Using Micro-simulation to Evaluate Traffic Delay Reduction from Workzone Information Systems

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Introduction

• Work zone
  – Noticeable source of accidents and congestion

• AWIS:
  – Automated Workzone Information Systems
  – Components:
    • Sensors
    • Portable CMS
    • Central controller
  – Benefits:
    • Provide traffic information
    • Potentially
      – Improve safety
      – Enhance traffic system efficiency
• AWIS systems in market
  – ADAPTIR by Scientex Corporation
  – CHIPS by ASTI
  – Smart Zone by ADDCO Traffic Group
  – TIPS by PDP Associates
  – Quixote, Road Traffic Technology
  – Intelligent Zones, National Intelligent Traffic Systems (NITS)

• Evaluation studies
  – Most
    • System functionalities
    • Reliability
  – Few
    • Effectiveness
    • Delay saving
Study site and CHIPS system

• Site Location
  – City of Santa Clarita, 20 miles north of LA
  – On I-5: 4-lane freeway with the closure of one lane on the median side
  – Construction zone: 1.5 miles long
  – Parallel route: Old Road
  – Congestion: occurred in Holidays and Sundays

• CHIPS configuration
  – 3 traffic sensors
  – 3 message signs
### System Setup

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Queue Detector</th>
<th>CMS Combo Message</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RTMS-1</td>
<td>RTMS-2</td>
</tr>
<tr>
<td>SBS01</td>
<td>F</td>
<td>F</td>
</tr>
<tr>
<td>SBS02</td>
<td>T</td>
<td>F</td>
</tr>
<tr>
<td>SBS03</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>SBS04</td>
<td>T</td>
<td>T</td>
</tr>
</tbody>
</table>

T = Queue being detected, F = No queue being detected

- **CMB06**: SOUTH 5/TRAFFIC/JAMMED, AUTOS/USE NEXT/EXIT
- **CMB07**: JAMMED/TO MAGIC/MOUNTAIN, EXPECT/10 MIN/DELAY
- **CMB08**: JAMMED/TO MAGIC/MOUNTAIN, EXPECT/15 MIN/DELAY
- **CMB09**: JAMMED TO MAGIC MTN, AVOID DELAY USE NEXT EXIT
- **CMB11**: SOUTH 5 ALTERNAT ROUTE, AUTOS USE NEXT 2 EXITS
CHIPS System Structure
Caltrans pilot evaluation study

• Evaluation aspects
  – Functionality
  – Reliability
  – Effectiveness
    • Safety
    • Diversion
    • Drivers’ acceptance
  – Cost and benefits

• Method
  – Field operational test for the first three aspects
Purpose of this study

• Traffic delay reduction because of AWIS
  – Quantify delay reduction
  – To justify the benefits of AWIS

• Methods?
  – Field operational test
    • Uncontrolled factors, e.g. incidents, variations of demands
  – Traffic analysis tools
    • Microscopic simulation
      – Model vehicles in fine details

• When to select micro-simulation?
  – ITS strategy
  – System wide congestion that changes dynamically, etc
  – Diversion

• AWIS planning, last slice
Microscopic simulation introduction

• Microscopic simulation
  – a software tool to model traffic system, including roads, drivers, and vehicles, in fine details.
  – models: AIMSUN, CORSIM, MITSIM, PARAMICS, TransModeler, VISSIM…

• Why simulation?
  – Can capture detailed traffic flow dynamics
  – Can be calibrated to reproduce real world scenarios
  – Can provide a visualization tool to evaluate traffic management and operational strategies
  – answer “what if” questions
Applications

- Traffic control
  - Signal
  - Ramp metering
- ITS evaluation
- Policy investigation
- Operational improvement
- Corridor management planning
- Construction management
- TMC operator training
PARAMICS: PARAllel MICroscopic Simulation
- a suite of software tools for micro traffic simulation, including:
  - Modeller, Analyzer, Processor, Estimator, Programmer
- developer: Quadstone, Scotland

Features
- large network simulation capability
- modeling the emerging ITS infrastructures
- OD estimation tool
- Application Programming Interfaces (API)
  - access core models of the micro-simulator
  - customize and extend many features of Paramics
  - model complex ITS strategies
  - complement missing functionalities of the current model
How to model ITS: Application Programming Interfaces

Diagram:
- User
- Input Interface
- Output Interface
- API
- Core Model
- Professional Community Oversight
- GUI
- Tools

Legend:
- Application Programming Interfaces
- User Interface
- API
- Delay saving after the use of AWIS: Before-after study

* Use same demand in the evaluation
Building network

- Based on
  - aerial photos
  - geometry maps

- inputs:
  - roadway network,
  - traffic detection,
  - traffic control,
  - vehicle data,
  - driving behavior
  - route choice
  - traffic analysis zones
Calibration

• Calibration:
  – Adjust model parameters to obtain a reasonable correspondence between the model and observed data
  – Time-consuming, tedious
  – Models need to be calibrated for the specific network and the intended applications

• Methods
  – Trail-and-error method
  – Gradient-based and GA

• Proposed 3-step method:
  – Capacity calibration
    • One major bottleneck, i.e. lane drop (4->3 lanes)
  – Simultaneous estimation of OD matrix and route choice
  – Network performance calibration & validation
Data collection

- Before: May 18\textsuperscript{th}, 2003
- After: Sep 1\textsuperscript{st}, 2003 (Labor Day)
- Link flows:
  - 3 on-ramps and off-ramps
  - Several link/cordon flows
  - RTMS-1 and RTMS-3
  - Loop detector station at Hasley Canyon Rd
- Probe data
  - Two routes:
    - Mainline and the Old road
  - GPS-equipped vehicles
Capacity Calibration

- Calibrate capacities at major bottlenecks
- Three parameters:
  - Mean headway
  - Drivers’ reaction time
  - Headway factor for mainline links

- Trial-and-error method
  - Choose several parameter combinations
  - Check their performances

- Results:
  - Mean headway = 0.9
  - Drivers’ reaction time = 0.8
  - ML Headway factors
    - Before model: 1.0
    - After model: 1.2
Simultaneous estimation of OD and routing parameters

- Connected and affected each other
- Formulated as

\[
\text{Min } L(q^{rs}, \theta) = \sum \left[ x_a^{\text{sim}} - x_a^{\text{obs}} \right]^2
\]

\[
x_a^{\text{sim}} = \sum_{rs} q^{rs} \left( \sum_k P_k^{rs}(\theta) \cdot \delta_{ak} \right)
\]

s.t.

\[
q^{rs} \geq 0
\]

- Solution algorithm:
  - Heuristic search method
Solution algorithm

- (1) Choose \( n \) routing parameters \( \theta_1 \) to \( \theta_n \)
- (2) Let \( i = 1 \), set \( \theta = \theta_i \).
- (3) Use PARAMICS OD estimator to estimate OD table \( \Gamma_i \).

\[
\text{Min } L(\theta) = \frac{1}{N} \sum_{a=1}^{N} GEH(x_a) = \frac{1}{N} \sum_{a=1}^{N} \left( \frac{2}{x_a^{\text{sim}}(\theta) + x_a^{\text{obs}}} \left( x_a^{\text{sim}}(\theta) - x_a^{\text{obs}} \right)^2 \right)
\]

- (4) Use PARAMICS Modeler to run simulation with OD table \( \Gamma_i \) and routing parameter \( \theta_i \).

\[
\text{MAPE}(i) = \frac{100}{N + M} \left\{ \sum_{a=1}^{N} \left| \frac{x_a^{\text{obs}} - x_a^{\text{sim}}}{x_a^{\text{obs}}} \right| + \sum_{b=1}^{M} \left| \frac{p_b^{\text{obs}} - p_b^{\text{sim}}}{p_b^{\text{obs}}} \right| \right\}
\]

- (5) If \( i < n \), set \( i = i + 1 \) and go to step 2; otherwise go to Step 6.
- (6) Obtain \( \Gamma_{\mu} \) and \( \theta_{\mu} \), whose combination yields the best calibrated OD table and routing parameter vector.
OD and routing calibration

- Route choice model
  - Dynamic feedback assignment
  - Parameters:
    - Feedback cycle (set to 1 min to simply the problem),
    - Compliance rate
- Routing parameter $\theta$ in solution algorithm:
  - 1 parameter: compliance rate
- Inputs to OD estimator:
  - Reference OD table from planning model
  - 6 cordon flows
  - 5 link flows
- Simulation period: 3-5 pm
  - Warm-up: 3-4 pm
OD and routing calibration results

- Calibrated compliance rate
  - Before model: 3%
  - After model: 18%
- Calibrated OD table:
  - Before model: mean GEH = 4.51; After model: mean GEH = 2.46
### Calibrated “after” model

<table>
<thead>
<tr>
<th>Location/Route</th>
<th>Observed</th>
<th>Simulated</th>
<th>APE (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic count (veh/hour)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>main_Hasley</td>
<td>3890</td>
<td>3867</td>
<td>0.59</td>
</tr>
<tr>
<td>main_Rye Canyon</td>
<td>4568</td>
<td>4526</td>
<td>0.92</td>
</tr>
<tr>
<td>off_Hasley</td>
<td>764</td>
<td>813</td>
<td>6.41</td>
</tr>
<tr>
<td>on_SR-126</td>
<td>480</td>
<td>477</td>
<td>0.63</td>
</tr>
<tr>
<td>on_Magic Mountain</td>
<td>713</td>
<td>674</td>
<td>5.47</td>
</tr>
<tr>
<td>Travel Time (min)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainline</td>
<td>13</td>
<td>13.1</td>
<td>0.48</td>
</tr>
<tr>
<td>Old Road</td>
<td>11</td>
<td>11.1</td>
<td>0.92</td>
</tr>
<tr>
<td>MAPE</td>
<td></td>
<td></td>
<td>2.20</td>
</tr>
</tbody>
</table>
Evaluation

- Run two simulation models:
  - Demand: after OD table
  - Before:
    - Calibrated before network, 3% compliance rate
  - After:
    - Calibrated after network, 18% compliance rate
- Number of simulation runs
  - Median run with respect to VHT

\[ N = \left( t_{\alpha/2} \cdot \frac{\delta}{\mu \cdot \varepsilon} \right)^2 \]
### Evaluation results

<table>
<thead>
<tr>
<th></th>
<th>Without AWIS</th>
<th>With AWIS</th>
<th>Reduction</th>
<th>Reduction Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Mainline Delay (hr)</strong></td>
<td>1133.4</td>
<td>672.3</td>
<td>461.1</td>
<td>40.7%</td>
</tr>
<tr>
<td><strong>Average Mainline Travel Time</strong> (min)</td>
<td>21.8</td>
<td>13.5</td>
<td>8.3</td>
<td>38.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Without AWIS</th>
<th>With AWIS</th>
<th>Increase</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total Delay on the Old Road (hr)</strong></td>
<td>7.6</td>
<td>29.9</td>
<td>22.3</td>
<td>293.2%</td>
</tr>
<tr>
<td><strong>Average Travel Time on the Old Road (min)</strong></td>
<td>9.1</td>
<td>11.1</td>
<td>2.0</td>
<td>22.0%</td>
</tr>
</tbody>
</table>
### Evaluation results (cont.)

<table>
<thead>
<tr>
<th></th>
<th>Without AWIS</th>
<th>With AWIS</th>
<th>Reduction</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>VHT (Vehicle Hours Traveled )</td>
<td>2266.7</td>
<td>1434.7</td>
<td>832.1</td>
<td>36.7%</td>
</tr>
<tr>
<td>VMT (Vehicle Miles Traveled)</td>
<td>27357.6</td>
<td>31350.9</td>
<td>-3993.3</td>
<td>-14.6%</td>
</tr>
<tr>
<td>Average Speed (mph) = VMT/VHT</td>
<td>12.1</td>
<td>21.9</td>
<td>-9.8</td>
<td>-81.0%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Without AWIS</th>
<th>With AWIS</th>
<th>Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diversion Volume on Hasley off-ramp</td>
<td>145</td>
<td>369</td>
<td>224</td>
</tr>
<tr>
<td>Diversion Rate on Hasley off-ramp</td>
<td>3.5%</td>
<td>7.8%</td>
<td>4.3%</td>
</tr>
</tbody>
</table>
Conclusion

• Contribution
  – Introduction of a microscopic simulation method to evaluate traffic delay reduction from AWIS
    • Calibration of two simulation models
  – Calibration
    • a simultaneous estimation of OD table and routing parameters
• Evaluation shows AWIS can effectively:
  – Reduce traffic delay
  – Improve overall performance of the traffic system
• Outreach: publications
  – TRB, TRR
Use of the method for AWIS planning

- Develop a simulation model for the existing network
  - Baseline OD table
- Build simulation model for the WZ case
  - Capacity calibration (i.e. calibrate mainline headway factor)
    - Use HCM capacity value as target value
  - Routing: compliance rate $\alpha$
    - Network geometry
    - Percentage of familiar drivers
- Build simulation model for the WZ+AWIS case
  - Capacity calibration
    - Use an expected capacity value, or
    - Apply 1.2 headway factor derived from this study
  - Routing: compliance rate $\beta$ could vary (maximum 20%)
    - Network geometry
    - Traffic information
- Simulation for two scenarios:
  - (1) WZ model with Baseline OD table and routing $\alpha$
  - (2) WZ+AWIS model with Baseline OD table and routing $\beta$
- Delay/benefit calculation
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Some technical information about micro-simulation:
http://www.clr-analytics.com