Dynamic Intersection Signal Control Optimization (DISCO)

Hong K LO 罗康锦
cehklo@ust.hk

Civil Engineering
Hong Kong University of Science and Technology
Existing Traffic Signal Control Approaches

• Static Models
  – don’t work well for congested traffic
  – e.g. TRANSYT, MAXBAND, PASSER

• Dynamic Models
  – don’t work for light traffic
  – ignore the fundamental diagram
Flow-density Relationship

Flow $f$

Density $k$

$Q_{\text{max}}$

$(f, k_1)$

$(f, k_2)$

$k_1$

$k_2$

$k_{\text{jam}}$
Potential Problems

• No operational model for over-saturated traffic
• Traffic conditions fluctuate from light to saturated daily
• Frequent manual overrides are common
Features of This New Formulation

• Models dynamic traffic
• Captures queue dissipation and formation dynamics, kinematic waves.
• Covers the entire range of traffic conditions
• Modify traffic density to the optimum flow level in over-saturated traffic
Dynamic Intersection Signal Control Optimization (DISCO)

- Minimize total dynamic delay, subject to
  - Cell-Transmission Model (Daganzo, 1994, 1995) (CTM) to model traffic dynamics
  - Timing plan constraints, max green, cycle time, etc.
Simplified Flow-density Relationship

Flow $f$ vs. Density $k$

- $Q_{\text{max}}$
- $k_{\text{jam}}$

**Simplified**

**Original**
Model Components

• Cell-Transmission Model (Daganzo, 1994, 1995) (CTM) to model traffic dynamics
  – a convergent approximation to the Lighthill and Whitham (1955) and Richards (1956) (LWR) model

• Mixed-integer programming technique to incorporate CTM into a mathematical program
Simplified Flow-density Relationship

Flow \( f \) vs. Density \( k \):

- **Simplified**
- **Original**

- \( Q_{\text{max}} \)
- \( k_{\text{jam}} \)
Network Example
Cell-Transmission Model: Basic conditions

- **Cell inflow equation:**
  \[
  f_{i,j+1}(t) = \min \left\{ Q_{i,j+1}(t), n_{i,j}(t), \frac{W}{V} \left[ N_{i,j+1}(t) - n_{i,j+1}(t) \right] \right\}
  \]

- **Conservation condition for normal cell:**
  \[
  n_{i,j}(t+1) = n_{i,j}(t) + f_{ij}(t) - f_{i,j+1}(t)
  \]

\[\begin{array}{c}
\text{Cell } i, j \quad f_{i,j} \quad N_{i,j} \quad f_{i,j+1} \quad N_{i,j+1} \quad f_{i,j+2} \\
\end{array}\]

- Inflow Capacity Flow waiting Available space
Cell-Transmission Model: Merges

- Conservation condition for merges:

\[
S_C(t) = \min\{n_C(t), Q_C(t), \delta[N_E(t) - n_E(t)]\}
\]

\[
S_B(t) = \min\{n_B(t), Q_B(t), \delta[N_E(t) - n_E(t)]\}
\]

\[
f_E(t) = S_C(t) + S_B(t)
\]
Cell-Transmission Model: Diverges

- Conservation condition for diverges:

\[ S_B(t) = \min \left\{ \frac{n_B(t)}{\min\{Q_E(t), \delta[N_E(t) - n_E(t)]/\beta_E\}}, \frac{Q_B(t)}{\min\{Q_C(t), \delta[N_C(t) - n_C(t)]/\beta_C\}} \right\} \]

\[ f_C(t) = \beta_C \cdot S_B(t) \]

\[ f_E(t) = \beta_E \cdot S_B(t) \]
Signal Control Formulation (1)

- Objective function: minimize delay

\[
J = \min_{g, r} \sum_{t} \sum_{i \not\in E} \sum_{j} n_{ij}(t) - f_{ij}(t)
\]

- Dynamic Demand:

\[
Q_{i2}(t) = D_i(t) \quad i \in \Omega
\]
Signal control methods

Fixed Green
Fixed Cycle (FGFC)

Variable Green
Fixed Cycle (VGFC)

Variable Green
Variable Cycle (VGVC)
Test Site: Mong Kok
Model Construction
Model Validation

Delay on Intermediate Links

- Link 3 (Argyle Street-TH)
- Link 4 (Argyle Street-LT)
- Link 7 (Argyle Street-TH)
- Link 8 (Argyle Street-RT)

Average Delay (sec)

- Observed
- ctm: 50% jam
Results: Uncongested Case

Figure 5-6: Average Delay
Uncongested Flow, 50% initial cell occupancy (unc50)
Results: Congested Case

Figure 5-3: Average Delay
Congested Flow, 100% initial cell occupancy (con100)
Performance of Genetic Algorithm

- Chart showing the performance of genetic algorithms over generations.
- Legend indicating Generation 1 and Generation 10.
- X-axis: Total Delay (veh-sec)
- Y-axis: Probability Density Function (pdf)
- Comparison between different generations.
## Results

<table>
<thead>
<tr>
<th>Delay (veh-hr)</th>
<th>Existing</th>
<th>FGFC</th>
<th>VGFC</th>
<th>VGVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Demand</td>
<td>12.0</td>
<td>7.5</td>
<td>7.4</td>
<td>7.4</td>
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<tr>
<td>Time-variant Demand</td>
<td>14.9</td>
<td>10.1</td>
<td>10.0</td>
<td>10.0</td>
</tr>
<tr>
<td>Halfly-preloaded</td>
<td>19.5</td>
<td>11.5</td>
<td>11.3</td>
<td>10.9</td>
</tr>
<tr>
<td>Fully-preloaded</td>
<td>50.5</td>
<td>34.6</td>
<td>34.3</td>
<td>33.8</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>% change</th>
<th>Existing</th>
<th>FGFC</th>
<th>VGFC</th>
<th>VGVC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Demand</td>
<td>0.0</td>
<td>37%</td>
<td>38%</td>
<td>38%</td>
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<tr>
<td>Time-variant Demand</td>
<td>0.0</td>
<td>32%</td>
<td>33%</td>
<td>33%</td>
</tr>
<tr>
<td>Halfly-preloaded</td>
<td>0.0</td>
<td>41%</td>
<td>42%</td>
<td>44%</td>
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<tr>
<td>Fully-preloaded</td>
<td>0.0</td>
<td>32%</td>
<td>32%</td>
<td>33%</td>
</tr>
</tbody>
</table>
Conclusions

• DISCO works for all traffic conditions
• DISCO has superb performance for congested traffic
• DISCO shows promise as a future dynamic traffic control system