CIVL6415

TRAFFIC ANALYSIS AND SIMULATION

MODULE 2

Introduction to traffic simulation

Lecture Week 4

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Outline

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- **Transportation systems**
  - – **Supply systems**
  - – **Demand modelling**
  - – **Decisions on transportation systems**
    - **short-term, medium-term, long-term**

- **Role and structure of transport models**
  - – **Time-Space representation**
  - – **Static-Dynamic models**
  - – **Micro-Meso-Macro models**

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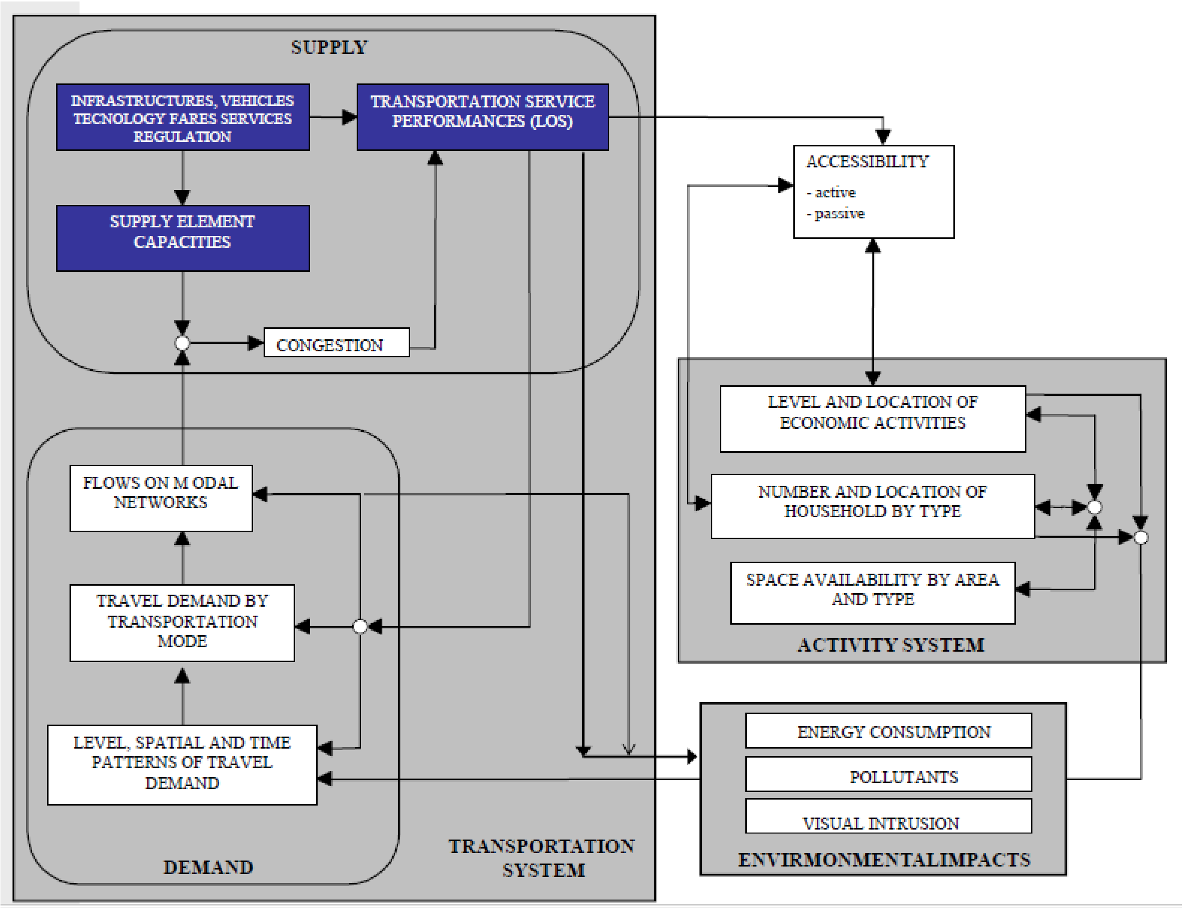
  - Micro-Meso-Macro models

Transportation systems

- Complex relationships
- Supply, Demand, Activity (Land use)



Supply systems

- Infrastructure
  - – Roadways, Public transport facilities,
  - – Parking, etc.

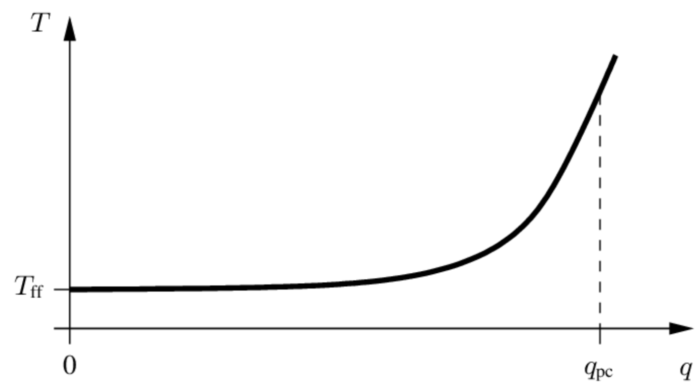
- Vehicles
  - – Private cars, Public transport vehicles
  - – Bicycles, Active transport

- Technologies
  - – Traffic signals, Smart management
  - – Traveller information systems

Supply systems

- Capacity
- Congestion and Travel times

- Congestion influences
  – Travel times
  – Reliability of the system
  – Emissions
  – Wellbeing

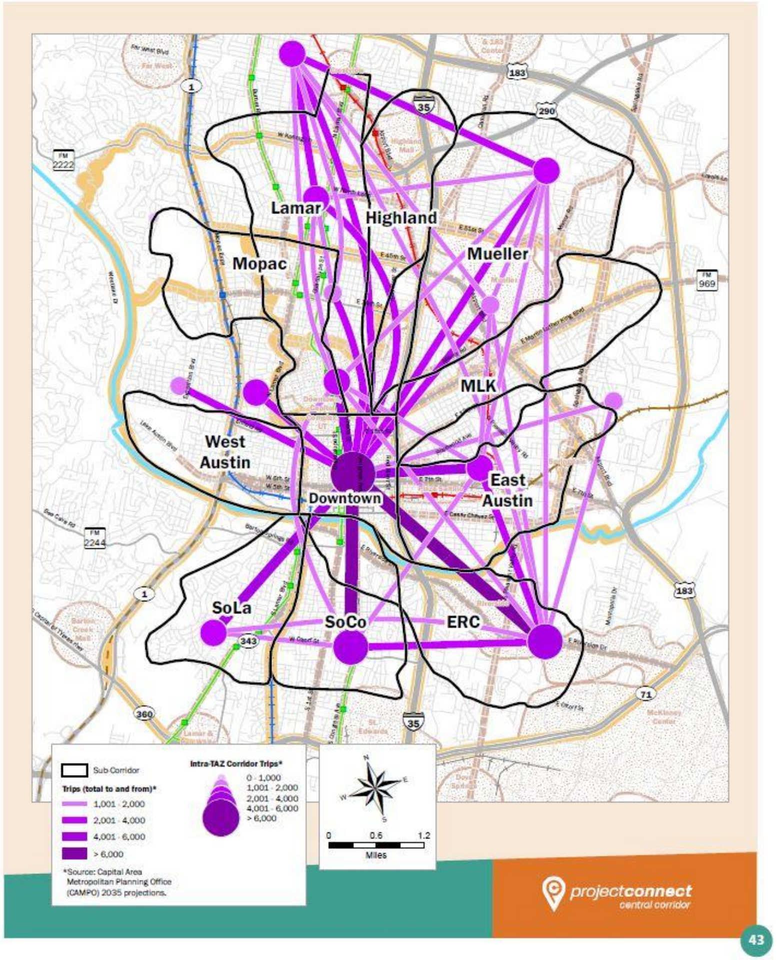


Bureau of Public Roads (BPR) function – Travel time vs. Volume

Travel demand

- Travel demand is a “derived function” from the participation of people in activities
- Land use (residential and work areas)
- Average number of daily trips
- Mode distribution
- Probabilistic choices
  - Route
  - Departure time
  - Mode

TRAVEL DEMAND MODEL 2035 ORIGIN-DESTINATION TRIPS (CENTRAL CORRIDOR) B



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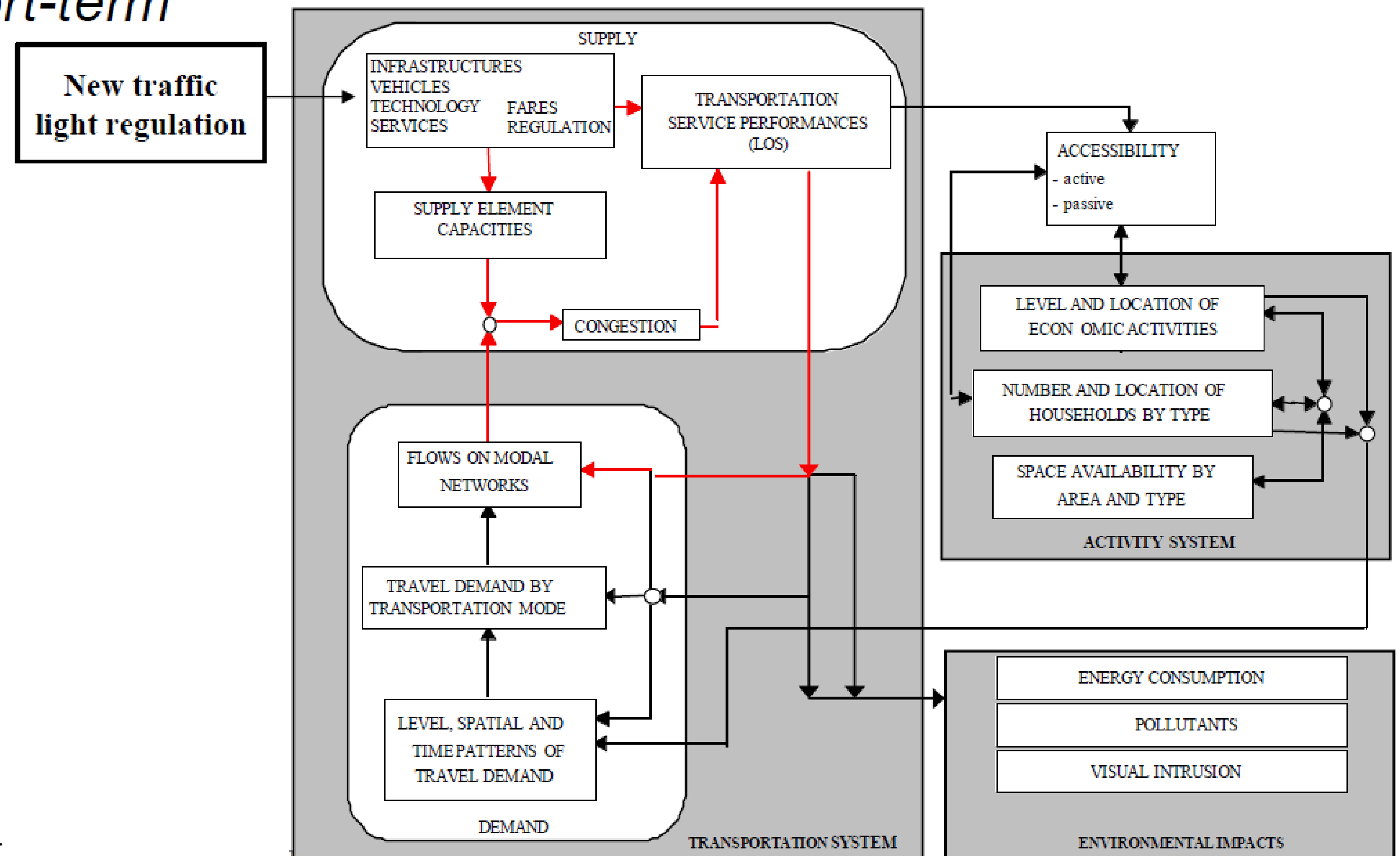
Decisions

Feedback loops

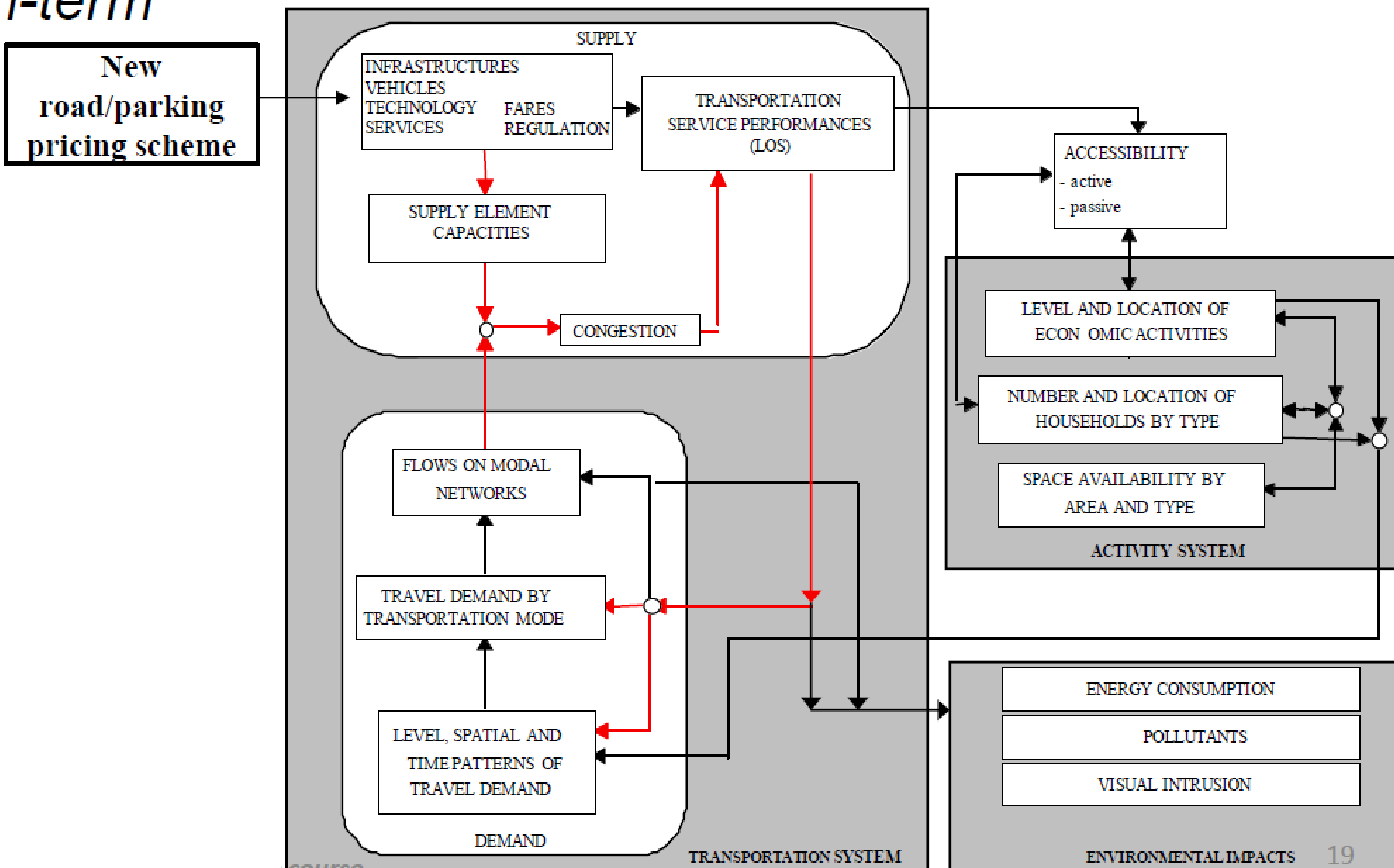
Short-term



From Cascetta
Introduction to traffic modelling

Feedback loops

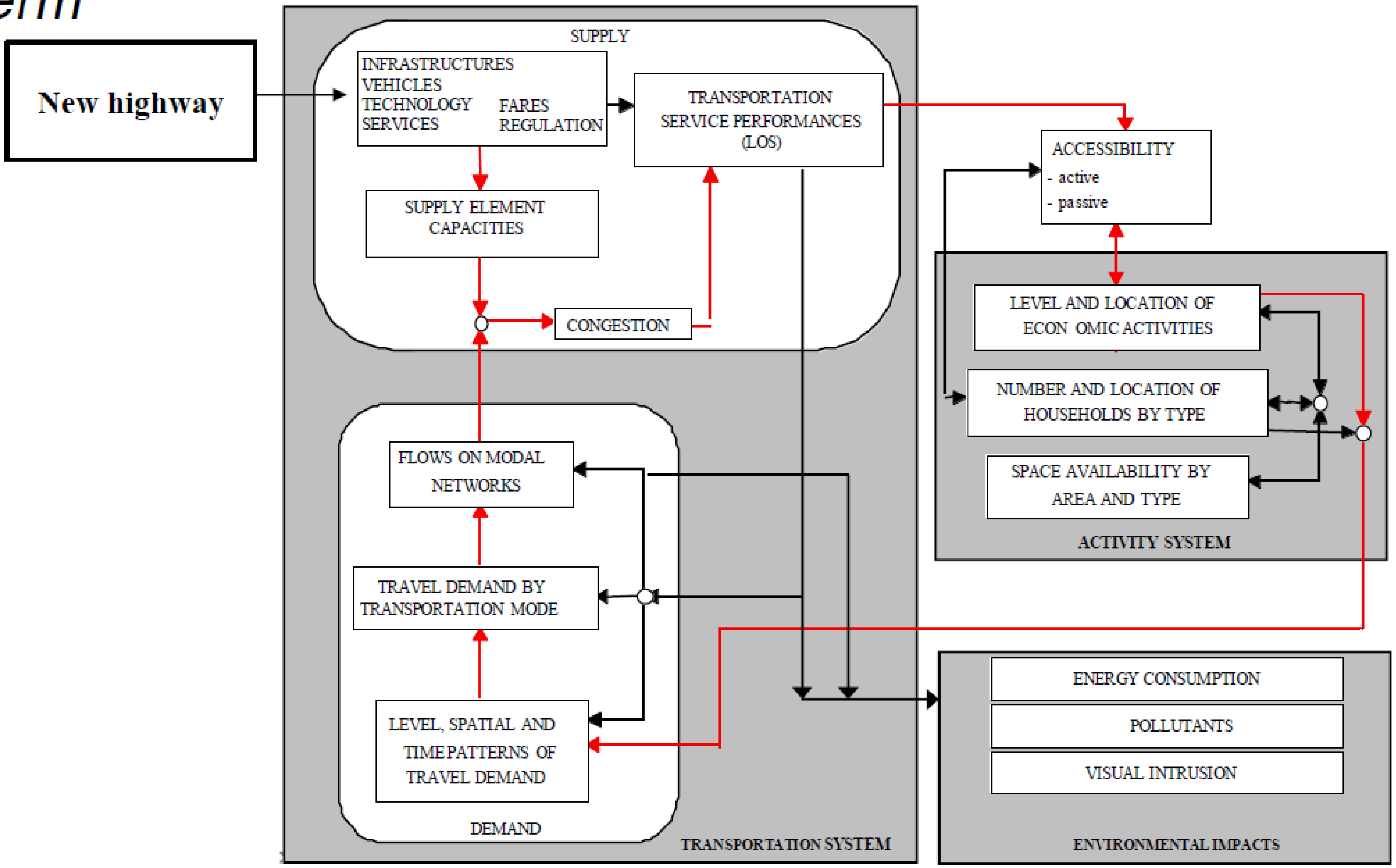
Medium-term



From Cascetta
Introduction to traffic modelling

Feedback loops

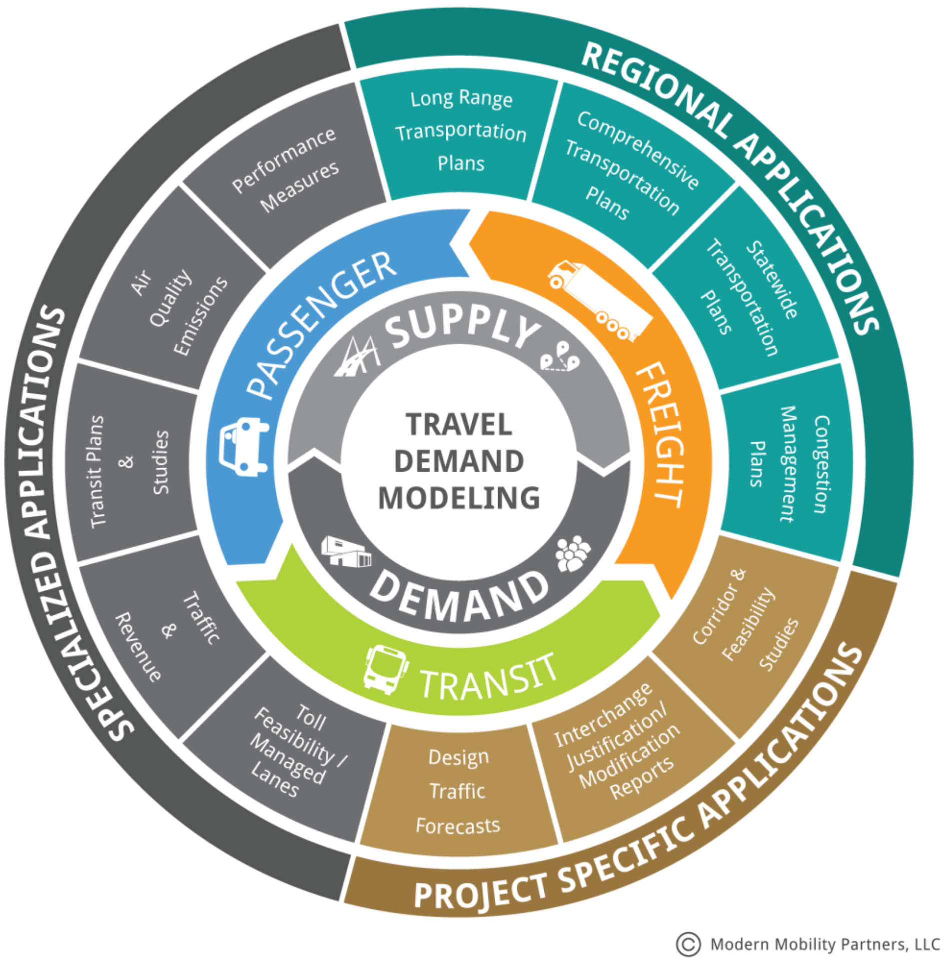
Long-term



From Cascetta
Introduction to traffic modelling

Decisions

- Transport Infrastructure
  - Building new roadways
  - Upgrading existing facilities
- Public Transport
  - Fares, timetables
- Vehicles & Technologies
  - Fleet composition, car-sharing
  - ITS technologies
- Policy / Regulations
  - Parking policy
  - Land use regulations, economic activities



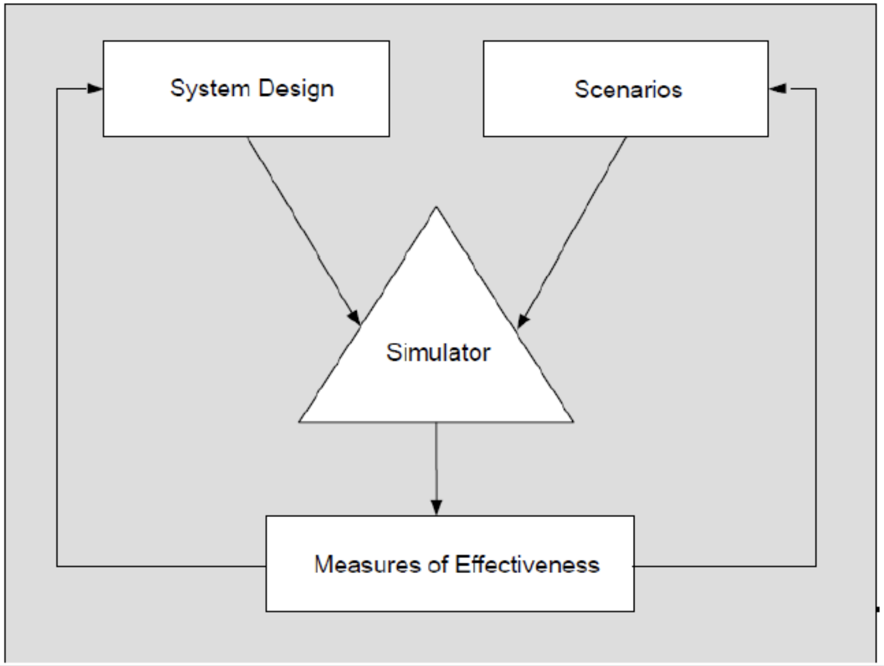
Applications

- Off-line evaluation
  - – Future system and network modifications
  - – Pricing policy changes
  - – Before-After comparison

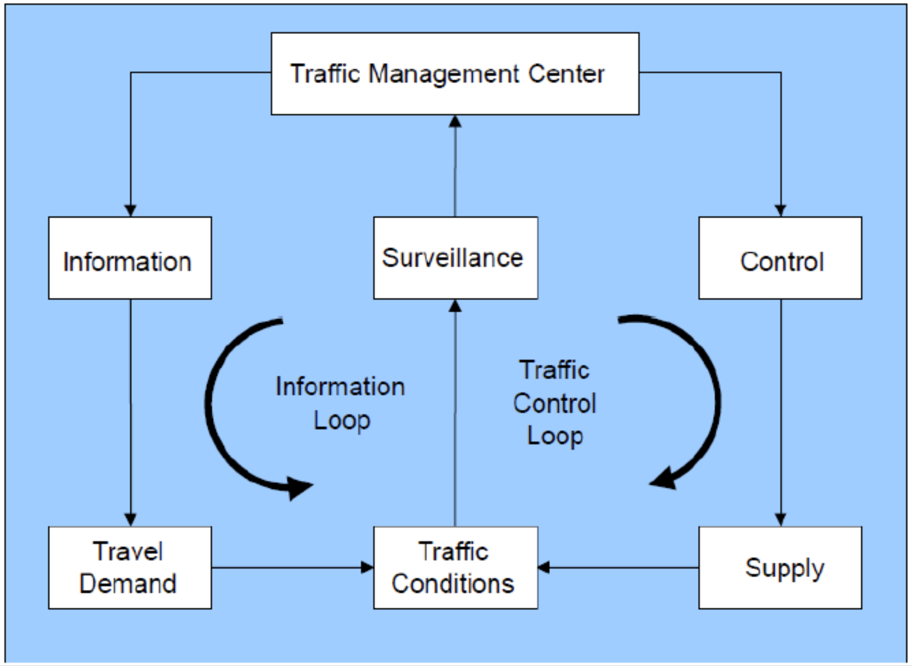
- On-line or Real-time decision support systems
  - – Route guidance
  - – Adaptive traffic control
  - – Traffic management

Offline vs Online

- Offline evaluation



- Online decisions



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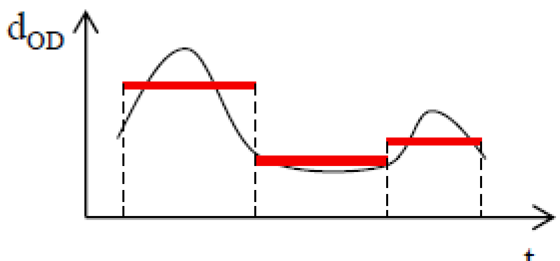
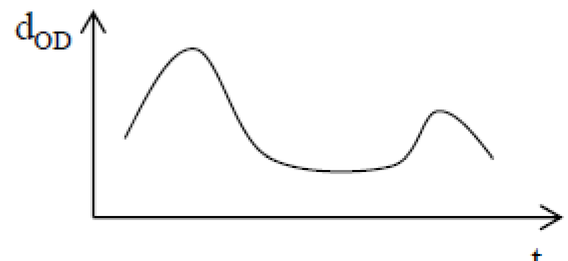
  - **Time-Space representation**
  - **Static-Dynamic models**

Levels of representation

- Time representation



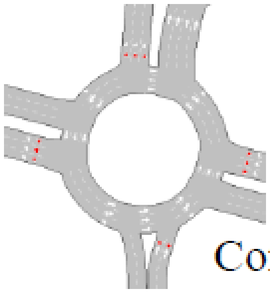
Within-day static



Within-day dynamic

- Space representation

Discrete



Continuous

Regional

- User representation
  - Discrete particles
  - Continuous fluid

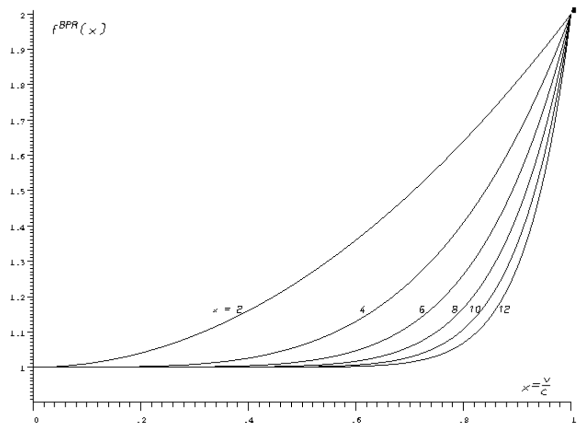
STATIC TRAFFIC MODELS

Static traffic models

- Off-line evaluation
- Planning purposes

- ***4-Step Modelling***
  - Trip generation (Estimate trips produced and attracted in each zone)
  - Trip distribution (Find O-D flows)
  - Mode split (Consider alternative transport modes)
  - **Traffic assignment (Route choice for O-D car flows)**
    - **Static traffic models with travel time functions**
    - **Equilibrium**

Roadway performance function



Bureau of Public Roads (BPR) - travel time function

- Travel time is assumed to increase with traffic flow
  – Linearly (not realistic)
  – Nonlinearly (e.g., BPR)

$$T_f = T_o * \left(1 + \alpha * \left[\frac{V}{C}\right]^{\beta}\right)$$

where:

T_f = final link travel time
T_o = original (free-flow) link travel time
alpha = coefficient (often set at 0.15)
V = assigned traffic volume
C = the link capacity
beta = exponent (often set at 4.0)

Graph, Links, Paths

- **GRAPH**

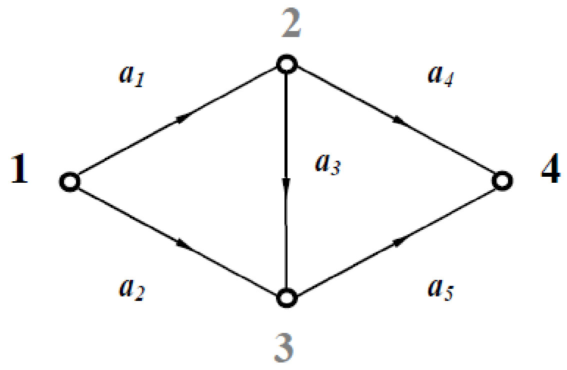
Ordered pair of sets G(N,L) representing network connections

N = {1, 2, 3, 4}

L = {a1, a2, a3, a4, a5}

Origin centroid: 1

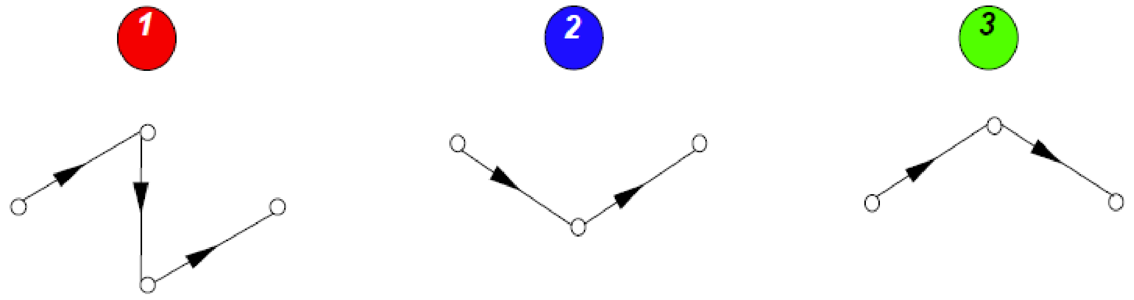
Destination centroid: 4



- **Path k:**

Sequence of links representing “typical” trips allowed by the supply system modelled

Path set K = {1, 2, 3}

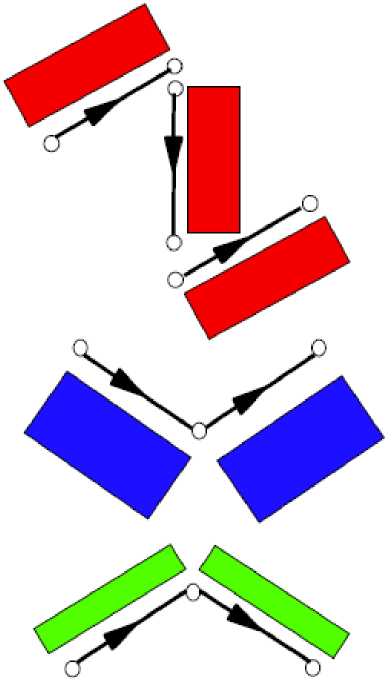


Path flows

Simulation period = simulation life= 1 hour

- **PATH FLOWS**

  $\bar{h}_k$: (average) flow along path *k* during the simulation period T [veh/h]



$\Rightarrow \quad \bar{h}_1$ = **800 veic/h**

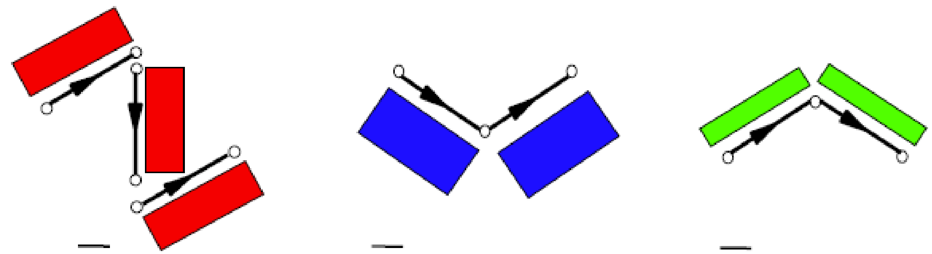
$\Rightarrow \quad \bar{h}_2$ = **1200 veic/h**

$\Rightarrow \quad \bar{h}_3$ = **400 veic/h**

2.400 veic/h

Path flows are propagated simultaneously on each link belonging to the path

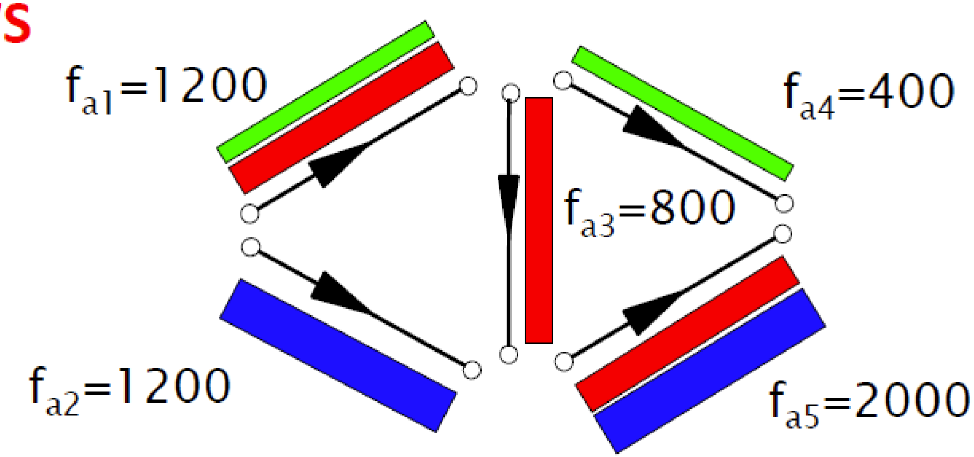
Link flows



$\bar{h}_1 = 800$ $\bar{h}_2 = 1200$ $\bar{h}_3 = 400$

Network flow propagation

LINK FLOWS



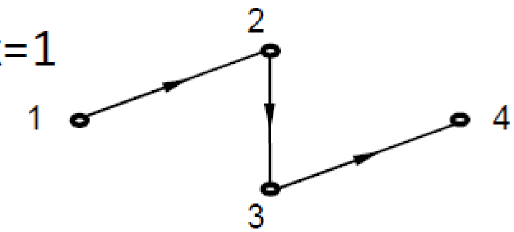
DYNAMIC TRAFFIC MODELS

Time-dependent flows

Path flows (time dependent)

(2/2)

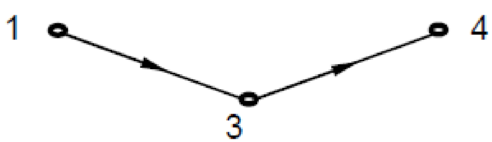
Path k=1



$$h_1 = \begin{bmatrix}200\\10\\400\\100\end{bmatrix}\begin{array}{l}1_1\\1_2\\1_3\\1_4\end{array}$$

$\bar{h}_1$ = **800 veic/h**

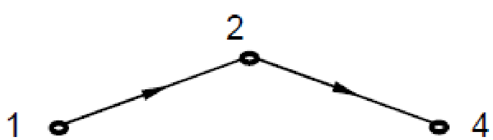
Path k=2



$$h_2 = \begin{bmatrix}300\\300\\200\\400\end{bmatrix}\begin{array}{l}2_1\\2_2\\2_3\\2_4\end{array}$$

$\bar{h}_2$ = **1200 veic/h**

Path k=3



$$h_3 = \begin{bmatrix}0\\100\\300\\0\end{bmatrix}\begin{array}{l}3_1\\3_2\\3_3\\3_4\end{array}$$

$\bar{h}_3$ = **400 veic/h**

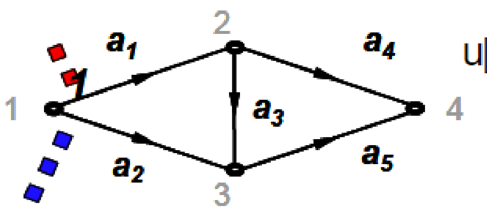
Each square represents 100 vehicles

Time-dependent flows

Total inflows at links

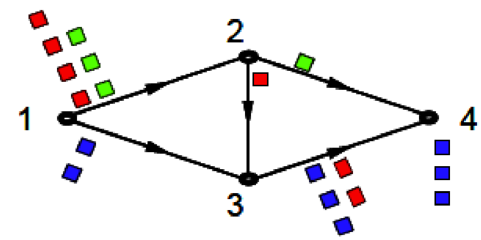
k

$\tau_1 = 15$



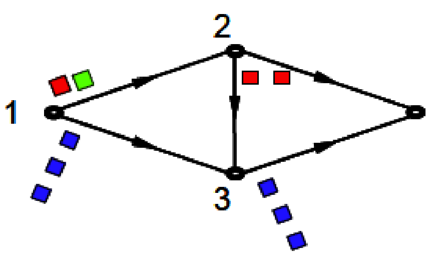
$$u[j=1] = \begin{array}{c} \begin{bmatrix} 200 \\ 300 \\ 0 \\ 0 \\ 0 \end{bmatrix} \end{array} \begin{array}{c} (a_1) \\ (a_2) \\ (a_3) \\ (a_4) \\ (a_5) \end{array}$$

$\tau_3 = 45$



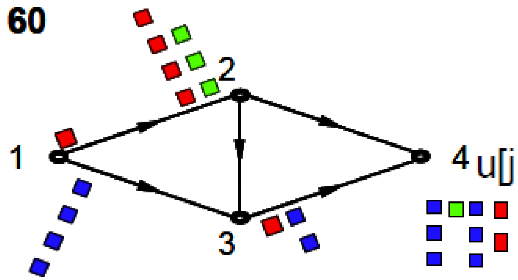
$$u[j=3] = \begin{bmatrix} 700 \\ 200 \\ 100 \\ 100 \\ 500 \end{bmatrix}$$

$\tau_2 = 30$



$$u[j=2] = \begin{bmatrix} 200 \\ 300 \\ 200 \\ 0 \\ 300 \end{bmatrix}$$

$\tau_4 = 60$



$$u[j=4] = \begin{bmatrix} 100 \\ 400 \\ 0 \\ 0 \\ 300 \end{bmatrix}$$

note: in the pictures, each unit represents 100 vehicles

Assume vehicles move one link at each time step

Representation

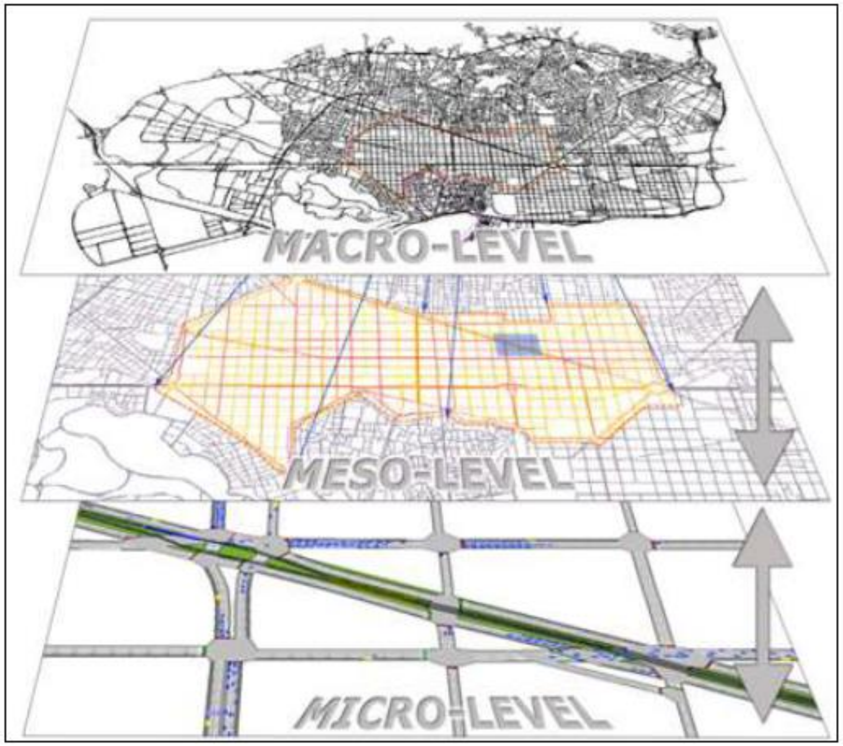
- **User variables** *how vehicles are simulated*
  - AGGREGATE
    - i.e. traffic stream as a continuous fluid
  - DISAGGREGATE
    - i.e. traffic stream composed by single vehicles

- **Speed variables** *how network performance are simulated*
  - AGGREGATE
    - i.e. each link with an average speed for all vehicles on it
  - DISAGGREGATE
    - i.e. each single vehicles with its own speed

Modelling approaches

Speed variables / ***user variables***	Aggregate $u(x,t)$	Disaggregate $u_i(t)$
Aggregate $q(x,t)$, $k(x,t)$	MACRO scopic	
Disaggregate $x_i(t)$	MESO scopic	MICRO scopic

Modelling approaches



Source: Barcelo, J. Casas J, Garcia D & Perarnau J (2005)

❑**Static:**

- Large scale, strategic, no detailed representation of congestion.

❑**Meso:**

- Medium scale, models intersections in detail, capable of dynamic assignment.

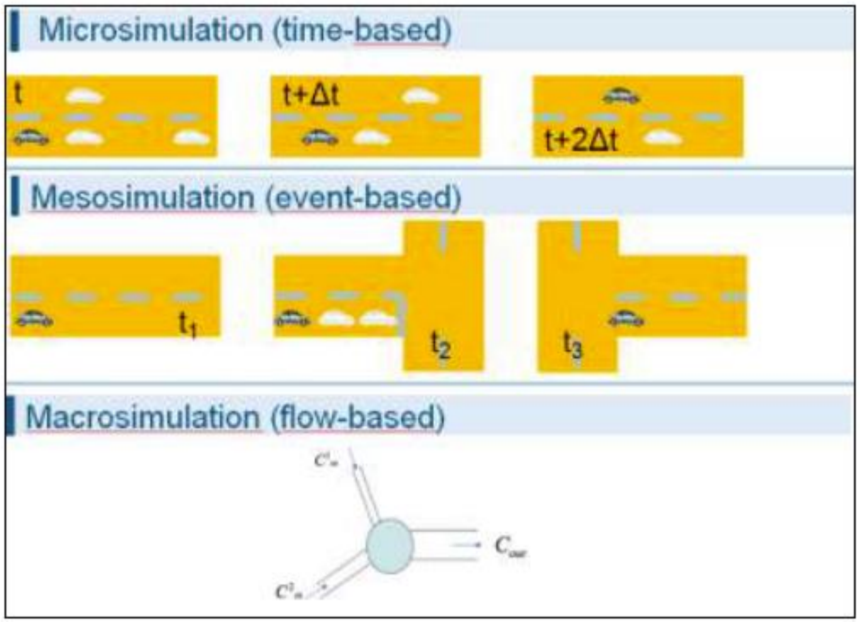
❑**Micro:**

- Finest level of detail, complex signal operation, models individual vehicle movements.

Traffic models

- True/False questions:
  - All traffic models capture the time dependent nature of traffic.
  - Mesoscopic models are used in the four-step planning framework.
  - Microscopic models build on car following and lane changing models.
  - Static traffic models model individual vehicles in the network.

Modelling approaches



Source: TSS Aimsun 8.1.4 User's Manual 2016

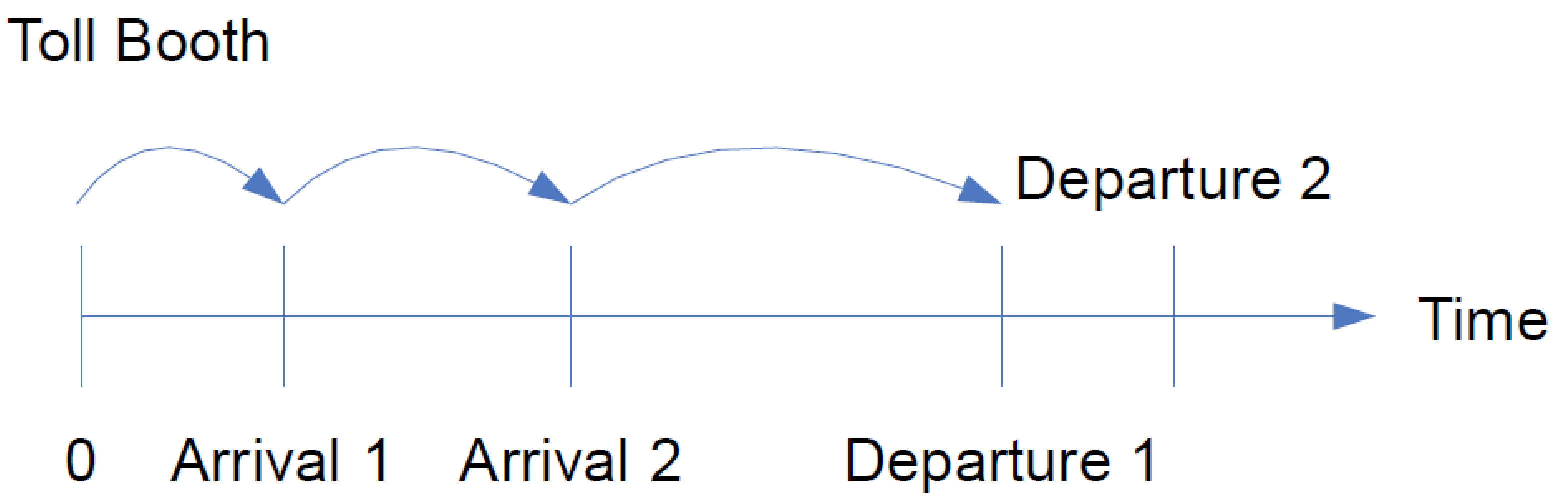
- Discrete event simulation: Simulation time changes when an event occurs.
  - Vehicle generation, vehicle node movement, traffic signal change.
  - Simplified car-following and gap acceptance model
- Vehicle considered only as it enters and exits a node section.
- Does not consider acceleration/ deceleration or details lane changing behaviour.

Time-based simulation

- Pre-defined equal time intervals
  - at each time step update system state
  - process all events occurring at *(t-Δt, t]*

Event-based simulation

- Maintain list of upcoming events
- Process events of current time
- Advance clock to time of the next event



Stochastic simulation

- Inputs, models are probabilistic

Monte Carlo simulation

- Calculate probability of event
- Draw random numbers to realize event

Implications

- Input distributions
- Outputs are random variables

Traffic models

- True/False questions:

  - Event-based simulation requires a list of upcoming events.
  - In time-based simulation, time interval can vary.
  - In time-based simulation, system state has to be updated only when a new event occurs.
  - Static traffic models build on an event-based simulation technique.

Macroscopic models

- Common for evaluation of freeway corridor operations

- Traffic dynamics
  - Macroscopic traffic flow
- Basic approach
  - Numerical solution
  - Discretization of space and time

Macroscopic models

- **Objective**: Provide fundamental relationships among macroscopic traffic stream characteristics for uninterrupted flow conditions
  - *Speed-density*
  - *Flow-density*
  - *Speed-flow*

➢ *Does not consider individual vehicles*

➢ *Fluid approximation*

Macroscopic models

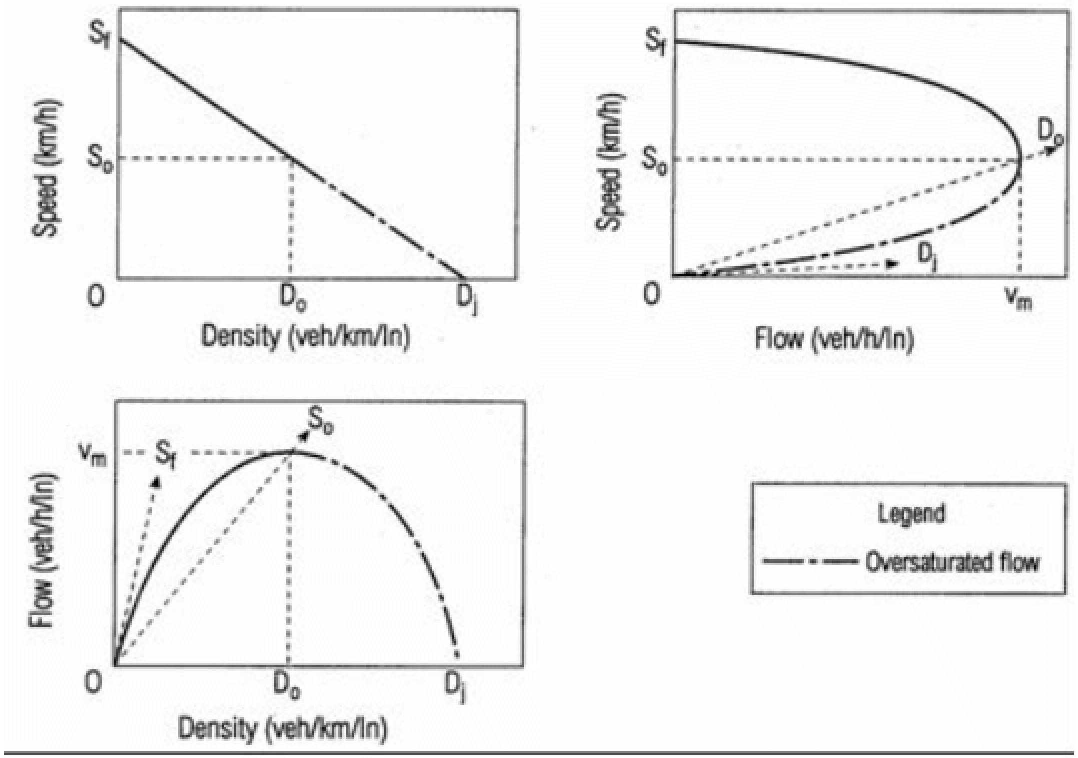
- **Fundamental relationship**

$$q = v\,k$$

q = flow [veh/h]

v = speed [km/h]

k = density [veh/km]



Macroscopic models

▪ Models to represent the fundamental diagram

Greenshield's model:

$$u = u_f \left(1 - \frac{k}{k_j} \right) \qquad q = uk = ku_f \left(1 - \frac{k}{k_j} \right)$$

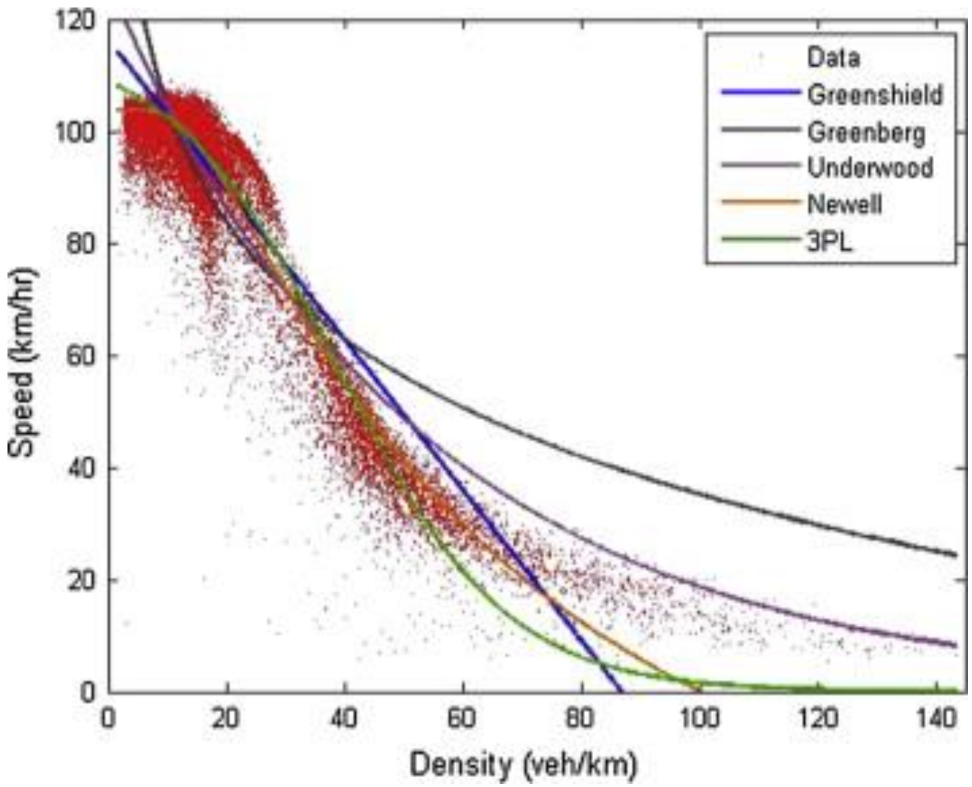
Greenberg's model:

$$u = c \ln \left(\frac{k_j}{k} \right) \qquad q = uk = k_j u \, e^{-u/c}$$

u_f, k_j are the parameters to be calibrated

Macroscopic models

- **Models to represent the fundamental diagram**



from Qu *et al*. (2015)

All models are wrong, but some are useful!!

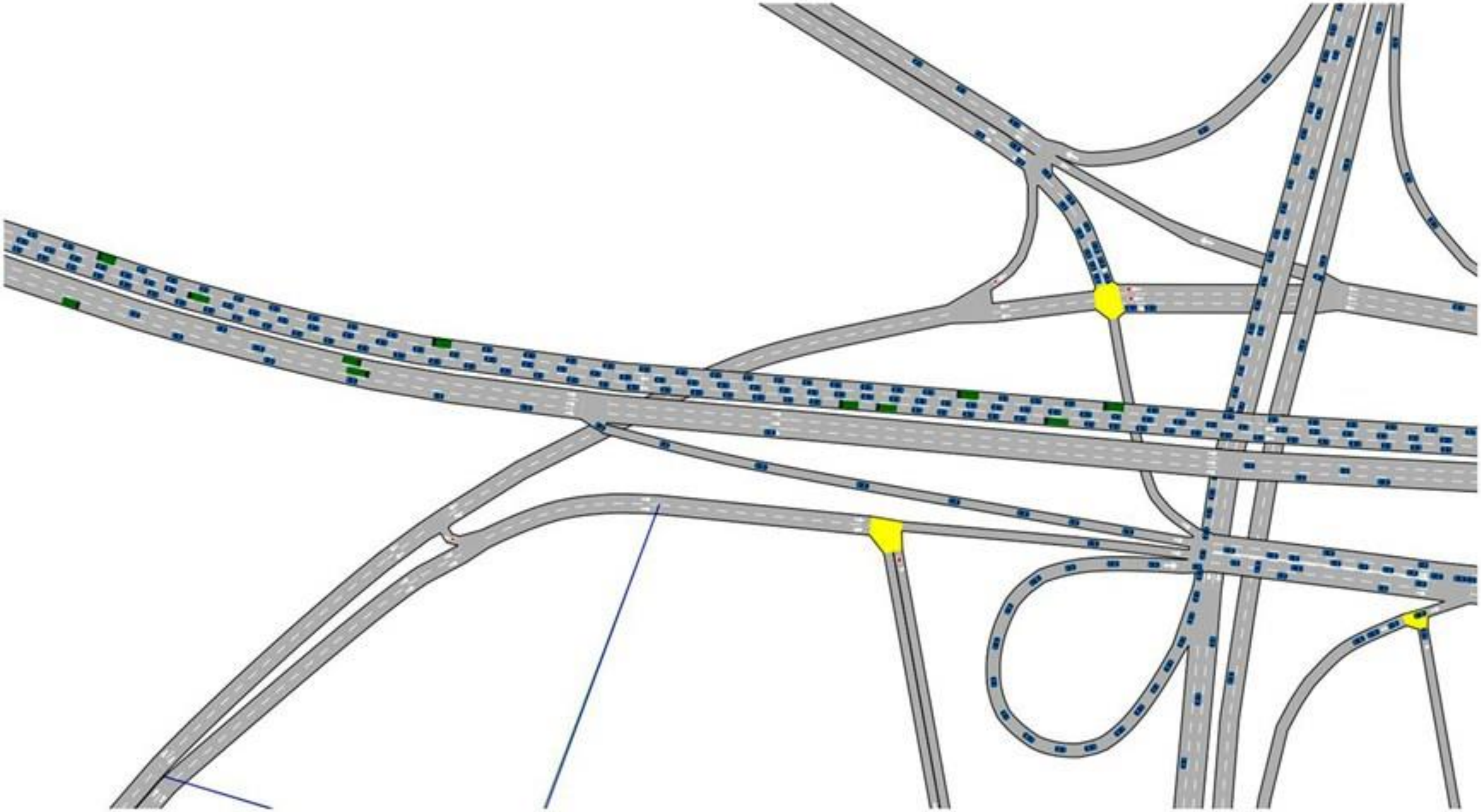
Macroscopic models

- **Traffic stream examples**

- FREFLOW (Payne et al, 1973)
- NETCELL (Daganzo et al., 1994)
- METANET (Papageorgiou et al., 2006)

- Freeway networks
- Ramp metering strategies
- Traffic control
- **1st order vs 2nd order models**

Microscopic models



Microscopic models

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- Detailed models
- Synthesis of
  - Driving behaviour (e.g, car following)
  - Control strategies (e.g., traffic signals)

- Time-based simulation (e.g., 0.1-1s)
- Both freeways and urban networks can be modelled
- Multiple driver classes (with different characteristics)
- Stochastic

Microscopic models

- **Commercial models**
  - Aimsun
  - Vissim
  - Paramics
  - Etc.

- **Research-oriented**
  - MITSIMLab
  - SUMO (Open-Source)
  - etc.

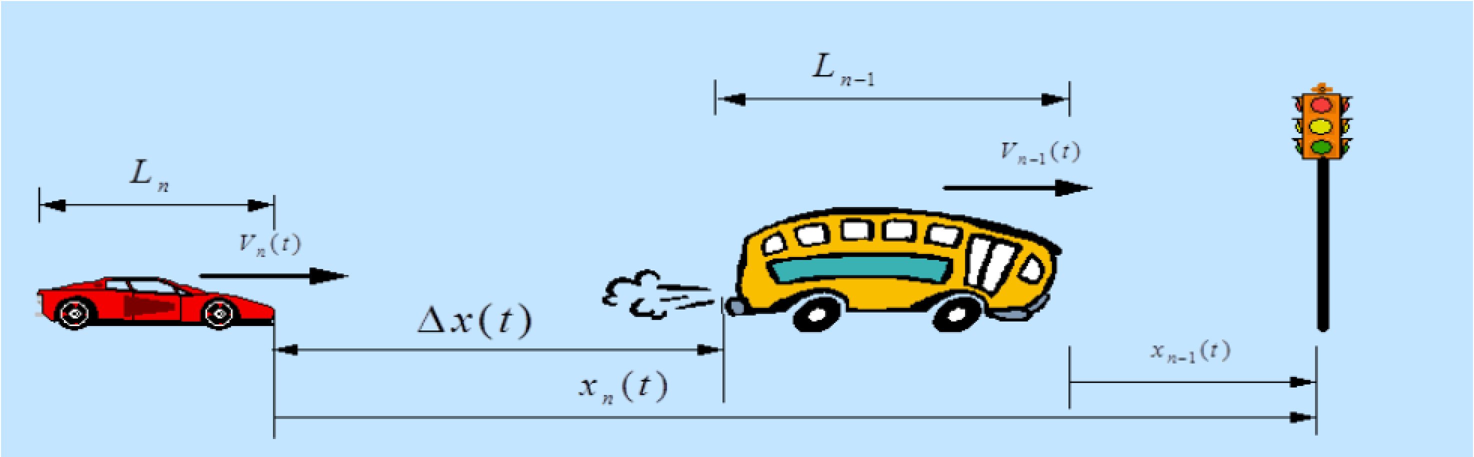
Microscopic models

- Driving behaviour

- Car following (Acceleration)
- Lane changing
- Gap acceptance

Microscopic models

- **Car following**



Common Model: *Response(t) = sensitivity • stimulus(t-τ)*

τ : reaction time
Stimulus: Δv (relative speed), Δx (relative distance)
Sensitivity: function of Δx, speed, traffic conditions
Response: acceleration, speed

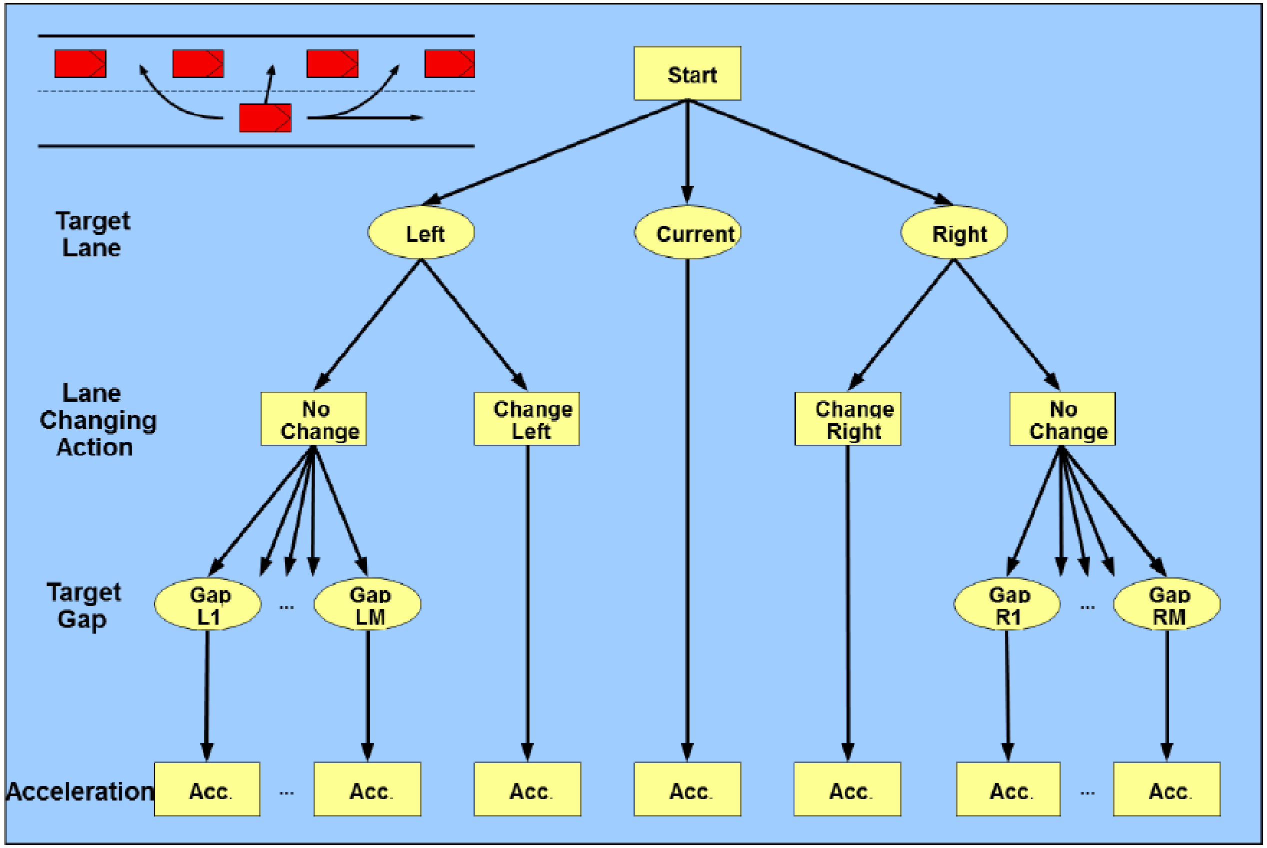
Microscopic models

- **Lane changing**

- Mandatory and discretionary lane-changing
- ***Mandatory***: getting off the current lane in order to continue on the desired path (e.g. exiting), or to avoid lane closure
- ***Discretionary:*** attempting to achieve desired speed, avoid following trucks, avoid merging traffic, etc.

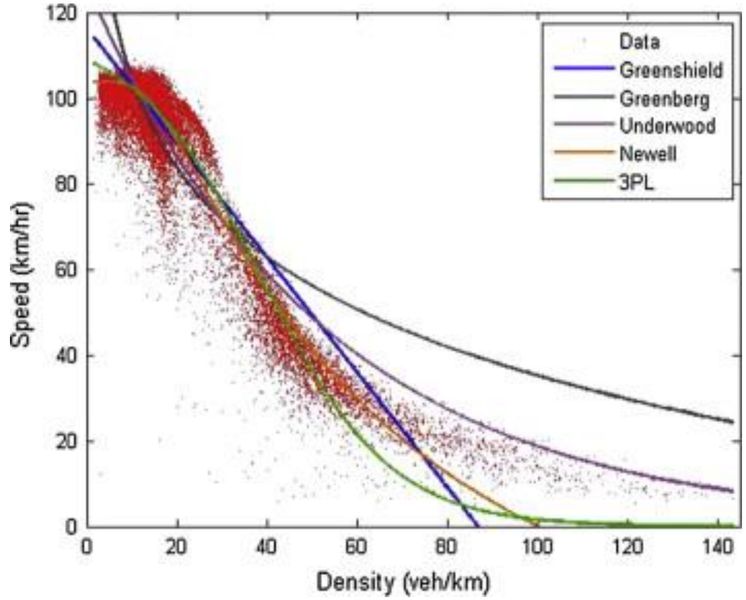
Microscopic models

- **Integrated model**
- Toledo, 2002



Mesoscopic models

- **User representation**
  - Disaggregate
  - Individual vehicles or packets of vehicles
- **Speed representation**
  - Aggregate
  - Fundamental relationship
  - Queuing models
- **Traffic control**
  - Adjusting the capacities (e.g., traffic signals)
- ***Event-based simulation***



Mesoscopic models

- **Application**

- Dynamic traffic assignment (DTA)
  - Network performance
  - Prediction
  - State estimation
- Planning and policy analysis
- Network design

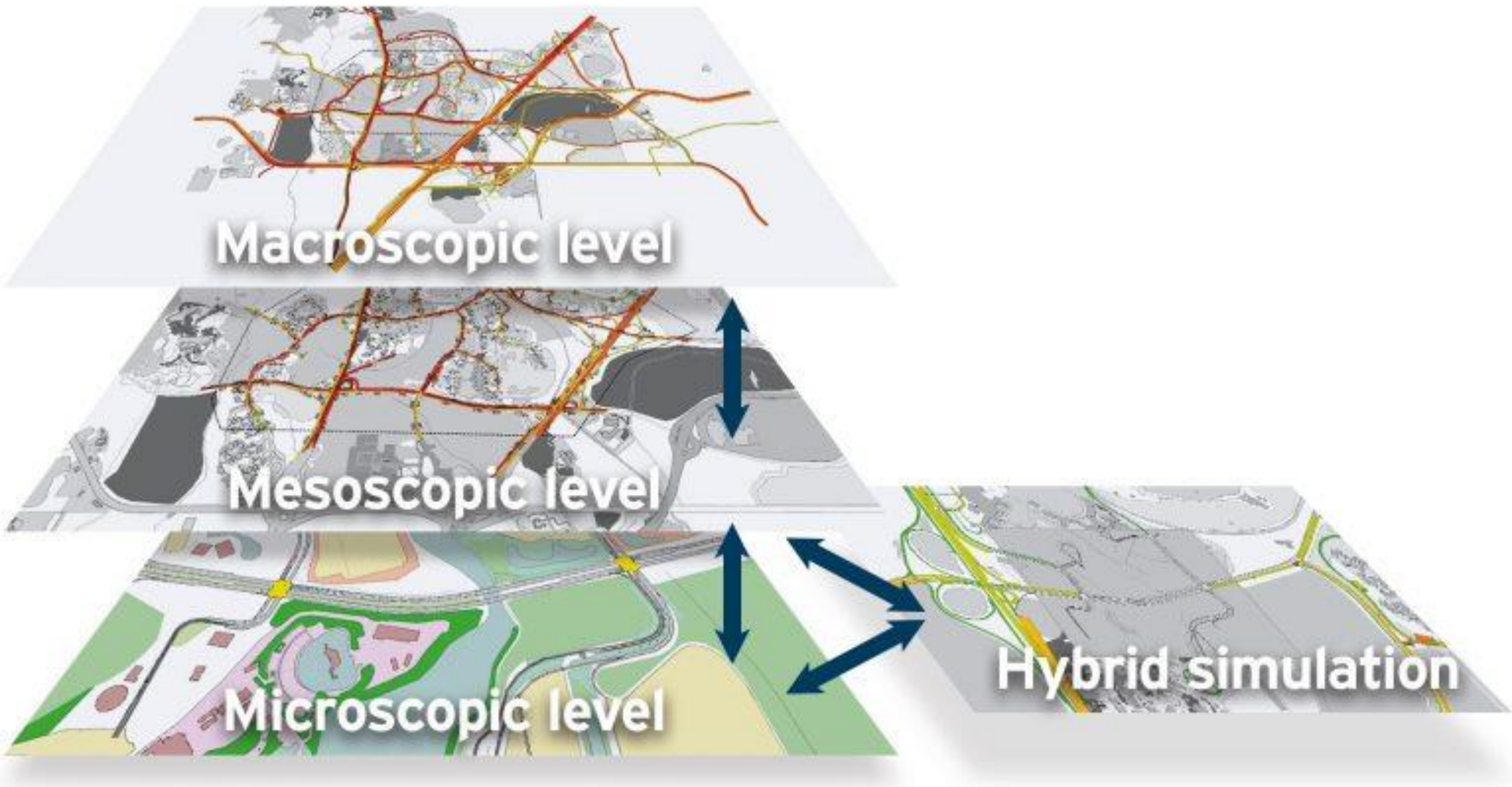
- **Fast computation!!**

Mesoscopic models

- **Examples**

CONTRAM	TRRL	Operations evaluation, planning, DTA
DYNAMEQ	Mahut, Florian	ITS, DTA, planning
DynaMIT	Ben-Akiva, Koutsopoulos, …	ITS, DTA, evaluation, prediction, short-term planning
DYNASMART	Mahmassani	
Dynemo	Schwerdtfeger PTV	ITS, prediction
INTEGRATION*	Van Arde	ITS, evaluation
METROPOLIS	De Palma	Planning
Mezzo and BusMezzo	Burghout, Koutsopoulos, Cats	DTA, short-term planning

Hybrid Models



Hybrid Models

- Combine different levels of resolution at different parts of the network
  - Microscopic in areas of interest, high congestion
  - Mesoscopic in remaining network

- Many advantages
  - Computational
  - Data preparation
  - Calibration
  - Scope of applications
- [Example]

Next

This week

- Tutorial on Thursday
- Computer Exercise 1 will be posted on Thursday

Next week

- A new module on microscopic models
- A/Prof Zuduo Zheng