel
  - Junctions
  - Edges
  - Edge systems
- EdgeSystem
  - Vehicles
  - Distance gone
  - Total ideal time
  - Update entered ()
  - Update left ()
  - Compute metrics ()

Maintaining Hierarchies of MOEs

- RoadNetworkModel
  - Multi edge systems

- Multi Edge System
  - Edge systems
  - Overwritten update entered vehicle

Problem 2

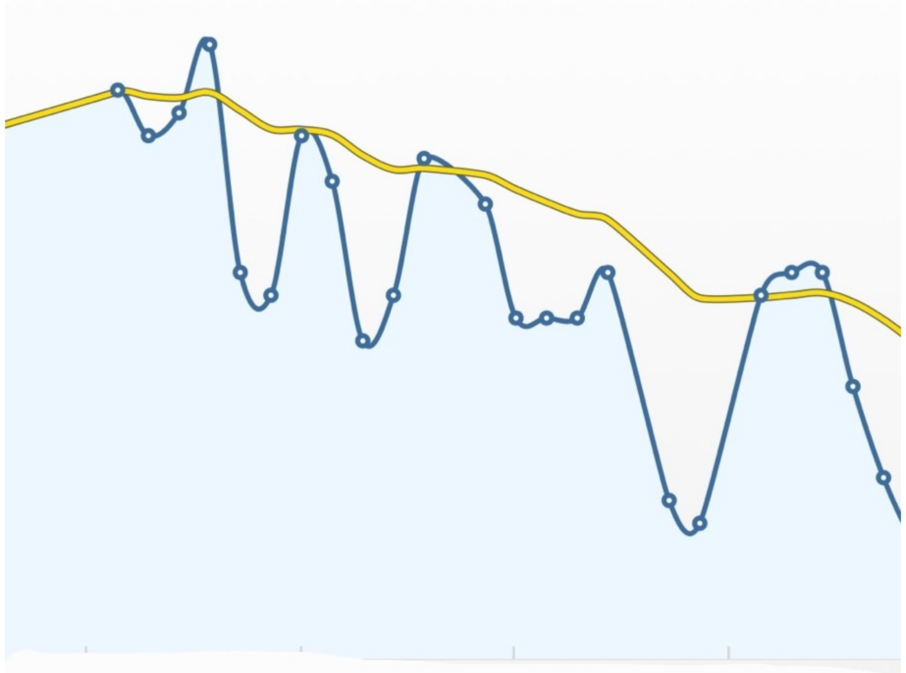
Time Series Forecasting

- What is a time series forecasting problem?
  - Scientific predictions based on historical time stamped data.
- What is structural time series?
  - Exhibiting some periodic patterns

- Why is this a time series forecasting problem?
  - TTI time series for each intersection
- Is my time series structural?
  - Hourly and daily patterns

Structural Time Series (STS)

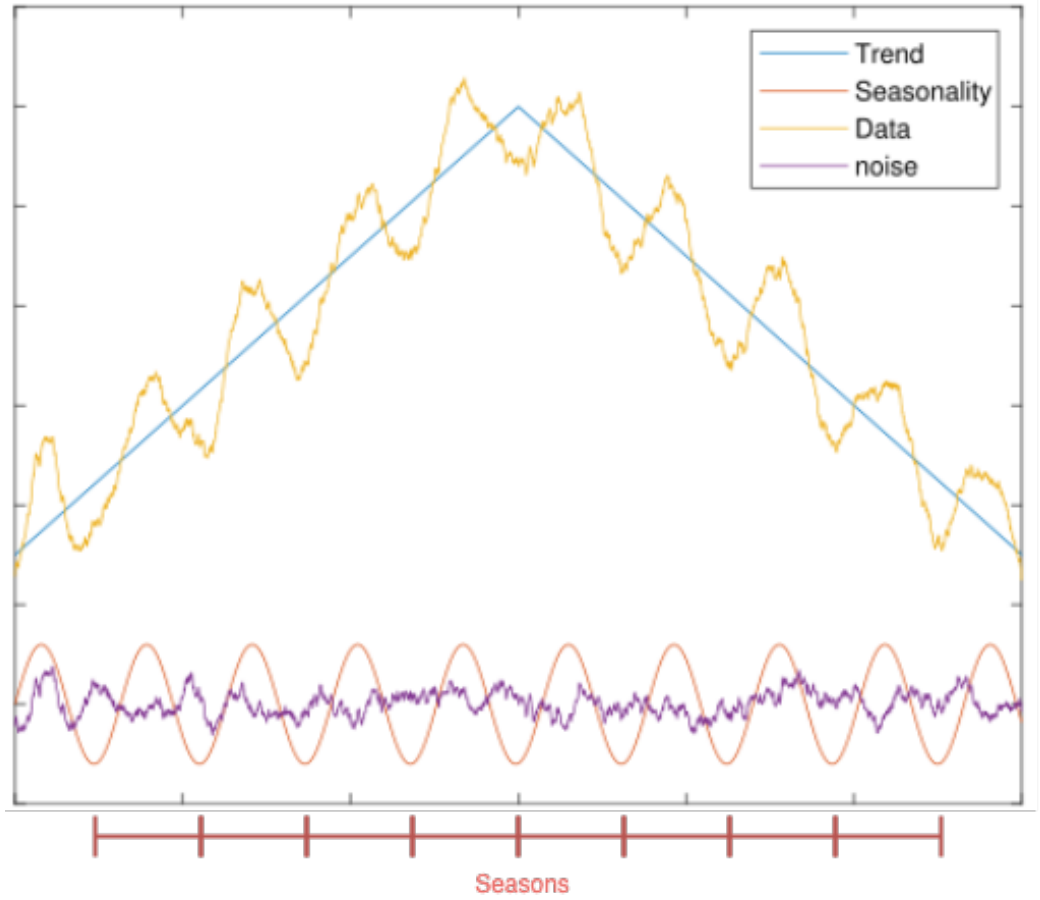
Smoothing



- Reason: short-term fluctuations
- Solution: smoothing the time series

$$\bar{y}_t = \frac{y_t + y_{t-1} + \ldots + y_{t-w-1}}{w}$$

STS Components



$$f(t) = f_1(t) + f_2(t) + \ldots + f_n(t) + \varepsilon; \varepsilon \sim N(0, \sigma^2)$$

STS Components

- Trend: Local linear trend component
- Seasonality: Fourier component
- External data: Regressor component
- Noise: Auto regressive component

Bayesian Forecasting

Likelihood

observed data given parameters

Prior

Parameters independently

Posterior

parameters given the observed data

$$P(z|y) = \frac{P(y|z).P(z)}{\int p(y|z)p(z)\,\mathrm{d}z}$$

Evidence

observed data independently

Approximations

- **Prior**: Independence assumption, and distribution assumption
- **Likelihood**: Production rule, analytical form computed
- **Evidence (marginal likelihood)**: Complex to solve, becoming constant after observations
- **Posterior**: Has to be approximated numerically using variational inference and ELBO

Predictions

$$p\left(x_T \mid y_{1:T}, z\right) \rightarrow p\left(x_{T+1} \mid y_{1:T}, z\right) \rightarrow p\left(x_{T+2} \mid y_{1:T}, z\right) \rightarrow \cdots \rightarrow p\left(x_{T+i} \mid y_{1:T}, z\right)$$

$$\downarrow \qquad\qquad \downarrow \qquad\qquad \downarrow$$

$$p\left(y_{T+1} \mid y_{1:T}, z\right) \rightarrow p\left(y_{T+2} \mid y_{1:T}, z\right) \rightarrow \cdots \rightarrow p\left(y_{T+i} \mid y_{1:T}, z\right)$$

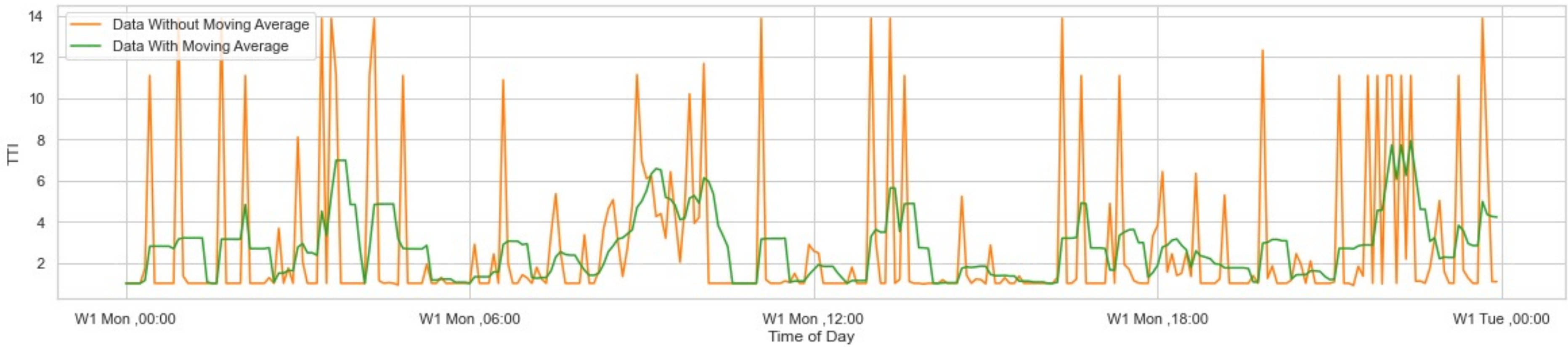
Experimental Evaluation

Data Description

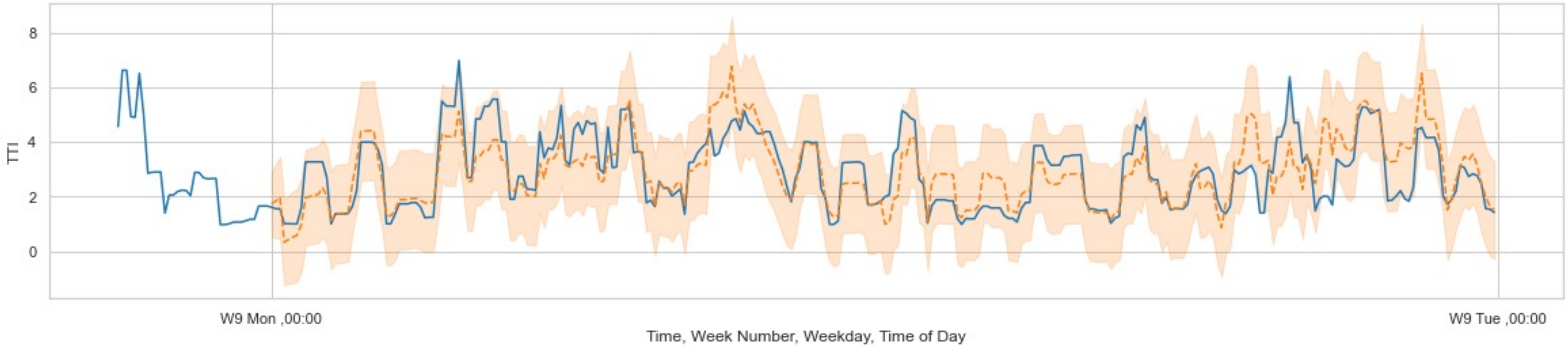
- Network data: map of York University area between Keele st, Jane st, Steeles ave, and Finch ave.
- Traffic flow data: Synthetic traffic flow dataset using the generator described in the next section.
- Duration: 9 weeks
- Training set: 8 weeks
- Test set: 1 week
- Total population residing in the network: 10,000
- Number of intersection in map: 28
- Observation rate: 5 minutes

Data Preparation

Smoothing



Forecasting

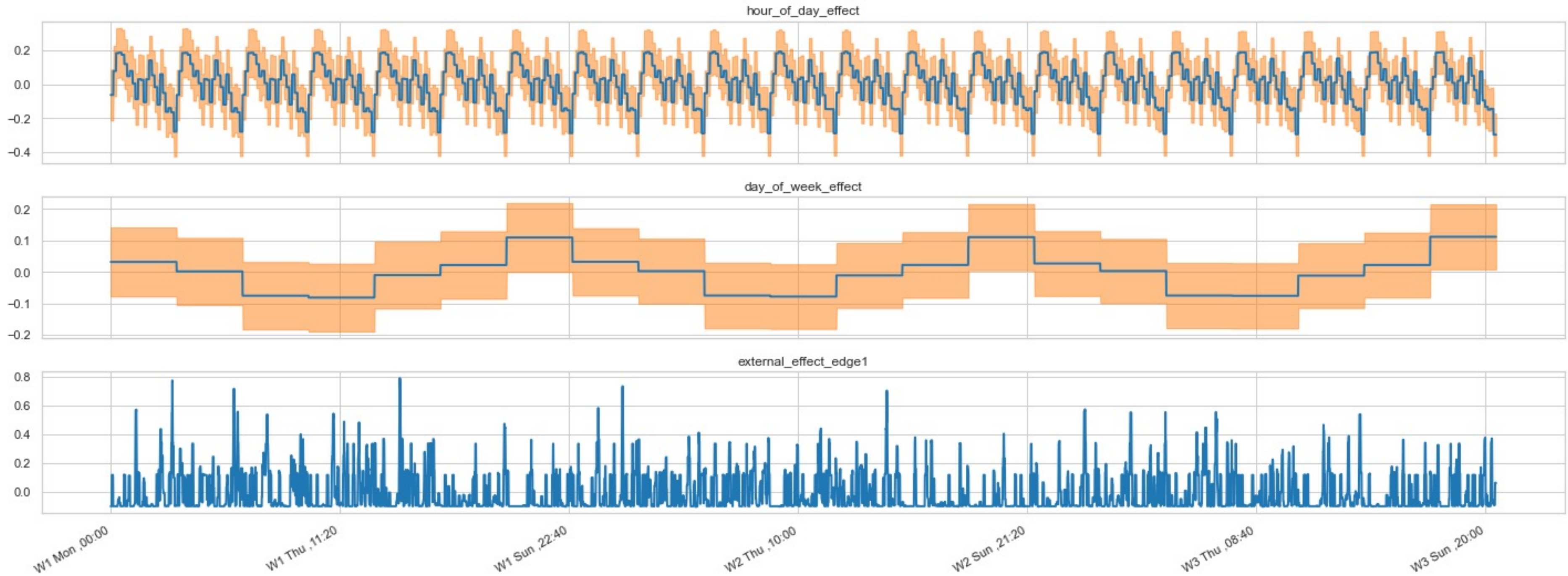


STS Decompositions

Hour of day

Day of week

External data

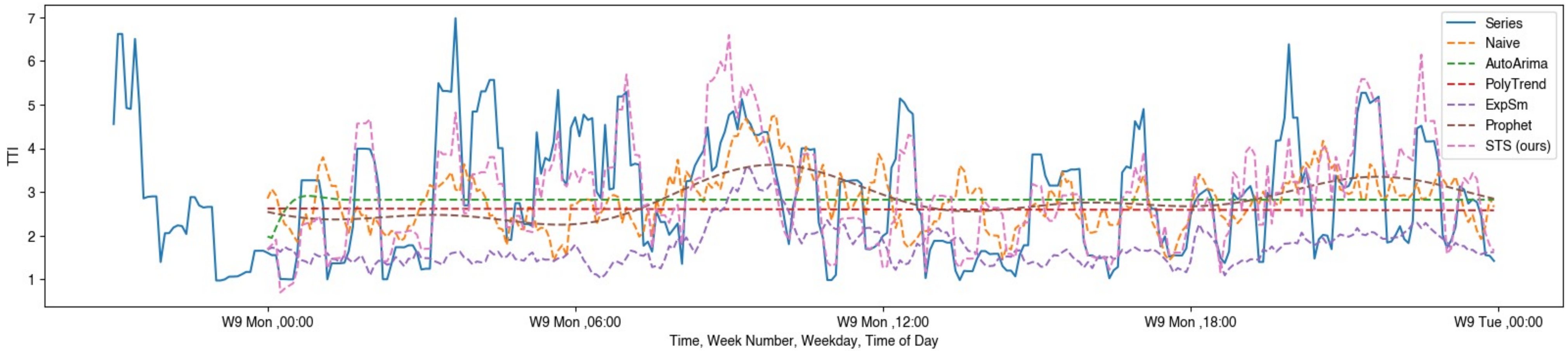


Results

Naive	AutoArima	PolyTrend	ExpSm	Prophet	STS (ours)
1.24	1.22	1.25	2.25	1.19	**0.66**

Accuracy performance of the forecasting models

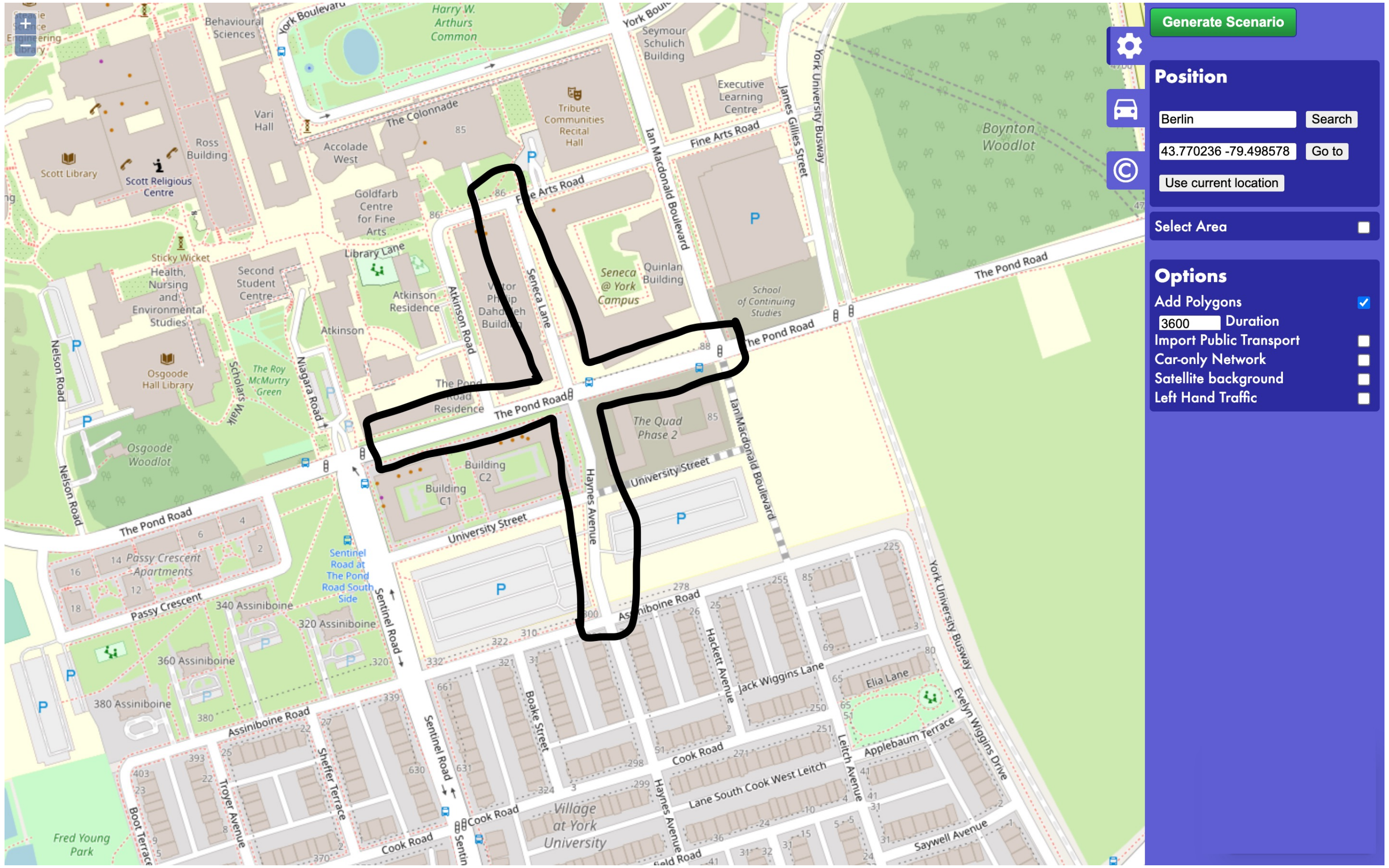
Behavior of Methods



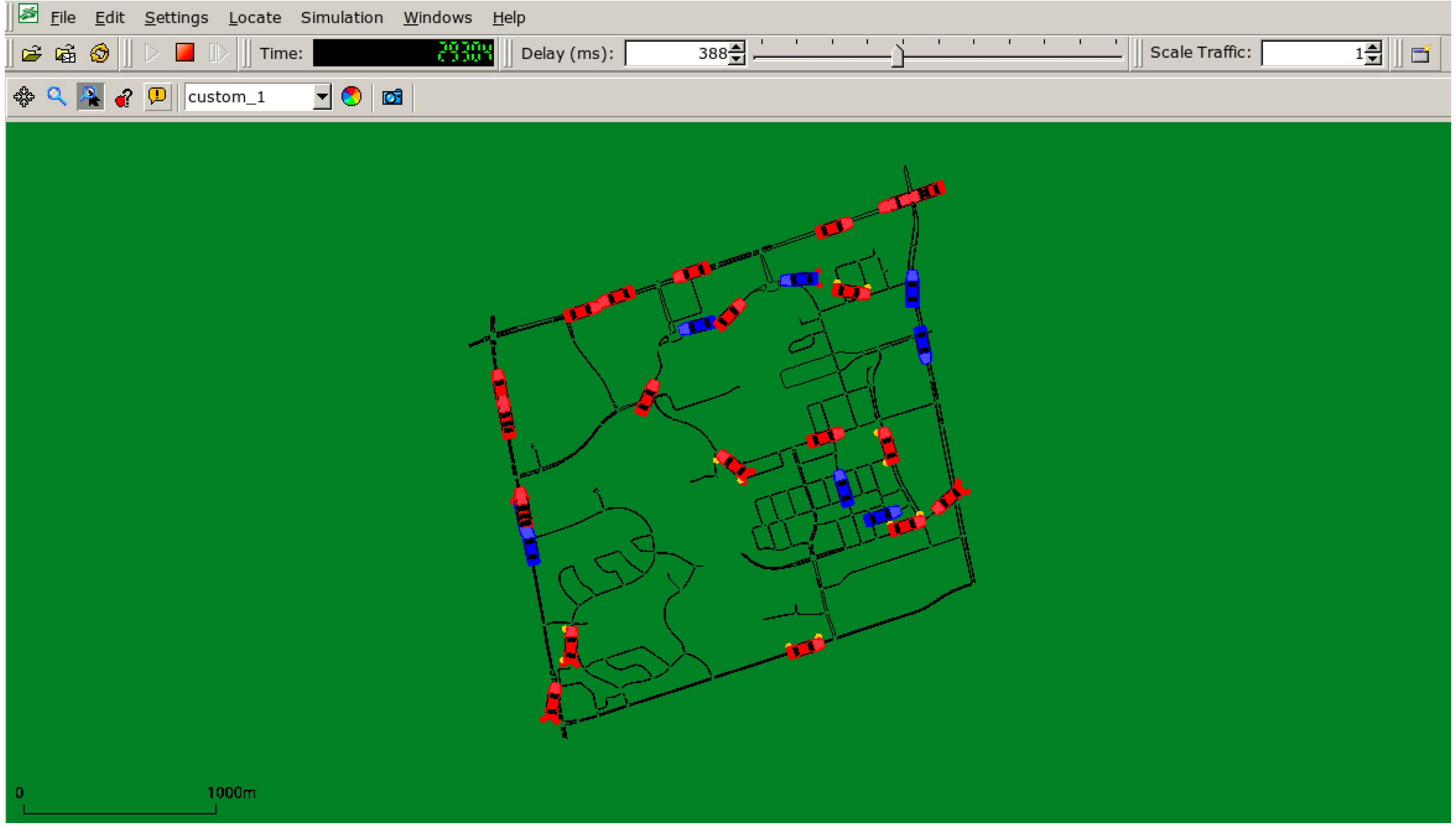
Accuracy performance of the forecasting models (visualization)

System Proof of Concept

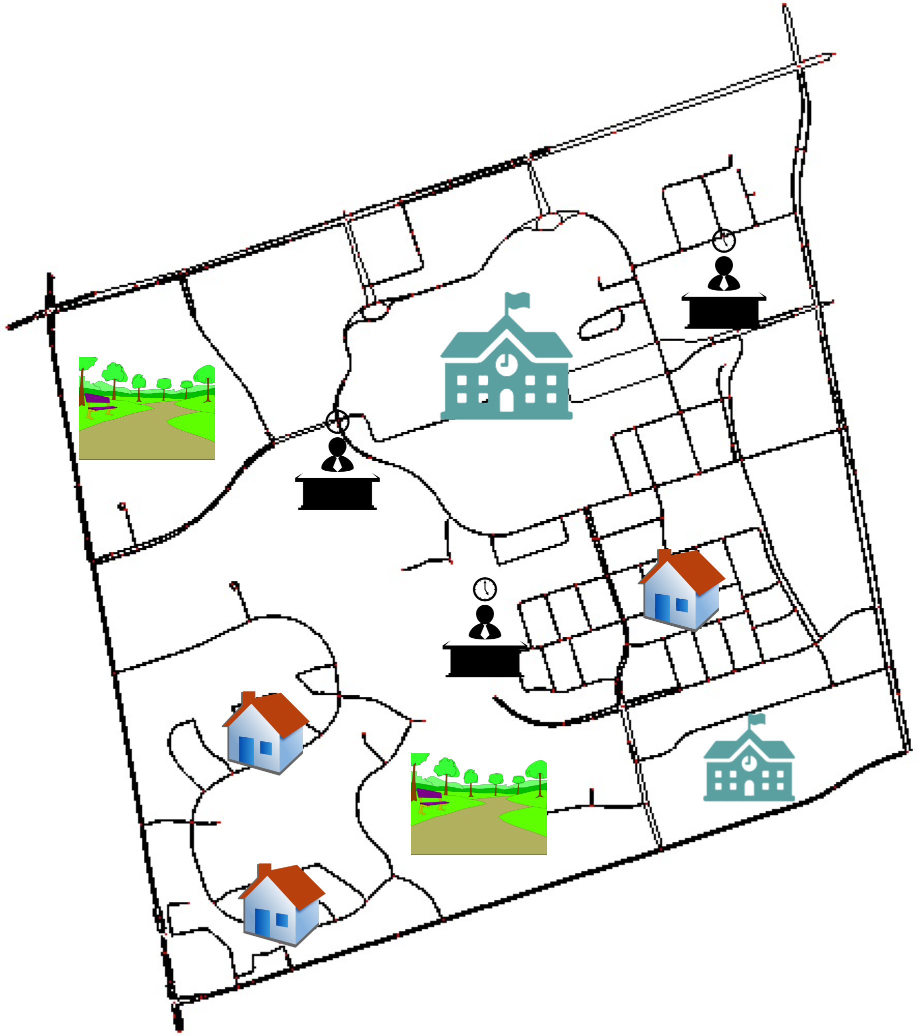
Road Network Extraction



Traffic Flow Generation



Activitygen



Dashboard

System Configuration

Network: yorku.net.xml

Edges: 3215
Junctions: 626
Paths: 740
Length: 90.842 km

Shortest paths only: ☑
Hide internal edges: ☑

Simulation: yorku.xml

Obsrv. rate: 300 s

Passenger Car Equivalent:

Passenger	1
Motorcycle	0.5
Truck	3.5
Bus	3.5
Taxi	1
Other	1

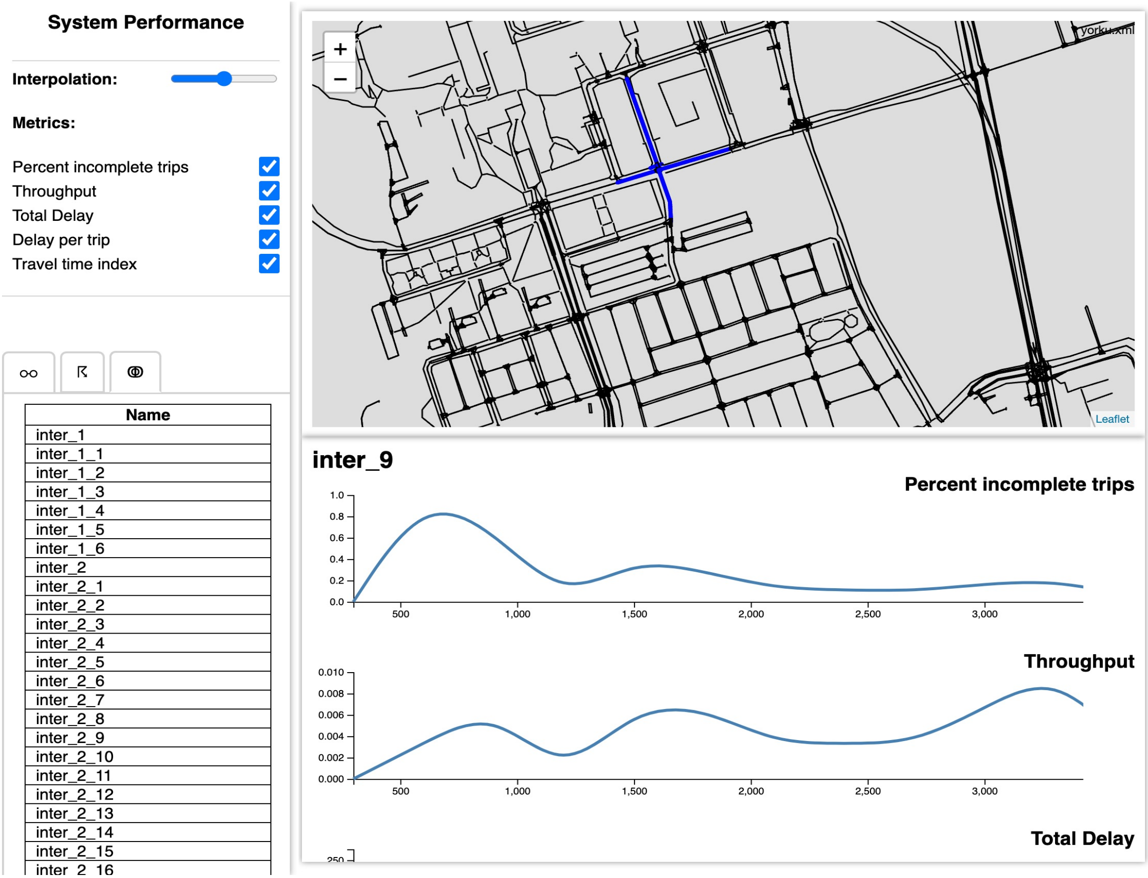
Analyze

Edges | Paths | Intersections

Create group | Group name | All | None

ID	Type	Lanes	Speed	Length
35981828#0	railway.subway	1	100 km/h	4519.11 m
8630756#1	railway.subway	1	100 km/h	4519.44 m
-219267291#0	highway.unclassified	1	30 km/h	393.61 m
219267291#0	highway.unclassified	1	30 km/h	398.07 m
839208338#2	highway.footway	1	10 km/h	941.29 m
-8068384#0	highway.tertiary	1	40 km/h	431.96 m
8068384#0	highway.tertiary	1	40 km/h	432.67 m
751431965#0	highway.footway	1	10 km/h	290.41 m
839208338#1	highway.footway	1	10 km/h	104.06 m
839208339#0	highway.footway	1	10 km/h	157.95 m
868470361#3	highway.footway	1	10 km/h	150.27 m
868470361#0	highway.footway	1	10 km/h	0.2 m
868470361#1	highway.footway	1	10 km/h	23.33 m
839208338#0	highway.footway	1	10 km/h	2.78 m
185940540#0	highway.footway	1	10 km/h	1.98 m
868470361#2	highway.footway	1	10 km/h	44.56 m

Dashboard


System Performance
Interpolation:
Metrics:
Percent incomplete trips
Throughput
Total Delay
Delay per trip
Travel time index
Name
inter_1
inter_1_1
inter_1_2
inter_1_3
inter_1_4
inter_1_5
inter_1_6
inter_2
inter_2_1
inter_2_2
inter_2_3
inter_2_4
inter_2_5
inter_2_6
inter_2_7
inter_2_8
inter_2_9
inter_2_10
inter_2_11
inter_2_12
inter_2_13
inter_2_14
inter_2_15
inter_2_16
yorku.xml
Leaflet
inter_9
Percent incomplete trips
Throughput
Total Delay

Contributions and Future Work

Contributions

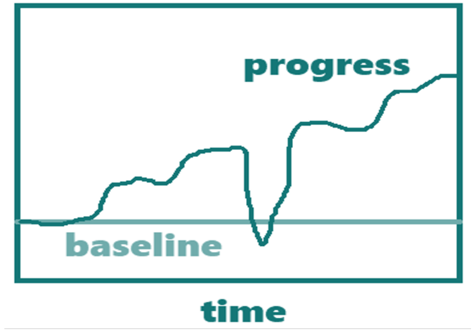
Operational Performance

Industry Standards

Real-time MOE Calculation

Congestion Forecasting

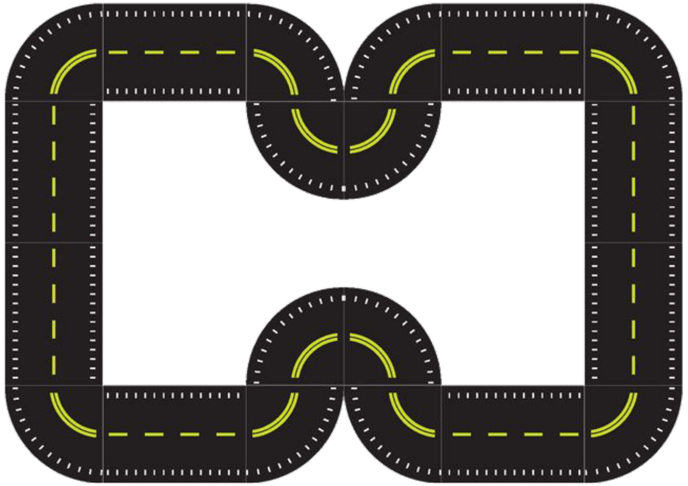
Safety and Efficiency



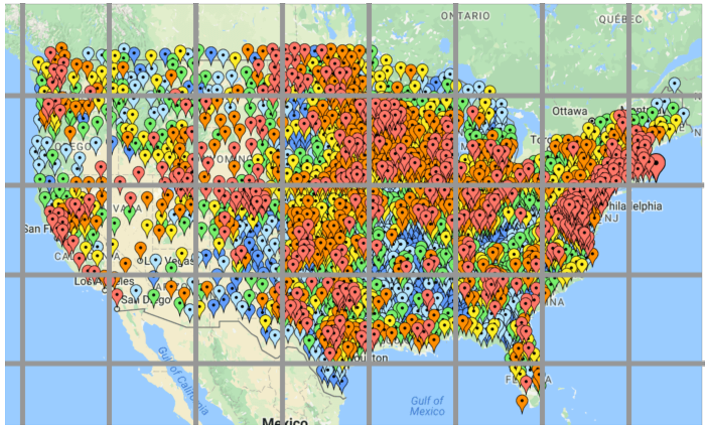
Realistic Empirical Study

Future Work

Real World Data



Travel Time Estimation



Network Summarization

Thank you

Questions?