The Evolution of Transport Planning

INRO

Modeling HOT Lanes with

DYNAMEQ

… in 5 minutes or less.

What is Dynameq?

Traffic Simulation Model

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Traffic Simulation Model →

- ⇒ moves individual vehicles
- ⇒ lane-based network
- ⇒ explicit traffic signals

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Traffic Simulation Model → ⇒ moves individual vehicles
⇒ detailed network
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Simpler car-following & lane changing models

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iterative dynamic equilibrium assignment procedure

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Simpler car-following & lane changing models

↓

iterative dynamic equilibrium assignment procedure

↓ ↓

True dynamic equilibrium

Realistic traffic simulation

HOT lane decision

Multi-class model ⇒ HOT lane decision in route choice model

Multi-class assignment

Multi-class model $\Rightarrow$ HOT lane decision in route choice model

- HOV: travel time only
- LOV-toll: generalized cost

Network Effects

Assignment Models

Multi-class model ⇒ HOT lane decision in route choice model

HOV: travel time only

LOV-toll: generalized cost

Recurrent traffic conditions:
Pre-trip decision ⇒
Dynamic Equilibrium

Non-recurrent traffic conditions:
En-route decision ⇒
Driver Decision Model

Traffic Model Fidelity

Multi-class model $\Rightarrow$ HOT lane decision in route choice model

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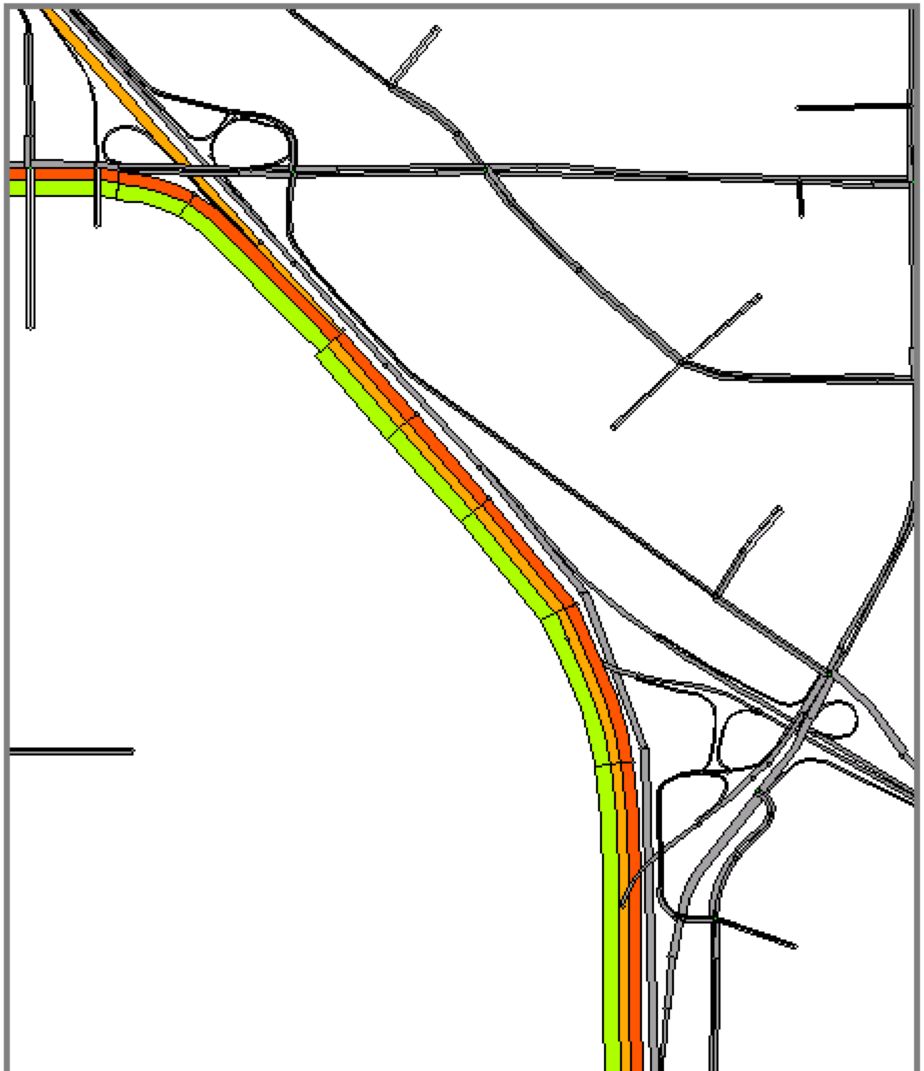
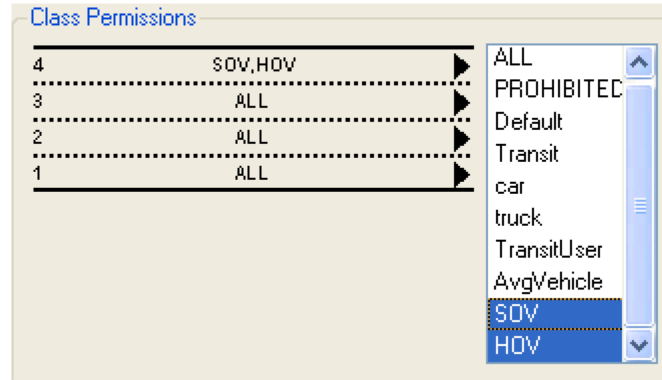
Recurrent traffic conditions:
Pre-trip decision $\Rightarrow$
Dynamic Equilibrium

Non-recurrent traffic conditions:
En-route decision $\Rightarrow$
Driver Decision Model

Weaving sections $\Rightarrow$ weaving capacity
Lane-based effects $\Rightarrow$ longitudinal and lateral congestion spillover

Class permissions by lane





Exogenous Inputs

Multi-class model ⇒ HOT lane decision in route choice model

HOV: travel time only

LOV-toll: generalized cost

Recurrent traffic conditions:
Pre-trip decision ⇒
Dynamic Equilibrium

Non-recurrent traffic conditions:
En-route decision ⇒
Driver Decision Model

Weaving sections ⇒ weaving capacity
Lane-based effects ⇒ longitudinal and lateral congestion spillover

1 – toll cost ⇒ $ for each link ($/mile)
2 – value of time ⇒ mathematical distribution ($/hr)

Proven Dynameq Framework

Traffic Simulation Model

⇒ moves individual vehicles
⇒ detailed network
⇒ explicit traffic signals

Simpler car-following & lane changing models

iterative dynamic equilibrium assignment procedure

True dynamic equilibrium
Realistic traffic simulation

Driver Decisions

Expected / Recurrent Traffic Conditions

Unexpected / Non-recurrent Traffic Conditions

Multi-class model $\Rightarrow$ Toll decision handled by route choice model

Pre-trip decision $\Rightarrow$
Dynamic Equilibrium
Generalized Cost Assignment

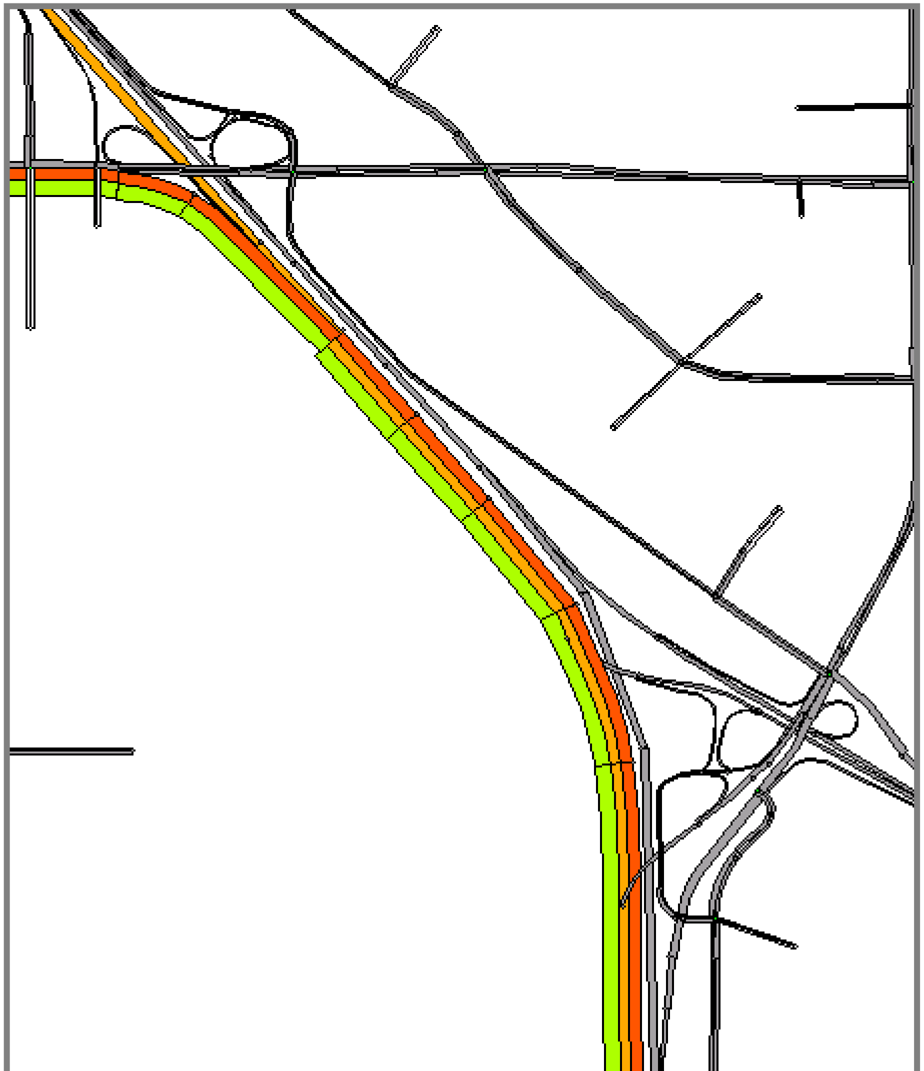
En-route decision $\Rightarrow$
Driver Decision Model

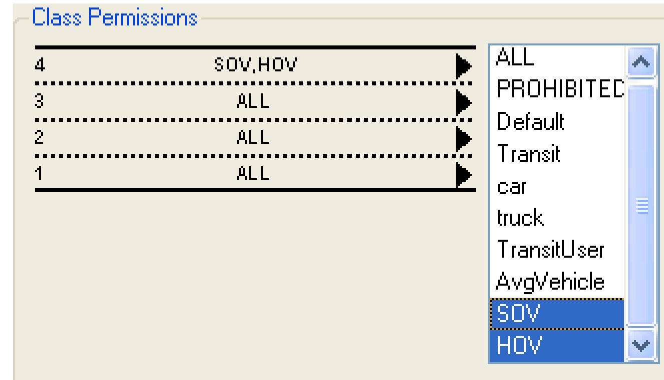
Weaving sections $\Rightarrow$ weaving capacity
Lane-based effects $\Rightarrow$ longitudinal and lateral congestion spillover

1 – toll cost $\Rightarrow$ \$ for each link (\$/mile)
2 – value of time $\Rightarrow$ mathematical distribution (\$/hr)

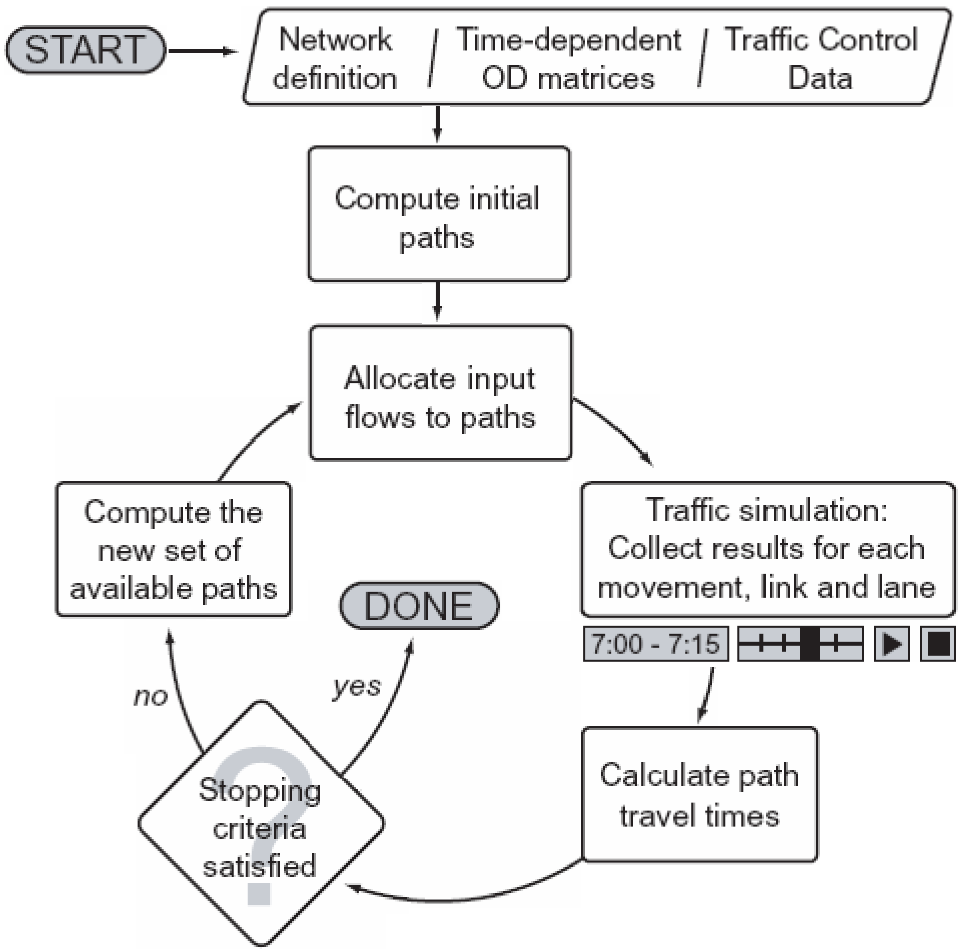
Non-freeway alternative paths

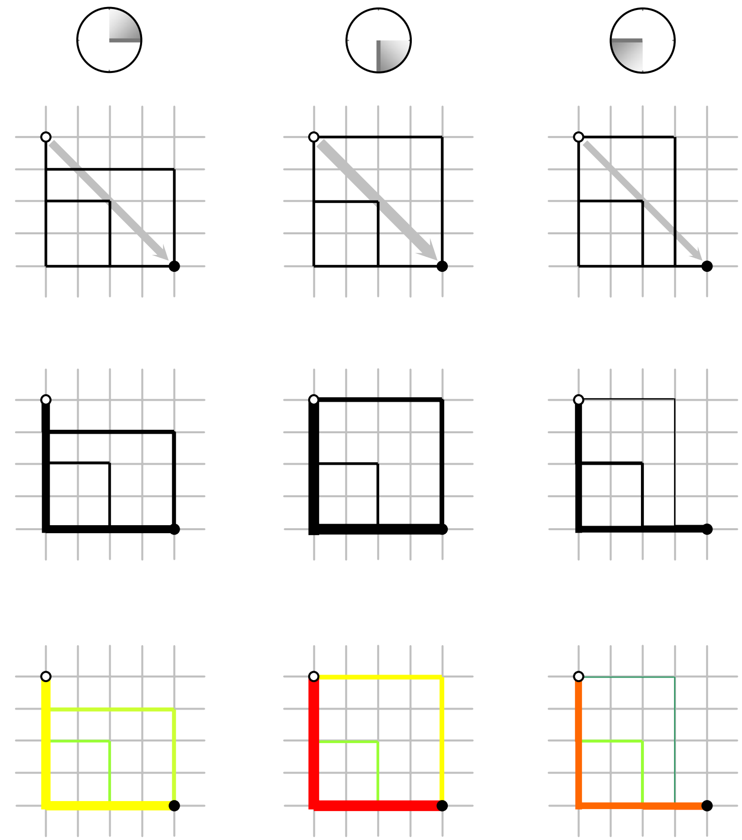
Non-freeway alternative paths





1.2 Equilibrium DTA





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1.3 Time Scales

DEMAND

- demand interval (D)

DTA parameters:

- assignment interval (A)
- simulation results interval (T)

SIMULATION

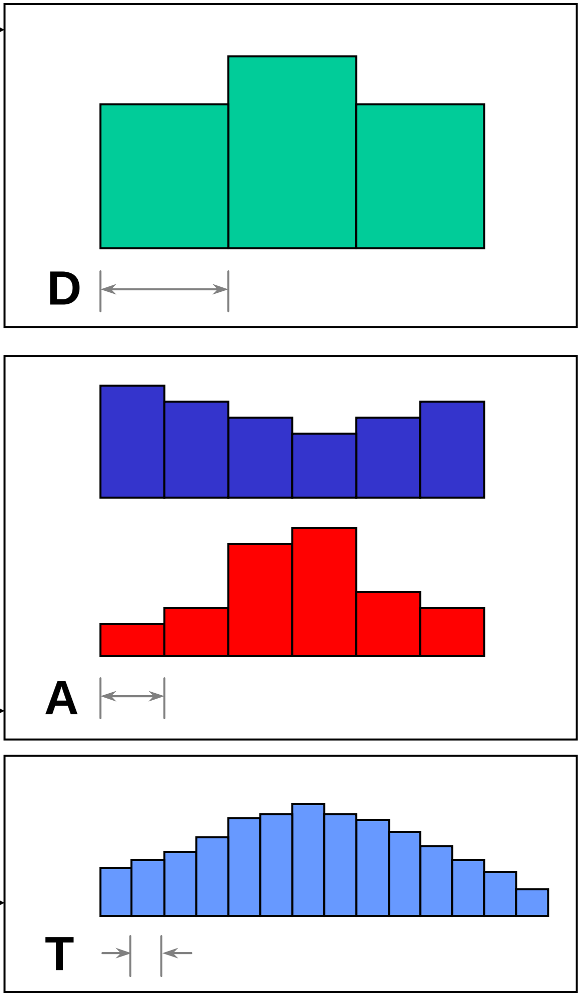
- continuous time

PATH RESULTS

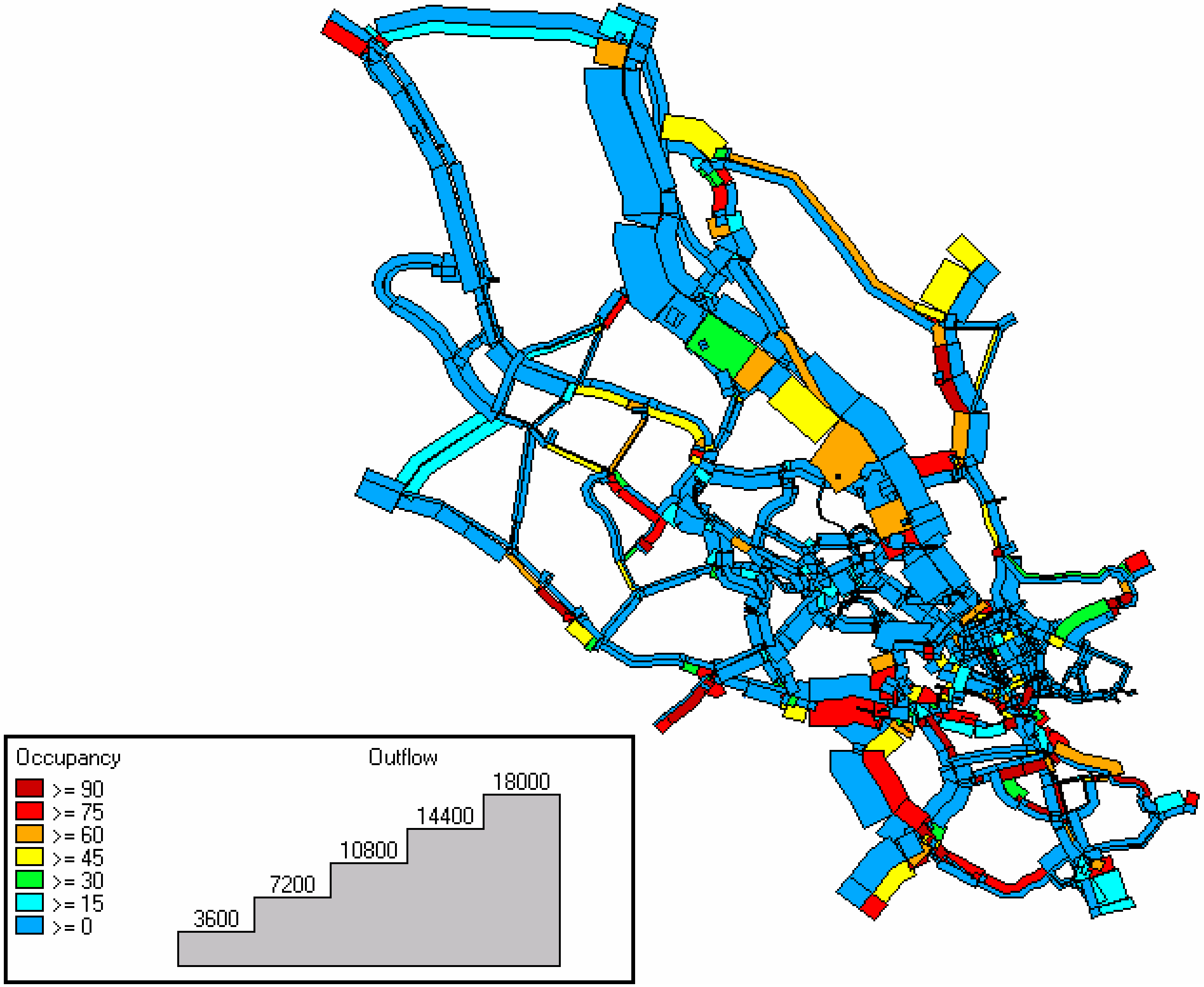
- by assignment interval

SIMULATION RESULTS

- by simulation results interval



1.4 Simulation Results



1.5 Path Results

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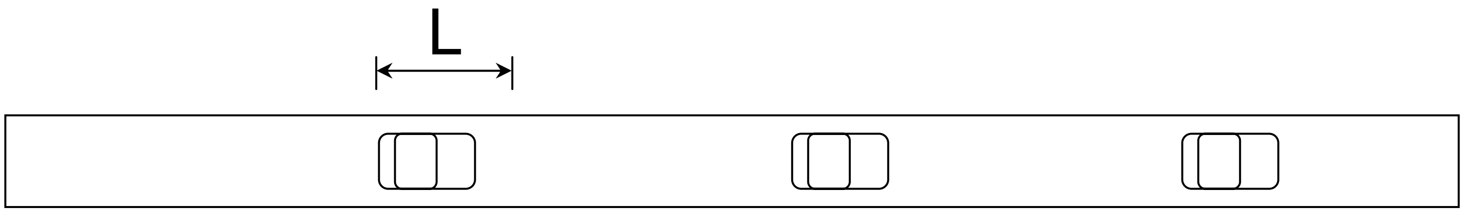
2 – Traffic Parameters and Measurements

2.1 Traffic Stream Parameters



$\mathbf{L} = \text{effective vehicle length } (\mathbf{m})$

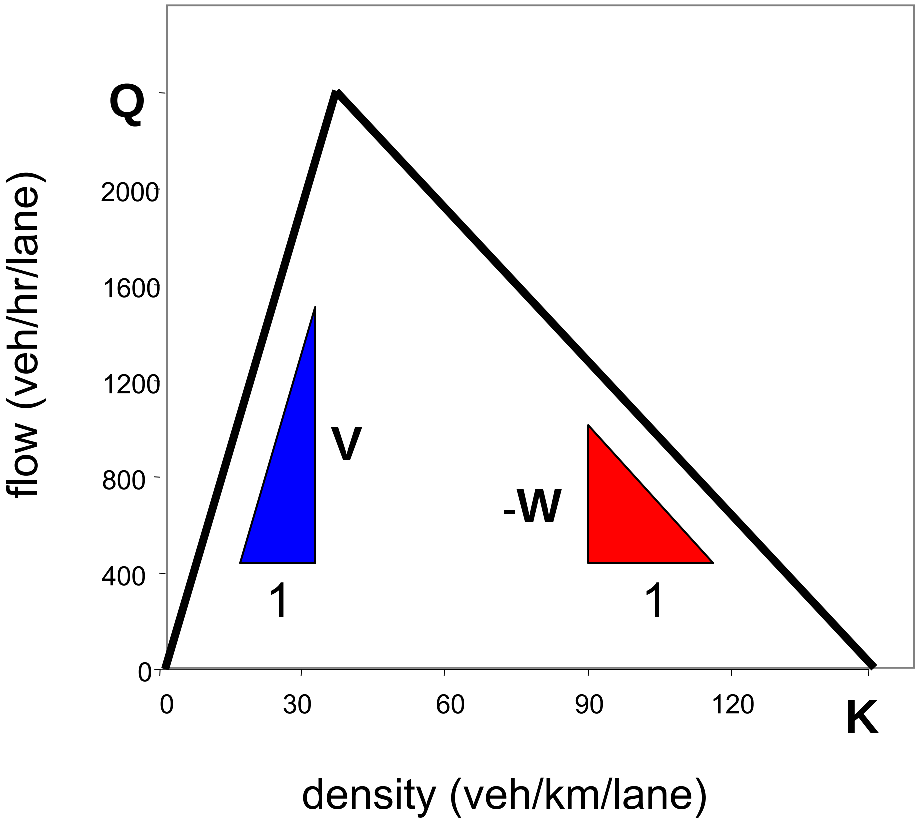
$\mathbf{R} = \text{driver/vehicle response time } (\mathbf{s})$

$\mathbf{V} = \text{free-flow speed } (\mathbf{m}/\mathbf{s})$

$$\Rightarrow \quad \mathbf{R} + \frac{\mathbf{L}}{\mathbf{V}} = \text{minimum time separation - } \textbf{headway}\,(\mathbf{s})$$

$$\Rightarrow \quad \frac{\mathbf{3600}}{\mathbf{R} + \frac{\mathbf{L}}{\mathbf{V}}} = \text{maximum flow rate - } \textbf{capacity}\left(\frac{\mathbf{veh}}{\mathbf{hr}}\right)$$

2.2 Fundamental diagram



$$V\left(\frac{m}{s}\right) = \text{free speed}$$

$$Q\left(\frac{veh}{hr}\right) = \frac{1}{R+\frac{L}{V}}$$

$$K\left(\frac{veh}{km}\right) = \frac{1000}{L}$$

$$W\left(\frac{m}{s}\right) = \frac{L}{R}$$

2.3 Traffic Measurement (1)

T (s) = simulation results interval

$$\textbf{inflow}\,(\textbf{veh/hr}) = \frac{\text{entering count}}{T/3600}$$

$$\textbf{outflow}\,(\textbf{veh/hr}) = \frac{\text{exiting count}}{T/3600}$$

$$\textbf{travel time}\,(\textbf{s}) = \frac{sum[\text{exiting travel times}]}{\text{exiting count}}$$

$$\textbf{speed}\,(\textbf{km/hr}) = \frac{\text{link length}}{(\text{travel time})/3600}$$

2.4 Traffic Measurement (2)

T (s) = simulation results interval = 300

L (m) = 6.25

link length (km) = 0.1

3 – Gap-acceptance modeling

3.1 Gap-acceptance (1)

Time to collision point

- t_L: low-priority vehicle
- t_H: high-priority vehicle

Waiting time

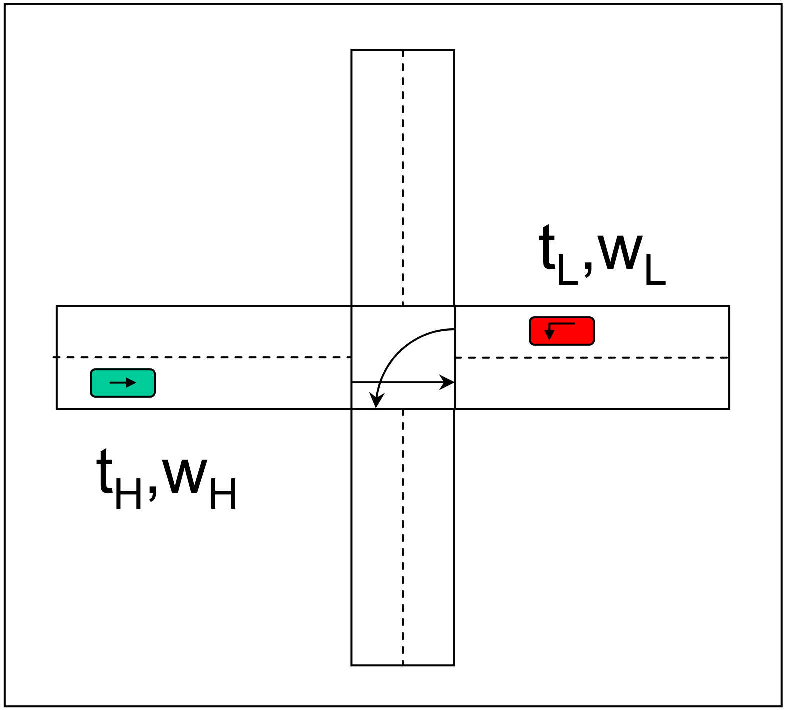
- w_L: low-priority vehicle
- w_H: high-priority vehcle

Available Gap

$$g_{avail} = t_H - t_L$$

Relative Wait

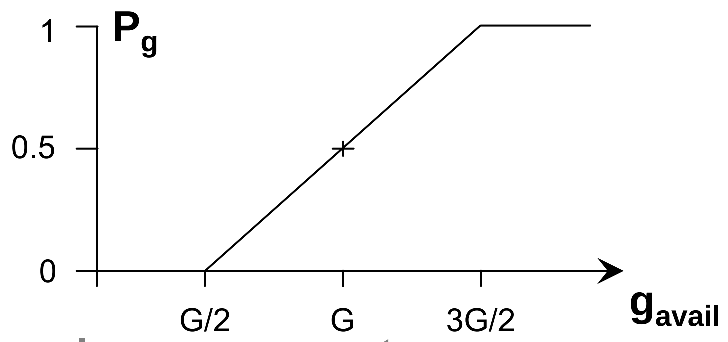
$$w_{rel} = w_L - w_H$$



3.2 Gap-acceptance (2)

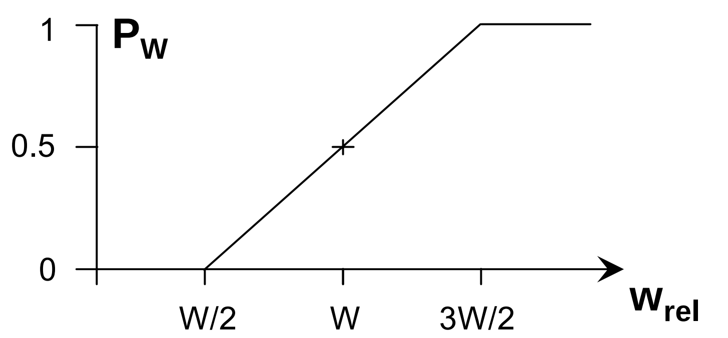
"Gap" probability (P_g)

- probability that available gap is enough
- critical gap parameter: G



"Wait" probability (P_w)

- probability that driver's patience has run out
- critical wait parameter: W



Precedence probability (P)

- $P = \max [P_g, P_w]$

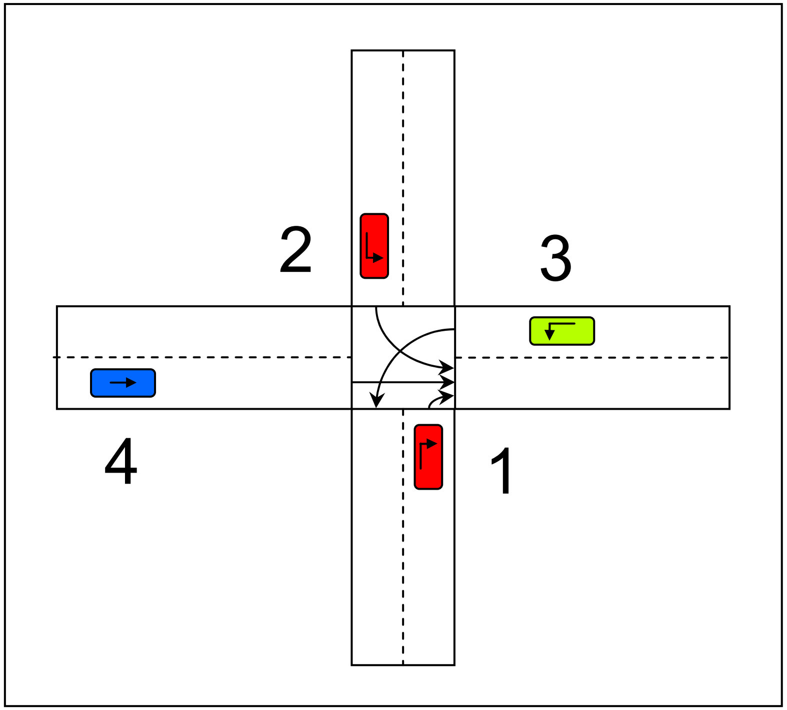
3.3 Node Model

P_{jk} = probability that vehicle j precedes vehicle k

- P_{14}, P_{12}
- P_{24}, P_{23}
- P_{34}

Requires a **Node Model**:

- resolve cycles
- move vehicles efficiently and realistically



4 – Traffic Signal Synchronization

Motivation

"Credible Dynamic Traffic Assignment on medium-to-large scale networks"

- Need to model increasingly *larger networks*, while maintaining a *detailed* and *realistic* representation of the traffic system
- Typical applications:
  - Operational (short term) planning
  - Adaptive and/or coordinated traffic control
  - Driver information systems
  - Network reliability
  - Evacuation models

General Approach

Embed a traffic simulation model inside a traffic assignment algorithm:

- Assignment model:
  - User equilibrium
  - Deterministic
  - Pre-trip (path-based)
- Traffic Simulation:
  - Models individual vehicle interactions
  - Detailed (lane-based) network topology
  - Explicit representation of traffic control devices

Challenges

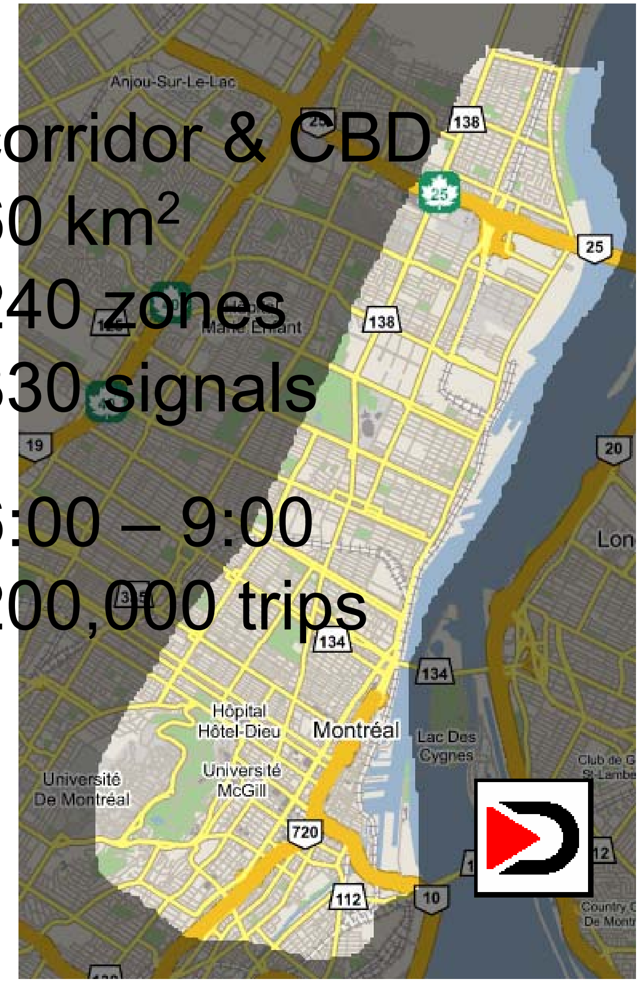
- Traffic simulation models
  - Are computationally intensive (slow)
  - Many parameters (calibration can be hard)
  - Tend to “lock-up” on large, congested networks
- Traffic assignment
  - Most algorithms from static assignment not directly applicable (no gradients)
  - Must be very robust due to noisy and ill-behaved mapping represented by the simulation (solution space not convex)

Solutions

- A "simpler" simulation model
  - computationally much faster (≈ 100x)
  - fewer parameters (easier to calibrate)
  - adaptive "dead-lock avoidance" algorithm
- MSA for traffic assignment
  - does not use gradients
  - well suited for noisy problems (stochastic)
  - robust performance: tends to converge well even for highly congested networks

Example: iterative micro-simulation DTA

Notre-Dame

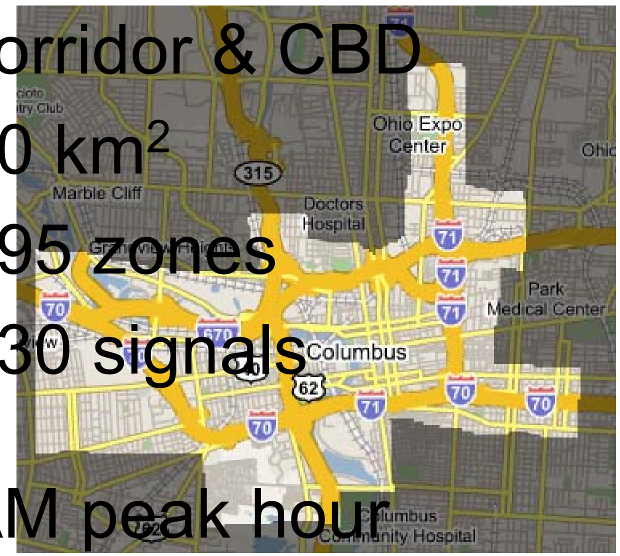


- corridor & CBD
- 60 km^2
- 240 zones
- 330 signals

- 6:00 – 9:00
- 200,000 trips

Columbus

TRB



- corridor & CBD
- 30 km^2
- 295 zones
- 330 signals

- AM peak hour
- 100,000 trips

v. conventional microsimulation

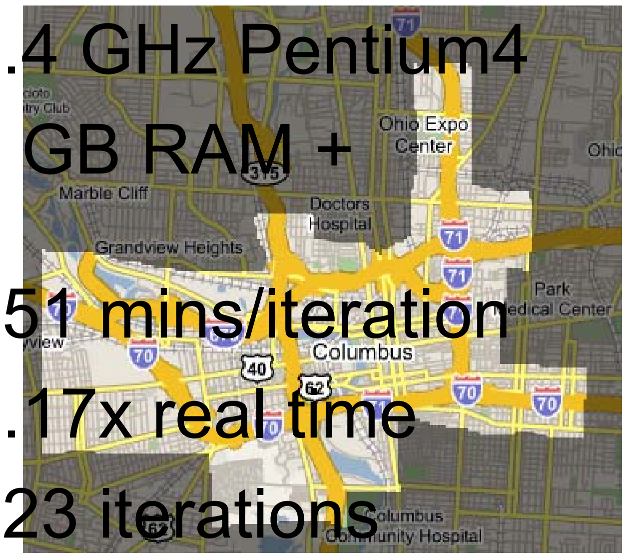
Performance Comparison

Notre-Dame

- 1.6 GHz PentiumM
- 1 GB RAM
- 3 mins/iteration
- 86x real time
- 50 iterations
- 2.5 hours/DTA

Columbus

TR TRB 92



- 3.4 GHz Pentium4
- 3 GB RAM +
- 351 mins/iteration
- 0.17x real time
- 123 iterations
- 720 hours/DTA

v. conventional microsimulation

Current Research

Assignment algorithms suitable for a wider variety of modeling scenarios:

- time-varying supply-side parameters
  - e.g. turning movement restrictions
- en-route re-assignment
  - unexpected traffic conditions (incidents)
  - driver information systems
- generalized cost
  - time-varying tolls

Alternative Approaches

Two basic formulations available:

- Path-based
  - Best suited to pre-trip assignment models
  - No obvious extension to en-route re-assignment
- Splitting Rates
  - Natural formulation for:
    - time-varying supply-side parameters
    - time-varying decision processes (incidents)
  - Well suited for both
    - iterative (optimisation) assignment
    - and non-iterative (reactive) assignment

Dynamic Assignment Model

Solution space (output)

- turning movement volumes (not path volumes), per origin, per departure interval

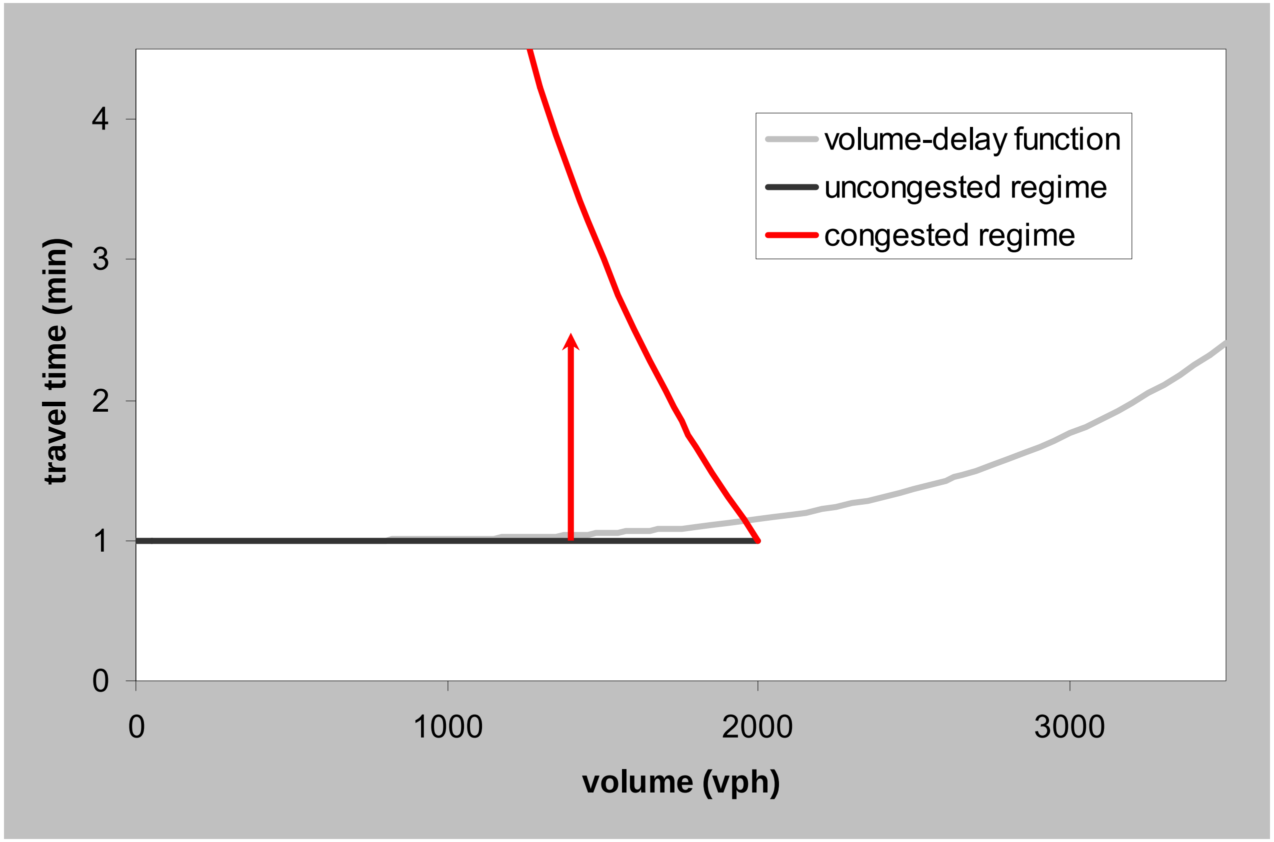
Basis (input)

- observed movement capacities (previous iteration)

Requirements

- path generation algorithm that results in an acyclic origin-based sub-graph (for each origin)

Static vs. Dynamic Models



Conclusions - 1

Simulation-Based User Equilibrium Assignment

- pre-trip, deterministic assignment
- stochastic micro-simulation model
- unique combination of robust assignment & detailed traffic

Successful Applications

- real-world projects: large by “simulation standards”
- good convergence of algorithm
- very good calibrations against traffic counts

Performance

- very reasonable CPU and RAM requirements

Conclusions - 2

New dynamic equilibrium model

- splitting-rate formulation
- can also work with destination-based matrices

Performance

- convergence and queue lengths better than path-based approach (MSA)

Future work

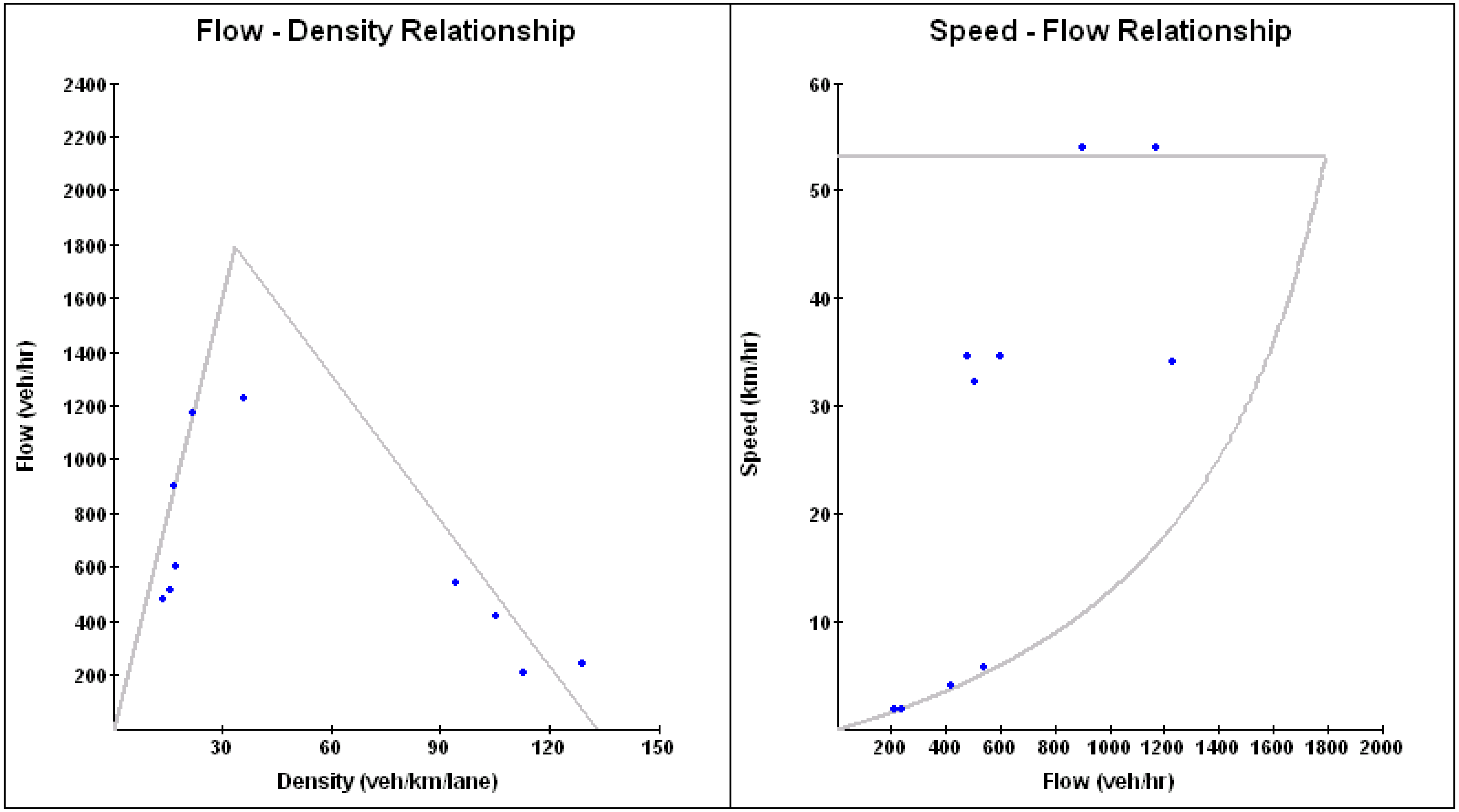
- extend methodology to handle en-route re-assignment:
  - Driver information systems
  - Incident response plans (Off-line optimisation)

The Evolution of Transport Planning

Network modeling methodologies

	static TDM	macro/meso DTA	microscopic
assignment	user/system optimal equilibrium	iterative (UE/SO) - - - - - one-pass reactive	iterative (UE) - - - - - one-pass reactive
traffic model	volume-delay function	macroscopic (fluid or discrete)	car following lane changing gap acceptance traffic signals

Macroscopic vs. Microscopic



Methodology behind Dynameq

Combination of iterative assignment and micro-simulation:

- iterative assignment model
  - approximates dynamic user-equilibrium (UE) conditions
  - *rational* basis for scenario comparisons
- traffic simulation model
  - simplified models of vehicle interaction
    - Car following, lane changing, gap acceptance
  - sophisticated rule-based driver models:
    - lane selection (+ look-ahead), un-signalized nodes
  - fast computation time

Car following model

$$x(t,n) = MIN\left[x(t-R,n) + V \cdot R, x(t-R,n-1) + L\right]$$

variables

t = time

n = vehicle number by order of arrival to lane

$x(t,n)$ = position of n at t

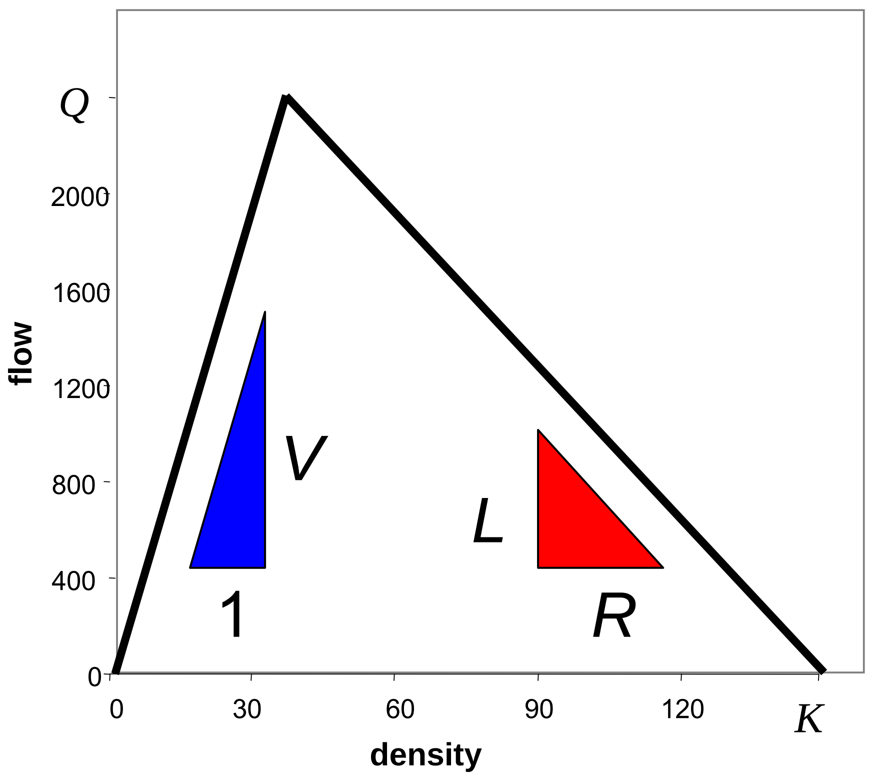
parameters

L = effective vehicle length

R = driver/vehicle response time

V = free-flow speed

Fundamental diagram



Inputs

V = free-flow speed

L = vehicle length

R = driver response time

Outputs

Max flow = $\frac{1}{L/V + R}$

Jam density = $1/L$

Summary - 1

Two basic components to any network modeling methodology

- 1 – Assignment (routing) model
  - Iterative
    - assigns O-D demands to path flows
    - user or system optimal (equilibrium) conditions
    - assignment reflects drivers' knowledge of expected travel times on alternative paths
  - Reactive
    - rule-based driver decision model
    - drivers react to traffic conditions (congestion) as they evolve in time: no prior knowledge of expected travel time

Summary - 2

Two basic components to any network modeling methodology

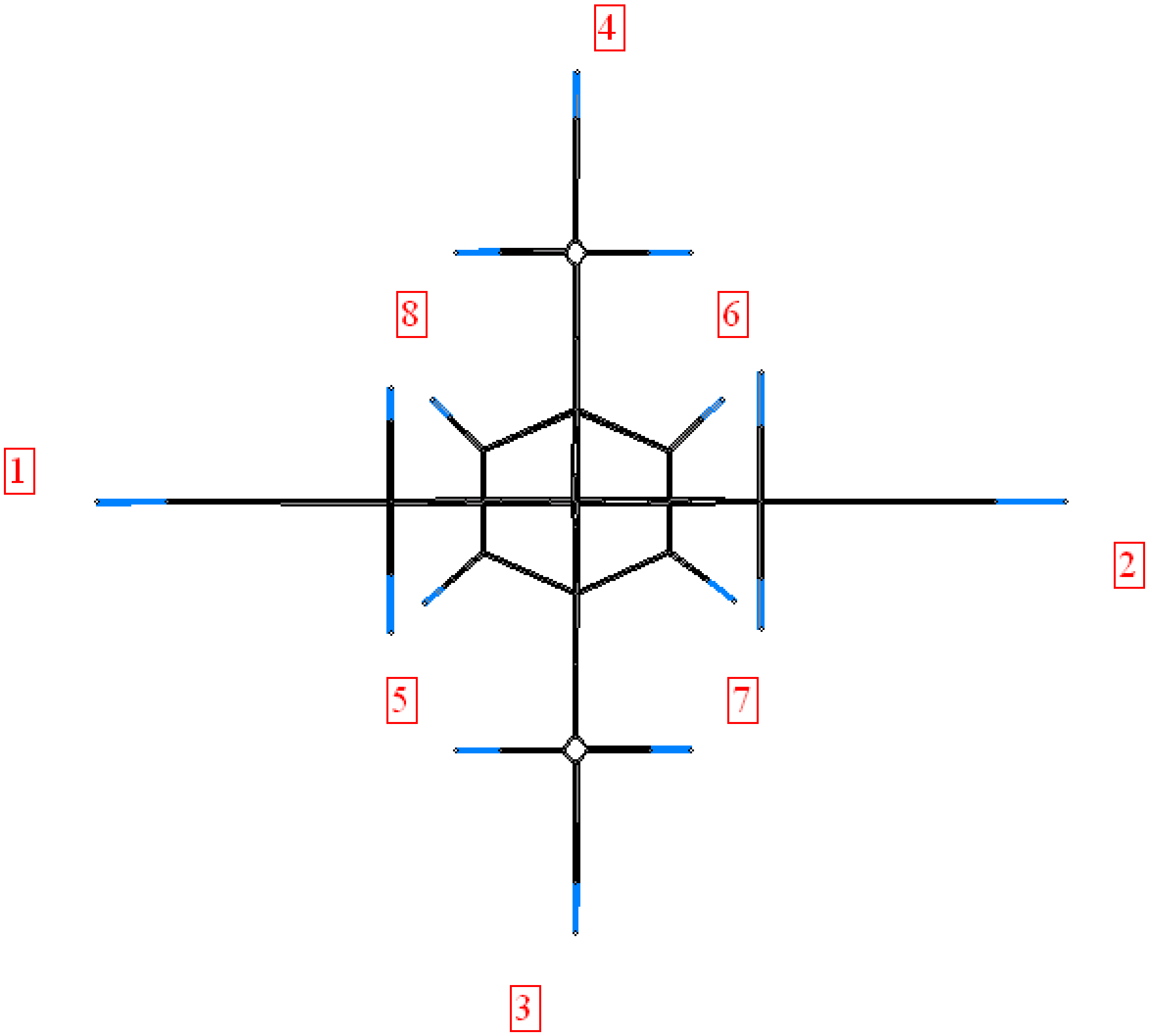
- 2 – Traffic model
  - Volume-delay function
    - does not capture congestion correctly, nor time-varying conditions, nor spill-back of congestion
  - Macro- (meso-) scopic
    - Coarse: does not represent lanes or lane-based effects
    - Limitations for multi-class modeling, ATMS/ATIS
  - Microscopic
    - Limited only by quality of the model, availability and quality of input data

Summary - 3

Methodology behind Dynameq

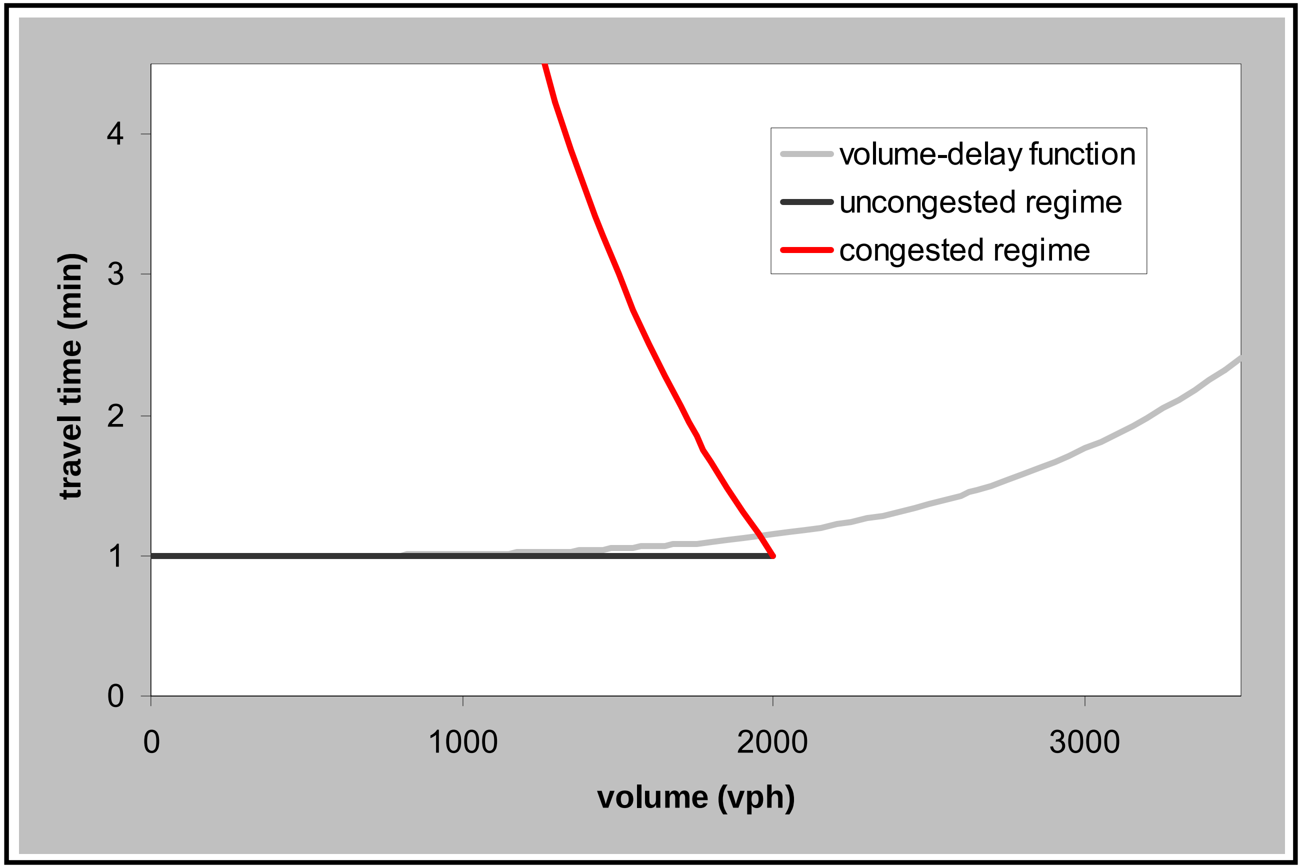
- 1 – Assignment model
  - iterative: approximates dynamic UE conditions and reflects drivers' knowledge of expected traffic conditions
  - provides a basis for *rational* scenario comparisons
- 2 – Traffic model
  - lower-order car-following model
  - lane changing
  - gap acceptance
  - traffic signals

Example 2 - Network



Example 2 - Convergence

Static vs. Dynamic Models 1



Static vs. Dynamic Models 2