Evaluating and Forecasting the Operational Performance of Road Intersections

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M.Sc. Thesis of Ali Nematichari
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

- Intersection
- Lanes in the same edge
- Single edge (curved shape)
- Edges
- Junctions
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 $\tau = \{C_i\}$
• Registry of vehicles $C_i = \{(t_i, e)\}$

Problem 1 (Real time analysis)
Given a road intersection $v \in V$ of the road network $G$ and $\tau$, we want to compute the TTI of the intersection during $[0, T]$

Problem 2 (Time series forecasting)
Given a road intersection $v \in V$ of the road network $G$ and $\tau$, we want to forecast the TTI of the intersection for the period $[T, T + \Delta]$, where $\Delta > 0$
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

\[ y_t = \frac{y_t + y_{t-1} + \ldots + y_{t-w-1}}{w} \]
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

Posterior
parameters given the observed data

Likelihood
observed data given parameters

Prior
Parameters independently

Evidence
observed data independently

\[
P(z|y) = \frac{P(y|z) \cdot P(z)}{\int p(y|z)p(z) \, dz}
\]
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

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

\[ \downarrow \qquad \downarrow \qquad \downarrow \]

\[ p(y_{T+1} \mid y_{1:T}, z) \rightarrow p(y_{T+2} \mid y_{1:T}, z) \rightarrow \cdots \rightarrow p(y_{T+i} \mid y_{1:T}, z) \]
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

Accuracy performance of the forecasting models

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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
Dashboard

System Performance

Interpolation: 

Metrics:
- Percent incomplete trips
- Throughput
- Total Delay
- Delay per trip
- Travel time index

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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?