Future Directions for Dynamic Traffic Assignment

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USE CASES OF DTA
Transport planning and network simulation

SUPPLY

DEMAND

COSTS

FLOWS

DESIGN

New challenges for real-time transportation and smart mobility using models

Rome, 12.03.2014
Travel time prediction and traffic forecast

New challenges for real-time transportation and smart mobility using models
Advantages of DTA in off-line and real-time applications

- Use cases of DTA models
  - transport planning and management through off-line equilibrium
  - traffic monitoring and control through real-time propagation

- Main advantage
  - explicitly reproduce vehicle queues along links and their spillback at intersections
    - thus overcoming the weak representation of congestion by volume delay functions in static assignment models
  - react to unpredicted events (accidents, road works) and control countermeasures (vms, traffic lights)
    - thus overcoming the weak sensitivity of pattern recognition models
Critical modelling choice: How does traffic look like?

- Granularity (time and space)
  - Microsimulation, Mesoscopic, Macroscopic

- Traffic model (types of congestion)
  - Under saturation - queues only in front of signals, but vanishing every cycle
  - Over saturation on the link - persistent queues
  - Spillback - queue spillovers to backward links
SUPPLY DEMAND EQUILIBRIUM
- Assuming FIFO
- Min ratio between receiving and splitted sending
- Splitting rates (not destination specific) come from
  - route choice, for each destination
  - demand flow propagation on the network
Node Model Merging

- Partition of scarce resource (receiving flow) among BS links, based on turn capacities and priorities
- If a sending flow does not fully exploit the assigned resource the rest is shared among hungry links

EWGT 2012
G. Gentile and L. Meschini - From the theory of DTA models to the practice of traffic management centers
Link Model

Guido Gentile - Shaping Transportation 2014, Berlin
Future Directions for Dynamic Traffic Assignment
Link Transmission Model for DNL with fixed splitting rates

G. Gentile and L. Meschini - From the theory of DTA models to the practice of traffic management centers
Dynamic User Equilibrium
no convenience to change route

Elastic Demand

OD Matrices

Turn Probabilities

Flow Propagation Model

Averaging for Convergence

Route Choice Model

Link Travel Times

Dynamic Network Loading

EWGT 2012
G. Gentile and L. Meschini - From the theory of DTA models to the practice of traffic management centers
OPEN AND CLOSED ISSUES
Issues on the supply side

- Intersection simulated in all their aspects (traffic signals, conflict areas, complex geometry)
- Time discretization with (possibly) short intervals (<5 sec) vs aggregated representation
- Theory of Kinematic Waves with extension of Newell approach (cumulative flows) to concave fundamental diagrams
- Spillback representation, i.e. non separable performance function in time and space
- Multimodality
Issues on the demand side

- Time discretization with long intervals (>5 min)
- RCM with implicit path enumeration
- Stochastic route choice
- Temporal Layer vs Trajectory approach
- Keep destination flows in RAM
- Allow rerouting for ITS applications
- Convergence to equilibrium without MSA
- Model calibration
FORMULATION OF DTA
Fixed-Point schema of DTA model with implicit path enumeration
Variables

- $p_{agd}(\tau)$ probability that, at time $\tau \in T$, users of class $g \in G$ directed toward destination $d \in Z$ choose to enter arc $a \in A$ conditional on being at its tail.
- $d_{odg}(\tau)$ demand flow of class $g \in G$ travelling from origin $o \in Z$ to destination $d \in Z$ and departing at time $\tau \in T$.
- $\delta_a(\tau)$ characteristic vector of arc $a \in A$ at time $\tau \in T$.
- $q_{agd}(\tau)$ flow of class $g \in G$ users entering arc $a \in A$ at $\tau \in T$ directed to $d \in Z$.
- $q_a(\tau)$ volume entering arc $a \in A$ at time $\tau \in T$.
- $\theta_a(\tau)$ exit time of arc $a \in A$ for users entering at time $\tau \in T$.
- $c_{ag}(\tau)$ cost of arc $a \in A$ perceived by users of class $g \in G$ entering at $\tau \in T$.
- $w_{agd}(\tau)$ expected disutility perceived by users of class $g \in G$ entering arc $a \in A$ at time $\tau \in T$ and directed toward destination $d \in Z$. 
Functionals

- ACM - Arc Cost Model
  \[ c_{ag}(\tau) = c_{ag}^{toll}(\tau) + \beta^{voff}_{g} \cdot (\theta_{a}(\tau) - \tau) \]

- RCM - Route Choice Model
  \[ w_{idg}(\tau) = \text{Min}(w_{adg}(\tau), \forall a \in i[+]) \]
  \[ w_{adg}(\tau) = c_{ag}(\tau) + w_{a[+]dg}(\theta_{a}(\tau)) \]
  \[ (w_{adg}(\tau) - w_{idg}(\tau)) \cdot p_{adg}(\tau) = 0 \]

- FPM - Flow Propagation Model
  \[ q_{idg}(\tau) = d_{idg}(\tau) + \sum_{a \in i[-]} q_{adg}(\theta_{a}^{-1}(\tau)) \cdot \frac{\partial \theta_{a}^{-1}(\tau)}{\partial \tau} \]
  \[ q_{adg}(\tau) = p_{adg}(\tau) \cdot q_{idg}(\tau) \]

- NCM - Network Congestion Model
  \[ \theta_{a}(\tau) = \theta_{a}(q_{A}, \tau) \]
Variational Inequality problem

- Focus on local choices at each node $i \in N$ among its forward star made by users of class $g \in G$ directed toward each destination $d \in Z$
- VI problem defined on flows (that must be feasible and cope with DNL), while feasible set defined on probabilities
- Cost functional does not include the solution of DNL

\[
\sum_{d \in Z} \sum_{g \in G} \sum_{i \in N} \sum_{a \in [+] \tau \in T} w_{adg} (q_{ADGT}^*, \tau) \cdot \left( q_{adg}^* (\tau) - p_{adg} (\tau) \cdot \sum_{b \in i[+]} q_{bdg}^* (\tau) \right) \cdot d\tau \leq 0 , \forall p_{ADGT} \in S_p^{ADGT}
\]

\[
S_p^{ADGT} = \left\{ p_{ADGT} \in \mathcal{P}^{ADGT} : p_{adg} (\tau) \geq 0 , \forall a \in A , \forall d \in Z , \forall g \in G ; \sum_{a \in [+] p_{adg} (\tau) = 1 , \forall i \in N - d , \forall d \in Z , \forall g \in G \right\}
\]
Gap function

- Measures how close we are from a dynamic user equilibrium
- Ranges from 1 to 0 (equilibrium)
- How much better users can do if they could choose again their local route without changing costs
- Small cost variations can imply large flow variations
- Local equilibrium implies global equilibrium

\[
\gamma(q^*_{ADGT}) = 1 - \frac{\sum_{d \in Z} \sum_{g \in G} \sum_{i \in N - \{d\}} \int_{\tau \in T} w_{idg} (q^*_{ADGT}, \tau) \cdot \sum_{b \in i[+]} q^*_{bdg} (\tau) \cdot d\tau}{\sum_{d \in Z} \sum_{g \in G} \sum_{i \in N - \{d\}} \sum_{a \in i[+]} \int_{\tau \in T} w_{adg} (q^*_{ADGT}, \tau) \cdot q^*_{adg} (\tau) \cdot d\tau}
\]
SOLUTION ALGORITHM
- If $c_1$ and $c_2$ are equal, then we have equilibrium and the search direction is null.
- When heading towards the equilibrium we do smaller moves.
- Proper scaling with $\sigma = 1/c_{\text{min}}$.
Numerical example
Dipole with bottleneck

In the proposed numerical examples, all links share the following characteristics: free flow speed of 90 km/h, capacity of 1800 veh/h, jam density of 150 veh/km, jam wave speed of 30 km/h, parabolic hypocritical branch of the fundamental diagram, linear hypercritical branch.

Figure 3. Dipole network. The links of the deviation 2-5 and 5-3 have length of 5 km each; all other links have equal length of 1 km. The bottleneck 2-3 has a capacity of 500 veh/h. Travel demand is constant for 40 min with entry: $d_{14} = 1500$ veh/h.
Results for dipole with bottleneck with different time discretizations
Numerical example
Exagon

Figure 5. Hexagon network. All links have equal length of 10 km, and final bottleneck of 1000 veh/h. Travel demand is constant for one hour with entries: $d_{14} = 2000$ veh/h, $d_{24} = 1000$ veh/h, $d_{16} = 500$ veh/h.
Results for Exagon with different algorithms

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