TRAFFIC FLOW SIMULATION USING MESOSCOPIC APPROACH

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TRANSPORT AND TELECOMMUNICATION INSTITUTE

LABORATORY OF APPLIED SOFTWARE SYSTEMS
TRANSPORT AND TELECOMMUNICATION INSTITUTE

I am from Latvia…

Time line

1919 — Aircraft Technician School (Kiev)

1946 — Higher Military School for Aviation Engineers (Riga)

1960 — Riga Institute for Civil Aviation Engineers (Riga)

1992 — Riga Aviation University

1999 — **TSI University of applied sciences**

Key data

- **Number of students:** > 2900
- **Faculties:**
  - Computer Science and Telecommunication
  - Management and Economics
  - Transport and Logistics
- **Levels:**
  - Bachelor/Professional qualification
  - Master
  - PhD
- **Staff:** >160 teaching staff

Key research directions

ICT (Telematics)	• Smart Cyber-Physical Systems • Internet of Things and Platforms for Connected Smart Objects • Robotics • Cyber Security • Big Data and Data Mining • Virtual Reality Applications
Smart Solutions in Transport and Logistics	• Aviation • Intelligent transport systems • Transport Simulation and Modelling • Smart Logistics • Applications of Ground Penetrating Radar
Digital Society and Economy	• Smart City and Urban Mobility • Content technologies and information management • E-Education • Information Technologies for Enterprises • Human-centric Digital Age • Business Intelligence

alliance

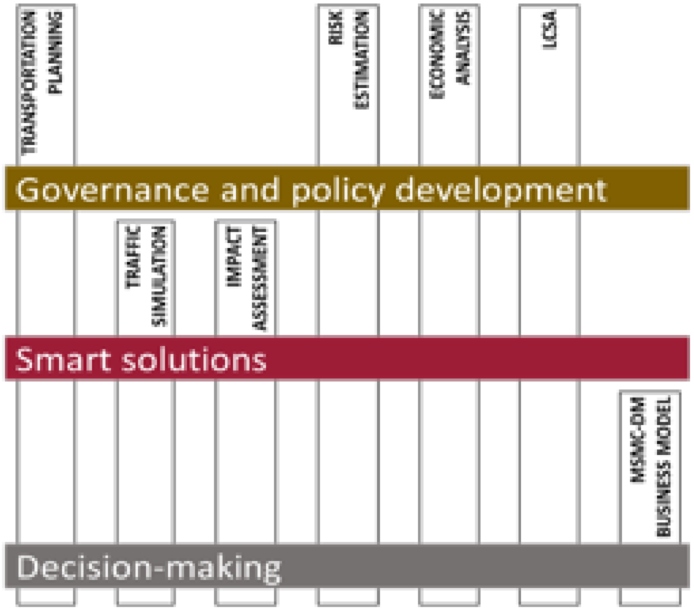
Enhancing excellence and innovation capacity in sustainable transport interchanges

Scope

- Link Transport and Telecommunication Institute (TTI) with University of Thessaly (UTH) and Fraunhofer Institute for Factory Operation and Automation (Fraunhofer)
- Provide knowledge to TTI research staff in the field of smart interconnecting sustainable transport networks
- Facilitate stakeholder collaboration and develop strong linkage among education, research and industry
- Create a doctoral programme in Transport Economics and Management at TTI

Concept

- Needs' analysis of Latvia and the surrounding region of the Baltic sea (Lithuania, Estonia, Poland) on intermodal transportation terminals
- Consideration of the relations among policy makers, industry and education/research
- Development of a coherent educational/training program, structured around 3 pillars:
  - ✓ Organizational/governance
  - ✓ Operational/services
  - ✓ Service quality/customer satisfaction



Program's thematic areas

Partners

TSI TRANSPORTA UN SAKARU INSTITŪTS

UNIVERSITY of THESSALY

Traffic, Transportation and Logistics Laboratory

Fraunhofer IFF

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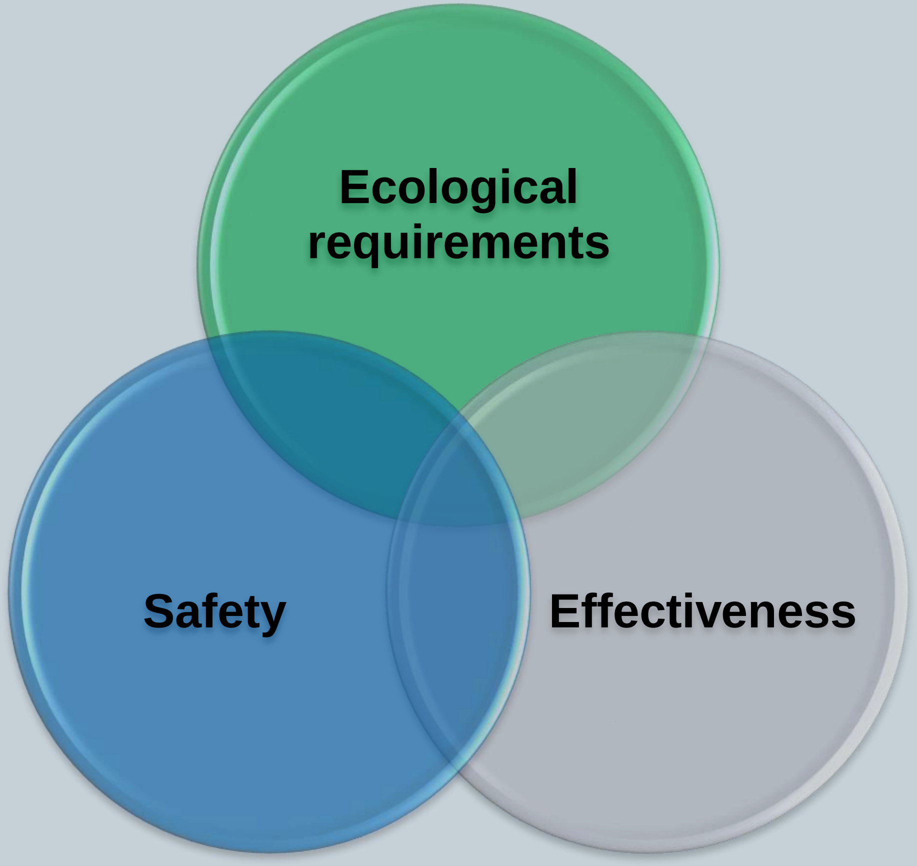
www.alliance-project.eu

Contents

- Introduction
  - Fundamentals of mesoscopic discrete rate approach
  - Formulation of discrete rate traffic reference model
  - Case-study: simulation of the two connected crossroads
  - Case-study: Urban transport corridor mesoscopic simulation

Requirements to the modern transport system

- **Transport** – key element of modern economics



Sustainable development

- **Sustainable development** is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs

- Transport sustainable development tools:
  - use of ITS (Intelligent Transportation Systems)
  - use of P&R (Park and Ride)
  - optimization of existing transport infrastructure
  - development of intermodality
  - implementation of new transport infrastructure elements on the base of doing strict impact analysis
  - use of sound tax policy
  - etc

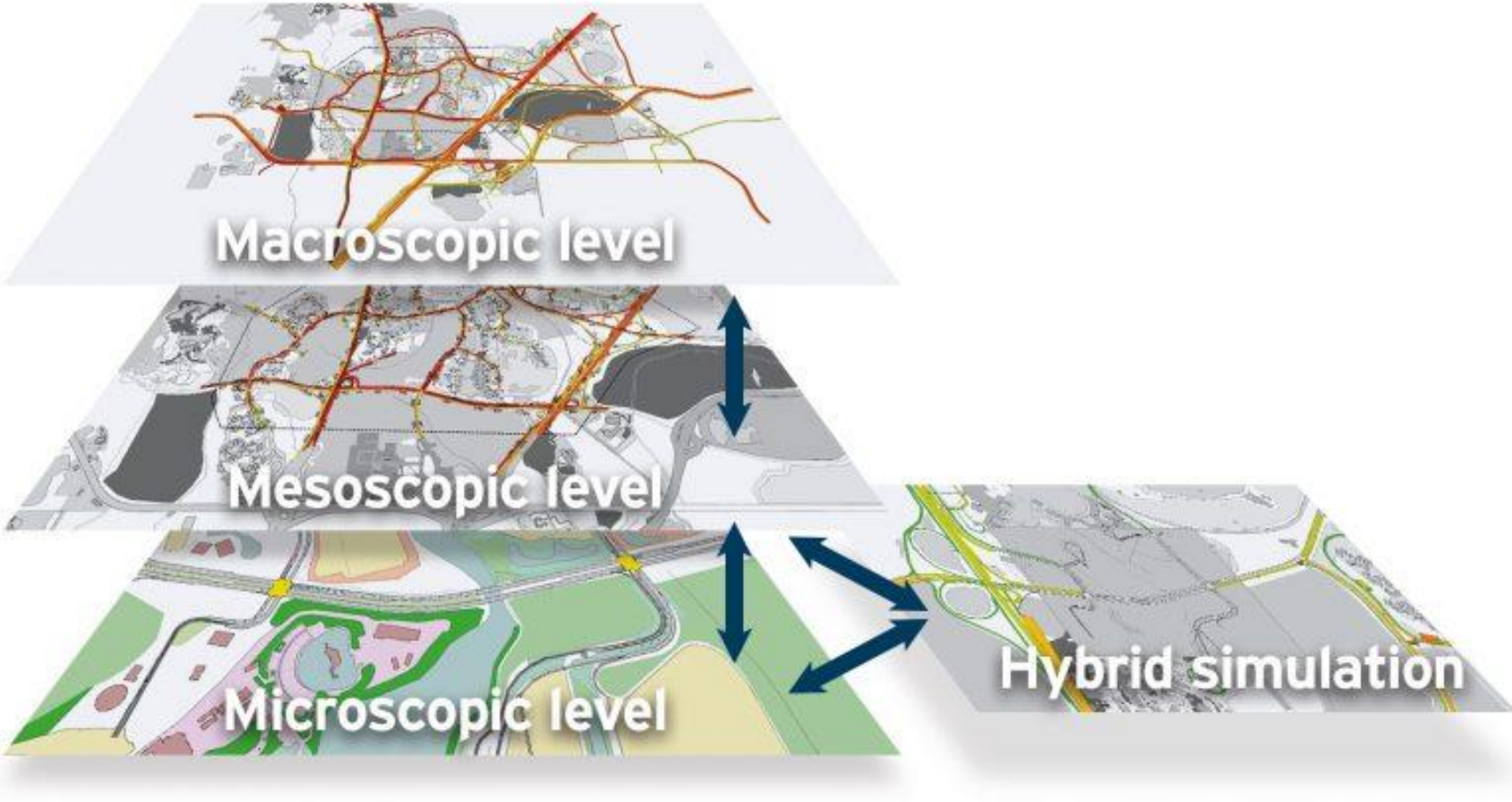
Traffic analysis tools

A traffic analysis tools is a collective term used to describe a variety of software-based analytical procedures and methodologies that support different aspects of traffic and transportation analyses

Traffic analysis tools:

- Sketch –planning tools
- Travel demand models
- Analytical deterministic tools (HCM, ICU…)
- Traffic signal optimization tools
- Macroscopic simulation models
- Mesoscopic simulation models
- Microscopic simulation models

Macro- , Mezo- , Micro-



Mesoscopic models

- **Mesoscopic models** combine the properties of both microscopic and macroscopic simulation models. These models simulate individual vehicles, but describe their activities and interactions based on aggregate (macroscopic) relationships [1]

- **Mesoscopic models** of traffic flow are based on estimation macroscopic indices on microscopic level [2]

- **Mesoscopic models** combine the properties of both microscopic and macroscopic simulation models. These models simulate individual vehicles **or group of vehicles**, but describe their activities and interactions based on aggregate (macroscopic) relationships

1) http://www.dot.ca.gov
2) Gilkerson G. et al. 2005. Traffic Simulation

Some mesoscopic models

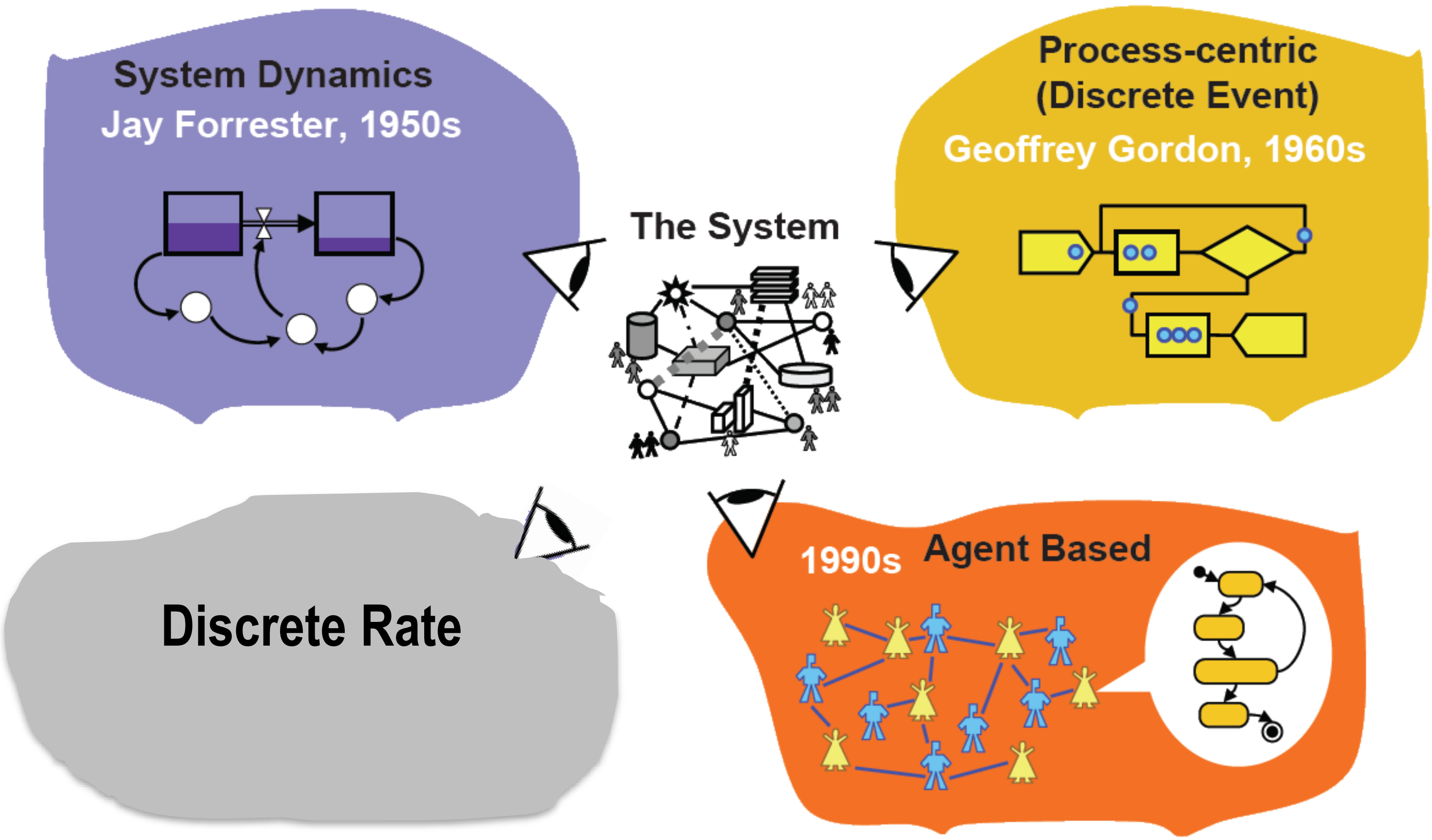
- CONTRAM (Leonard, D.R. et al. 1989)
- Cellular Automata (Nagel K. and Schreckenberg M. , 1992)
- DYNASMART (Jayakrishnan, R. et al. 1994)
- DYNAMIT (Ben-Akiva, M. 1996)
- FASTLANE (Gawron, C. 1998)
- DTASQ (Mahut, M. 2001)
- MEZZO (Burghout, W. 2004)
- AMS (Y. C. Chiu, L. Zhou, and H. Song, 2010)

Common disadvantages:

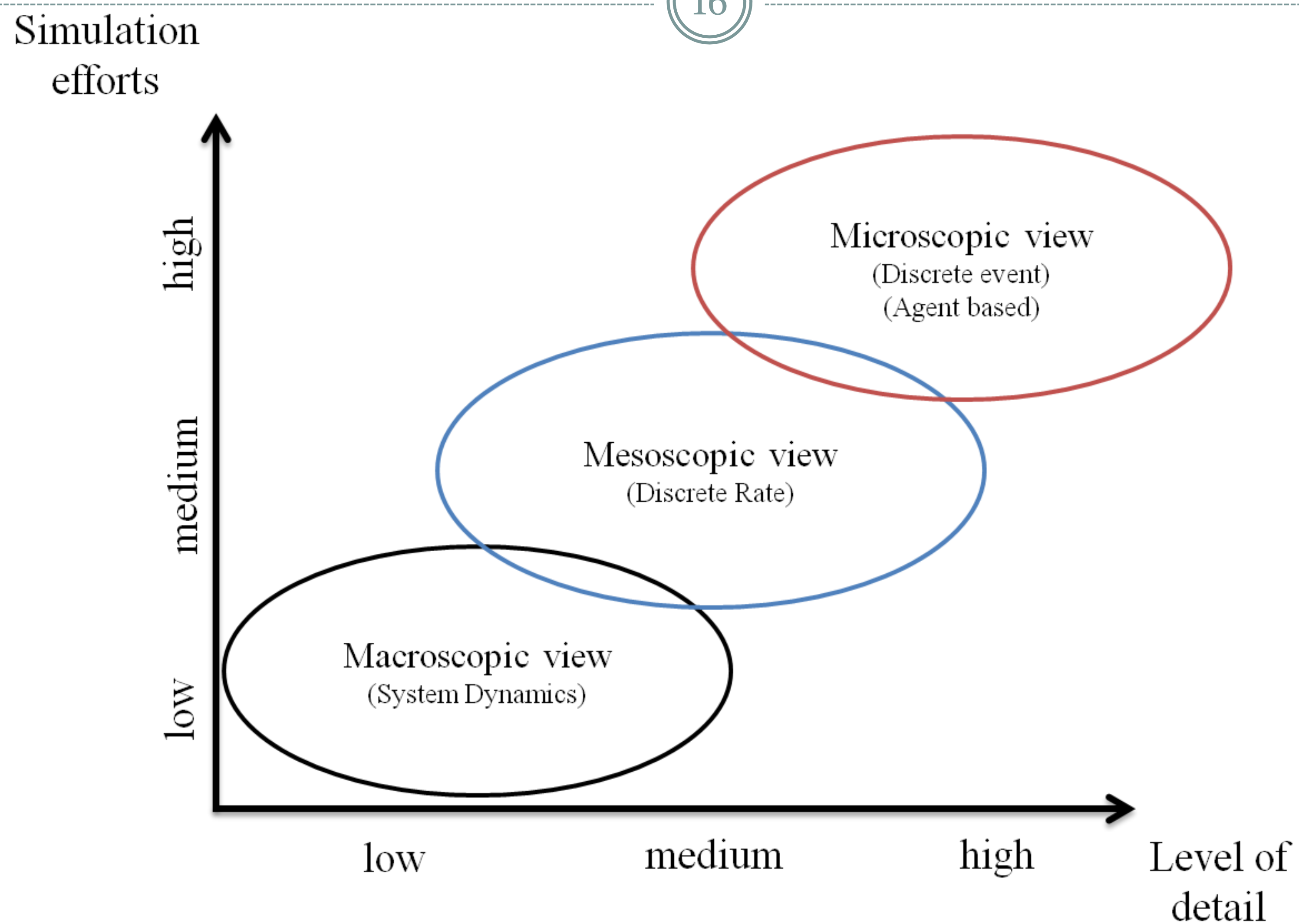
- Realised in proprietary software
- Defined only theoretically

Fundamentals of **discrete rate approach**

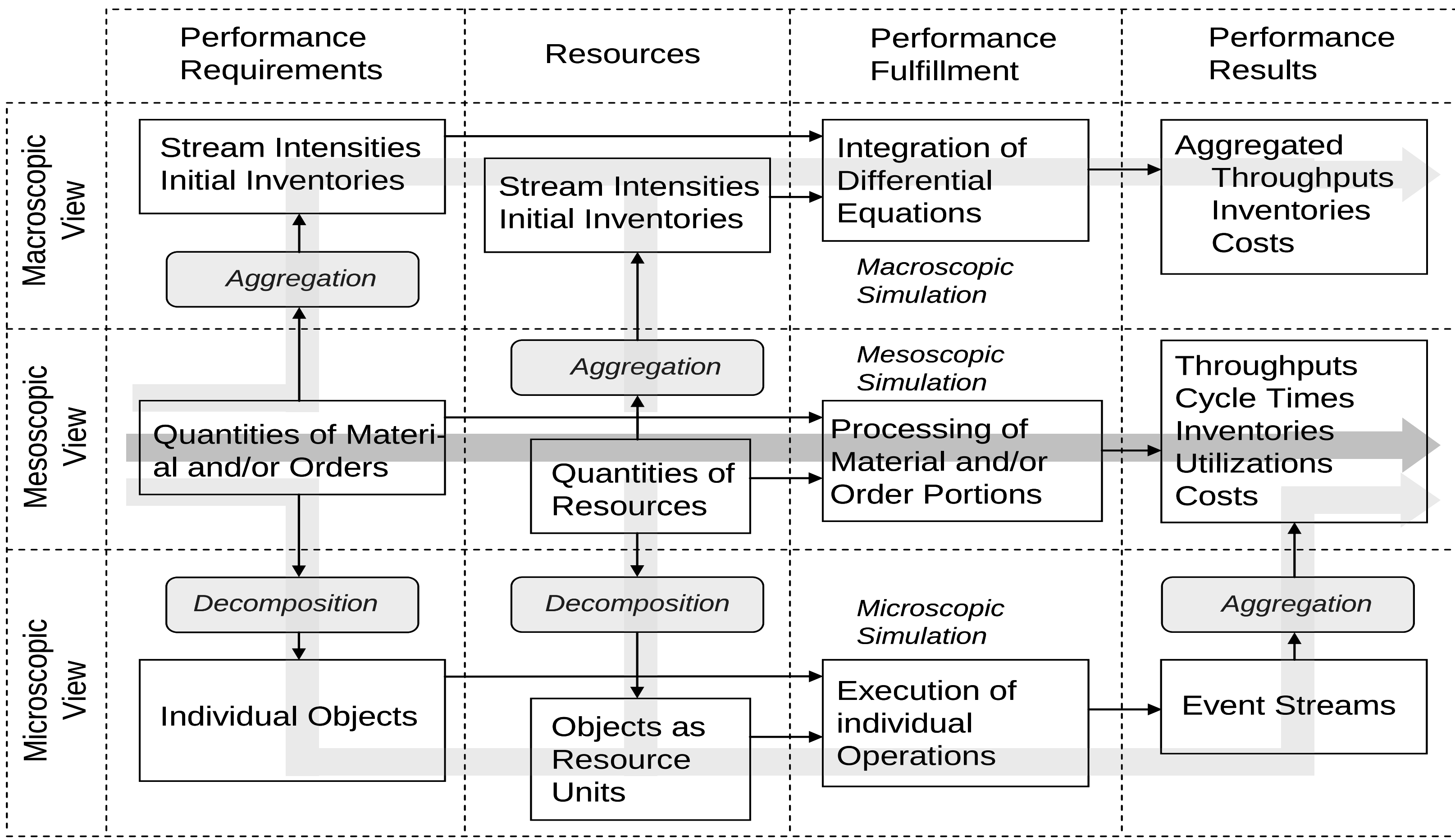
Traditional simulation approaches



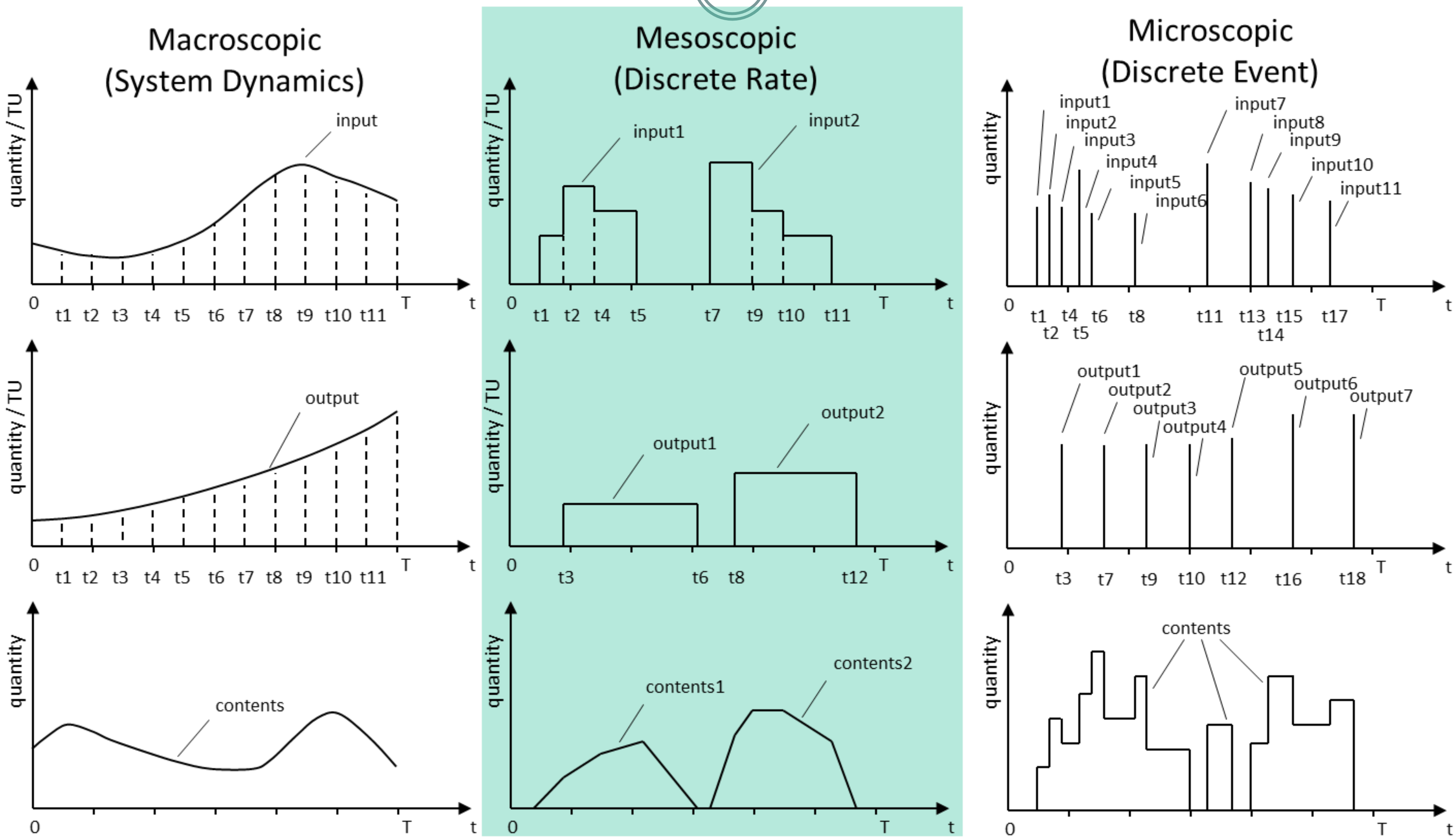
Level of detail VS simulation efforts



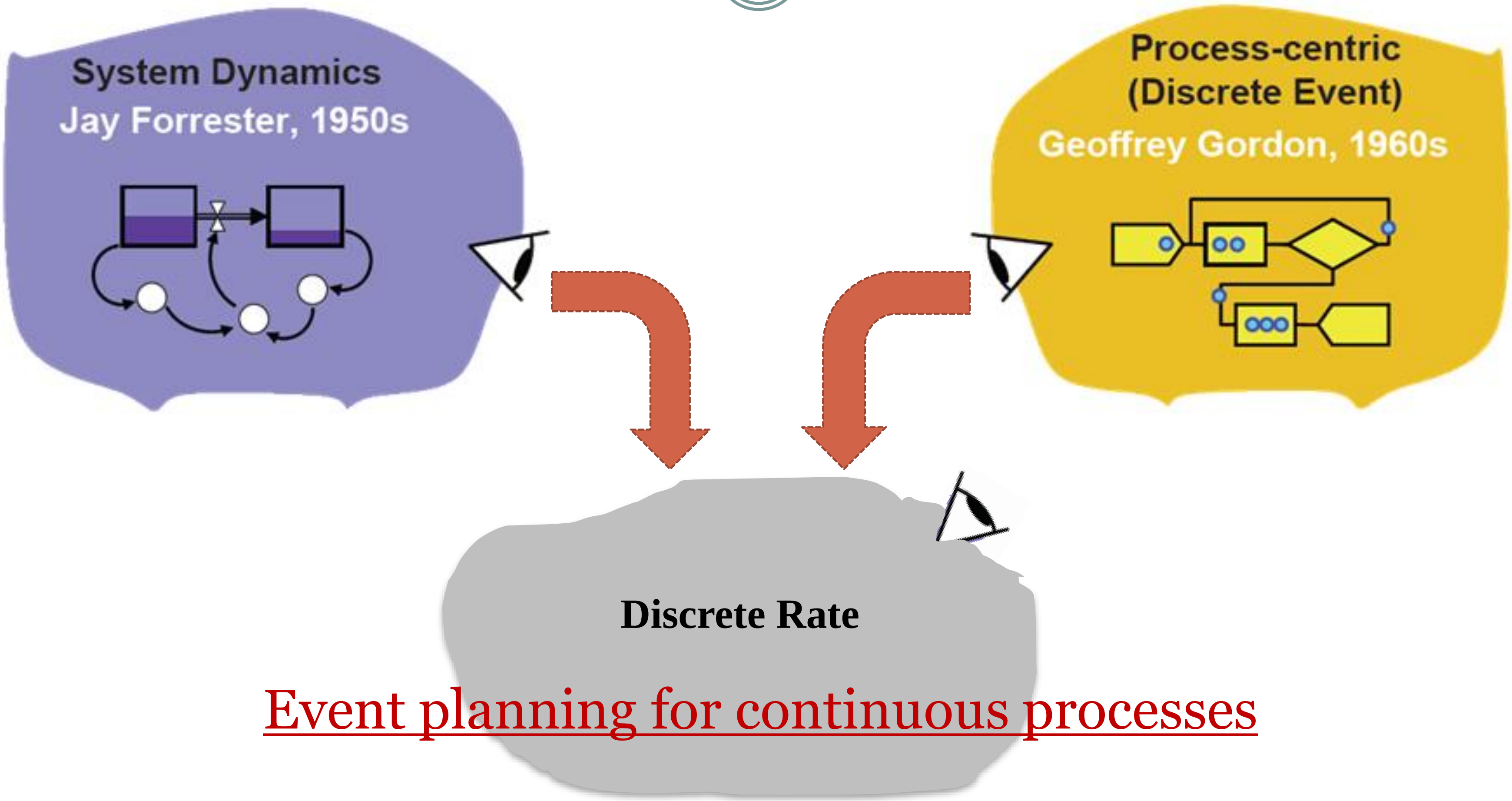
General comparison of approaches



Flow process models

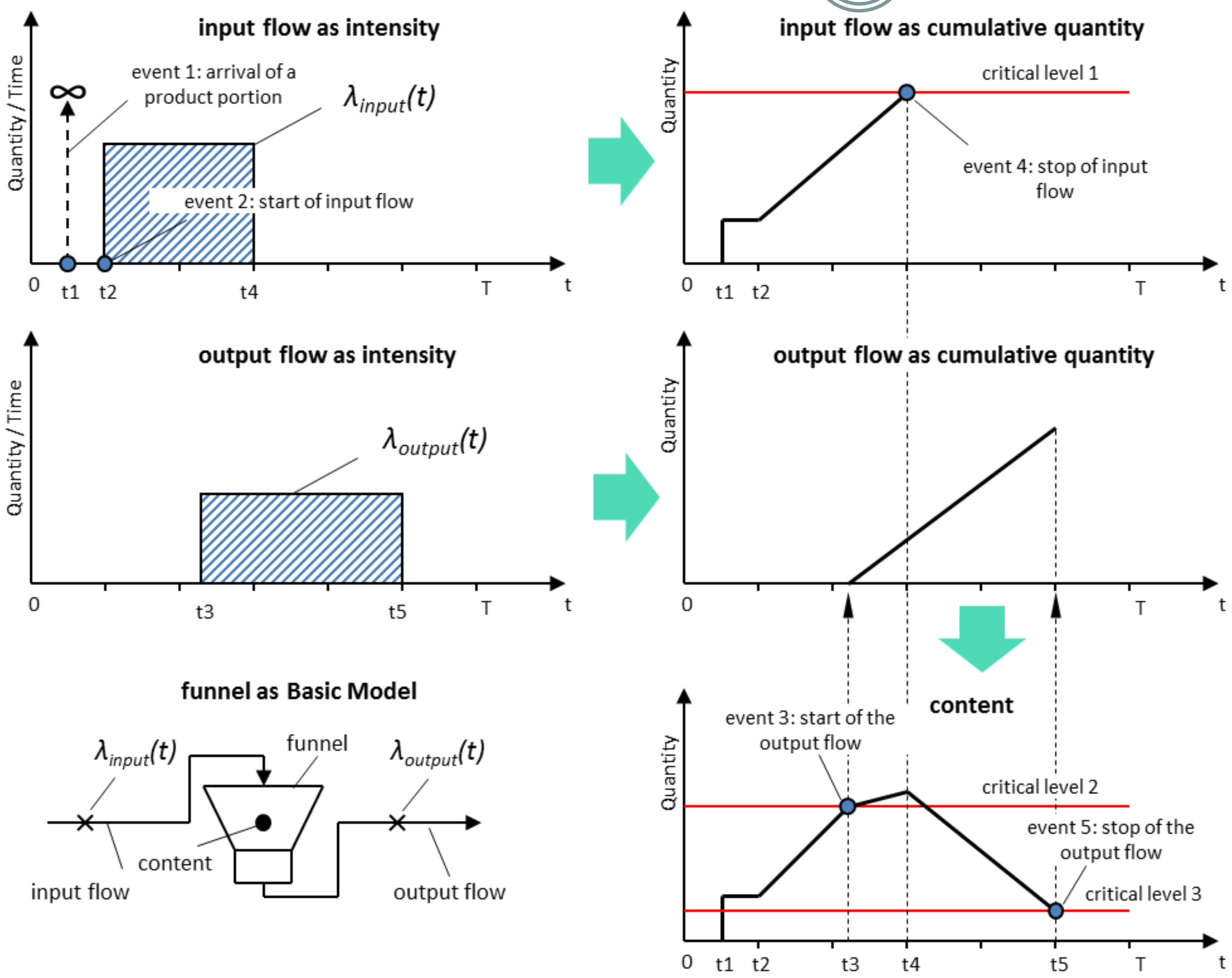


Characteristics of the mesoscopic discrete rate approach



Event planning for continuous processes

Hybrid characteristics of a mesoscopic discrete rate approach

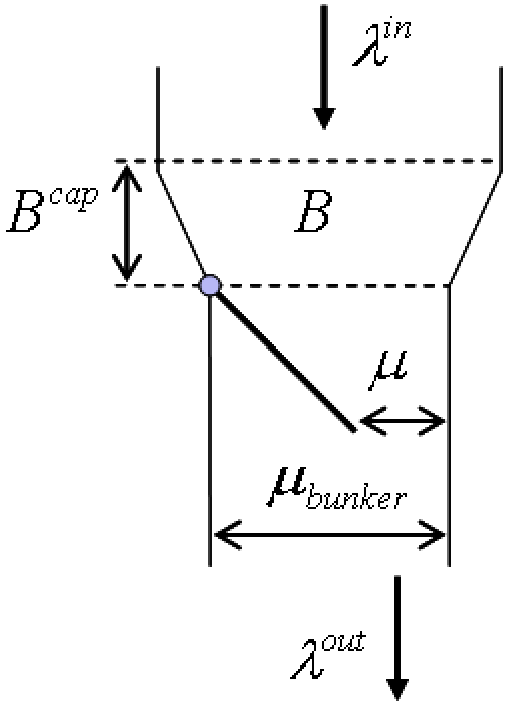


Hybrid Characteristics

- Flow processes with intensity $\lambda(t)$ (as in continuous simulation)
- Impulse-like product fractions and scheduling of future events (as in discrete event simulation)

Concepts of discrete rate approach

- Formally mesoscopic models can be represented as funnel



$\lambda^{in}(t) -$ arrival rate (cust/h)

$\mu(t) -$ process rate (cust/h)

$\lambda^{out}(t) -$ interarrival rate(cust/h)

B^{cap} – funnel volume

$\mu \le \mu_{\text{funnel}}$

$B\ (t) \le B^{cap}$ and $\lambda^{out}(t) \le \mu\ (t)$

The idea of calculation current value of output flow can be presented:

$$\lambda^{out} = \begin{cases} 0, \text{ if } \lambda^{in} = 0 \text{ and B=0} \\ \lambda^{in}, \text{ if } \lambda^{in} > 0 \text{ and } \lambda^{in} \le \mu \text{ and B=0} \\ \mu\ , \text{ if } B > 0 \end{cases}$$

$$B\ (t_{j-1} + \Delta t_j) = B\ (t_{j-1}) + \left(\lambda^{in} - \lambda^{out}\right) \cdot \Delta t_j$$

$\mu(t)$ - controlled parameter, can be set in any time point $t_j = t_{j-1} + \Delta t_j$

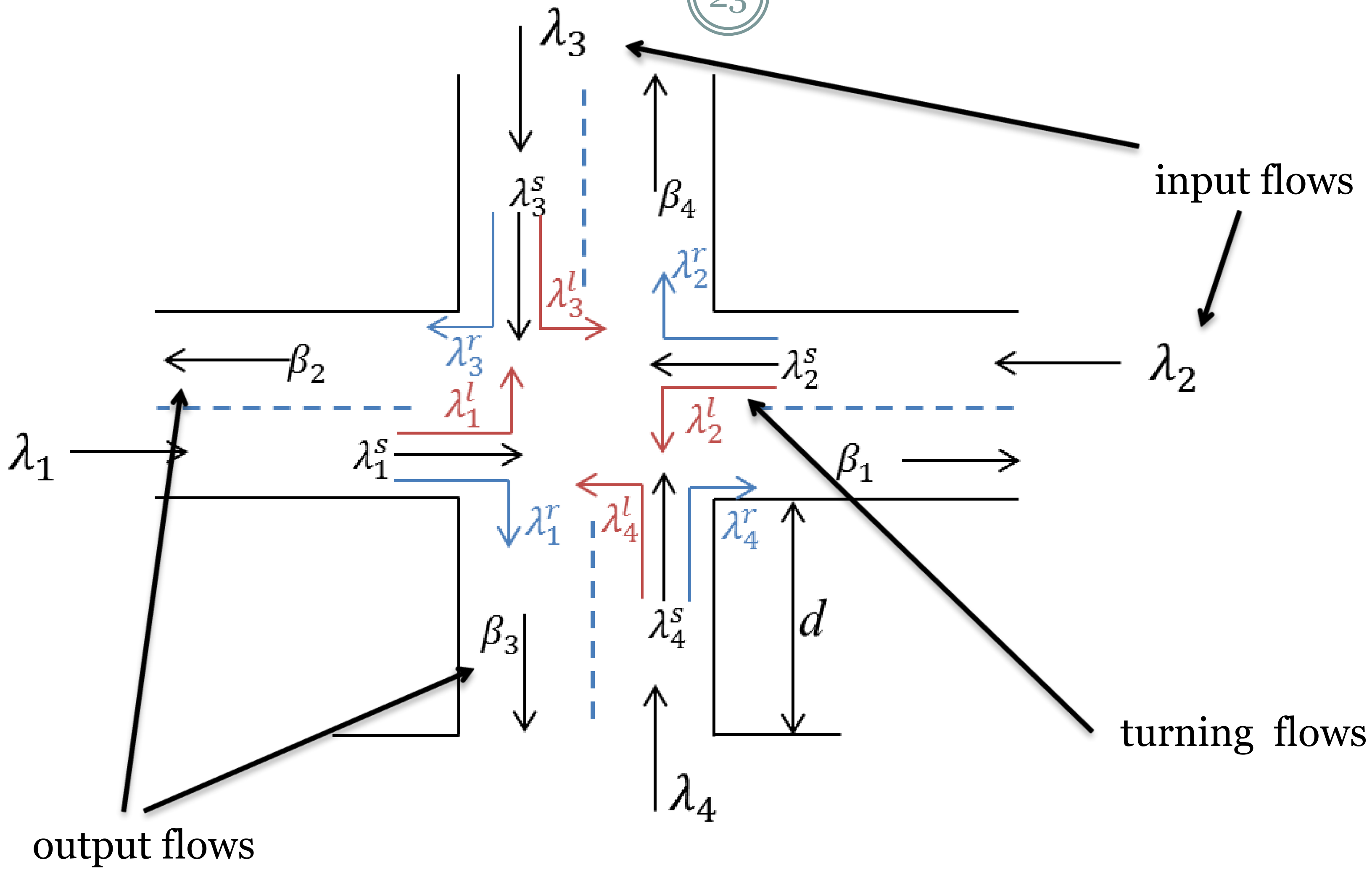
M. Schenk, Y. Tolujew, and T. Reggelin, "A Mesoscopic Approach to the Simulation of Logistics Systems," Advanced Manufactoring and Suistainable Logistics Lecture Notes in Business Information Processing, vol. 46, no. 1, pp. 15-25, 2010.

Formulation of DRTRM
(discrete rate traffic reference model)

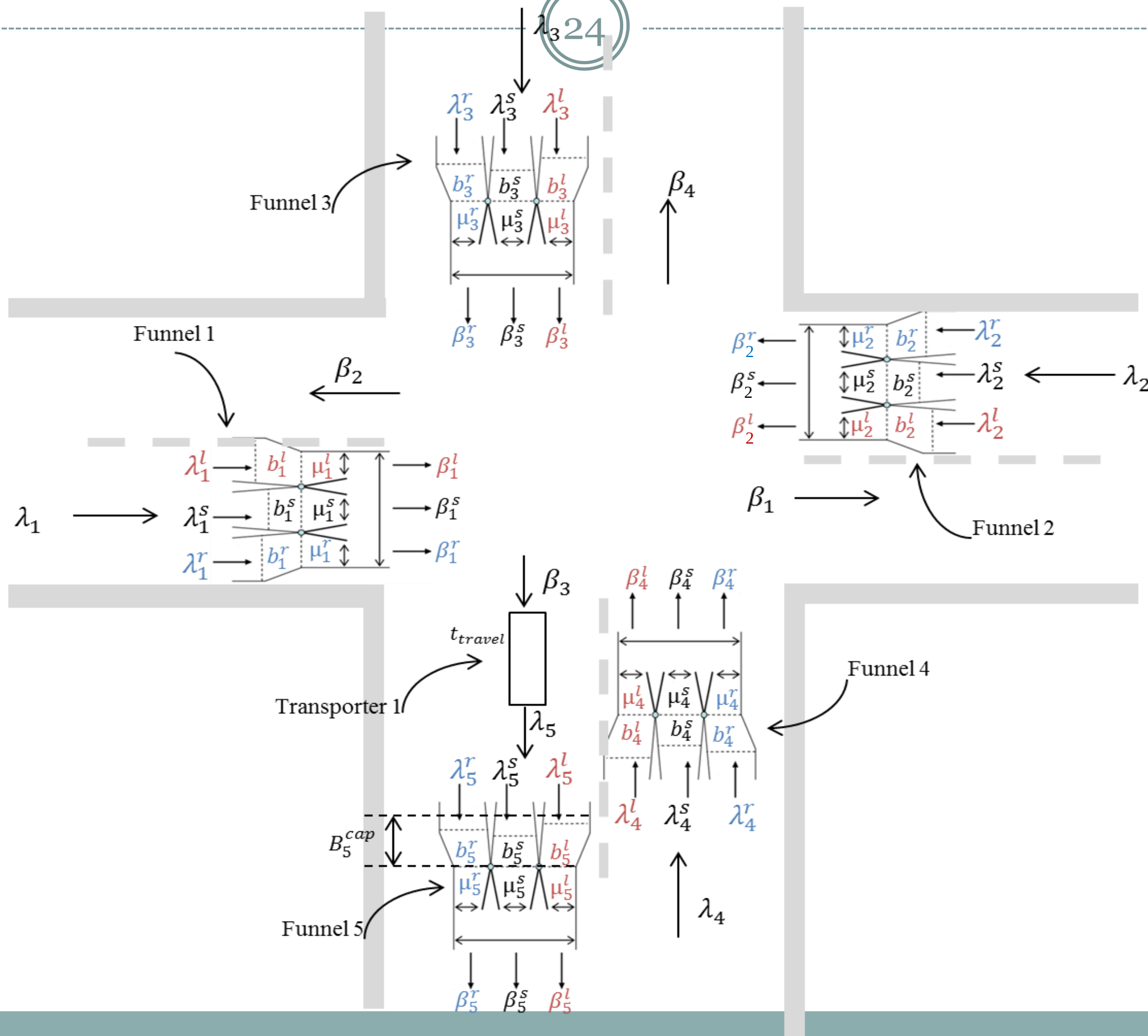
MODEL FOR UNCONGESTED NETWORK

MODEL FOR CONGESTED NETWORK

Example of transport node



Transport network in DRTRM notation



Mathematical Representation (1/4)

- λ_i – input intensity of the flow from direction *i=1..5 (*used units: PCU per time unit);
- β_i- output flow value from direction *i=1..5 (*used units: PCU per time unit);
- λ_i^l, λ_i^s, λ_i^r - intensity of the flow for the turns (*l-left; s-straight; r-right*) from direction *i=1..5* (used units: PCU per time unit);
- b_i^l, b_i^s, b_i^r- queue length for the turns (*l-left; s-straight; r-right*) from direction *i=1..5* (used units: PCU);
- μ_i^l, μ_i^s, μ_i^r-the processing rate for the turns (*l-left; s-straight; r-right*) from direction *i=1..5* (used units: PCU per time unit);
- β_i^l, β_i^s, β_i^r – output flow rate for the turns (*l-left; s-straight; r-right*) from direction *i=1..5* (used units: PCU per time unit);
- β_i – total output flow to direction *i=1..5* (used units: PCU per time unit);
- B_5^{cap} - the maximum value of queue length for direction 4 (used units: PCU);

Mathematical representation (2/4)

The following equations could be written:

$$\begin{cases} \lambda_i^r(t) = \lambda_i(t)p_i^r \\ \lambda_i^s(t) = \lambda_i(t)p_i^s \\ \lambda_i^l(t) = \lambda_i(t)p_i^l \\ p_i^r + p_i^s + p_i^l = 1 \end{cases} \tag{5.1}$$

where:

- p_i^r, p_i^s, p_i^l – a probability of turns (*l-left; s-straight; r-right*) from direction *i=1..5;*
- t – current time.

$$\begin{cases} \beta_1(t) = \beta_1^s(t) + \beta_4^r(t) + \beta_3^l(t) \\ \beta_2(t) = \beta_2^s(t) + \beta_3^r(t) + \beta_4^l(t) \\ \beta_3(t) = \beta_3^s(t) + \beta_1^r(t) + \beta_2^l(t) \\ \beta_4(t) = \beta_4^s(t) + \beta_1^r(t) + \beta_2^l(t) \\ \beta_5(t) = \beta_5^s(t) + \beta_5^r(t) + \beta_5^l(t) \end{cases} \tag{5.2}$$

Mathematical representation (3/4)

$$\begin{cases} \mu_i^r(t) = f_i^r(\Delta t(t)) \\ \mu_i^s(t) = f_i^s(\Delta t(t)) \end{cases} \quad (5.3)$$

where

$\Delta t(t)$– time step in time t (in this demonstration equal to duration of green phase (for simplification t_{green}) is equal for all directions and all crossroads;

$f_i^n()$ – function (called passing function), which determines throughput capacity from direction $i=1..5$ and turn $n \in (l, s, r)$.

$$\beta_{i\in(1,2,4,5)}^s(t) = \begin{cases} 0, \ \lambda_i^s(t) = 0 \ and \ b_i^s(t) = 0 \\ \lambda_i^s(t), \lambda_i^s(t) > 0 \ and \ \lambda_i^s(t) \le \mu_i^s \ and \ b_i^s(t) = 0 \\ \mu_i^s, b_i^s(t) > 0 \end{cases} \quad (5.4)$$

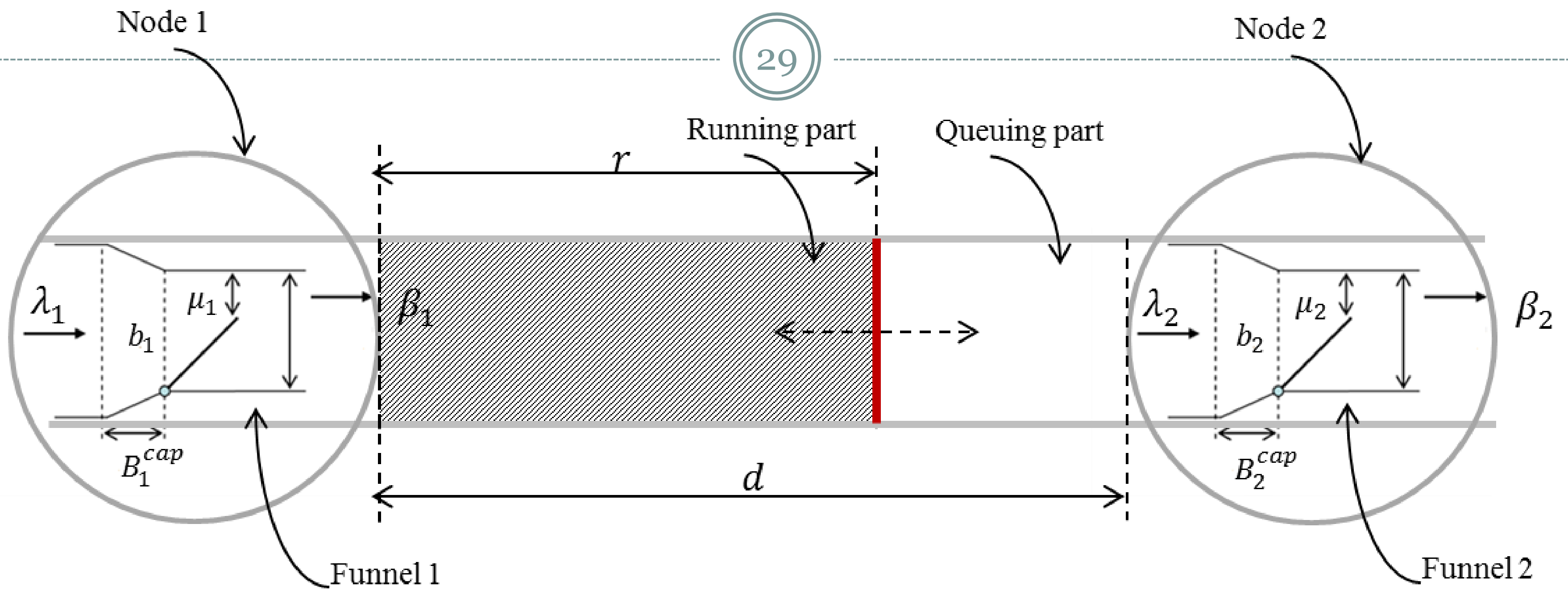
$$\beta_{i\in(2,3,4,5)}^r(t) = \begin{cases} 0, \ \lambda_i^r(t) = 0 \ and \ b_i^r(t) = 0 \\ \lambda_i^r(t), \lambda_i^r(t) > 0 \ and \ \lambda_i^r(t) \le \mu_i^r \ and \ b_i^r(t) = 0 \\ \mu_i^r, b_i^r(t) > 0 \end{cases} \quad (5.5)$$

Mathematical Representation (4/4)

$$\begin{cases} \mu_1^l = f_1^l\left(t_{green} - f_2^{s-1}\left(\beta_2^s(t)\right)\right) + h \\ \mu_2^l = f_2^l\left(t_{green} - f_1^{s-1}\left(\beta_1^s(t)\right)\right) + h \\ \mu_3^l = f_3^l\left(t_{green} - f_4^{s-1}\left(\beta_4^s(t)\right)\right) + h \\ \mu_5^l = f_5^l(t_{green}) + h \end{cases} \quad (5.6)$$

$$\beta_{i\in(1,3,5)}^l(t) = \begin{cases} 0,\ \lambda_i^l(t) = 0\ and\ b_i^l(t) = 0 \\ \lambda_i^l(t), \lambda_i^l(t) > 0\ and\ \lambda_i^l(t) \le \mu_i^l\ and\ b_i^l(t) = 0 \\ \mu_i^l, b_i^l(t) > 0 \end{cases} \quad (5.7)$$

Model for congested network



$$r(t) = d - b_2(t) \tag{5.10}$$

$$\begin{cases} t_{cur} = t_0(1 + a * sat^b) \text{ if sat<sat}_{crit} \\ t_{cur} = t_0(1 + a * sat^b) + (q - q_{\max})d \text{ if sat} \geq \text{sat}_{crit} \end{cases}$$

$$sat = \frac{q}{q_{\max} c}$$

$$sat_{crit} = 1$$

Compare micro-, meso-, macromodels parameters and characteristics

Microscopic models

Traffic flow

- Intensity of the flows
- Different types of vehicles with different characteristics
- Interaction between vehicles
- Queuing is possible
- Influence on speed from other vehicles

Infrastructure

- Real sizes of the road (including lane number)
- Geometry of the road
- Topology of the crossroads
- Traffic lights data
- Priority rules

Mesoscopic models

Traffic flow

- Volume of traffic
- Homogeneous flow
- Interaction between flows
- Queuing is possible
- Influence on speed in form of VDF

Infrastructure

- Link-node notation
- Length of the links
- Traffic lights data
- Priority rules

Macroscopic models

Traffic flow

- Volume of traffic
- Homogeneous flow
- No interaction between flows
- Queues are not taken into account
- Influence on speed in form of VDF

Infrastructure

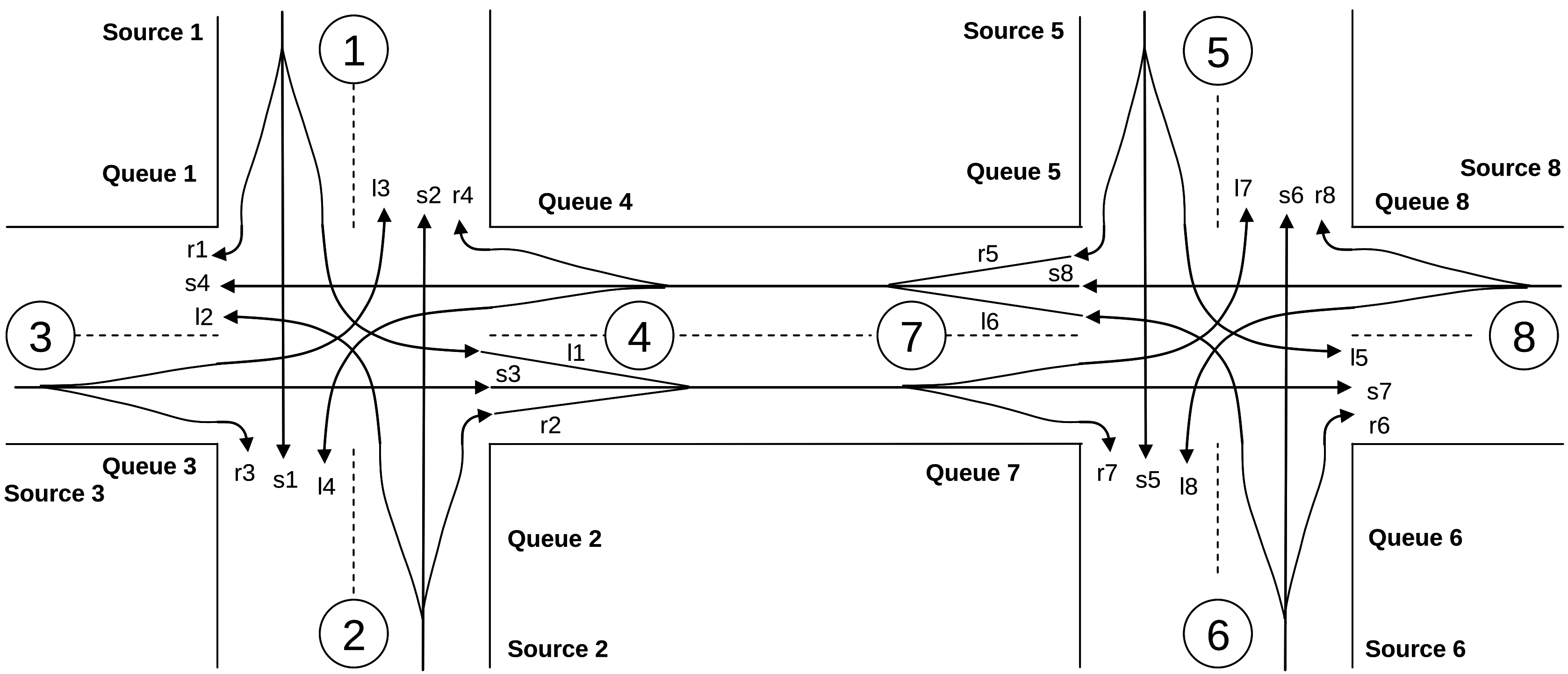
- Link-node notation
- Length of the links
- Traffic lights are not taken into account
- No priority rules

Case-study: simulation of the two connected crossroads

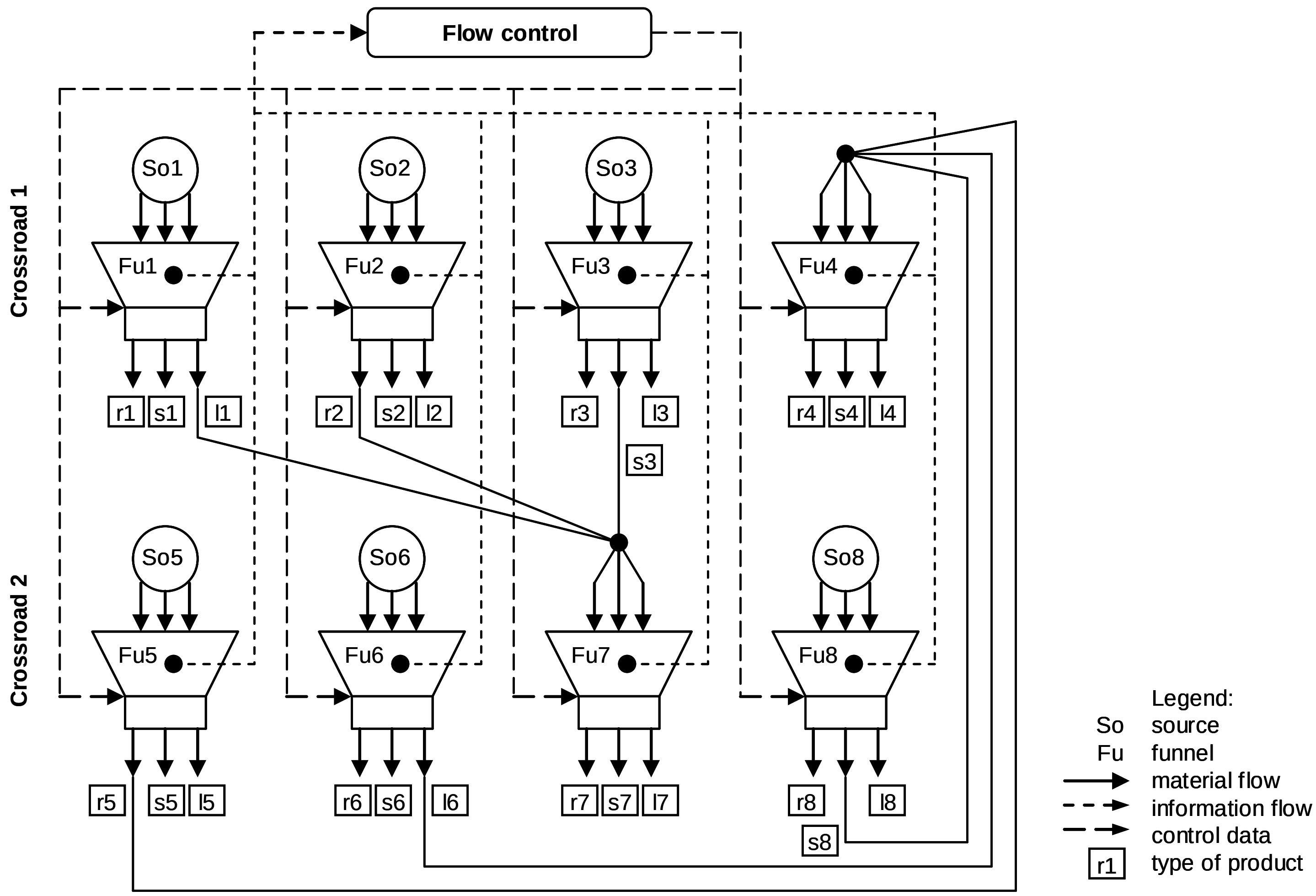
Simulation object

1st Crossroad (left)					Cycle time
	25 s	5 s	25 s	5 s	60 s
2nd Crossroad (right)					Cycle time
1st variant	30 s	5 s	30 s	5 s	70 s
2nd Crossroad (right)					Cycle time
2st variant	40 s	5 s	40 s	5 s	90 s

Incoming flow	Distribution law	Flow intensity mean value (m/min)	Crossroad passing
r	Uniform	20	0,6
s	Uniform	65	0,8
l	Uniform	10	0,6

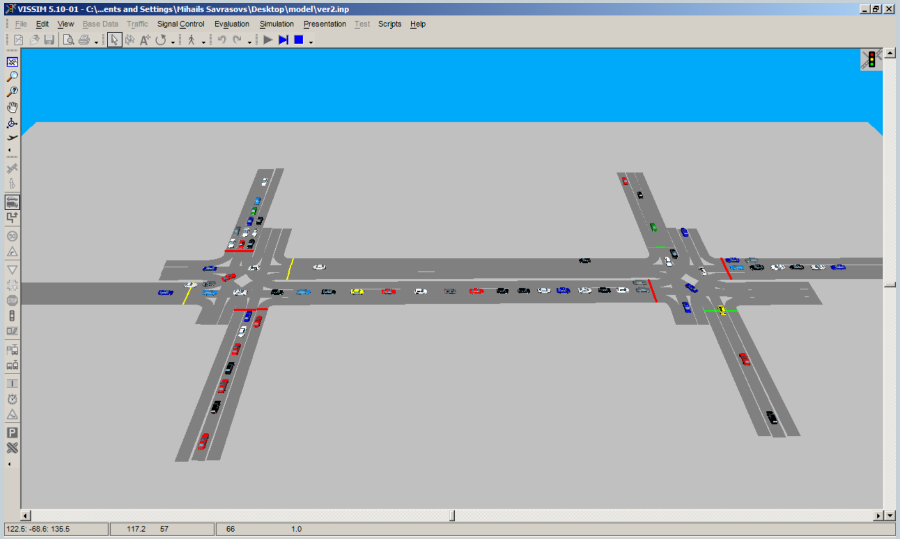


Structure of mesoscopic model



Microscopic model

- PTV VISION VISSIM
  - Number of links and connectors – 66
  - Number of vehicle inputs – 18
  - Number of routes – 24
  - Number of conflict areas – 8
  - Number of traffic lights – 24
  - Data collection points – 24

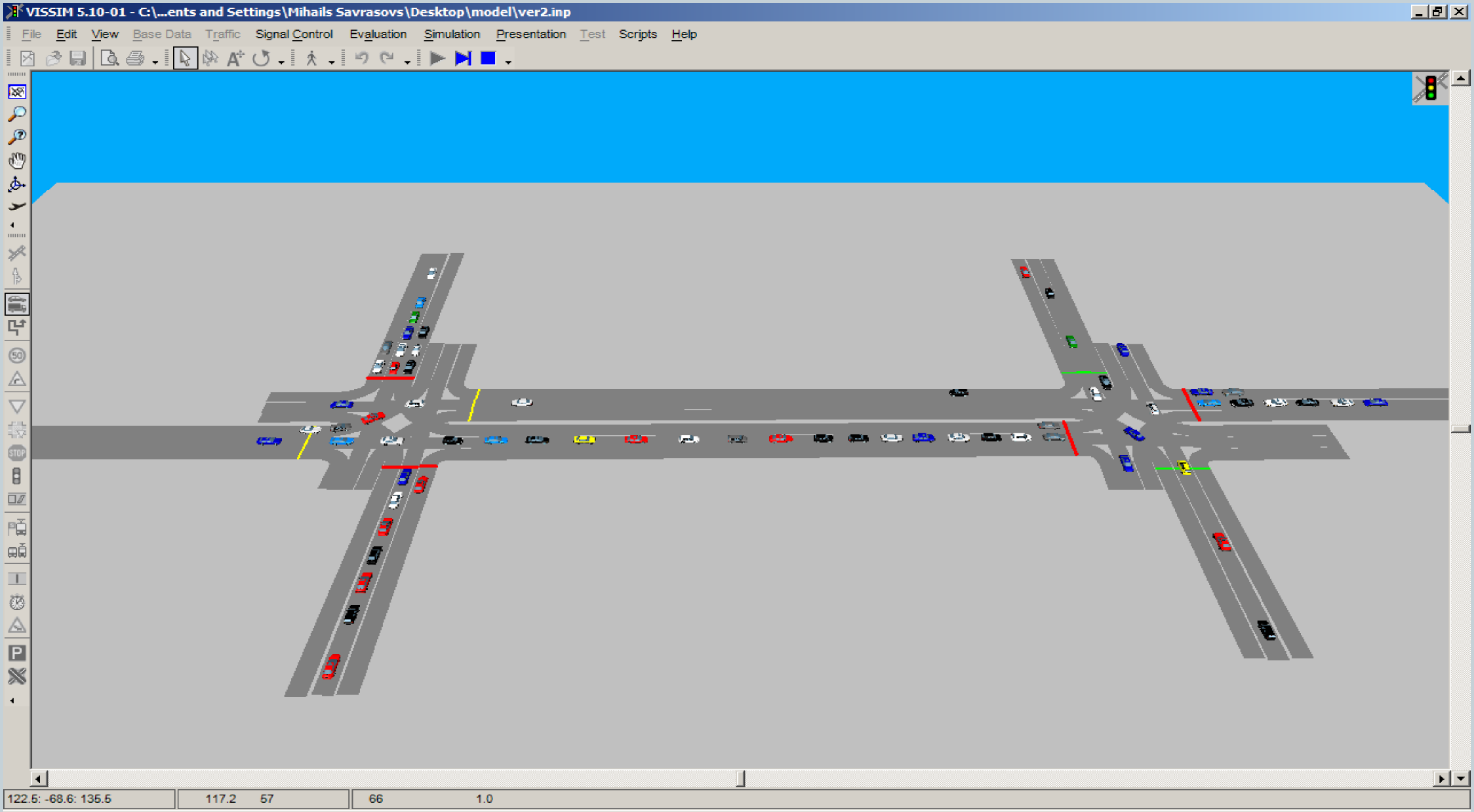


Validation of mesoscopic model

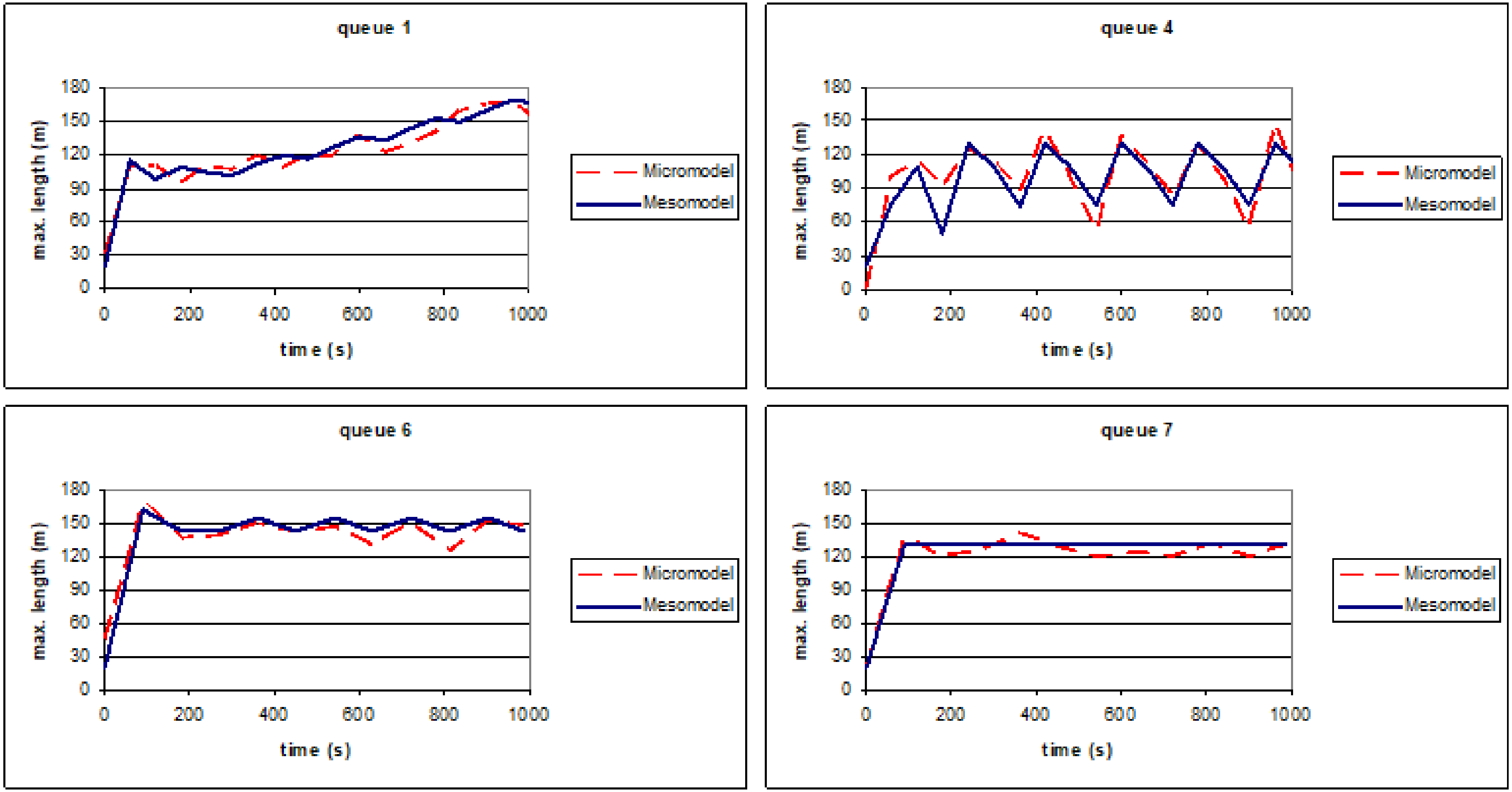
Main hypothesis:
no significant difference between output from microscopic and mesoscopic models

- Qualitative
  - Animation
  - Queue dynamics comparison
  - Box-Whisker plots
- Quantitative
  - Test for homogeneity
    - Student t-test
    - Mann-Whitney u-test
  - Confidence interval test
  - Naive test
  - Novel test

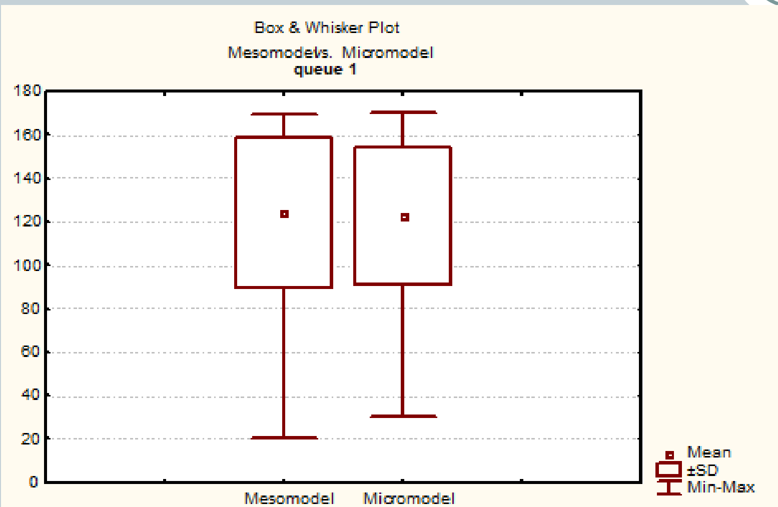
Validation results (animation)

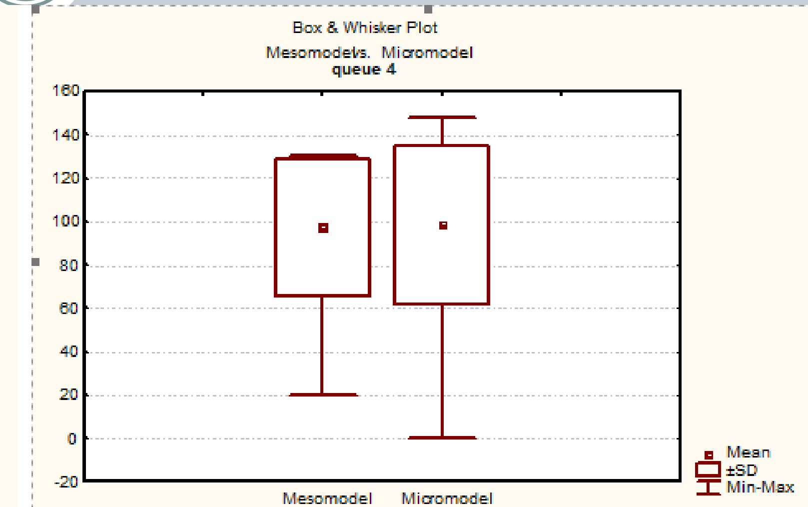


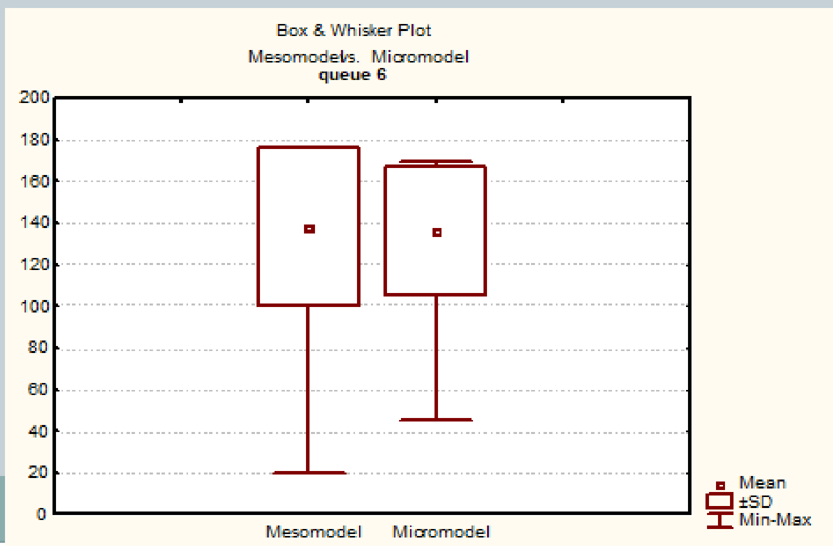
Validation results (queue dynamics comparison)

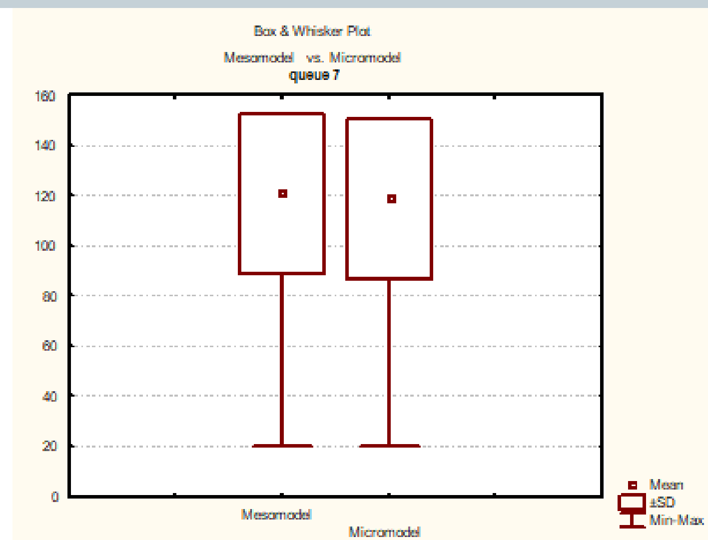


Validation results (Box-Whisker plots)









Validation results

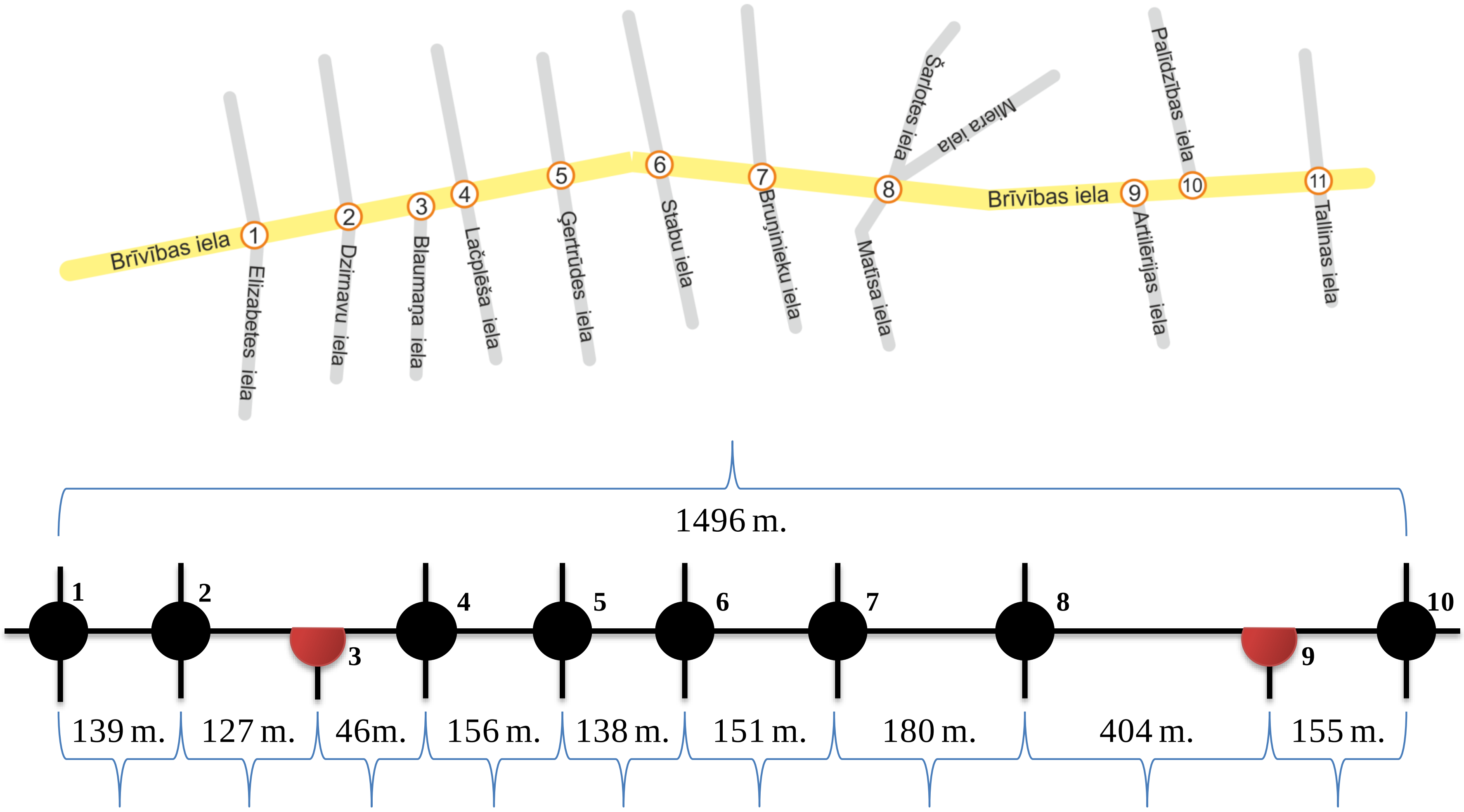
Data set	Qualitative validation (animation)	Test for homogeneity	Confidence interval test	Naive test	Novel test
Queue 1	Valid	Valid	Valid	Valid	Valid
Queue 2	Valid	Valid	Valid	Valid	Not valid
Queue 3	Valid	Valid	Valid	Valid	Valid
Queue 4	Valid	Valid	Valid	Not valid	Not valid
Queue 5	Valid	Valid	Valid	Valid	Valid
Queue 6	Valid	Valid	Valid	Valid	Not valid
Queue 7	Valid	Valid	Valid	Not valid	Not valid
Queue 8	Valid	Valid	Valid	Valid	Not valid

Case-study: Urban transport corridor mesoscopic simulation

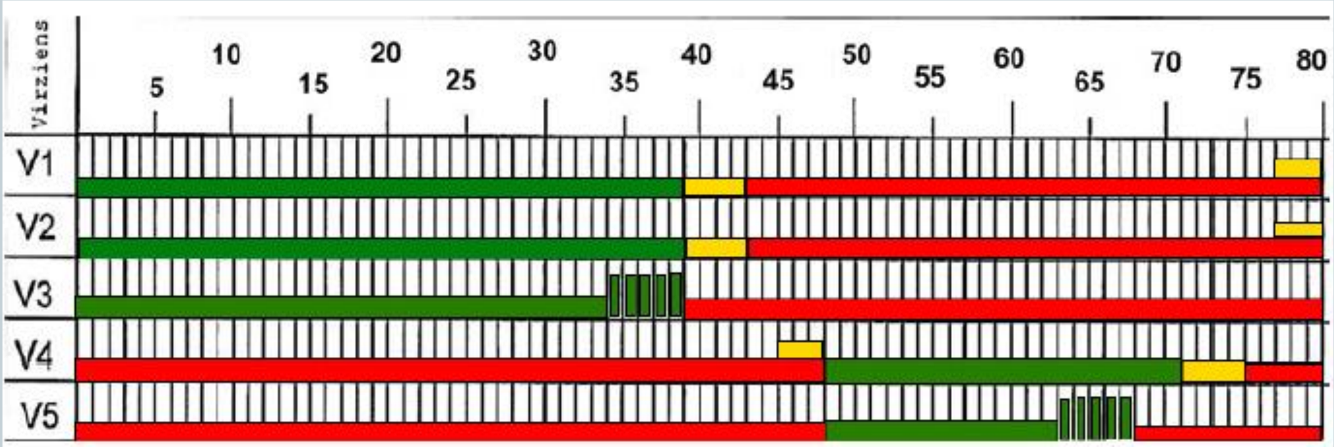
TASKS IN FRAME OF APPROBATION ON REAL DATA:

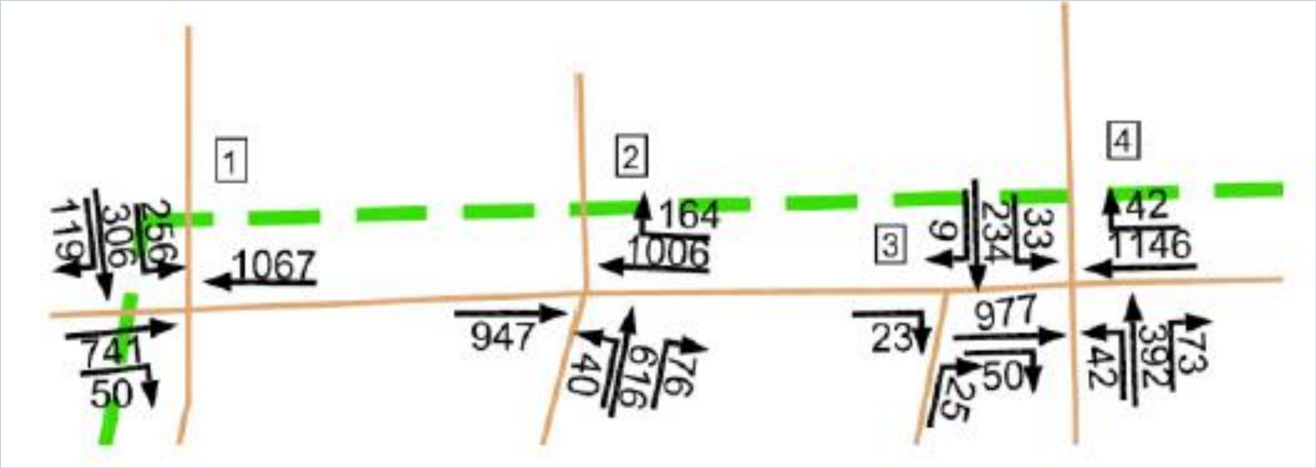
1) DETERMINE INPUT DATA FOR MESOSCOPIC MODEL
2) MODEL DEVELOPMENT
3) ESTIMATION OF LOS
4) COMPARE OUTPUT RESULTS WITH MICROSCOPIC SIMULATION

Simulation Object



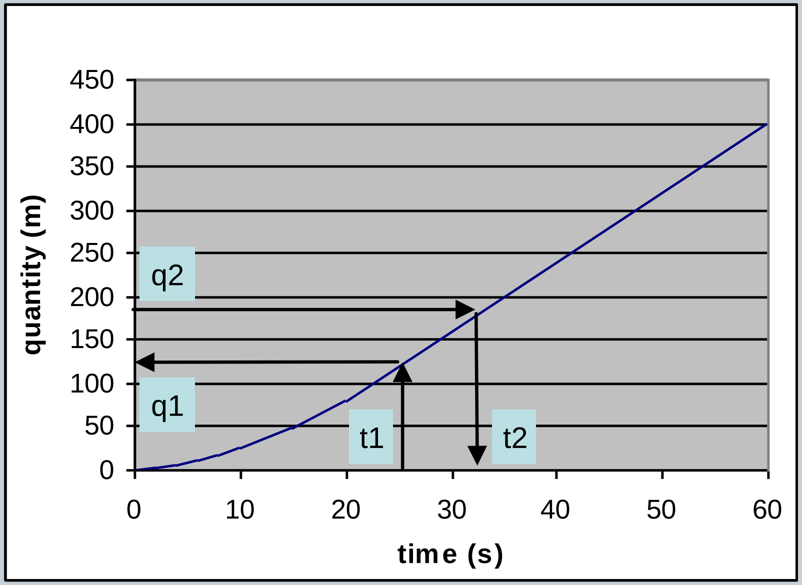
Input Data: Traffic light data and volume of traffic

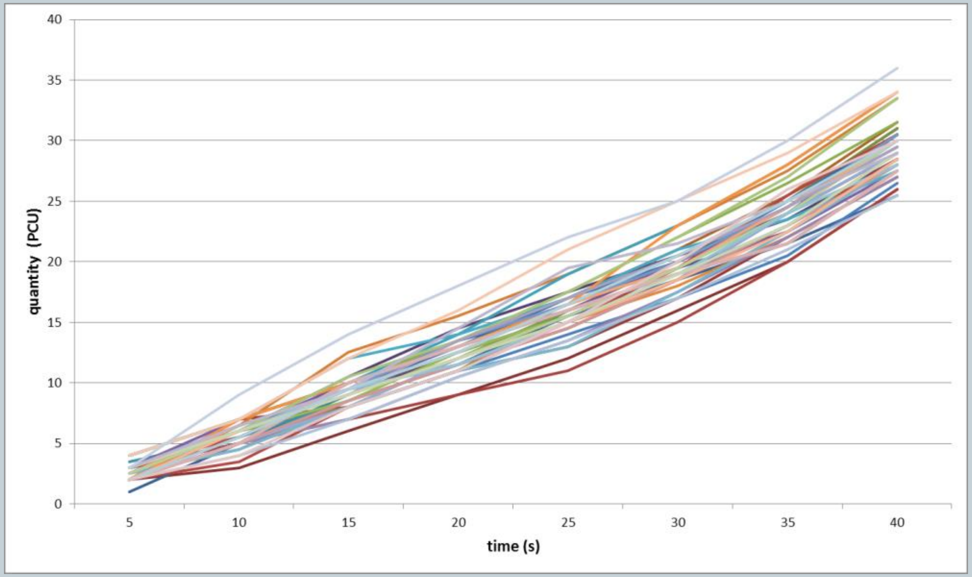




Input Data: Passing function estimation

- More than 7 hours of video from two crossroads
- More than 400 observations

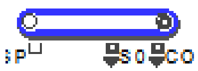
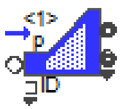
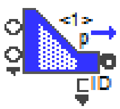
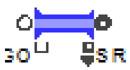
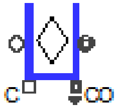
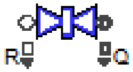




ExtendSim simulation software

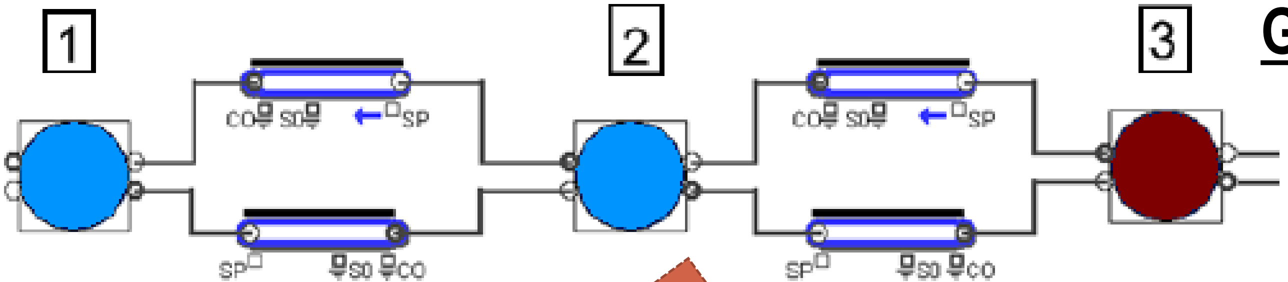
https://www.extendsim.com

ExtendSim Discrete Rate library application

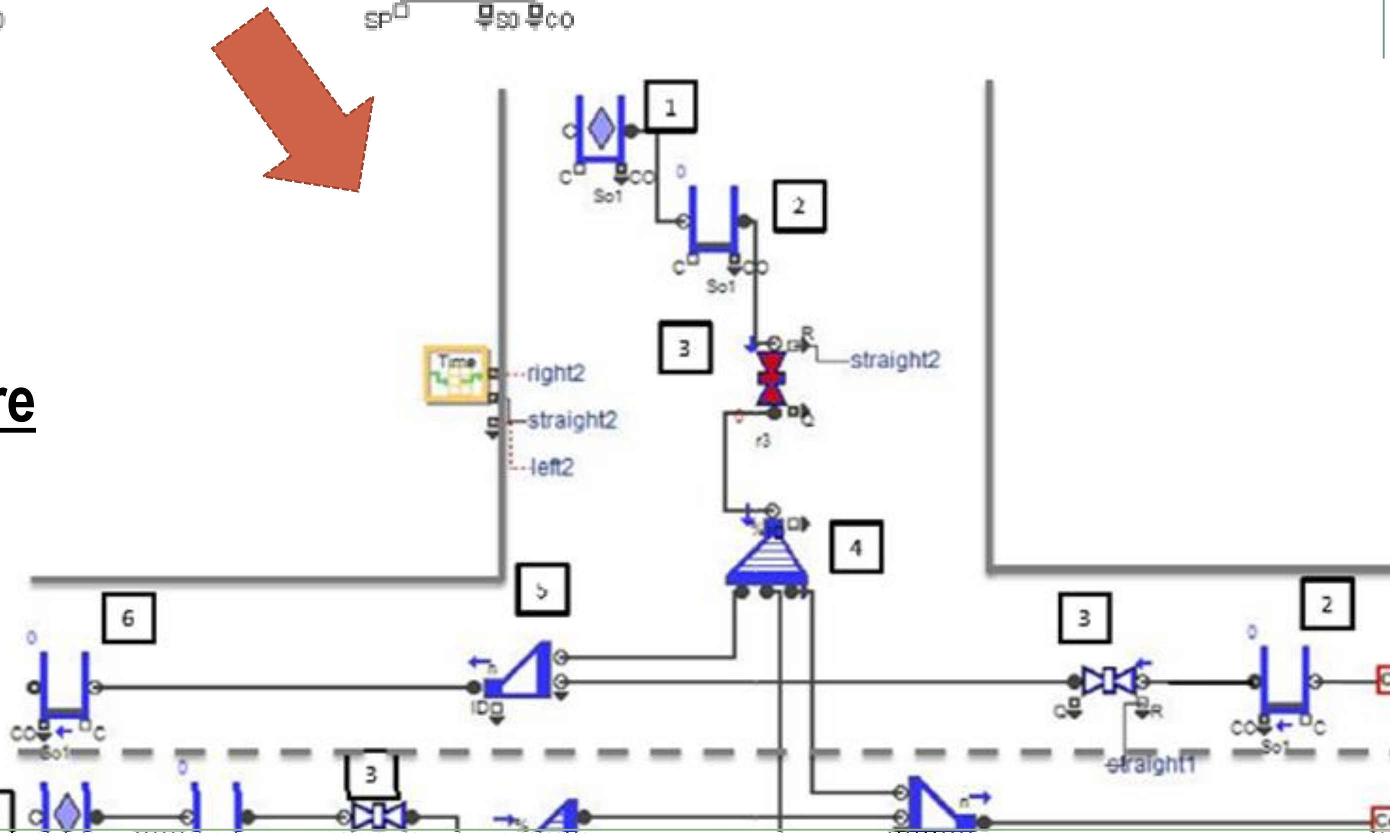
Block	Block name	Main role in transport model
	Convey Flow	Could be used to simulate a movement between two geographical point (at example between two crossroads)
	Diverge	Could be used to simulate a splitting of the transport flow by different direction (at example on crossroads turning left, turning right, moving forward)
	Merge	Could be used to merge traffic flows together
	Sensor	Could be used for as the main source of information for controlling flows and to control flow interaction
	Tank	Could be used as a source and sink. Also could be used to represent capacity of the road
	Valve	Controls, monitors, and transfers traffic flow.

Model constructed in ExtendSim

General model



Internal structure of node



Output results

Crossroad Number	Microscopic model		Mesoscopic model	
	LOS	Average delay time (s)	LOS	Average delay time (s)
1	B	14.5	B	18.6
2	B	13.8	B	17.5
3	A	1.6	A	1.2
4	B	17.3	B	17.6
5*	B	18.1	C	21.6
6	B	11.2	B	14.3
7	C	20.6	C	30.8
8*	C	31.2	D	45.5
9	A	2.1	A	1.2
10*	D	41.5	E	55.6

Mesoscopic vs Microscopic (time resource)

Development and experimentation issue	Microscopic model	Mesoscopic model
Transport network implementation (min)	175	60
Implementation of traffic lights (min)	60	30
Conflict areas and priority rules implementation (min)	115	60
Movement routes implementation	30	30
Traffic flow implementation (min)	30	60
Time spend on experimentation (min)	350	10
Total implementation and experimentation time (min)	**760**	**250**

Publications (1/2)

- Savrasovs M. "Traffic Flow Simulation on Discrete Rate Approach Base", Transport and Telecommunication, Vol. 13, April, 2012, pp. 167-173.
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- M. Savrasov, I. Yatskiv, A. Medvedev and E. Yurshevich. "Simulation as a Tool of Decision Support Process: Latvia-based Case Study". In Proceedings of 1-st International Conference on Road and Rail Infrastructure (CETRA 2010). 2010. pp. 217-222.
- Savrasovs M. “Mesoscopic Simulation Concept for Transport Corridor”, the 12th World Conference on Transport Research (WCTR 2010). Lisbon, Portugal, 2010.

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- Yatskiv, I., Savrasovs, M. “Development of Riga-Minsk Transport Corridor Simulation Model”. Transport and Telecommunication, 2010, Volume 11, No 1, pp. 38-47.
- Savrasovs, M. “Overview of Traffic Mesoscopic Models”, the 2nd International Magdeburg Logistics PhD Students’ Workshop, 2009, pp. 71-79.
- Savrasovs M. “Flow Systems Analysis: Methods and Approaches” Computer Modelling and New Technologies, 2008, Volume 12, No 4, pp. 7-15.
- Savrasovs, M., Toluyew, Y. “Transport System’s Mesoscopic Model Validation Using Simulation on Microlevel”, the 8th International Conference, Reliability and Statistics in Transportation and Communication, 2008, pp. 297-304.
- Savrasovs, M. “Overview Of Flow Systems Investigation And Analysis Methods”, the 8th International Conference, Reliability and Statistics in Transportation and Communication, 2008 pp. 273-280.
- Toluyew, Y., Savrasov, M. “Mesoscopic Approach to Modelling a Traffic System”, International Conference, Modelling of Business, Industrial and Transport Systems, 2008, pp. 147-151.
- Savrasov, M., Toluyew, Y. “Application of Mesoscopic Modelling for Queuing Systems Research”, the 7th International Conference, Reliability and Statistics in Transportation and Communication, 2007, pp. 94-99.