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

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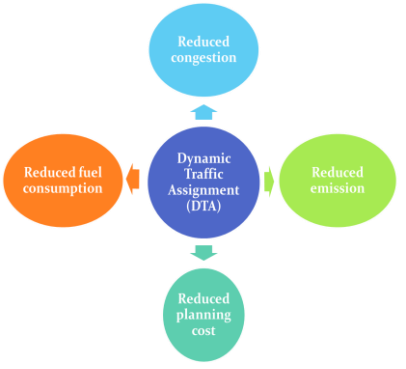
Motivation: Reduce Congestion

- 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 → fatigue → higher number of accidents
- Dynamic Traffic Assignment (DTA) can provide solution to these problems.



Dynamic Traffic Assignment (DTA)

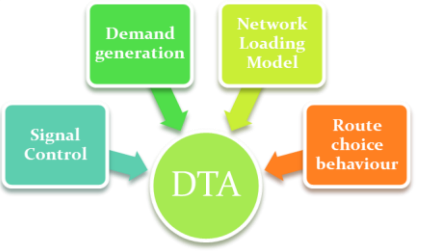
"DTA describes time-varying network and demand interaction using a behaviourally sound approach"-TRB

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:**
    - I. Minimize system-wide travel time
    - II. Minimize system-wide congestion
    - III. Minimize system-wide emission
  - **Applications**
    - I. System design
    - II. Performance evaluation
    - III. 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:**
    - I. Minimize user's travel time
    - II. Minimize user's fuel consumption → emission
  - **Applications**
    - I. Performance evaluation
    - II. 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

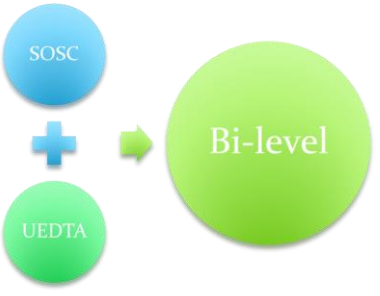
Bi-level = SODTA+UEDTA

Upper level: SODTA

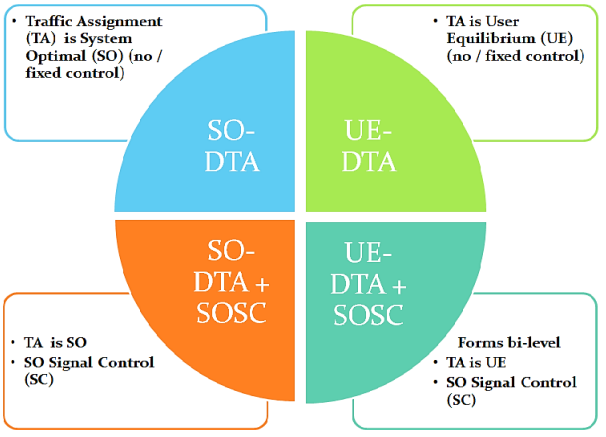
SODTA = SO Signal Control

Lower level: UEDTA

UEDTA = traffic assignment



Summary of DTA

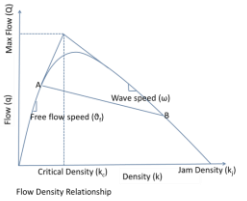


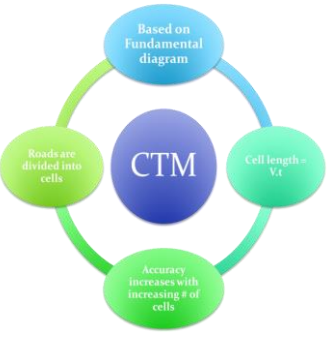
Dynamic Network Loading Model

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

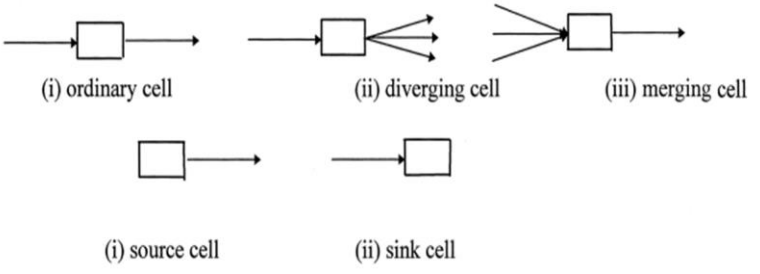
Cell Transmission Model (CTM)

- 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



Linear Formulation of the CTM

Source cell

$$x_i^t = x_i^{t-1} + d^{t-1} - y_{ij}^{t-1}$$
$$y_{ij}^t - x_i^t \le 0$$
$$y_{ij}^t \le Q_i^t$$
$$y_{ij}^t \le Q_j^t$$
$$y_{ij}^t + \delta_j^t x_j^t \leqslant \delta_j^t N_j^t.$$

Ordinary cell

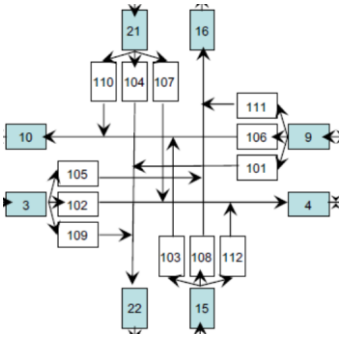
$$x_i^t = x_i^{t-1} + y_{ki}^{t-1} - y_{ij}^{t-1}$$
$$y_{ij}^t - x_i^t \le 0$$
$$y_{ij}^t \le Q_i^t$$
$$y_{ij}^t \le Q_j^t$$
$$y_{ij}^t + \delta_j^t x_j^t \leqslant \delta_j^t N_j^t.$$

Merge and diverge: similar model except sum factors to define number of incoming and out going flows respectively

Sink cell: $y_{ki}^t - x_k^t \le 0,\ y_{ki}^t \le Q_k^t$

Continuous Signal Control

$$q_i^t = \begin{cases} w_i^t Q_i & \forall\, i \in C_I,\ \forall t \in T, \\ Q_i & \text{otherwise.} \end{cases}$$
$$w_{i+p}^t = w_{i+p+4}^t \quad \forall i \in I,\ p \in \{1,2,3,4\},\ \forall t \in T,$$
$$\sum_{p=1}^{4} w_{i+p}^t \leqslant 1 \quad \forall i \in I,\ \forall t \in T,$$
$$w_{i+2p}^t = w_{i+p+8}^t \quad \forall i \in I,\ p \in \{1,2,3,4\},\ \forall t \in T.$$
$$w_i^t \geqslant G_{min} \quad \forall i \in C_I,\ \forall t \in T.$$



Emission Estimation

Speed $$v_i^t = min\left\{v, \frac{Q_i^t/\tau}{x_i^t/L}, \frac{(w/v)(N_i^t - x_i^t)/\tau}{x_i^t/L}\right\}$$

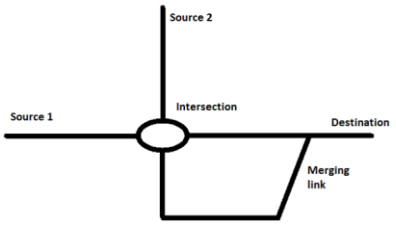
Emission Factor

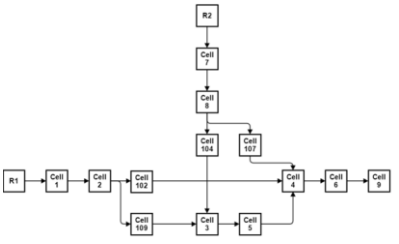
$$EF = [a + b.v_i^t + c.(v_i^t)^2 + d.(v_i^t)^3 + e.(v_i^t)^4 + f.(v_i^t)^5 + g.(v_i^t)^6]/(v_i^t)$$

Emission estimation model for CTM $$E_e = \sum_i \sum_t x_i^t EF_e(v_i^t)\tau$$

Results and Analysis: Network Topology

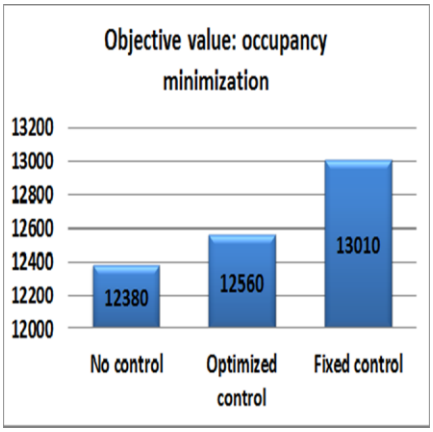
Cell →	1	2	102	109	7	8	104	107	3	4	5	6
Q_i	6	6	6	6	6	6	6	6	6	6	6	6
N_i	18	18	18	18	18	18	18	18	18	18	18	18
δ_i	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Speed limit(m/s)	15.24	15.24	15.24	15.24	15.24	15.24	15.24	15.24	15.24	15.24	15.24	15.24





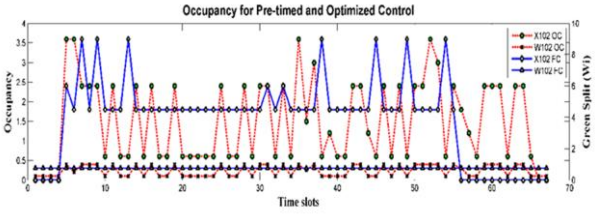
Results: Traffic Signal Control

No control	• Vehicles free to move • Overly optimistic performance • Time to clear: 660
Pre-timed control	• Not flexible • Lowest performance • Time to clear: 820 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: higher queue length • Pre-timed SC: less fluctuation
1.2	• SOSC Green split proportional to queue length

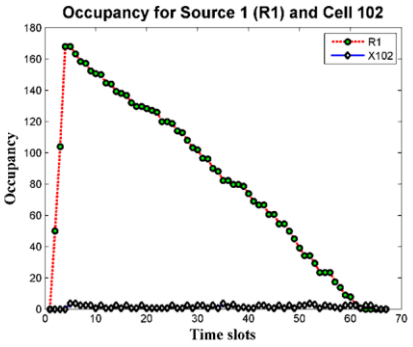


Results: Structure of the Solution

Structure of the SO-DTA solution

2.1 Optimization sees bottleneck

2.1 Holds at the source

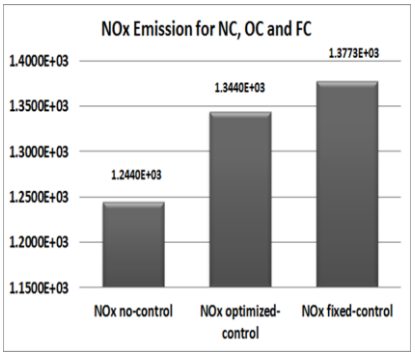


Results: Emission

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



Results: Time Scale of CTM

Cases	Normalized Objective	Emission	Clearance Time	Obj Value
1 Cell per link no control	1.3398	1.24400E+03	660 sec	12380
2 cells per link no control	1.432765	1.35030E+03	655 sec	24400
1 Cell per link OPTIMIZED control	1.34	1.34400E+03	670 sec	12560
2 cells per link OPTIMIZED control	1.442773	1.46410E+03	660 sec	24758

Questions???