Urban Traffic Flow Prediction Based on Macroscopic Road Network Model

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Outline

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Introduction

Problem Statement
As one of the major elements of ITS and key technology for the advanced traffic management and traveler information services, traffic flow prediction takes advantage of data collected with various facilities to produce accurate and timely short-term traffic states like traffic flux, travel time, and vehicle density.

Classification by Road Model

- Prediction on freeway (specific point, whole freeway link)
- Prediction on urban road network (specific segment, whole network)
Underlying Prediction Methods

1. Time series based methods
2. Spatio-temporal correlation methods

We developed...

Spatial prediction approach based on a macroscopic urban traffic network model. In the view of:

- the substantial mechanism of vehicles transmission on the road segment
- topological model of the entire urban network
- speed-density model based on the macroscopic fundamental diagram
Urban Traffic Network Model

A basic urban traffic network

Urban traffic simulated using CORSIM

Yanyan Xu, ICNSC2012, Beijing
Network Model

Urban traffic network topology

\[ 
\begin{pmatrix}
0 & S_N & 0 & S_N & 0 \\
S_W & + & T_N & + & S_E \\
0 & T_W & + & + & S_E \\
S_W & T_S & + & T_E & 0 \\
0 & 0 & S_S & S_S & 0
\end{pmatrix}
\]

9 different kinds of structures
Network Model

Decompose a road network into basic elements

- \( E(i,j) \) is defined by the coordinate \((i,j)\) and links assembling to the junction.
- \( E(i,j) \) can express any kind of element, such as “Cross”, “T-shape”, “Source”...
How to get the traffic flux of a link?
Network Model

Number of departure vehicles turning $t$ from link $D$

$$d_{Dt}(i, j, k) = \begin{cases} 
\min\{x_{Dt}(i, j, k) + a_{Dt}(i, j, k), \\
f_{Dt, dsi}(i, j, k), \\
s_{Dt}(i, j) T \} 
\end{cases}$$

if $g_{Dt}(i, j, k) = 1$

$$0$$

if $g_{Dt}(i, j, k) = 0$

where

$$s_{Dt}(i, j) = \begin{cases} 
1/t_h & \text{if } t = \{l, r\} \\
1/t_h \cdot (W_D(i, j) - 1) & \text{if } t = s, \ T\text{-shape} \\
1/t_h \cdot (W_D(i, j) - 2) & \text{if } t = s, \ Cross 
\end{cases}$$
So, the free space of link $D$ in $E(i, j)$ is updated by

$$f_D(i, j, k + 1) = f_D(i, j, k) - d_{in,D}(i, j, k) + d_{out,D}(i, j, k)$$
Road link model with fixed-time signal

Number of vehicles access in and departure from link $D$:

$$d_{in,D}(i, j, k) = \sum_{D_u \in D_{upl}} d_{D_u,D}(i, j, k)$$

$$d_{out,D}(i, j, k) = d_{Ds}(i, j, k) + d_{Di}(i, j, k) + d_{Dr}(i, j, k)$$
Link Model

Number of vehicles arriving at the tail of the queue

\[
a_D(i, j, k) = \left( \frac{T - \gamma_D(i, j, k)}{T} \right) d_{in,D}(i, j, k - \delta_D(i, j, k) - \sigma) + \left( \frac{\gamma_D(i, j, k)}{T} \right) d_{in,D}(i, j, k - \delta_D(i, j, k) - 1 - \sigma)
\]

where

\[
\delta_D(i, j, k) = \text{fix} \left( \frac{(C_D(i, j) - x_D(i, j, k))L_{veh}}{W_D(i, j)v_D(i, j, k)T} \right)
\]

\[
\gamma_D(i, j, k) = \text{rem} \left( \frac{(C_D(i, j) - x_D(i, j, k))L_{veh}}{W_D(i, j)v_D(i, j, k)T} \right)
\]

Finally, the number of waiting vehicles in queue is updated by:

\[
x_{Dt}(i, j, k + 1) = x_{Dt}(i, j, k) + a_{Dt}(i, j, k) - d_{Dt}(i, j, k)
\]
Speed-Density Model

Motivation

- Vehicles would not keep free flow speed all the time on the link, especially located in a high density segment.
- Apply a speed-density model to the link model to make the travel time more close to the real traffic situation.

Macroscopic Fundamental Diagram

\[
\text{average traffic flow rate} \leftrightarrow MFD \leftrightarrow \text{average traffic density}
\]
Speed-Density Model

Macroscopic Fundamental Diagram (MFD)

In MFD, \( v_0 \) is known, \( q_m = W_D(i, j)/t_h, \) \( r_{jam} = W_D(i, j)/L_{veh} \).
Average speed in link $D$ of $E(i,j)$ at time $k$ can be calculated as follows:

$$v_D(i,j,k) = \frac{q}{r} = \begin{cases} 
    v_0^0(i,j) & 0 \leq r < r_1 \\
    \frac{q_m v_0^0(i,j)}{r_{jam} v_D^0(i,j) - q_m} \cdot \frac{r_{jam} - r}{r} & r_1 \leq r \leq r_{jam}
\end{cases}$$

where

$$r_1 = \frac{q_m(i,j)}{v_D^0(i,j)}$$

and

$$r = \left[1 - \frac{f_D(i,j,k)}{C_D(i,j)}\right]/L_{veh}$$
The microscopic traffic simulation software package TSIS-CORSIM exploited by FHWA is employed to simulate the real traffic.

Predict the future average traffic flux at the interval of 5 minutes during 4 hours.

The sampling time interval $T$ is equal to 1s, both for CORSIM and the proposed UTN model.

Evaluation with MaxAPE, MinAPE, MAPE.
A Simulation Case Study

**Figure:** Network input flow rate
A Simulation Case Study

**Figure:** Prediction result of link #1

**Figure:** Prediction result of link #2
### A Simulation Case Study

#### Error analysis of link #1

<table>
<thead>
<tr>
<th></th>
<th>MaxAPE(%)</th>
<th>MinAPE(%)</th>
<th>MAPE(%)</th>
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<tbody>
<tr>
<td>Lin’s Model</td>
<td>23.46</td>
<td>0.50</td>
<td>8.22</td>
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<td>Proposed Model</td>
<td>20.03</td>
<td>0.21</td>
<td>7.51</td>
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#### Error analysis of link #2

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<th>MaxAPE(%)</th>
<th>MinAPE(%)</th>
<th>MAPE(%)</th>
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<tbody>
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<td>Lin’s Model</td>
<td>35.26</td>
<td>0.64</td>
<td>12.74</td>
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<tr>
<td>Proposed Model</td>
<td>34.47</td>
<td>0.13</td>
<td>11.16</td>
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</tbody>
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Conclusions and Future work

Conclusions

- Predict traffic flow of urban arteries with fixed-time signalized junctions
- Based on the macroscopic spatial structure of UTN
- Considering the mechanism of traffic flow transmission
- Without historical traffic data
- Suit for real-time prediction

Future work

- Acquire more precise queue on the link (GPS?)
- Transplant our model to real urban road network
Thank you!

& Questions?