URBAN TRANSPORT CORRIDOR MESOSCOPIC SIMULATION

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ABSTRACT

Currently different categories of traffic analysis tools exist. Among them simulation models can be marked as one of the most powerful approach to do traffic analysis researches. In classical literature simulation models are divided on macroscopic, mesoscopic and microscopic models. Microscopic and macroscopic modelling are well known and widely used, but both of them have disadvantages and limitations, which make them in some conditions hard to apply. The term "mesoscopic modelling" itself, is interpreted by different scientists in different ways. In general under mesoscopic traffic flow models should be understood as models where traffic flow is described with high level of detail, but at the same time flow behaviour and flows interaction are presented at a low level of description. The proposed earlier new simulation approach called by authors "mesoscopic simulation" was applied for traffic flow simulation. The main goal of this paper is to present an example of application of discrete rate approach of the ExtendSim simulation software for urban transport corridor simulation. The discrete rate approach fully covers ideas of mesoscopic simulation. The literature survey showed that mainly discrete rate approach is used in logistics, but not in transport area. So the tasks of the paper are to present main techniques of model implementation using discrete rate approach and to apply this approach for urban transport corridor simulation.

INTRODUCTION

A lot of new mathematical models for traffic systems have been developed in the past. Almost all of them can be categorized as macroscopic or microscopic models. Macroscopic models (Kühne and Rödiger 1991) use differential equations and describe the behaviour of traffic flows. In such models long periods of time (days, hours) can be observed. Microscopic models use standard simulation models based among other things on discrete events (Yatskiv et al. 2007) and cellular automats (Esser and Schreckenberg 1997).

Models of this class are used to model short periods of time with a very high level of detail. In (Tolujew and Alcalá 2004; Savrasovs and Tolujew 2007) a new class of so-called mesoscopic models has been described.

The purpose of this model class is to take advantage of the two traditional approaches to modelling flow systems by avoiding their disadvantages like the time and labor consuming creation and implementation of microscopic models.

The basic principles of mesoscopic modelling can be described with "algorithmic management and analytical calculation" and "discrete time and continuous quantities". The second phrase shows that the philosophy of mesoscopic modelling has similarities with macroscopic modelling with differential equations. However, this analogy can be observed only in the numerical results presentation. Results are presented as process graphs with the time step Δt. In mesoscopic models relationships between variables are often implemented as complex algorithms and not as concrete formulas. This is characteristic of microscopic simulation.

A mesoscopic model uses mathematical formulas to calculate the results as continuous quantities in every step Δt of the discrete modelling time. In contrast to the microscopic approach, the mesoscopic approach monitors quantities of objects that belong to a logical group instead of individual flow objects (e.g. customers in queuing systems). In contrast to macroscopic models, in mesoscopic models any number of groups of objects can exist at the same time and interactions between them can be implemented.

In (Savrasovs and Tolujew 2007) it has been shown that "multichannel funnels" can be effectively used as the main structural component of mesoscopic models. The process of product accumulation and processing can be modelled with this component. Flow processing is done through different strategies of resource usage.

Advantages of the mesoscopic approach are its high flexibility in preparing input data for the simulation, its universal and easy structure of the internal model data, that no restrictions for modelling complex control algorithms exist, its high performance for computing the model code and its clear presentation of simulation results.

The following reference (Tolujew and Savrasovs 2008) demonstrates an example of using mesoscopic approach for modelling a controlled crossroad. Also

the following paper (Savrasovs and Tolujew 2008) demonstrates the validation of mesoscopic models on the base of microscopic models. Mentioned above references concerns, that mesoscopic simulation can be used to model a crossroad or a small group of crossroads. Unfortunately further investigation (Savrasovs and Tolujew 2008) showed that to model more complex transport objects like transport corridors Microsoft Excel with VBA could not be used, because of programming complexity. The research of possible replacement of Microsoft Excel revealed that ExtendSim simulation software can be used (Savrasovs 2010). ExtendSim has a special library called "Rate" approach (Krahl 2009). The description of this approach fully filled in the frames of described mesoscopic approach for traffic simulation. This paper demonstrates the results of application mesoscopic approach (discrete rate library of ExtendSim) for simulation of a real urban object.

MODELLING OBJECT DESCRIPTION AND PROBLEM FORMULATION

The object of the research is the urban transport corridor located in Riga city. This transport corridor connects the center of the city and living districts inside and outside the city.
The modeled part of the transport corridor consists of 10 crossroads. The length of researched part of the transport corridor is approximately 1500 meters. The schema of transport corridor is presented in figure 1.
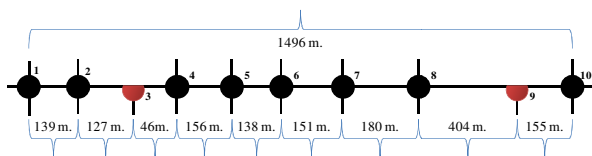

Figure 1: Schema of Transport Corridor

To simplify reference to crossroads of the transport corridor all crossroads are numbered. It also should be noted that direction from city center goes from left to right. Mostly all crossroads are controlled by traffic lights except crossroads number 3 and 9. The traffic lights are organized to produce green wave. The data about traffic lights were obtained from city council and shows the duration of cycle and duration of each light. The example of data about traffic light work in 1st crossroad is presented in figure 2.
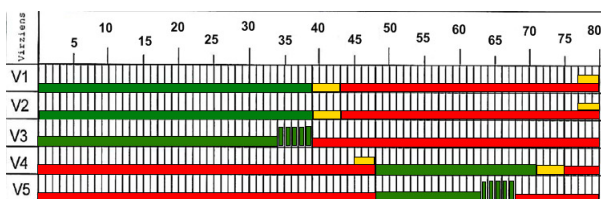

Figure 2: Example of Traffic Light Data

The volumes of traffic were obtained during traffic counts. The traffic counts were estimated during morning peak hours from 8:00-9:00. During traffic counts a number of vehicles types were differentiated: bicycles, motorcycles, passenger vehicles, light cargo trucks, HGV, buses, single trolleybuses and twin trolleybuses. The mesoscopic approach in current formulation does not take into account types of vehicles; that is why all collected data were aggregated into PCU (passenger car unit). The conversion was done according to this table of the multiplication coefficients for each type of vehicle.

Table 1: Multiplication Coefficients

Vehicle types	Coefficients
Bicycles	0.3
Motorcycles	0.5
Passenger vehicles	1
Light cargo trucks	1.5
HGV	2
Busses	2.5
Single trolleybuses	3
Twin trolleybuses	4

Finally all traffic volumes are presented in PCU. The schema, which shows the example of calculated volumes, can be observed in figure 3 (the numbers in rectangle identify the crossroad).

Figure 3: An Example of Volumes of Traffic in PCU

Here it should be noted that defined volumes are used as input volumes and for calculation of probability of further movement. Each crossroad is described using a schema of crossroad and allowed movements. The example of such description can be seen on figure 4.
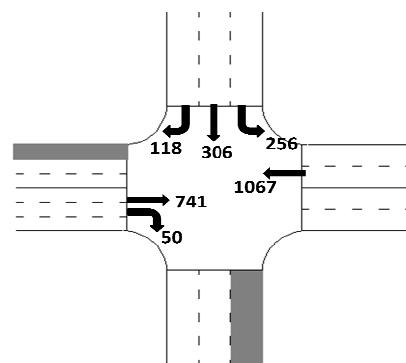

Figure 4: Crossroad Schema

Finally it should be noted following general information about the transport corridor:

- allowed speed across transport corridor is 50 km/h;
- transport corridor has two lanes per direction;
- all public transport stops are made outside main roads and are located in pockets;
- traffic lights are managed for creating a green wave across all transport corridor.

The main task is to model described transport corridor and define using simulation results level of service (LOS) for each crossroad. It is necessary to underline here that LOS will be calculated based on average delay value on crossroad. The following table demonstrates the LOS levels according HCM 2000 standard (Transportation Research Board 2000).

Table 2: Level of Service

Level of Service	Average delay time (s)
A	≤ 10
B	> 10 – 20
C	> 20 – 35
D	>35 – 55
E	> 55 - 80
F	>80

In general first 3 levels (A, B, C) can be treated as normal delay time on crossroad. The D level signalises about possible problems. And finally the last 2 are the worst levels which point out the problem of crossing this crossroad.

As the presented mesoscopic approach is quite new and not widely used the simulation results data validation is required. For model output data validation will be used LOS levels defined using microscopic model constructed in PTV VISION VISSIM software. Microscopic simulation results can be observed in table 3.

Table 3: Microscopic Model Output Data

| Crossroad Number	Level of service	Average delay time
1	B	14.5
2	B	13.8
3	A	1.6
4	B	17.3
5	B	18.1
6	B	11.2
7	C	20.6
8	C	31.2
9	A	2.1
10	D	41.5
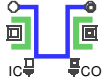
As can be seen from table 3, the transport corridor is not too congested. Mostly the LOS for crossroads is A and B. Only 3 crossroads have a level C and D. So the same results are expected from mesoscopic model.
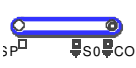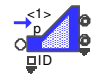
DISCRETE RATE LIBRARY

Discrete rate approach is presented in ExtendSim library by 11 blocks which can be used for model construction. As it was mentioned before mostly the discrete rate approach is used to simulate material flows. That is why each block can execute predefined operations with the flow. The following description can be given for each block.

Table 3: Rate Library Blocks

Block	Block name	Description
	Bias	Prioritizes the flow going through it.
	Catch Flow	This block catches flow sent by Throw Blocks or Diverge blocks
	Change unit	Changes the flow unit of measurement.
	Convey Flow	Delays the movement of flow from one point to another.
	Diverge	Distributes the input flow to two or more outputs.
	Interchange	The Interchange block represents a tank, or holding area, where flow can interact with items generated by discrete event blocks
	Merge	Merges flows from multiple inputs into one output.
	Sensor	Reports the potential upstream supply rate and potential downstream demand rate.
	Tank	Acts as source, intermediate storage, or sink. As a residence type block the Tank has the capacity to hold defined amounts of flow as time advances.
	Throw flow	This block sends flow received by Catch Blocks or Merge blocks even though the blocks
	Valve	Controls, monitors, and transfers flow.

As can be seen some of blocks can be treated as the main blocks (Valve, Tank etc.) of library, some of the blocks are used as helpers (at example Interchange). Of course blocks from other ExtendSim libraries can be used in discrete rate models. For simulating transport flow we do not use all the described above blocks. The following table can be constructed to show the main role of the blocks in transport model (table 4). As can be seen from table 4 we need only 6 main blocks to construct a transport model. Of course additional ExtendSim blocks can be involved to collect and visualise output data.

Table 4: Main Role of Block in Transport Model

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

MESOSCOPIC MODEL DEVELOPMENT

Mesoscopic model of the urban transport corridor was developed in ExtendSim software using a discrete rate library, which is described above. As was mentioned not all library blocks were used, but only some of them.

It is possible to create hierarchical structure of model in ExtendSim application. That is why to simplify a process of model development were created (Savrasovs 2010) custom library blocks: called "node_sig" and "node". These blocks present crossroads with different management strategy:

- Signalised crossroads (node_sig) – crossroads which are controlled by traffic light with defined length of cycle. This group includes 8 crossroads (crossroads numbers: 1, 2, 4, 5, 6, 7, 8 and 10).
- Non-signalised crossroads (node) – crossroads which are not controlled by traffic light. This group includes only 2 crossroads (crossroads numbers: 3 and 9).

The general high-level model of the transport corridor is presented in figure 5.
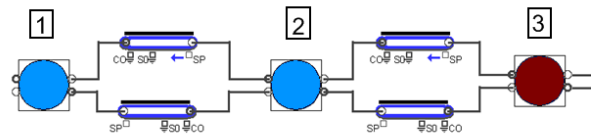

Figure 5: The Example of Constructed General High-level Model

Custom library blocks are presented as circles. The blue color circles (light circles) present signalises crossroads, the red color (dark circle) non-signalised crossroads.

The example of internal structure of the block "node" is presented below (figure 6).
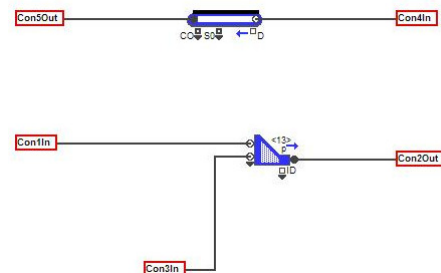

Figure 6: Internal Structure of the Block "node"

As can be seen from figure 6 the internal structure of the block is very simple. The traffic flow which goes to the city center does not meet any problems; that is why input of the block is directly connected to the output of the block via "convey flow" block with very small delay time equal to 0.0001. The flows going from the center and from bottom input must be merged; this is done using "merge" block from standard rate library. Flows have different priorities. Higher priority is assigned to flow which goes from city center; the lower priority is assigned to the flow which goes from the bottom.

The structure of block "node_sig" is much more complex compared to "node" block. It is due to complexity of the crossroads and due to traffic light existing in crossroads. The work of the traffic light is modelled by using "Lookup Table" from Value library block. The input parameter of the block is a current time in model, the output of the block presented by three outputs: r (right), s (straight), l (left). The output values are determined according to a predefined table. Possible values of outputs are defined as 0 and 1. The 0 means that movement in direction is forbidden, 1 means that movement is allowed. Each leg of the

crossroad has its own control block "Lookup Table" except legs are controlled by one traffic light program. The figure 2 shows the traffic light data for the first crossroad. The figure 8 demonstrates the controlled legs of the crossroad.
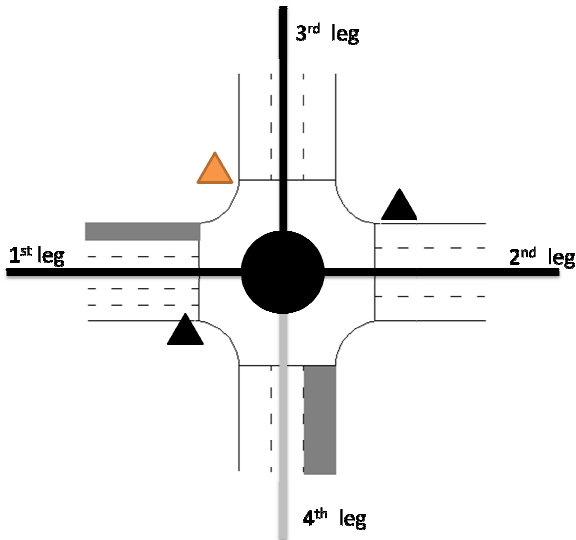

Figure 7: Signal Heads of the Traffic Light

As can be seen from figure 8 legs number 1 and 2 have the same program, leg number 3 has separate program that is why 2 blocks "Lookup Table" were used to define control on this crossroad. The table 5 demonstrates the content of the two Lookup Tables used to model traffic light control in this crossroad.

Table 5: Example of Lookup Table for Leg 1 and 2

Record ID	Time	left	straight	right
1	0	1	1	1
2	43	0	0	0
3	80	1	1	1

Table 6: Example of Lookup Table for Leg 3

Record ID	Time	left	straight	right
1	0	0	0	0
2	47	1	1	1
3	80	0	0	0

It should be noted that some directions mentioned in tables 5 and 6 are not allowed for movement (see figure 4), but still have 1 in this direction, it does not influence on model validity, because traffic flow distribution is not controlled by lookup tables. The parameter of Lookup Table "Repeat table every:" should be adjusted to traffic light cycle length in this case 80 seconds.

Each movement on the crossroad is presented by fixed sequence of the Rate library blocks. The figure 8 shows the sequence of the blocks for 1st crossroad.
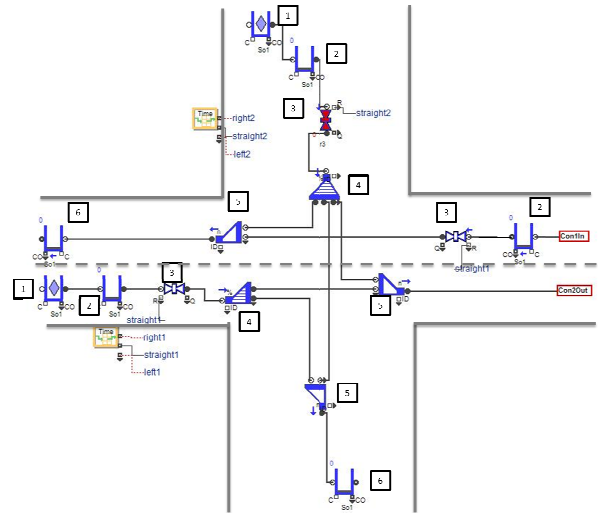

Figure 8: The Example of Internal Structure of the Block "node_sig" for 1st Crossroad

The internal structure of block "node_sig" for 1st crossroad consists of 14 main blocks and 2 additional blocks. Additional blocks are required to simulate traffic light work. Main blocks define the behaviour of the traffic flow. The description of functionality of each block used in this structure can be found below:

- Blocks marked by 1 are required to generate input flow. Rate library block "Tank" is used.
- Blocks marked by 2 are used to accumulate traffic flow before crossroad passing. Rate library block "Tank" is used in capacity mode.
- Blocks marked by 3 control passing of the crossroad by traffic flow with given intensity. Rate library block "Valve" is used. Here it should be noted that these blocks are controlled using additional "Lookup table" blocks.
- Blocks marked by 4 are used to split traffic flow by different directions. Rate library block "Diverge" is used in proportional mode.
- Blocks marked by 5 are used to combine traffic flow from different directions. Rate library block "Merge" is used in neutral mode.
- Blocks marked by 6 are used to store a traffic flow which leaves the system. Rate library block "Tank" is used in capacity mode.

Finally the constructed model of the urban transport corridor has approximately 132 blocks, among them 16 are additional blocks used to simulate traffic light work. Of course for output data collection and processing additional blocks were used from different ExtendSim libraries.

RESULTS COMPARISON AND SIMULATION OUTPUT DATA ANALYSIS

The constructed mesoscopic model of the urban transport corridor was used to simulate traffic movement across corridor in morning peak hour from

8:00-9:00. Constructed model requires validation because new approach of traffic simulation was used. For validation microscopic model, developed earlier and validated on real survey data, was used. The validation of the mesoscopic model was done by using two different types of the output data, available in microscopic and mesoscopic level: observed volumes of traffic and delay time one crossroads (LOS). The required data were obtained from microscopic model by executing 50 runs. Aggregated data were processed by calculating mean value. Comparison of the simulated volumes of traffic showed in average difference in 20% between results simulated by microscopic and mesoscopic models. The comparison of the delay times is proposed in table 7.

Table 7: Delay and LOS Comparison

Crossroad Number	Microscopic model		Mesoscopic model	
	LOS	Average delay time	LOS	Average delay time
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

As can be seen from table 7, not looking on difference on average by 20% in volumes, LOS for crossroads mainly are matched. Of course it should be noted, that delay time for all crossroads has a difference, and sometimes this difference does not influence the LOS, except LOS for crossroads number 10, 8 and 5. For crossroad number 10 the difference is equal to 14 seconds. For 8 and 5 the difference is not so significant.

Mainly the behaviour of traffic flow in the mesoscopic model is very close to real situation in this urban transport corridor. The difference of the output data can be explained by higher level of abstraction of the mesoscopic model. In the same time the speed of development mesoscopic model is 5 times less. In general big difference in development time is connected with simplification of the network representation in mesoscopic level. In the same time the difference between output data is not significant. This is a main advantage of the mesoscopic approach significant decrease of development time and expectable precessions of the output results.

In the same time must be pointed out, that developed model can be used only for uncongested network. If the network will be congested higher error in the output

results will be expected. It is connected with the fact that growth of queue does not influence on running distance between crossroads. In this model the running distances between crossroads were constants.

CONCLUSIONS

In conclusion must be noted that, because of disadvantages of microscopic simulation and disadvantages of macroscopic simulation a new mesoscopic approach for traffic modelling was proposed in this article for urban transport corridor modelling. Earlier to demonstrate the possibilities of the new approach were used Microsoft Excel and VBA. Unfortunately with the big number of simulation object the complexity of programming is growing extremely. That is why ExtendSim simulation software was used. A discrete rate approach used in this software fully realises all ideas of mesoscopic simulation. This article demonstrates how discrete rate approach can be used to simulate urban transport corridors. The analysis of the block set of the library showed, that only 6 of 11 blocks can be used for traffic flow simulation. And these 6 blocks fully cover all required functionality to construct the model.

The model of the existing urban transport corridor was constructed using mesoscopic approach in ExtendSim simulation software. Total number of blocks used in model is approximately 132. Additional blocks were required to collect and to process data.

To validate constructed model an output data from microsimulation model were used. Among all possible data volumes of traffic and average delay time in crossroad were used for validation. Output data comparison showed the difference in average 20%. At the same time the difference in LOS is not so significant.

It must be emphasized, that development time of the mesoscopic model is approximately 5 times less than a development of the same microscopic model. This can be treated as advantage of mesoscopic simulation.

It must be noted that developed mesoscopic model can be used only for uncongested network. If the network will be congested the higher error in the output results will be expected. It is connected with the fact that grow of queue does not influence running distance between crossroads.

Further development of the model must include features which take into account congested network.

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