Traffic Study for Deerfoot Trail, Calgary

Capacity Drop, Hysteresis, MFD and METANET Model for Deerfoot Trail

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Karan Arora joined University of Calgary in 2015.

He pursued his Bachelors in Civil Engineering, majored in Transportation Engineering and Business Management, from Indian Institute of Technology (IIT) Roorkee, India. He has a work experience of 1 year as a Graduate Highway Engineer with Systra MVA Consulting (France) Pvt. Ltd., New Delhi.

Currently, his research focuses on studying the impact of Intelligent Transportation System (ITS) – including Variable Speed Limit and Ramp Metering Design on various freeways and arterials in the city of Calgary.
Traffic Congestion
Introduction

To accommodate increasing traffic demand, **constructing new highways and adding lanes is not always the best option:**

<table>
<thead>
<tr>
<th>Category of Area</th>
<th>4 Lanes Highway</th>
<th>6 Lanes Highway</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural &amp; Suburban Area</td>
<td>$4-$6 million per mile</td>
<td>$8-$10 million per mile</td>
</tr>
<tr>
<td>Urban Area</td>
<td>~$7 million per mile</td>
<td>~$11 million per mile</td>
</tr>
</tbody>
</table>

Through proper management of existing transportation system, traffic condition can be improved to a very great extent.

For example, freeways traffic can be made more smoother with the help of **Ramp Metering**, **Variable speed limit design**, etc.

Traffic management for one expressway can never be applied to other expressways. **Every expressways and urban traffic have there unique characteristics of traffic movement**
Greenshield’s theory
Basic Theoretical Model

Van Aerde Car-Following Model
Practically the diagrams usually deviates

Fig. 1 Fundamental Diagrams of the Greenshield Traffic Flow Model.
Fig. 2 The Van Aerde Traffic Stream Model.
Deerfoot Data

- **Freeway section** of the Queen Elizabeth II Highway (Highway 2) in Calgary, Alberta, Canada
To examine the congestion phenomenon this study focuses on:

- Macroscopic Study
  i) Capacity drop
  ii) Hysteresis
  iii) Macroscopic Fundamental Diagram
  iv) METANET Model
    - Variable Speed Limit (VSL)
    - Ramp Metering (RM)
Existence of Capacity Drop at Bottleneck Locations

Flow-Density Diagram (07 08 2015, Detector 113)

- Uncongested
- Congested
- Capacity Drop
Hysteresis Phenomenon

- Existence of Hysteresis Loops at Bottleneck locations
- Hysteresis disappears in case of aggregate data
Macroscopic Fundamental Diagram (MFD)

Flow-Density Curve (Aggregated)

Scatter almost disappear after aggregating the data from different detectors

Weekdays Average  
Weekends Average
\[ q_{m,i}(k) = \rho_{m,i}(k) \cdot v_{m,i}(k) \cdot \lambda_m \]

\[ \rho_{m,i}(k + 1) = \rho_{m,i}(k) + \frac{T}{L_{m,i} \cdot \lambda_m} \cdot \left[ q_{m,i-1}(k) - q_{m,i}(k) \right] \]

\[ v_{m,i}(k + 1) = v_{m,i}(k) + \frac{T}{\tau} \cdot \left[ V(\rho_{m,i}(k)) - v_{m,i}(k) \right] + \frac{T}{L_{m,i}} \cdot v_{m,i}(k) \cdot \left[ v_{m,i-1}(k) - v_{m,i}(k) \right] - \eta_{m,i}(k) \cdot \frac{T}{\tau \cdot L_{m,i}} \cdot \frac{\rho_{m,i+1}(k) - \rho_{m,i}(k)}{\rho_{m,i}(k) + \kappa} \]

\[ V(\rho_{m,i}(k)) = \min \left( v_{t,m} \cdot \exp \left[ -\frac{1}{\phi_m} \cdot \left( \frac{\rho_{m,i}(k)}{\rho_{cr,m}} \right)^{\phi_m} \right], (1 + \alpha) \cdot v_{lim,m,i}(k) \right) \]

\[ \eta_{m,i}(k) = \begin{cases} \eta_{\text{high}} & \text{if } \rho_{m,i+1}(k) > \rho_{m,i}(k), \\ \eta_{\text{low}} & \text{else} \end{cases} \]

(Flow-Density Equation)

(Conservation of Vehicles)

(Speed-Dynamics Equation)

Relaxation, Convection and Anticipation

(Desired Speed)
Optimization Problem

- **Objective Function (Least Square Optimization Problem)**
  Minimize the error term:

  \[
  E_{RMS,\text{norm}} = \sqrt{\frac{1}{N_d \cdot N_k} \sum_{j=1}^{N_d \cdot N_k} \left( \frac{Q_{\text{sim},j} - Q_{\text{dat},j}}{2400} - 1 \right)^2 + \frac{1}{N_d \cdot N_k} \sum_{j=1}^{N_d \cdot N_k} \left( \frac{V_{\text{sim},j} - V_{\text{dat},j}}{120} \right)^2}
  \]

- **Parameters to Calibrate (with Lower and Upper Bound)**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Lower Bound</th>
<th>Upper bound</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\kappa$</td>
<td>Density offset</td>
<td>0</td>
<td>200</td>
</tr>
<tr>
<td>$\eta_{\text{high}}$</td>
<td>Anticipation increasing density</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>$\eta_{\text{low}}$</td>
<td>Anticipation decreasing density</td>
<td>0</td>
<td>120</td>
</tr>
<tr>
<td>$\phi_m$</td>
<td>Fundamental diagram parameter</td>
<td>0.1</td>
<td>30</td>
</tr>
<tr>
<td>$v_{f,m}$</td>
<td>Free flow speed</td>
<td>50</td>
<td>150</td>
</tr>
<tr>
<td>$\tau$</td>
<td>Speed changing response time</td>
<td>5</td>
<td>120</td>
</tr>
<tr>
<td>$\rho_{cr,m}$</td>
<td>Critical density</td>
<td>5</td>
<td>100</td>
</tr>
</tbody>
</table>
MATLAB "fminsearchbnd"
A tool to optimize unconstrained non linear functions
Uses Derivative free method

- Solves optimization problems
- Uses derivative-free method
- Outputs the optimum solution
<table>
<thead>
<tr>
<th>Symbol</th>
<th>Name</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \kappa )</td>
<td>Density offset</td>
<td>104.4357 veh/km/lane</td>
</tr>
<tr>
<td>( \eta_{\text{low}} )</td>
<td>Anticipation increasing density</td>
<td>99.9996 km(^2)/h</td>
</tr>
<tr>
<td>( \eta_{\text{high}} )</td>
<td>Anticipation decreasing density</td>
<td>20.0029 km(^2)/h</td>
</tr>
<tr>
<td>( \tau )</td>
<td>Fundamental diagram parameter</td>
<td>86.368 s</td>
</tr>
<tr>
<td>( V_{f,m} )</td>
<td>Free flow speed</td>
<td>105 km/h</td>
</tr>
<tr>
<td>( \phi_m )</td>
<td>Speed changing response time</td>
<td>0.539</td>
</tr>
<tr>
<td>( \rho_{\text{cr,m}} )</td>
<td>Critical density</td>
<td>239.994 veh/km/lane</td>
</tr>
</tbody>
</table>
*The Deerfoot Data here belongs to VISSIM Model
(Calibrated in such a way that the simulation run represent real time model)
Uncongested Flow  Congested Flow

*The Deerfoot Data here belongs to VISSIM Model
(Calibrated in such a way that the simulation run represent real time model)
Flow-Density Diagram for Uncongested and Congested Flow

Uncongested Flow (Flow - Density)

Fundamental Diagram (Flow - Density)

*The Deerfoot Data here belongs to VISSIM Model
(Calibrated in such a way that the simulation run represent real time model)
Conclusion & Future Work

- Study performed an analysis of:
  i) Capacity Drop
  ii) Hysteresis
  iii) Macroscopic/microscopic Calibration, of Deerfoot Traffic

- Future Study
  i) Further detailed study of Capacity Drop, Hysteresis
  ii) Creating Dynamic network using the concept of game theory
  iii) Impact of Variable Speed Limit Design (VSL)
  iv) Impact of Ramp Metering (RM)


Derivation of Van Aerde traffic stream model and studying the effect of Ramp Metering; By Karan Arora, Saeid Saidi, Bidoura Khondaker & Lina Kattan VOL 1, ISSUE 2, SEP-2015, International Journal of Advanced Research in Engineering (ISSN 2412 4362 Online)
http://researchplusjournals.com/index.php/journals/archive/international-journal-of-advanced-research-in-engineering-issn-2412-4362-online/1/2


ENCi 703/ENEL641 Lecture Notes UofC by Dr. Lina Kattan, Google images
QUESTIONS ?