

Overview on Traffic Modeling and Simulation

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Brief overview (1)

What is transportation?

(General View):

- **Movement of entities (e.g. People, Goods, Matter, Information/Messages, Energy, Sounds,.....) from one place/point to another.**

What is traffic?

➤ Transportation of

- ❖ Messages/information (telecommunications & Supply chains)
- ❖ Persons/Goods (Road traffic , Air traffic, Boat traffic, Rail traffic, etc.)

What is traffic theory?

- **Analysis of traffic phenomena/Issues/events**

Why are we analyzing traffic?

- Understand traffic issues/phenomena
- Improve traffic issue/phenomena
- Control traffic issue/phenomena
- Overcome/tackle/solve traffic problems

What are the analysis methods?

➤ Traffic modeling

- ❖ Mathematical (analytical)
- ❖ Graphical

➤ Traffic simulation

- ❖ Software/simulation tools



⊙ Road traffic



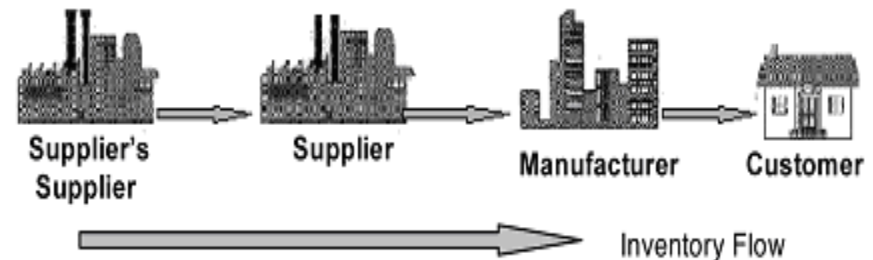
⊙ Rail traffic



⊙ Air traffic



⊙ Boat traffic



⊙ Supply Chain (traffic of Goods)

Brief overview (2)

What is simulation?

The imitation of:

- ❖ Reality (some real things/Behavior/events/phenomena)
- ❖ State of affairs,
- ❖ Behavior
- ❖ Process.

What is the reality?

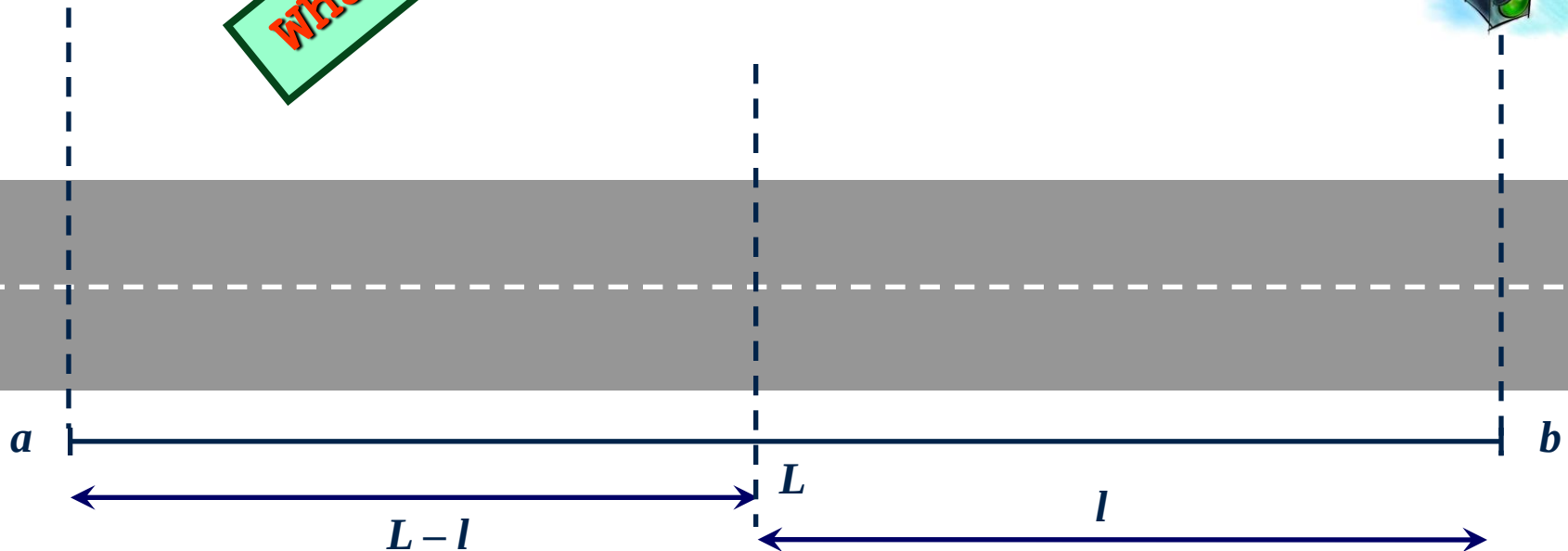
Some types of simulation

Computer simulation

- ❖ E.g. simulation of an abstract model of a particular system (algorithmic, numerical codes, etc...)

Simulation game

- ❖ E.g. simulation (or mimic) of various activities or "real life"



Brief overview (3)

Why simulation ? / What is the Goal?

- **Simulation can help to study:**
 - ❖ Systems performances
 - ❖ Systems operation modes
 - ❖ Systems dynamics
- **Simulation is important in case the real-system is: (**)**
 - ❖ **Not available** (e.g. Weather forecast)
 - ❖ **Complex** (e.g. Traffic scenarios/ space simulations)
 - ❖ **Costly** (e.g. flights simulation)
 - ❖ **Dangerous** (e.g. Nuclear explosion)
- **Simulation is important for: (*)**
 - ❖ A Quick evaluation of „**Design alternatives**“
 - E.g. Different system configurations, parameters, etc.
- **Simulation is important for:**
 - ❖ A validation of analytical predictions



Brief overview (4)

⊙ Advantages of traffic simulators?

- **Simulators can serve as complementary training for drivers**
- **Simulators provide the possibility of opening many research directions**
 - ❖ Drivers behavior
 - ❖ Architecture of roads
 - ❖ Pedestrians effects
- **Simulators will not replace real life training**
 - ❖ They just help for fast and easy traffic scenarios analyses

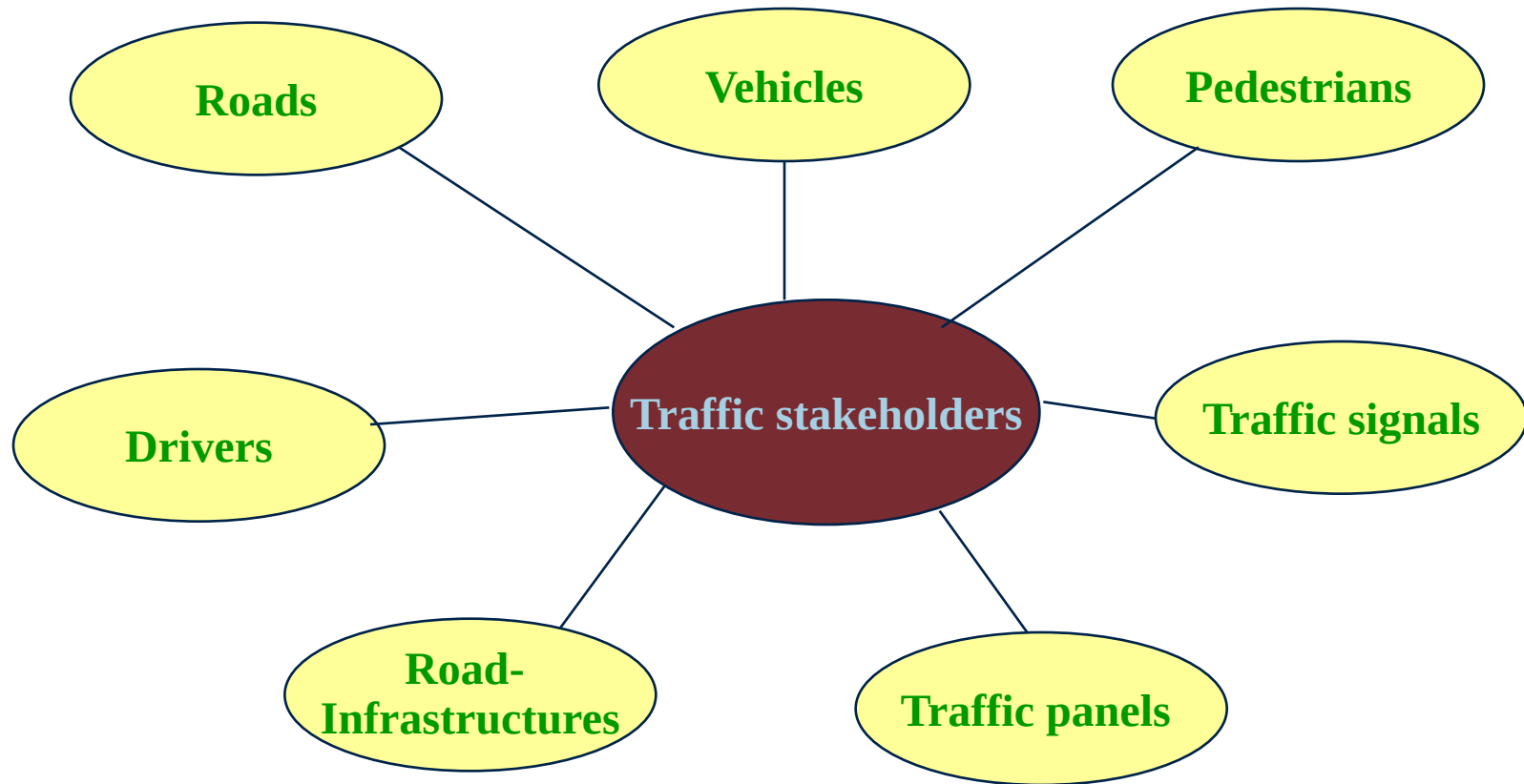
⊙ Drawbacks of traffic simulators?

- **Simulation does not reflect the reality**
 - ❖ Just a mimic !
- **Some types of training do not need simulators**
 - ❖ Because very critical
- **Profesionals do not loss a lot of time**
 - ❖ Very time consuming



Brief overview (5)

⦿ What are the traffic stakeholders?



What is then the Key Challenge ?

Brief overview (6)

⊙ What are the main traffic problems?

- Congestions/queuing
- Accidents (Road-traffic & Air- traffic,...)
- Traffic obstructions (Road traffic & Air-traffic,...)
- Packets loss (Telecommunications)

⊙ How to solve the traffic congestion problem?

- Very difficult to solve
- Solution is **integrating traffic management systems**
- Possibility of **extending the road network**
 - ❖ This solution is limited by
 - The number of lanes and lines (e.g. Changing the topology of roads)
 - * **There is no garanty there is space to construct new lanes and lines**
 - ❖ This solution is very expensive/costly
 - Another solution is encouraging people to **use public transportation cars** instead of private cars.



Brief overview (7)

◉ Why are we analyzing traffic?

- Estimate or Predict Traffic Performance for a Design
- Assess Capacity and LOS of a Transportation Facility

◉ Why are we simulating traffic?

- For protocols, scales, scenarios outside experimentation.
 - ❖ (But depends on good models)

◉ Consequences of Inappropriate Analysis Methods

- Unrealistic Results
- Incorrect Estimates of Traffic Performance
- Inappropriate Design of Control Strategies
- Wasted Resources
- Adverse Public Reaction to Changes



Applications of Traffic Simulation Models/Tools

⦿ Evaluation

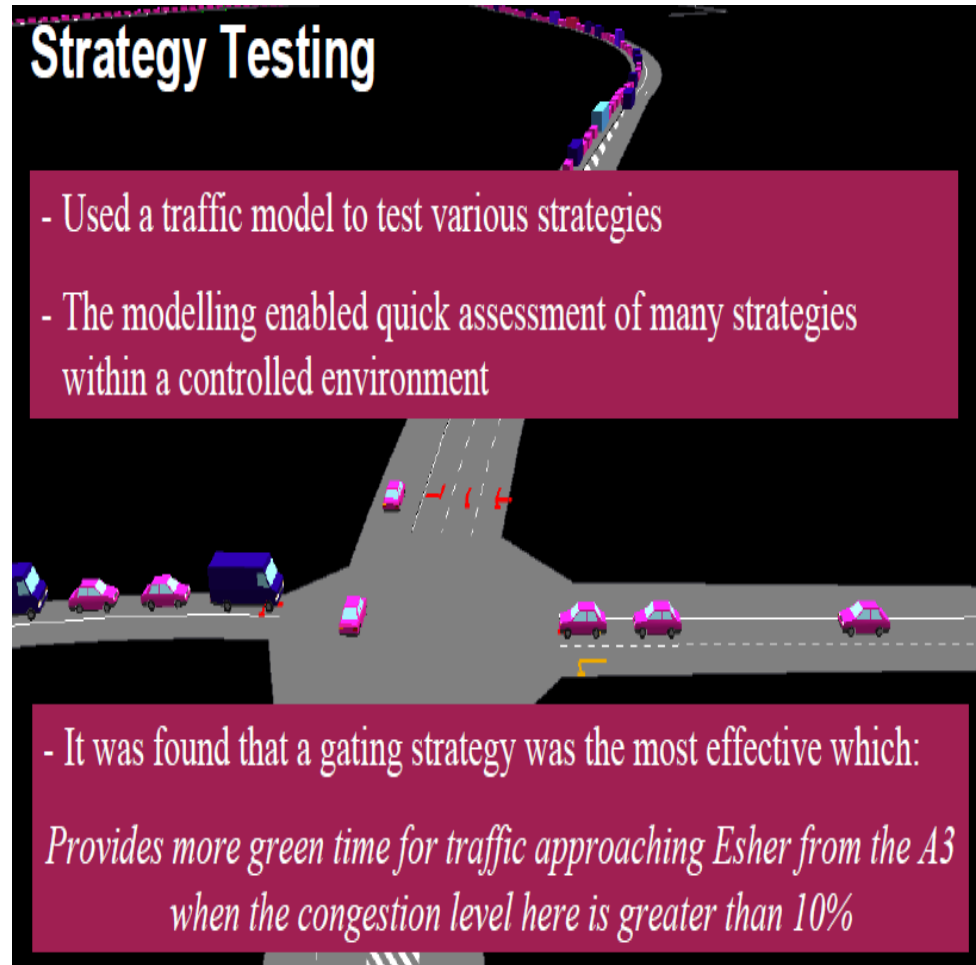
- **Traffic operations**
- **Intelligent Transportation Systems (ITS)**
 - ❖ Advanced Traffic Management Systems
 - ❖ Advanced Traveler Information Systems
 - ❖ Advanced Public Transportation Systems
- **Emergency Response**
- **Capacity Analysis**
- **Safety**

⦿ Design Refinement

- **Algorithms**
- **Strategies**
- **Geometric Design**

⦿ Advantage of Traffic Simulation Tools

- **Help to meet needs of planing, design, and operational applications**
- **Flexible, Accommodates traffic demands, Facility configuration, Management strategies, Traveler info systems, etc..**



Traffic Simulation Models/Tools

Traffic models classification (1)

- ◉ **Static**

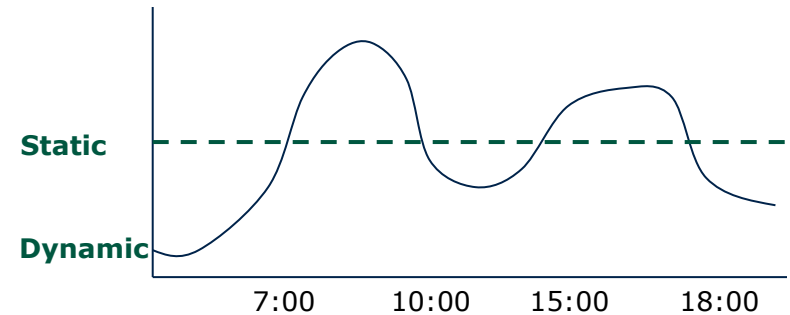
- Models average steady-state traffic situation

- ◉ **Dynamic**

- Models changes over time of the traffic situation

- ◉ **Discrete**

- The independent variable of the models i.e. "t" is the index of a time interval materialized by integers



- ◉ **Stochastic or Deterministic**

- **stochastic** modelling captures variation in e.g. reaction time, arrival processes, route choice. **But** every simulation run results in different outcome, so you need to **replicate simulation runs**

- ◉ **Time-stepped or event-based:**

- **Time stepped:** the model calculates the changes in the system for finite steps (e.g. 1 second)
- **event based:** the model calculates changes in the system when something 'happens' (events)

Traffic Models Classification(2)

- ⊙ Based on their properties;
 - *Physical Interpretation*
 - ❖ White Box Modelling
 - ❖ Black Box Modelling
 - ❖ Gray Box Modelling
 - *Discrete versus Continuous*
 - *Deterministic versus Stochastic*
- ⊙ Based on their flow and traffic dynamics representation traffic simulation models are characterized as:
 - *Macroscopic*
 - ❖ Fluid representation of flow (Like water flowing through a pipe)
 - ❖ Time and space discretization
 - *Mesosopic*
 - ❖ Individual vehicles (with aggregate behaviour) representation
 - ❖ Continuous space
 - ❖ Usually discrete time
 - *Microscopic*
 - ❖ *Individual vehicles (with detailed behaviour) representation*
 - ❖ *Traffic dynamics through vehicle interactions and movements*
 - *Nanosopic*
 - ❖ *Many common elements with microscopic*
 - ❖ *Detailed representation of vehicle dynamics*

Some Traffic Simulation Models (1)

❑	AIMSUN 2	Universitat Politècnica de Catalunya,	Spain
❑	ANATOLL	ISIS and Centre d'Etudes Techniques de l'Équipement	France
❑	ARTEMiS	University of New South Wales, School of Civil Engineering	Australia
❑	ARTIST	<i>Bosch</i>	<i>Germany</i>
❑	CASIMIR	Institut National de Recherche sur les Transports et la Sécurité	France
❑	CORSIM	<i>Federal Highway Administration</i>	<i>USA</i>
❑	DRACULA	Institute for Transport Studies, University of Leeds	UK
❑	FLEXSYT II	<i>Ministry of Transport</i>	<i>Netherlands</i>
❑	FREEVU	University of Waterloo, Department of Civil Engineering	Canada
❑	FRESIM	<i>Federal Highway Administration</i>	<i>USA</i>
❑	HUTSIM	Helsinki University of Technology	Finland
❑	INTEGRATION	<i>Queen's University, Transportation Research Group</i>	<i>Canada</i>
❑	MELROSE	Mitsubishi Electric Corporation	Japan
❑	MICROSIM	<i>Centre of parallel computing (ZPR), University of Cologne</i>	<i>Germany</i>
❑	MICSTRAN	National Research Institute of Police Science	Japan
❑	MITSIMLab	<i>Massachusetts Institute of Technology</i>	<i>USA</i>
❑	NEMIS	Mizar Automazione, Turin	Italy
❑	PADSIM	<i>Nottingham Trent University – NTU</i>	<i>UK</i>
❑	PARAMICS	The Edinburgh Parallel Computing Centre and Quadstone	UK

Some Traffic Simulation Models/Tools (2)

❑	PHAROS	Institute for simulation and training	USA
❑	PLANSIM-T	<i>Centre of parallel computing (ZPR), University of Cologne</i>	<i>Germany</i>
❑	SIGSIM	University of Newcastle	UK
❑	SIMDAC	<i>ONERA – Centre d'Etudes et de Recherche de Toulouse</i>	<i>France</i>
❑	SIMNET	Technical University Berlin	Germany
❑	SISTM	<i>Transport Research Laboratory, Crowthorne</i>	<i>UK</i>
❑	SITRA-B+	ONERA – Centre d'Etudes et de Recherche de Toulouse	France
❑	TRANSIMS	<i>Los Alamos National Laboratory</i>	<i>USA</i>
❑	THOREAU	The MITRE Corporation	USA
❑	VISSIM	<i>PTV System Software and Consulting GMBH</i>	<i>Germany</i>
❑	VISUM	<i>PTV System Software and Consulting GMBH</i>	<i>Germany</i>
❑	LISA++	<i>PTV System Software and Consulting GMBH</i>	<i>Germany</i>
❑	TRANSYT		
❑	CRONOS		
❑	SCOOTs	<i>TRL, Crowthorne, Berkshire (Split Cycle and Offset Optimisation Technique)</i>	<i>UK</i>
❑	SCATS	RTA, Sydney, NSW (Sydney Coordinated Adaptive Traffic system)	<i>Australia</i>
❑	MOTION		<i>Germany</i>
❑	SYNCHRO		<i>USA</i>
❑	HCS	(High way Capacity Software),	

Microscopic View

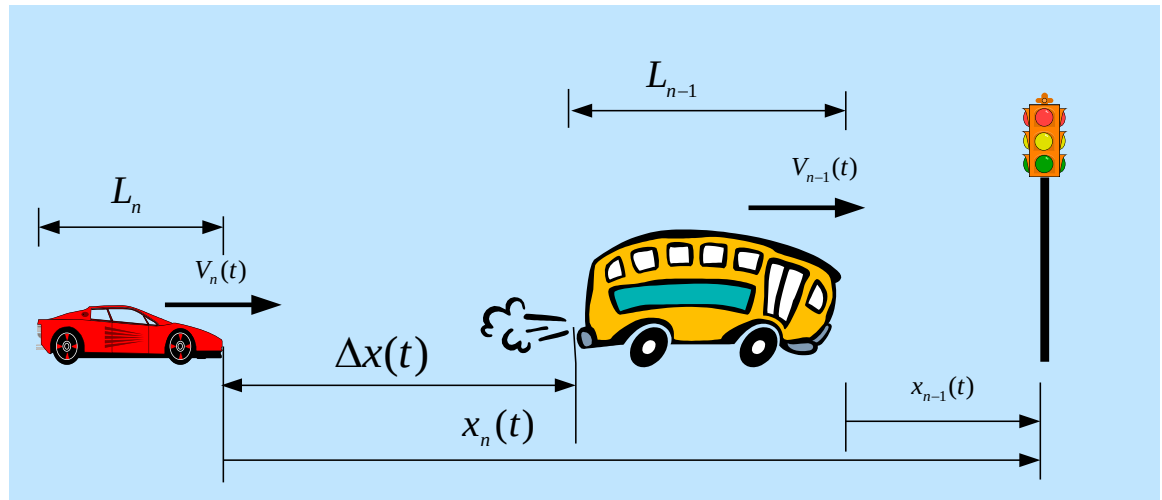
- ◆ Maps traffic flow as a set of individual vehicles
 - Represents
 - ◇ integrated networks in detail (freeways and urban streets)
 - ◇ wide range of surveillance and control devices
 - ◇ various vehicle classes (e.g information access)
 - Models individual vehicle movements
 - ◇ car-following
 - ◇ lane changing
 - ◇ gap acceptance
 - ◇ merging
 - ◇ Buses
 - Captures travel and driver behavior
 - ◇ pre-trip
 - ◇ en-route route choice
 - ◇ aggressiveness and compliance

Mathematical models for microscopic analysis

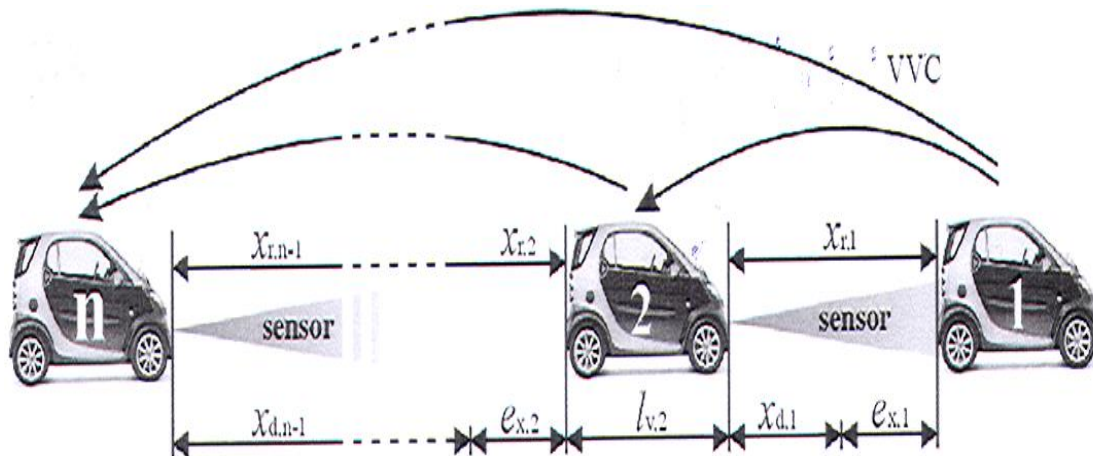
Car-Following Model

☆ Time- & Space- headway:

- Free-flow regime
- Car-following regime
- Emergency Regime



➤ Acceleration = Φ (distance, speed....)



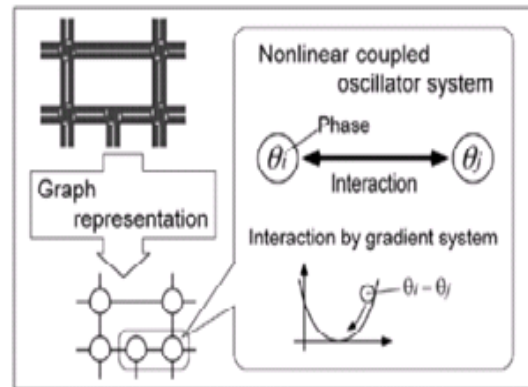
$$\begin{cases} \frac{d^2 x_{i-1}}{dt^2} = K_1 \cdot (x_{i-2} - x_{i-1} - h_d \cdot v_{i-1}) + K_2 \cdot (v_{i-2} - v_{i-1}) & (1) \\ \frac{d^2 x_i}{dt^2} = K_1 \cdot (x_{i-1} - x_i - h_d \cdot v_i) + K_2 \cdot (v_{i-1} - v_i) & (2) \end{cases}$$

Coupled model for cooperative ACC

Mathematical models for microscopic analysis

► Modeling Traffic Control:

Synchronized coupled oscillators can be used to model and optimize real-time self-organized traffic control in a city



$$\dot{x}_i = \omega_i + \sum_j u_{ij}(x_j - x_i)$$
$$u_{ij}(x_j - x_i) = \frac{1}{N} \sin(x_j - x_i)$$

Kuramoto Model

Efficient for Pretimed- Control

Not accurate enough for Actuated- Control

- [1] Stefan Lämmer, Hiroshi Kori, Karsten Peters, and Dirk Helbing, "Decentralised control of material or traffic flows in networks using phase-synchronization," Physica A, Vol. 1, pp. 363-363, 2006.
- [2] C. Gershenson, "Self-Organizing Traffic Lights ," Nonlinear Sciences, Complex Systems, Vol. 1, pp. 363-363, 2005.
- [3] Sugi, H Yuasa, T Arai, " Autonomous distributed control of Traffic Signal Networks," Intelligent Autonomous Systems 7, 2002

Advantages and Drawbacks microscopic Models

Advantages:

- Ease processing of heterogeneous vehicles
- Kinematics of realistic vehicles
- Easy implementation of stochastic aspects
- Valid for a single lane

Drawbacks:

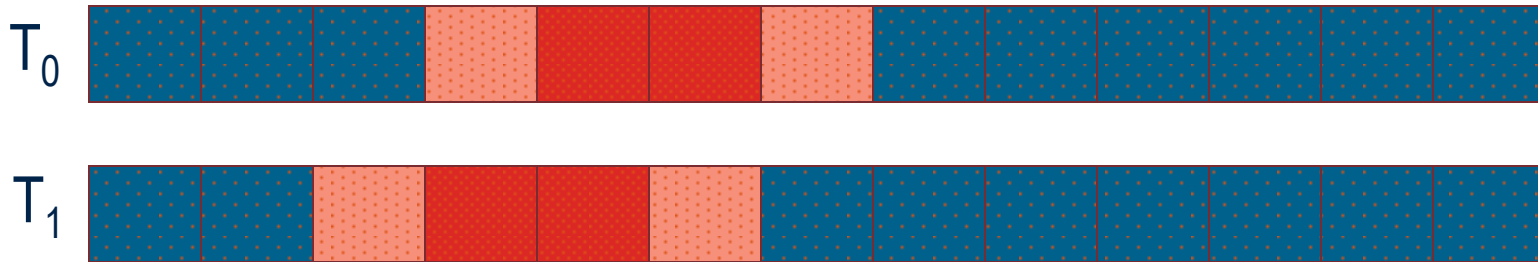
- Cannot model overtaking
- Cannot model the Driver behaviour
- Difficulty of calibration and validation (stability ...)
- When difference in speed = 0, the acceleration = 0 *even if the distance is very small*
- When small fluctuations in speed-difference result in changing the acceleration : unrealistic that driver can perceive small changes
- Drivers are 'dragged along' if the leader accelerates

=>

Interest of more comprehensive models

Macroscopic View (1)

- Types:
 - **Gas-kinetic diff. equations (e.g. Prigogine & Herman)**
 - **Fluid dynamic diff equations (e.g. Lighthill, Whitham & Richards)**
- Discretised over time and space
- Large networks, limited detail



- Maps traffic flow as a continuous unity of fluidized vehicles.
- No vehicle in the traffic flow is identifiable.
- The traffic flow is characterized by macroscopic state values like density, volume and mean velocity.
- The traffic flow is treated as a continuous fluid flow in fluid dynamics.

Macroscopic View (2)

- ◉ Three variables $Q(x,t)$, $K(x,t)$, $U(x,t)$
- ◉ Fundamental relationships:
 - The conservation equation $\frac{\partial Q}{\partial x} + \frac{\partial K}{\partial t} = 0$
 - $Q = KU$
 - Need of a third equation
 - ❖ *Equilibrium relationship $Q = Q_e(K)$ ou $U = U_e(k) \Rightarrow$ first-order models (LWR)*

Drawbacks Macroscopic Models

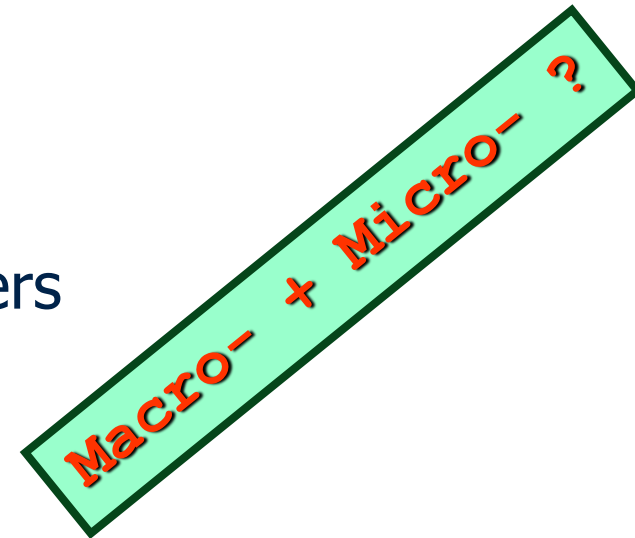
- ⦿ Cannot provide full insight of real- traffic scenario
- ⦿ Not efficient to analyze real- traffic scenarios
- ⦿ Only a global view is provided
- ⦿ Both Time & Space discretization lead to the loose of some key Insights or features of the real- traffic dynamics

=>

Interest of more comprehensive models

Mesoscopic View

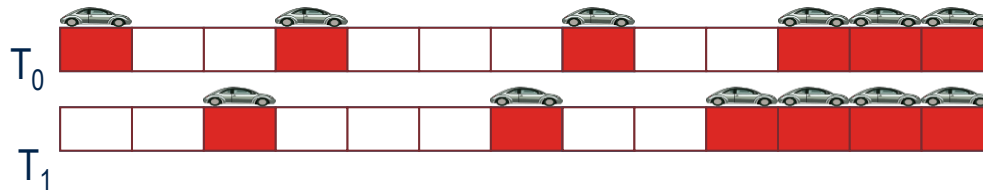
- ◉ Individual vehicles, aggregate behaviour on links.
- ◉ Types:
 - Queue-server at nodes, speed = $F(\text{density})$ on links
 - Cellular automata: cell-hopping vehicles
 - Packets of vehicles (CONTRAM)
- ◉ General Principle:
 - Define Rules for all traffic stakeholders
 - Define starting points



Meso-models: Cellular Automaton

<http://rcswww.urz.tu-dresden.de/~helbing/RoadApplet/>

1. Acceleration of free vehicles: IF ($v < v_{\max}$) THEN $v = v + 1$
2. Slowing down due to other cars: IF ($v > \text{gap}$) THEN $v = \text{gap}$
3. Stochastic driver behavior: IF ($v > 0$) AND ($\text{rand} < p_{\text{noise}}$) THEN $v = v - 1$

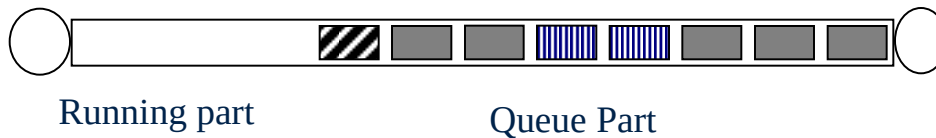


What are Rules ?

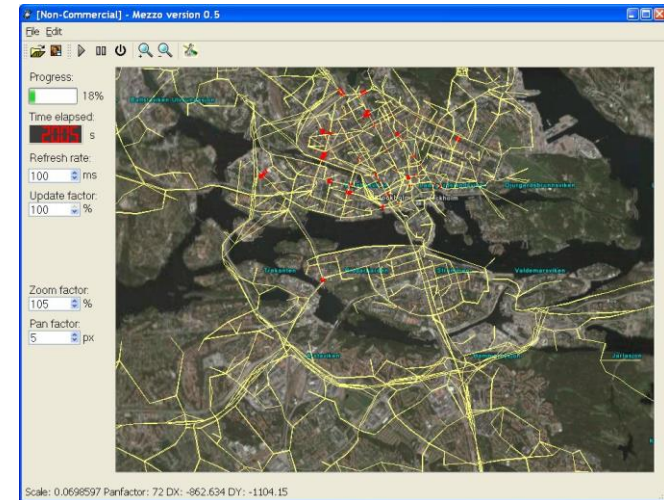
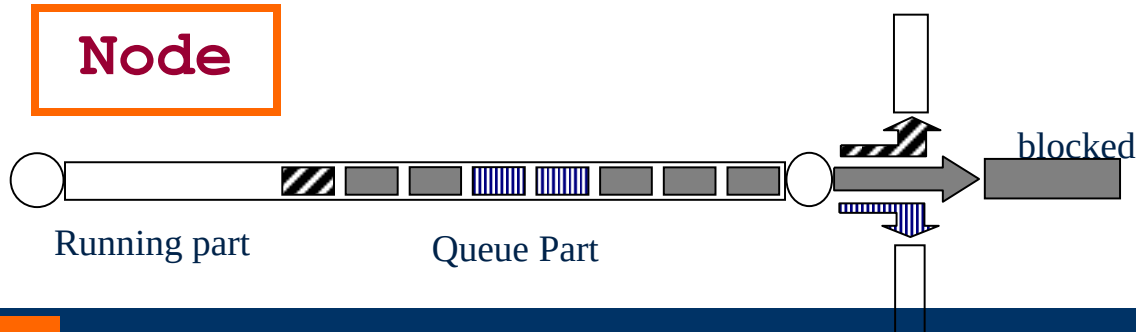
MEZZO: Event-Based Mesoscopic Model

- Designed for integration with micro models
- Vehicle-based, event-based
- Links: $\text{Speed} = f(\text{density})$
- Nodes: Queue-servers for each turning
- Queue formation and dissipation

Queue



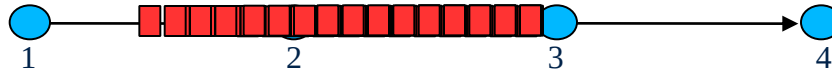
Node



Application of Meso. Models (1):

Shockwaves

- Many meso models generally do not model start-up shockwaves



- Essential in hybrid models for spilling over of queues at meso-micro boundaries
- Solution: Update the exit times according to shockwave theory (LWR)
 - Follow the queue front at start-up
 - Calculate the new exit time for each vehicle

Route choice

- Pre-trip choice with switching en-route
- Historical travel times for pre-trip choice
- Current (updated) travel times for en-route information & switching

What is Shockwaves?

SYNCHRO Vs. VISSIM (1)

⊙ Analytical software tools

- They are based on deterministic equations

- ❖ **SYNCHRO**
- ❖ HCS
- ❖ SIDRA
- ❖ RODEL
- ❖ HICAP
- ❖ Transyt 7F

A Survey conducted in August 2007

⊙ Simulation Tools

- They explicitly model the dynamics of individual vehicles

- ❖ SimTraffic
- ❖ Corsim
- ❖ **VISSIM**
- ❖ Paramics
- ❖ Aimsun
- ❖ Transmodeler

Figure 1a: Rate your Proficiency with the following ANALYTICAL tools.

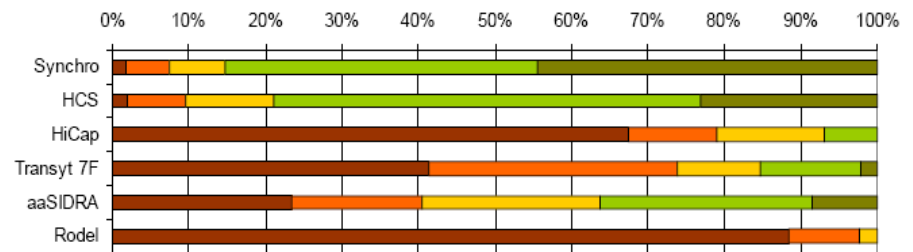


Figure 1b: Rate your Proficiency with the following SIMULATION tools.

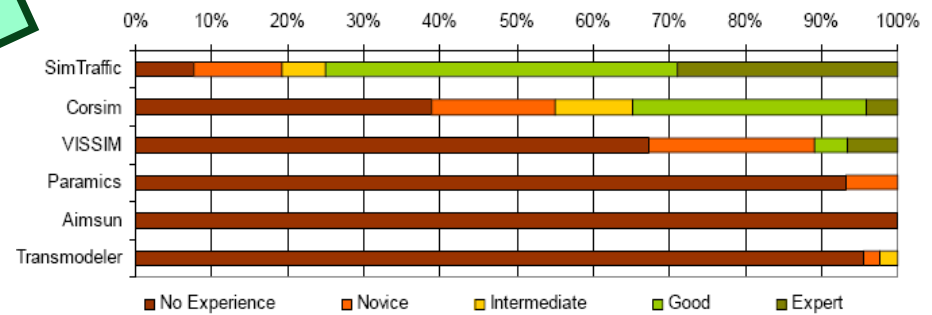
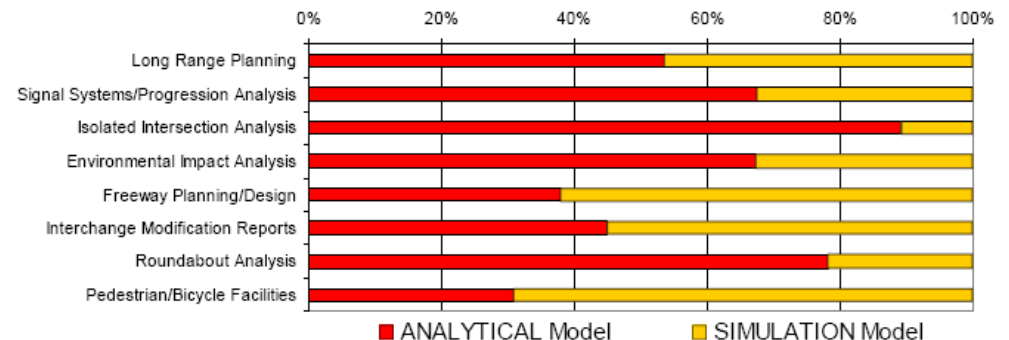


Figure 2: Which tool would you recommend for each subject area?



SYNCHRO Vs. VISSIM (2)

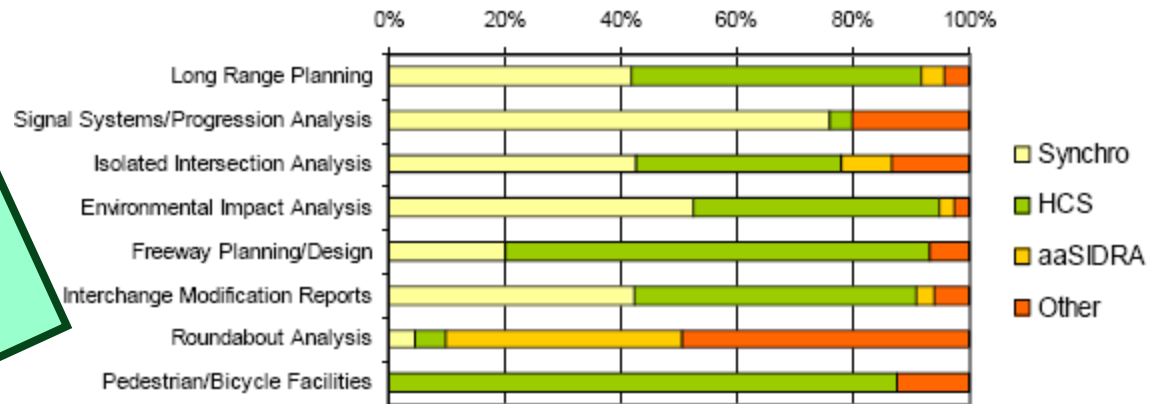
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**A Survey
Conducted
in August
2007**

Figure 3a: Which ANALYTICAL tool would you recommend?

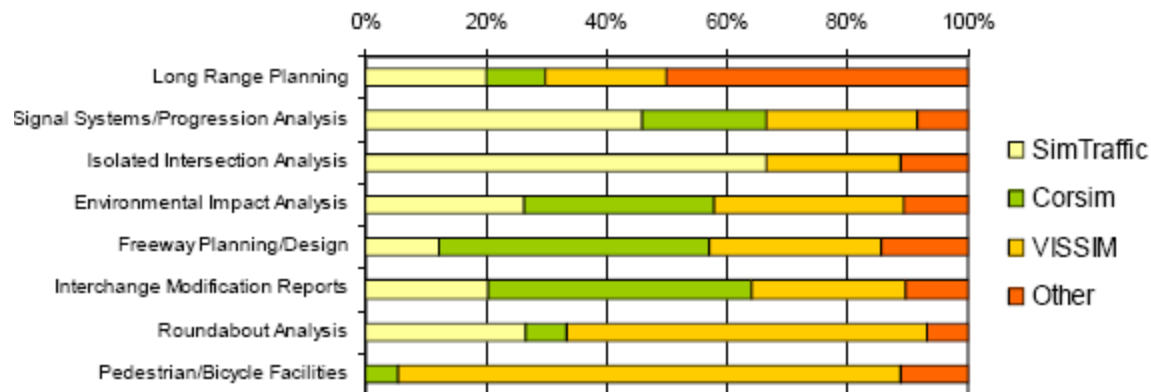


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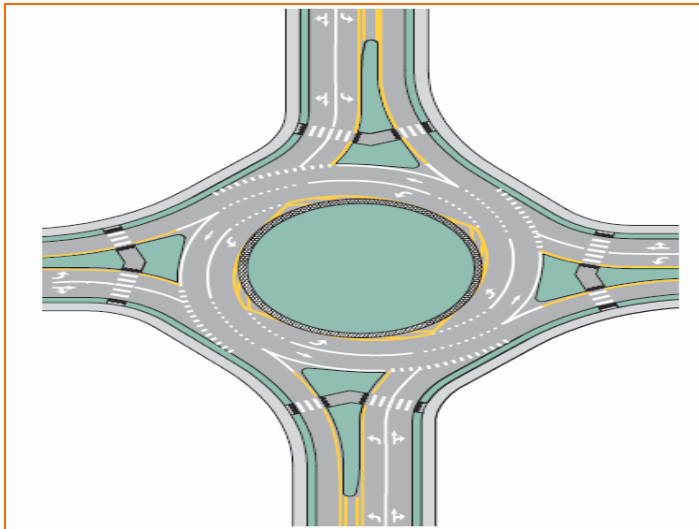
Figure 3b: What SIMULATION tool would you recommend?



SYNCHRO Vs. VISSIM (3)

◎ Some Key features of VISSIM

- Good for analyzing **freeway**
- Good for analyzing **roundabout**
- Good for analyzing **Pedestrian facilities**
- Good for analyzing **Bicycle facilities**
- Widely used
- Easy data entry / best graphic interface
- Integrated signal optimization
- Intersection los (hcm / icu)
- Queue length (percentile)
- Easy to create sub networks



Models/Tools for this Workshop

For this project

- ⊙ VISSIM
- ⊙ VISUM
- ⊙ LISA++

Classical Approaches

- ⊙ CELLULAR AUTOMATON
- ⊙ AGENTS
- ⊙ GENETIC ALGORITHM
- ⊙ PARTICLES SWARM

Challenging Ongoing-Project

- ⊙ **TRAFFIC- SIMULATION BASED CELLULAR
AUTOMATA HARDWARE IMPLEMENTATION**

On-Going Research
project,
Transportation
Informatics,
University of
Klagenfurt
(AUSTRIA)

