TRANSPORT SYSTEM'S MESOSCOPIC MODEL VALIDATION USING SIMULATION ON MICROLEVEL

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A lot of new mathematical models for traffic systems were developed in the past. Two approaches are widely used, namely microscopic and macroscopic models. Both approaches have several deficits. The mesoscopic approach presented here eliminates the deficits inherent in both the microscopic and the macroscopic approach [1]. The paper shows that the mesoscopic approach is suitable for reproducing process sequences in flow systems and describes the use of the mesoscopic approach to modelling and analysing a group of crossroads, which organizes transport network. There exist good results in modelling the particular crossroad, which could be found in [2]. But the task of modelling a transport network is still open. The paper presents the conceptual mesoscopic model of the defined transport network and its implementation with MS Excel plus VBA. The modelling task is to estimate the dynamics of all the queues and the crossroads capacity utilization.

The mesoscopic approach is quite new; there is only one paper, which validates mesoscopic approach, done for queuing systems [3]. That is why the task of mesoscopic models validation is implemented. To validate mesoscopic model we are using simulation on microscopic level, by development of the model in simulation package PTV VISION VISSIM 5.1 [4], which is widely used for traffic simulation [5].

Keywords: *mesoscopic modelling, crossroad modelling, crossroad capacity estimation, microsimulation*

1. 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 [6] 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 [5] and cellular automats [7]. Models of this class are used to model short periods of time with a very high level of detail. The mesoscopic approach is known in the field of the traffic simulation for a long time. In traffic simulation, the term mesoscopic is often applied to refer to a combination of macroscopic and microscopic simulation [1]. In [1, 3] a new class of 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 labour consuming creation and implementation of microscopic models. The basic principle of mesoscopic modelling can be described with "algorithmic control and analytical calculation". Flow intensity $\lambda(t)$ stays unchangeable in each interval of time between flow changes. Function $\lambda(t)$ could be called the slice constant function. The example of the process representation in mesoscopic model for a single stock is shown in Figure 1.

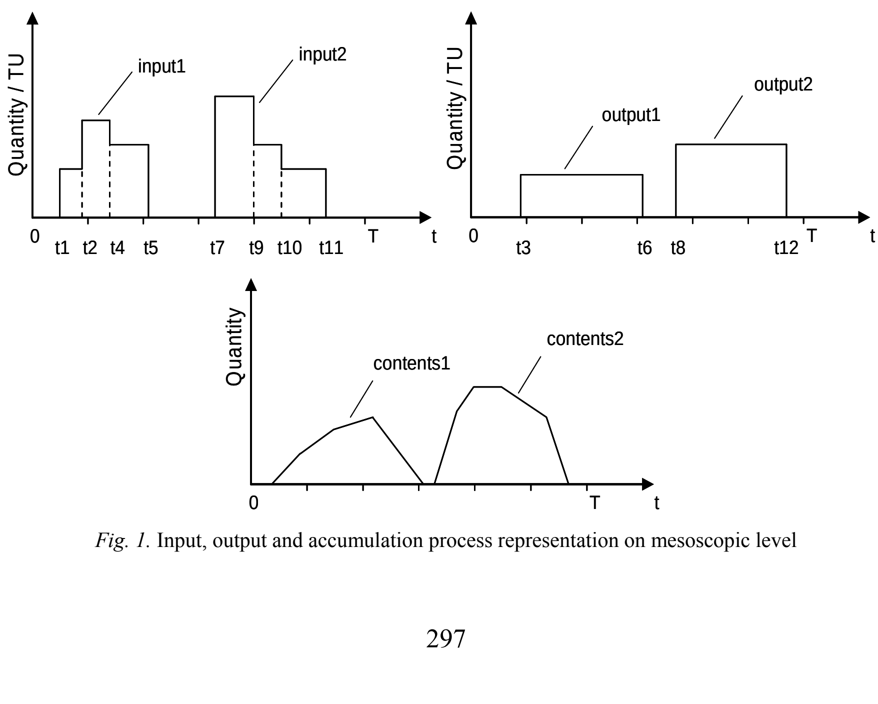

Fig. 1. Input, output and accumulation process representation on mesoscopic level

Mesoscopic model itself consists of different components like source, multichannel funnel, transport element and sink. Also mesoscopic model could contain some control elements, where main algorithm of the systems control is realized. The example of the mesoscopic model could be seen in Figure 2.

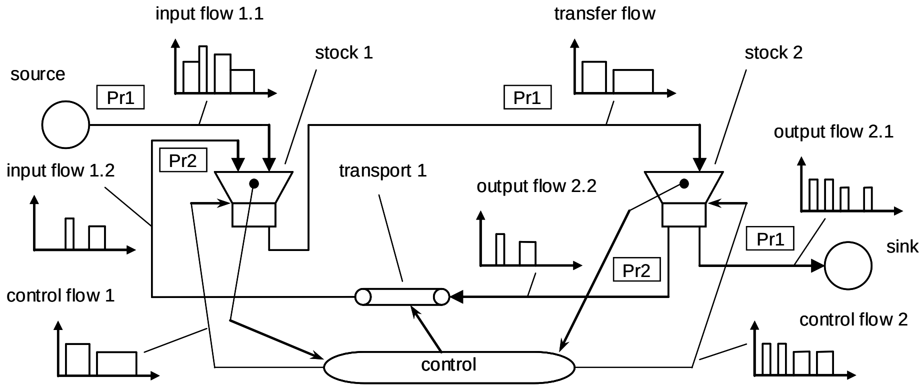

Fig. 2. Example of mesoscopic model structure

2. Modelling and Source Data Description

The modelling object is a fragment of city transport network. The conceptual model is presented in Figure 3. The fragment consists of two symmetric traffic-light signalised crossroads. Crossroads are connected with the road, which is a part of model. The flow of the vehicles enters the network from 6 zones, which are enumerated by numbers 1, 2, 3, 5, 6 and 8. Each income flow is divided on three moving directions: right (r), straight (s) and left (l). The geometry of the crossroads is constructed in a way, that vehicles entering the network from one zone and belonging to one direction r, s and l, can reach and pass the crossroad independently from other directions. Only vehicles which turn left (flow l), depends on flow s duration, which pass crossroad straight in counter lane, during green phase of traffic light. Because of the modelled object's topology the total entering flow of the left crossroad (Figure 1), which enter from zone 4, is equal to sum of flows r5, s8, and l6. In the same way, entering flow for right crossroad is calculated as sum of flows r2, s3, and l1. The modelling task is to estimate the dynamics of all 24 queues and the crossroad capacity utilization. Transport flows are given and traffic lights phases will be determined.

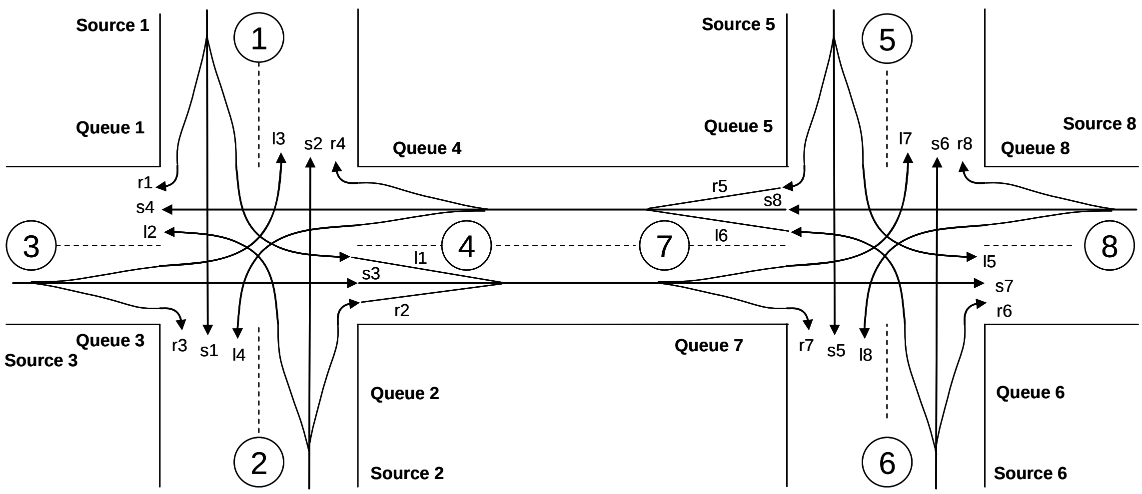

Fig. 3. Conceptual model of the transport network fragment

The mesoscopic approach uses the queue length of vehicles waiting at a crossroad for determining the quantity of vehicles (q). This concept is also used for describing the number of created vehicles and vehicles passing a crossroad. If the number of vehicles in the incoming flow is known, at example 10, the queue length of vehicles can be easily estimated using empirical data. The flows in the model will be described in meter/minutes (m/min).

Table 1 shows the numerical parameters of stationary incoming flows, which are used in the example presented here. The parameters for all 6 stationary flows are the same. The number of vehicles for each traffic light cycle is generated with given distribution laws taking into account cycle duration. In this example the cycle duration for first (left) crossroad is 60 seconds (25s+5s+25s+5s). For the second (right) crossroad two variants of cycles are implemented for the research. They are: the first variant is 70 seconds (30s+5s+30s+5s), the second one is 90 seconds (40s+5s+40s+5s). During flows generating the distribution on direction (r, s, l) is done according proportion r/s/l=0,25/0,6/0,15 .

Table 1. Parameters of the incoming vehicle flows

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

In model the real length of the road, which connects zones 4 and 7 is taken into account. So the maximal total amount of the vehicles for directions 7→4 (Queue 4) or 4→7 (Queue 7) should be defined. In this example for both directions, as the highest level limit is used value 130m. The queue length for internal flows (see Figure 1) is not limited.

For high plausibility maintenance of the crossroads passing is used empirical function (see Figure 4), which could be estimated during direct observing of the passing process, for each direction of crossroad passing. It is supposed that function is preserved for all directions and its numerical values could be obtained based on Exemplary chart, by the way of multiplying the value if function to the coefficient presented in Table 1 in column "Crossroad passing". The function is used in the model as direct and as inverse function. Figure 4 shows that during the first t1=25,5s of a traffic light cycle a vehicle flow with the length q1=122m can pass the crossroad and the flow of length q2=185m will need a t2=32,5s to pass the crossroad.

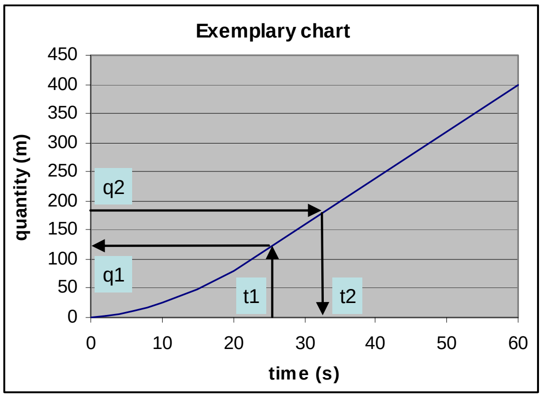

Fig. 4. Dynamic of vehicle flow during crossroad passing

3. Principes of a Mesoscopic Model for Two Crossroads

The principal structure of two crossroads model is presented on Figure 5. The model consists of eight fragments. Links between them are defined according vehicles flows (see Figure 3). Each fragment includes three parallel channels, which generate, delay and pass throw crossroad flows of vehicles. Last two functionalities are realized using "multichannel funnel", which is described in [3]. The content of each channel of the funnel is numerically equal to the length of the queue. The control component of the model (Flow Control) defines the quantity of vehicles which can pass the crossroad in each traffic light cycle for the different directions.

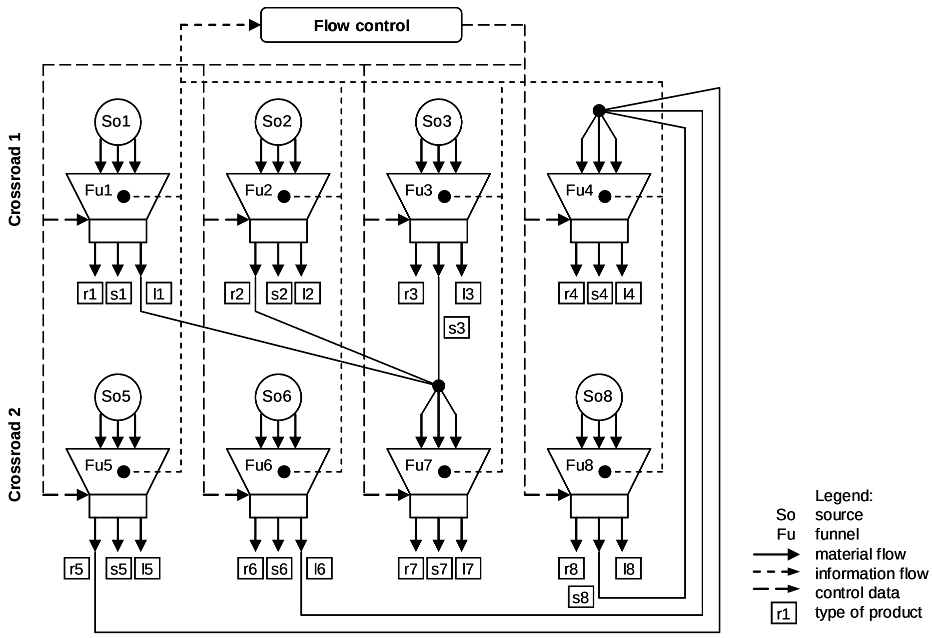

Fig. 5. Principal structure of the mesoscopic model for two crossroads

The kernel of the mesoscopic model of the one crossroad or several crossroads is presented in the Table 2. The event planning algorithm determine the next funnels pair, for which green phase is finishing. The model time is "jumping" to the moment then this event will happen. For these funnels new values of variables, listed in table heads are calculated. Calculation happens from left to right. The data calculation for direction l (left turn) is done after the data calculation for straight on flow s. After processing, the event planning algorithm chooses the next pair of funnels, for which green phase is finishing. For event planning and processing algorithm the variable t is defined for each crossroad: variable t1 for the events time of the first (left) crossroad and variable t2 for the second (right) crossroad events time. As time interval Δt is used, the corresponding duration of half-cycle of the traffic light "yellow + green". At example, for crossroad the first value is defined Δt1=30s, but for the second modelling is done with two variants Δt2=35s and Δt2=45s.

Table 2. Kernel of the two crossroads mesoscopic model

	Remaining from previous cycle (m)	Arrival per cycle (m)	Wish to drive through (m)	Duration of green phase (s)	Phase capacity (m)	Passed through volume (m)	Duration of pass flow (s)	Remaining on current cycle (m)
Crossroad 1		**Cycle number: 16**				**Time (s): 990**		
Funnel 1								
right (r1)	0,00	17,42	17,42	25	72,00	17,42	10,88	0,00
straight (s1)	0,00	44,09	44,09	25	96,00	44,09	16,11	0,00
left (l1)	31,52	7,76	39,28	25	72,00	17,10	7,05	22,18
total	31,52	69,26	100,78		240,00	78,60		22,18
Funnel 2								
right (r2)	0,00	17,21	17,21	25	72,00	17,21	10,80	0,00
straight (s2)	0,00	53,49	53,49	25	96,00	53,49	17,95	0,00
left (l2)	4,23	7,75	11,98	25	72,00	11,98	8,89	0,00
total	4,23	78,44	82,67		240,00	82,67		0,00
Funnel 3								
right (r3)	0,00	16,22	16,22	25	72,00	16,22	10,44	0,00
straight (s3)	30,85	56,37	87,22	25	96,00	87,18	23,62	0,04
left (l3)	0,00	9,45	9,45	25	72,00	9,45	3,64	0,00
total	30,85	82,04	112,89		240,00	112,85		0,04
Funnel 4								
right (r4)	0,00	30,28	30,28	25	72,00	30,28	15,39	0,00
straight (s4)	0,00	72,68	72,68	25	96,00	72,68	21,36	0,00
left (l4)	8,87	18,17	27,04	25	72,00	9,65	1,38	17,38
total	8,87	121,13	130,00		240,00	112,62		17,38
Crossroad 2		**Cycle number: 14**				**Time (s): 1015**		
Funnel 5								
right (r5)	18,86	26,11	44,97	30	96,00	26,18	14,05	18,79
straight (s5)	0,00	84,75	84,75	30	128,00	84,75	23,24	0,00
left (l5)	2,36	13,91	16,27	30	96,00	16,27	11,37	0,00
total	21,22	124,78	146,00		320,00	127,21		18,79
Funnel 6								
right (r6)	0,00	19,39	19,39	30	96,00	19,39	11,59	0,00
straight (s6)	0,00	56,99	56,99	30	128,00	56,99	18,63	0,00
left (l6)	29,17	9,32	38,50	30	96,00	0,00	6,76	38,50
total	29,17	85,70	114,87		320,00	76,38		38,50
Funnel 7								
right (r7)	0,00	28,97	28,97	30	96,00	28,97	15,04	0,00
straight (s7)	0,00	69,52	69,52	30	128,00	69,52	20,86	0,00
left (l7)	14,14	17,38	31,52	30	96,00	16,09	6,49	15,43
total	14,14	115,86	130,00		320,00	114,57		15,43
Funnel 8								
right (r8)	0,00	27,11	27,11	30	96,00	27,11	14,39	0,00
straight (s8)	0,00	86,43	86,43	30	128,00	86,43	23,51	0,00
left (l8)	0,00	12,44	12,44	30	96,00	12,44	9,14	0,00
total	0,00	125,98	125,98		320,00	125,98		0,00

The calculation algorithms of variables presented in the Table 2 for flows of type r, s and l are described in detail in [2]. Here it should be stressed that it is assumed that the defined minimal flow of vehicles can complete the left turn, even if the passer flow exist during all green phase of the traffic light. Before model execution it is possible to give a start condition of the queues. The value of the maximal modelling time is consequently defined. The model run could be done entirely or step-by-step and it will give possibility to control value of the variables in each step Δt. Also when the full mode is available then modelling result will be obtained.

4. Data Output and Interpretation of Simulation Results

Necessary data are copied from Table 2 to the process trace file during mesoscopic model execution. Diagrams of incoming flows (column "arrival per cycle") and outgoing flows (column "passed through volume") can be presented in differential and integral (cumulative) forms for all components of the model. The trace file also contains the contents of the funnels (column "remaining on current cycle").

In Table 3 presented the final data, which are obtained during model execution with model run time equal to 1000s. In frames "input (sum)" and "output (sum)", the length of the flow fixed on corresponding funnel enter and exit are presented. Frame "queue (maximum)" gives the maximum value of the queue during simulation.

Table 3. Output data of the mesoscopic model of a crossroad

Crossroad 1	Cycle number: 16					Time (s): 990					
Funnel 1											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
329,5	997,5	163,5	1490,4	334,5	1007,5	168,5	1510,4	24,6	89,2	15,0	119,1
Funnel 2											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
308,9	1028,1	164,1	1501,1	313,9	1038,1	169,1	1521,1	22,8	86,0	13,1	120,6
Funnel 3											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
309,0	1125,9	177,1	1612,0	314,0	1135,9	182,1	1632,0	25,0	126,5	18,2	155,3
Funnel 4											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
385,1	924,2	231,1	1540,4	390,1	934,2	219,9	1544,3	32,5	78,0	39,7	130,0
Crossroad 2	Cycle number: 14					Time (s): 1015					
Funnel 5											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
341,3	1027,9	173,3	1542,5	346,3	1037,9	178,3	1562,5	31,6	101,2	19,8	141,1
Funnel 6											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
343,3	1075,1	161,5	1579,9	348,3	1085,1	166,5	1599,9	28,9	99,5	34,3	151,7
Funnel 7											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
404,6	971,0	242,8	1618,3	409,6	981,0	244,1	1634,6	32,5	78,0	27,7	130,0
Funnel 8											
input (sum)				output (sum)				queue (maximum)			
right	straight	left	total	right	straight	left	total	right	straight	left	total
334,7	1111,7	178,1	1624,4	339,7	1121,7	183,1	1644,4	29,0	105,4	22,3	154,5

On Figure 6 the results of two experiments with different traffic light cycle duration are presented. For each direction is given only total length of the queue, the maximal value of queue could be obtained from Table 3 in column "queue (maximum)-total". As the input flows are stochastic, so the process is presented on Figure 6, is stochastic too.

a) traffic light cycle crossroad 1: 60s (25+5+25+5)
traffic light cycle crossroad 2: 70s (30+5+30+5)

b) traffic light cycle crossroad 1: 60s (25+5+25+5)
traffic light cycle crossroad 2: 90s (40+5+40+5)

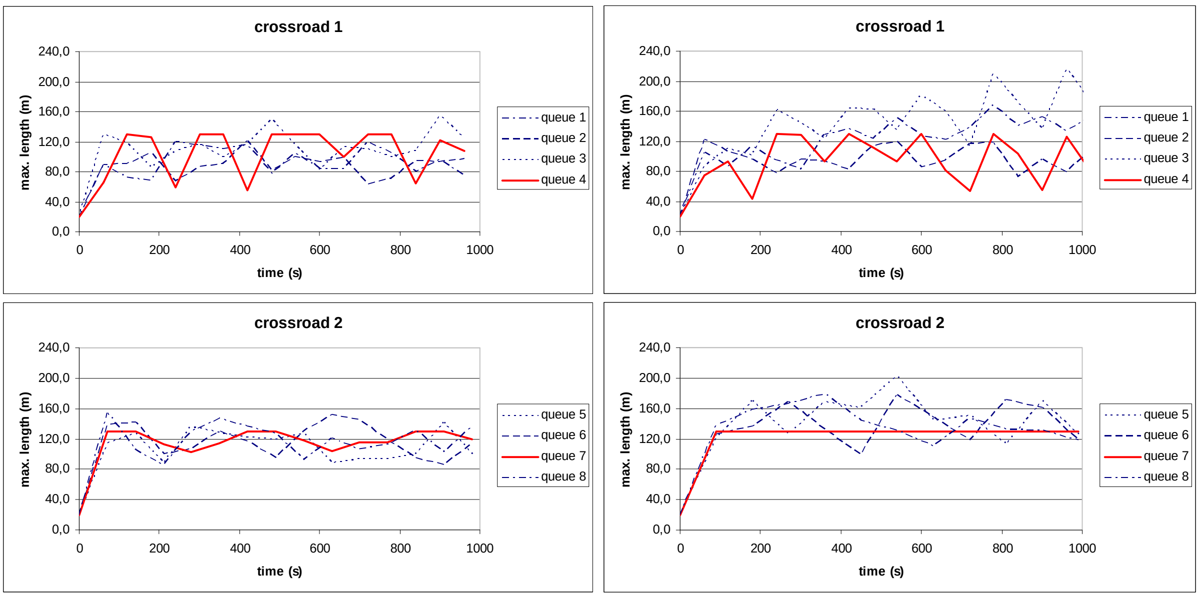

Fig. 6. Dynamics of queues for eight directions of vehicles income

During visual analysis of the runs results, the qualitative conclusion could be made for each queue, mostly for queues Queue 4 and Queue 7.

On Figure 6 it could be seen that during traffic light cycle increasing on crossroad 2:

- For each "red" phase of traffic light on crossroad 2 queue Queue 7 (the fragment of road 4→7) is filled to the maximum value 130m.

- Queues Queue 1 and Queue 3 have a tendency to the growth, the capacity of the crossroad 1 in directions 1→4 and 3→4 is not enough to pass flows, because of large amount of the vehicles in road 4→7.
- Queues Queue 2 and Queue 3 have a tendency to the stable state.

5. Mesoscopic Model Validation

To validate constructed mesoscopic model we are using simulation on microscopic level. According conceptual model (Figure 1) microscopic model of the crossroads was constructed. The model was developed in professional simulation software PTV VISION VISSIM [4]. This product is widely used for traffic microscopic simulation [5]. On Figure 7 screenshot from model animation is presented. To simplify validation process the type of all input flows was defined as deterministic.

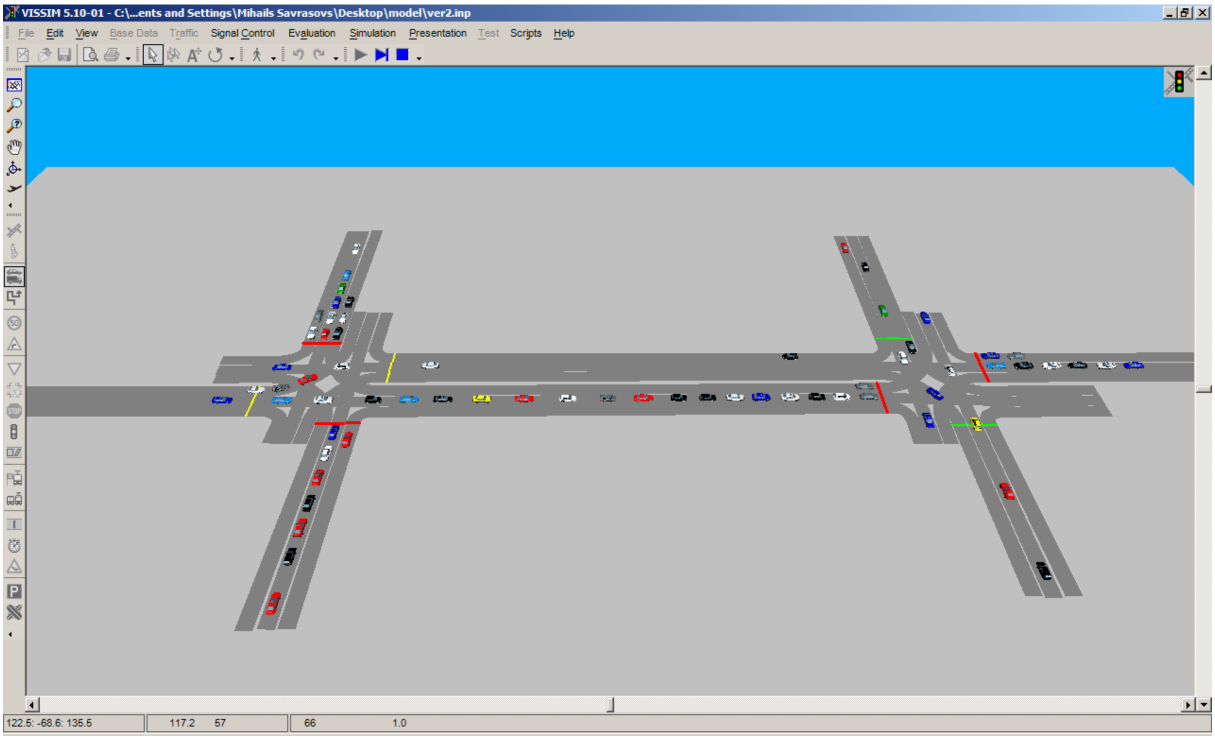

Fig. 7. Crossroads microscopic model realized in VISSIM

For model validation we used qualitative and quantitative approaches. So validation of the mesoscopic model has been done on two levels. The first level consists of comparison qualitative conclusions from mesoscopic model with microscopic animation.

<u>Qualitative validation</u>

According to the observed animation of the simulation process in microscopic model it could be concluded, that mesoscopic model on qualitative level represents microscopic level. Such conclusions are made on following points basis:

- According animation road 4→7 all the time is filled by vehicles, also it could be seen on Figure 3.
- Queue 1 is growing during simulation. Figure 3 demonstrates, that vehicles from direction 1→4 could not get to road because road 4→7 is already filled.
- During simulation animation demonstrated that there are some problems in direction 3→4, because of the road 4→7.
- Queues Queue 2 and Queue 4 according animation video have stable state, it means that during "red" phase of traffic light roads are filled, but during green phase almost all vehicles pass the crossroad.

So according to qualitative analysis all 3 conclusions which have been made according to mesoscopic models are also approved by microscopic model. The next step is qualitative comparison of the two models.

Quantitative validation

As a comparison parameters queues length is used. The comparison have been done for all queues, but in this article only the most interesting results are presented. On Figure 8 results for queue 1, queue 4, queue 6 and queue 7 are shown.

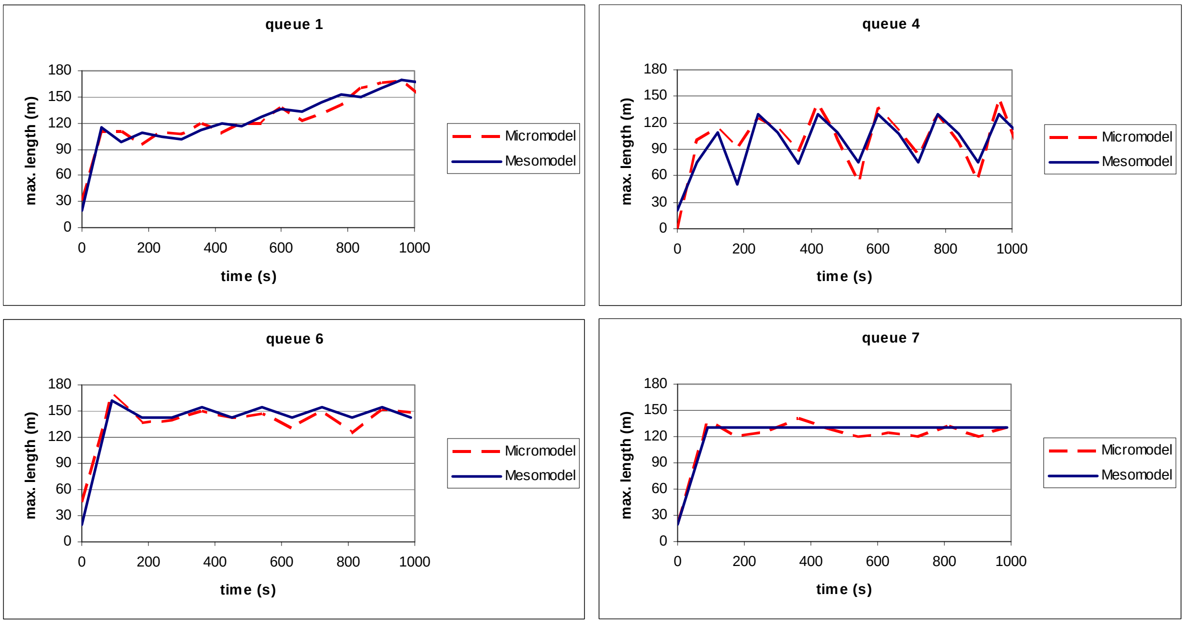

Fig. 8. Maximum length comparison for queues

According to the graphs on Figure 8 mesoscopic model successfully presents the queue accumulation process. Of course, there are some differences in results, but fluctuation in the microscopic model could be explained by random numbers, which are used at example for vehicle length, while in mesoscopic model all vehicles have the same size. Also the comparison of the results could be done using Box-Whisker plots.

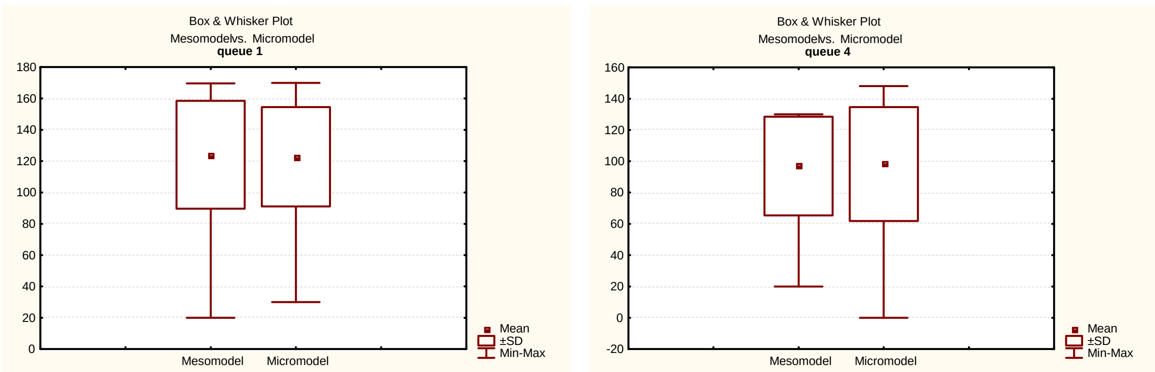

Fig. 9. Box-Whisker plot for queues 1 and 4

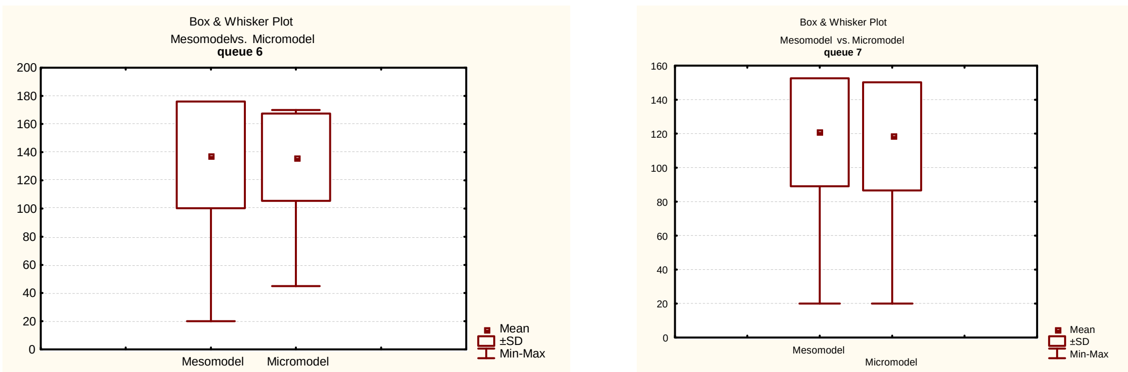

Fig. 10. Box-Whisker plot for queues 6 and 7

As it could be seen on Figure 9 and 10, queues mean length and length standard deviation are mostly the same that should concern us that data is homogeneous.

Conclusions

1. The main principles of mesoscopic modelling of flow systems were realized during the development of the model. The model does not present individual flow objects, but only defined sets of objects (groups of vehicles coming to the crossroad during one traffic cycle).
2. All parameters of the model can be directly estimated. Any empirical data can be used to model the flow dynamics. Incoming flows are modelled as random values of the length of the flow with any distribution law. The duration of a traffic light phase is defined as a parameter.
3. The model allows studying a stationary and non-stationary mode of crossroad processes. At example the start values for queues can be given and thus time of queues resolving and appearance could be estimated during special conditions.
4. First results of modelling can be shown as a detailed trace file of processes for every structural component and type of flow. Any characteristics of the crossroad processes can be calculated on the basis of the trace file. Graphs of process evaluation can also be constructed.
5. Mesoscopic model was validated by the microscopic model. According qualitative and quantitative analysis mesoscopic model passed validation. So it concerns us that mesoscopic approach could be used for traffic simulation.
6. The developed mesoscopic model could be used for qualitative and quantitative queues dynamic study. It could be easily changed and expanded. Also any algorithms of traffic light phase control algorithms could be integrated. The model has been developed on Microsoft Excel and Visual Basic for Application base. During the model size increasing programming could take a lot of time, therefore the development of special mesoscopic simulation software could be perspective.

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