Dynamic Traffic Assignment (DTA) with Traffic Signal Control (SC)

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Motivation: Reduce Congestion

- According to Australian Government, cost due to congestion is 15 billion AUD per year
- Will rise to 20 billion by 2020
- Congestion increases fuel consumption and emission by 30%
- Higher travel time $\rightarrow$ fatigue $\rightarrow$ higher number of accidents
- Dynamic Traffic Assignment (DTA) can provide solution to these problems.
Dynamic Traffic Assignment (DTA)

“DTA describes time-varying network and demand interaction using a behaviourally sound approach”-TRB

What is DTA?
- Is a model to understand network performance
- Input → demand, network topology
- Output → optimal solution to the problem
- Solution types: System Optimal (SO), User Equilibrium (UE), bi-level

Applications:
- Network modeling and analysis
- Inter-zonal travel cost
- Identify congested link → Network Design Problem (NDP)

Variants of DTA

System Optimal DTA (SODTA)
- Drivers comply with the SO direction to minimize total system cost
- May not benefit each and every user
- Examples:
  1. Minimize system-wide travel time
  2. Minimize system-wide congestion
  3. Minimize system-wide emission
- Applications
  1. System design
  2. Performance evaluation
  3. Network Design Problem (NDP)

User Equilibrium DTA (UEDTA)
- Objective is to minimize individual user’s cost
- At equilibrium no driver can reduce his/her travel costs by changing to another route
- May attain lower system-wise performance
- Examples:
  1. Minimize user’s travel time
  2. Minimize user’s fuel consumption → emission
- Applications
  1. Performance evaluation
  2. Network Design Problem (NDP)
Traffic Signal Control (SC)

Controls the traffic movements at the intersection
Control schemes:
  a) Fixed-SC: green splits are fixed or pre-timed
  b) System Optimal SC (SOSC): decision variables determines green splits
Formulations of SC:
  a) Mixed integer: on-off control
  b) Continuous: Cycle time = discrete time interval of DNL, splits are given
    to the phases based on decision variables
Consists of:
  a) Phases
  b) Cycle length
  c) Off-set
Forms a basis for bi-level

Bi-level

Bi-level = SODTA+UEDTA
Upper level: SODTA
SODTA = SO Signal Control
Lower level: UEDTA
UEDTA = traffic assignment
Summary of DTA

- Traffic Assignment (TA) is System Optimal (SO) (no / fixed control)
- TA in User Equilibrium (UE) (no / fixed control)

Dynamic Network Loading Model

- Heart of the DTA model is the DNL model
- Specifies how traffic propagates over a given network
- DNL examples:
  - Cell Transmission Model (CTM)
  - Point Queue Model (PQM), etc.
- CTM provides relatively realistic details about
  - Traffic propagation
  - Queue formation
  - Propagation of congestion
  - Easy to implement traffic signal control
Cell Transmission Model (CTM)

- Transformation of the differential equations of hydrodynamic model to simple difference equations
- Piecewise linear relationship between flow and density at the cell level

Classification of Cells

(i) ordinary cell  (ii) diverging cell  (iii) merging cell

(i) source cell  (ii) sink cell
Linear Formulation of the CTM

Source cell

\[
x_i^t = x_i^{t-1} + d_i^{t-1} - b_i^{t-1}
\]

\[
y_{ij} - x_i^t \leq 0
\]

\[
y_{ij} \leq Q_i^j
\]

\[
y_{ij} \leq Q_j^i
\]

\[
x_j^t + \delta_j y_{ij} = \delta_j N_j^i
\]

Ordinary cell

\[
x_i^t = x_i^{t-1} + y_{ii}^{t-1} - y_{ij}^{t-1}
\]

\[
y_{ij} - x_i^t \leq 0
\]

\[
y_{ij} \leq Q_i^j
\]

\[
y_{ij} \leq Q_j^i
\]

\[
x_j^t + \delta_j y_{ij} = \delta_j N_j^i
\]

Merge and diverge:

similar model except 
sum factors to define 
number of incoming 
and outgoing flows respectively

Sink cell:

\[
y_{ki} - x_k^t \leq 0, \quad y_k^t \leq Q_k
\]

Continuous Signal Control

\[
q_i^t = \begin{cases} w_{i,Q}, & \text{if } i \in C_i, \forall t \in T, \\ 0, & \text{otherwise.} \end{cases}
\]

\[
w_{i,p}^t = w_{i,p+4}^t, \quad \forall i \in I, p \in \{1,2,3,4\}, \forall t \in T.
\]

\[
\sum_{p=1}^{4} w_{i,p}^t \leq 1 \quad \forall i \in I, \forall t \in T.
\]

\[
w_{i,2p}^t = w_{i,p+8}^t, \quad \forall i \in I, p \in \{1,2,3,4\}, \forall t \in T.
\]

\[
w_i^t \geq G_{min} \quad \forall i \in C_i, \forall t \in T.
\]
Emission Estimation

\[ v_i = \min \left\{ v_i^*, \frac{Q_i^f}{\tau} \left( \frac{(w/v)(N_i^f - x_i^f)}{x_i^f/L} \right) \right\} \]

Emission Factor

\[ EF = [a + b.v_i^f + c.(v_i^f)^2 + d.(v_i^f)^3 + e.(v_i^f)^4 + f.(v_i^f)^5 + g.(v_i^f)^6]/(v_i^f) \]

Emission estimation model for CTM

\[ E_r = \sum_{i} \sum_{f} z_i^f (EF_i(v_i^f)/r) \]

Results and Analysis: Network Topology

<table>
<thead>
<tr>
<th>Cell</th>
<th>1</th>
<th>2</th>
<th>102</th>
<th>109</th>
<th>7</th>
<th>8</th>
<th>104</th>
<th>107</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
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<td>( Q_i )</td>
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<tr>
<td>( N_i )</td>
<td>18</td>
<td>18</td>
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</tr>
<tr>
<td>( \delta_i )</td>
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<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Speed limit (m/s)</td>
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</tr>
</tbody>
</table>

Source 1

Intersection

Destination

Merging link
Results: Traffic Signal Control

- No control:
  - Vehicles free to move
  - Overly optimistic performance
  - Time to clear: 660 sec

- Pre-timed control:
  - Not flexible
  - Lowest performance
  - Time to clear: 810 sec

- Optimized control:
  - Green split given based on the traffic condition
  - Better than pre-timed control
  - Time to clear: 670 sec

Results: Occupancy and Green Split

1.1
- SO-SC queue length fluctuates more
- Pre-timed has higher queue length
- Pre-timed traffic flow is less fluctuation

1.2
- SOIC green split proportional to queue length
Results: Structure of the Solution

Structure of the SO-DTA solution
2.1 Optimization sees bottleneck
2.1 Holds at the source

Results: Emission

NO CONTROL
- Free flowing vehicles
- Overly optimistic

PRE-TIMED CONTROL
- Highest emission
- Highest occupancy
- Longer time to clear the network

OPTIMIZED CONTROL
- Better than fixed-control
- Realistic (intersection)
- Higher emission than no-control case

NOx Emission for NC, OC and FC

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## Results: Time Scale of CTM

<table>
<thead>
<tr>
<th>Cases</th>
<th>Normalized Objective</th>
<th>Emission</th>
<th>Clearance Time</th>
<th>Obj Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Cell per link no control</td>
<td>1.3368</td>
<td>1.2440E+03</td>
<td>660 sec</td>
<td>12380</td>
</tr>
<tr>
<td>2 cells per link no control</td>
<td>1.432765</td>
<td>1.3503E+03</td>
<td>655 sec</td>
<td>24400</td>
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<tr>
<td>1 Cell per link OPTIMIZED control</td>
<td>1.34</td>
<td>1.3440E+03</td>
<td>670 sec</td>
<td>12560</td>
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<tr>
<td>2 cells per link OPTIMIZED control</td>
<td>1.442773</td>
<td>1.4641E+03</td>
<td>660 sec</td>
<td>24758</td>
</tr>
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</table>

## Questions???