Modeling Road Traffic Using Service Center

Iulia-Maria Haragos[1], Cosmin Cernazanu-Glavan[1]
[1]*Politehnica University of Timisoara, Computer Science Department, 300223, Romania*
cosmin.cernazanu@ac.upt.ro

***Abstract*— Transport systems have an essential role in modern society because they facilitate access to natural resources and they stimulate trade. Current studies aimed at improving transport networks by developing new methods for optimization. Because of the increase in the global number of cars, one of the most common problems facing the transport network is congestion. By creating traffic models and simulate them, we can avoid this problem and find appropriate solutions. In this paper we propose a new method for modeling traffic. This method considers road intersections as being service centers. A service center represents a set consisting of a queue followed by one or multiple servers. This model was used to simulate real situations in an urban traffic area. Based on this simulation, we have successfully determined the optimal functioning and we have computed the performance measures.**

***Index Terms*— computer simulation, mathematical model, queueing analysis, service center, traffic control.**

I. Introduction

The importance of road transport has increased due to construction of real road networks and the various technical and technological innovations in the automotive industry. Development in this area has lead to problems in the urban transport system. These problems are influenced by issues such as: participating vehicles, driver behavior, transport network topology.

The most common problems encountered in urban traffic are related to traffic congestion. In all the big cities there have been created periods of time in which the road is blocked. The major disadvantages of these blocks are: waiting too much time, physical resources spent in excess and the possible apparition of strained situations.

For this reason, the study of the transport system is interesting for understanding the relationships between their components or, for predicting how these act in new conditions[1]. From the technologies in use today, we have used modeling and simulation of transport system to determinate its performances.

Modeling and simulation methods are important, especially for the design and analysis of the transportation systems. These allow traffic engineers and researchers to perform theoretical studies and the possibility of evaluating and analyzing the results. In this way, there are determined opportunities to improve the traffic flow by providing alternatives to change the real road network. These are important for improving the transport, reducing the necessary time for crossing the road section and for reducing costs per route that involve crossing. The main goal in developing these methods is to achieve a road infrastructure which will take into account the human needs.

A model is a simplistic representation of a system which artificially reproduces and describes the original system, which allows the study system for understanding the properties of the original system and its behavior prediction. Model simulation is performed in order to find the system parameters and to determine its performance.

The scientific literature proposed more than one simulation model of the road traffic. Each of these solutions deals with traffic items but only the small ones, for example: Modeling a intersection or modeling a section of the road. There is another solution that can accurately model an important part of the urban traffic network.

This paper intends to continue by modeling the intersections of a section of the urban network using service centers. Service centers are the key elements used in performance evaluation of computer systems [12]. The essential element of this paper consists in applying a new analytical model based on traffic simulation using service centers.

The new model for estimating the throughput node of the network was proposed by the authors in previous work.[7]. This model is able to report successfully the situations of congestion and to calculate the node parameters value for a correct operating.

Our further work will analyze the current state of research in this area. In Section 2, we will define the analytical model and the used elements in building the traffic model of queueing theory. Section 3 will present how to use the model and illustrate the application of a traffic section. The results and conclusions close this paper.

A. Previous Work

The existing research literature is focused on optimizing the road traffic and evaluating the system performance [13]. In paper [2],Chen et all. considered that the city center and transport terminals of different modes of transport are defined as a central nodes and transfer nodes, in order to characterize the particular type of passenger travel. This model comes with an improvement in terms of generalization of the cost function and the way in which the algorithm chooses the route.

Another research proposed a model that allows the identification of the level of congestion in a intersection [3]. The proposed algorithm is applied to pattern recognition problems and is based on the technique of k-means clustering type. [21]. This is able to determine the car number by analyzing the images provided by a traffic

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camera.

Building a model is often expensive, requires much time and it is subject of errors [19]. For this reason in [4] is presented a model called simulation-before-construction. This simplified model requires only few input data, thus being able to predict the operating mode of a intersection. The model is composed of simple blocks [20], which represent the traffic way and the vehicle types. Its use can be relatively easy to simulate different types of intersections.

There are other papers that analyze the analytical models based on queues to optimize the traffic road. In [5] is proposed to simulate the traffic network using the queueing network with finite capacity. By analyzing the traffic from Lausanne city, in [9] the author proposes a queue for each lane of traffic. Thus, every time the road capacity is changing, he adds / removes each queue network from the system. The resulting street network is used to maximize the traffic lights time in the intersection of the city.

Another way to simulate urban traffic intersections using an queuing network with an analytical model was proposed in [14] [15]. Both methods are based on Expansion Method [16] and tries to define urban traffic as an extension of highway traffic.

Hiedemann shows a unique approach to both types of intersections: with and without traffic lights. [24][25]. These models are able to determine a realistic description of a segment from a road junction using queueing theory. Unfortunately, being an analytical method it cannot be generalized to multiple segments of road or to multiple intersections.

Using a Multiclass BCMP Queueing, Dad et all have tried to simulate traffic lights in a intersection with multiple lanes access. Thus, he defines a queue for each section of the intersection and calculates the values of performance indices attached. The proposed model is able to determine if there are situations of congestion and the time when these may appear.

II. Using Queueing Service Centers for Traffic Modeling

The problem is to find a model for a road representation in an uniform way and capable to help us for a better reflection of real situation.

One of the most important criteria for evaluating a system is his performance in day by day tasks. To achieve this goal, in the system design stage, the best solutions must be chosen, irrespective of the use mode of the system. Because of these criteria, the modeling and simulation phases before implementation phase are crucial for a better functioning.

Modeling a system using queue network is one of the best methods in the literature. It was originally applied in modeling of computer systems [17], where there were obtained very good results, and it spread to other real systems [18].

A *queue* is the implementation of a waiting list of jobs in order to obtain a service. Services may be provided by one or more servers. This set (queue + one or more servers capable of providing services) is called *service center* [11]. If we make an analogy with the real world, we can imagine one or more front desks that are accessed through a queue. All the front desks working in parallel and provide the same service, regardless of their position.

In queuing theory, a service center is schematically represented as in Fig. 1.

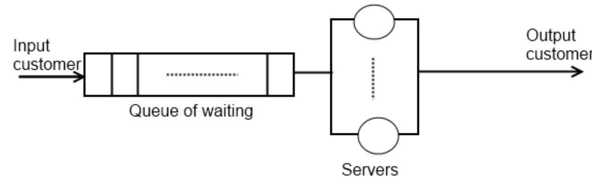

Figure 1. Service center (queue of waiting + one or many servers)

A model that uses one or more service centers is called a queueing model. To measure the performance of such a model we are using several performance measures. Below, we will present the most important performance measures that must characterize such a queueing model.

A. Performance Measures

A *queueing* model is a dynamic probabilistic model because it uses probabilities to represent the system evolution over time. The simplest performance measures are mean values for the number of customers that are in the system at a time and average response time for a customer. Further we define a few parameters that help calculate these values.

We denote by n_s the number of customers at a time system s. For its representation we use a random variable n, whose mean values cannot be calculated using a probability distribution. The expected value for the number of customers that are at a certain time in the system is called the nth moment about the origin of n and is calculated as follows:

$$E\left[n^k\right]=\sum_{i=0}^{\infty} i^k \operatorname{Prob}\left\{n=i\right\} \tag{1}$$

If we consider that $Prob\{n=i\}$ and $E[n^k]$ to be equal with averages over an infinitely long interval of time (long-run time averages) we have:

$$\operatorname{Prob}\left\{n=i\right\}=\lim_{s\to\infty}\begin{pmatrix}\text{first } s \text{ time when } i \text{ customers}\\ \text{are in the system}\end{pmatrix} \tag{2}$$

$$E\left[n^k\right]=\lim_{s\to\infty}\frac{1}{s}\int_o^s\left[n_u\right]^k du \tag{3}$$

Each client j that arrives in the system should spend some time before it is served. We define this time as the response time for customer j and it noted with r_j. If we consider that $Prob\{r\leq t\}$ and $E[r^k]$ are equal to averages over an infinite number of customers (*long-run customer averages*) we have the following formulae for probability distribution function and expected value.

$$\operatorname{Prob}\left\{r\leq t\right\}=\lim_{J\to\infty}\begin{pmatrix}\text{fraction of the first J customers}\\ \text{to arrive whose response times}\\ \text{are less or equal to } t\end{pmatrix} \tag{5}$$

$$E\left[r^k\right]=\lim_{J\to\infty}\frac{1}{J}\sum_{j=1}^{J} r_j^k \tag{6}$$

If our system is a stable one ($E[n]$ and $E[r]$ are finite numbers), the *throughput* Λ must be equal with the long-run rate for the customer arrivals, where Λ is defined as:

$$\Lambda = \lim_{s\to\infty} \frac{1}{s}\begin{pmatrix}\text{number of clients departed}\\ \text{in first } s \text{ time units}\end{pmatrix} \quad (7)$$

The time when a server is busy is called the *utilization* of the service center. If we denote by b_s the number of servers occupied at time s, we define U(utilization) as:

$$U = \lim_{s\to\infty} \frac{1}{s}\int_0^s b_u du \quad (7)$$

These four sizes of performance measurement are commonly used in queue network theory. Also, for the correct definition of the model, we need other time parameters which are enumerated below.

B. Queueing model parameters

Arrival rate (λ) represents the number of customers arriving at the service center at a certain time and is defined as:

$$\lambda = \lim_{t\to\infty} \frac{N(t)}{t} \quad (8)$$

Inter-arrival time is the interval of times between two successive arrivals. It's defined as inverse of arrival rate:

$$T_w = \frac{1}{\lambda} \quad (9)$$

Service demands represents the amount of service required by a customer when he arrived at service center and is noted by S. With μ we denote the number of service units provided by the server per time unit(*service rate*). The division between service demand and service rate is the amount of time spent by server for each customer and it have following formula:

$$T_s = \frac{S}{\mu} \quad (10)$$

C. Queueing Discipline

The queuing disciplines specify how customers from the queue are served by the server. The most commonly used methods are FCFS (*first-come-first-served*) [22] and *round robin*. The FCFS discipline (used in the present article) considers the service order to be the order in which they arrived in list. The *round robin* discipline used the *quantum* notation to serve the clients. Each customer which arrived at the server center is given continuous service for a fixed interval of time(*quantum*). If the customer demands are higher than the *quantum* interval, he reenters into the queue.

The model presented in this paper uses the FCFS discipline because it is natural for road sections or intersections with traffic lights. The *round robin* discipline can also be used, but only in roundabout type intersections.

D. M/G/1 Queueing Model

This notation is commonly used to indicate the type of queuing model. It is composed of three parts (inter-arrival time, service demand, number of servers). For our model we specify:

- inter-arrival time is an exponential random variable; the letter M is used to denote an exponential distribution
- service demand is general random variable; the letter G is used for an arbitrary(general) distribution
- we use only one server

To a unitary representation of all intersections from a road sector we chose this model because it is very close to the idea of intersection traffic. Thus, we can model both existing intersections: with and without traffic lights. Specific operating parameters are calculated after one traffic analysis.

The most important parameters for model simulation (arrival rates and service demands) are determined statistically by analyzing real parameters. In the next chapter, we will present one implementation of a road section with such a model. Based on this implementation we show how to modify the parameters and what the effects of these changes are. We will also perform simulations in case of congestion or traffic stress.

III. Model Simulation and Results

In this paper, the proposed model simulation was performed using the simulation environment Java Modeling Tools (JMT) [26].

Java Modelling Tools (JMT) is an integrated environment for workload characterization and performance evaluation based on queuing models. [8]. JMT supports simulation of several types of activities and allows the evaluation performance, such as capacity planning model simulation, workload characterization, automatic identification of bottlenecks in the network modeled and optimization of the analytical models.

A. Building model

To test the analytical model, we consider a section of the transport network in urban environment. Graphical representation of the road section is provided by Google Earth, and can be viewed in Fig. 2

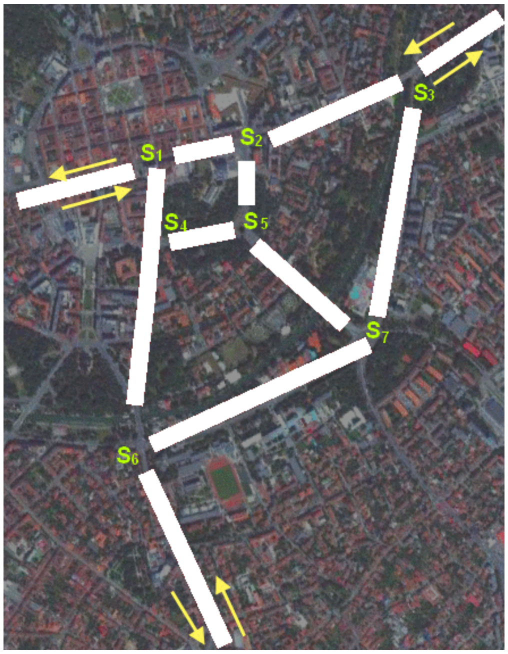

Figure 2. A road section of urban transport network

To achieve the simulation in JMT, we chose, from this figure, multiple roads and we defined the following components:

- White lines – represent the main road that connect the intersections (nodes) of network
- Yellow lines – represent the inputs and outputs of road section considered
- $S_1..S_7$ represent the intersection of road section analyzed

Each of these components must be translated in JMT, in order to perform an analytical analysis and to simulate the model. Thus, junctions become the service centers and the yellow arrows are Source/Sink in JMT.

Simulation graph associated with Figure 1 was created in JMT as in Fig. 2. You can see that the model which must be simulated consists of: a source of input , seven service centers and a source of output.

To build the simulation model of the queueing network, we consider a few aspects: the graphical representation of the road section analyzed, defining the types of customer classes, defining the performance indices.

Therefore, the proposed model simulation is represented graphically in Fig. 3

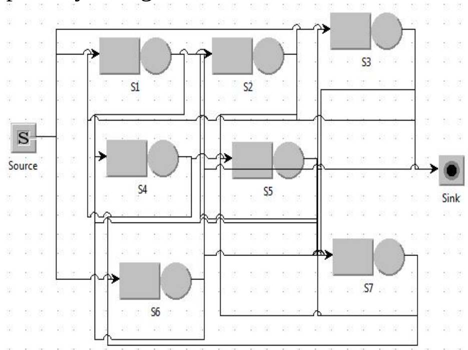

Figure 3. Road section from Fig.2 modeled with JMT

To simplify matters, it was considered that the inputs into the system are generated by one source. In this case, we will have a single source of all outputs.

Like a component, the input source is generating the traffic flow in the system. The distribution of traffic in the system is made according to the distribution type and to the arrival rate of the vehicles flow.

The source of output is used for types of customers which are leaving the system. This source is characterized by none of the parameters, so the customers are leaving the system in a “free” mode.

The next step in this simulation is to define classes of customers which transit through system.

The proposed example is using three types of customer classes: Auto(car), Bus, and Bicycle. Each class of customers has the only reference source, input source. These classes of customers are considered as open classes.

In this case, it is necessary to define the parameter that represents the arrival rate of customers in the system. The number of customers which arrive in the system is calculated based on exponential distribution. In the next table, it is presented the arrival rate for each class used.

TABLE I. ARRIVAL RATE OF CLASSES

	Auto	Bus	Bicycle
Arrival rate(job/sec)	0.6	0.143	0.033

For each service center of the system, we must specify the service time assigned to each class of customer. Service time was statistically calculated on the basis of real measurements. For the simplicity, the authors considered one time unit to be equal with 10 seconds in real time. In Table II, you can see the service time which was used in the simulation for all station/ classes defined.

TABLE II. INTERSECTION SERVICE TIME

Intersection	Auto	Bus	Bicycle
S_1	3.5	4.5	16.0
S_2	4.0	5.0	19.0
S_3	4.5	5.5	20.3
S_4	3.7	4.7	21.6
S_5	5.0	6.0	19.7
S_6	3.7	4.7	12.6
S_7	4.2	5.2	23.0

B. *Simulation methods*

JMT performed a simulation model according to selected performance indices. Thus, the system performance was determined: utilization, number of customers, throughput, and throughput system. The values of these parameters can be obtained only after the simulation and only if this went well. Otherwise the defined system cannot be simulated to obtain the specified indices.

In case you want a more detailed analysis of the system, then these are subjected to variations of one or more parameters. This method is realized by using the ”*What if*” method. After this type of simulation JMT displays the average and dispersion of performance parameter.

It should be noted that the results can fluctuate from simulation to simulation. For this reason, the authors encourage to make more simulations in order to establish final conclusions.

C. *Results and graphs*

For the proposed example in this paper, we will show the graphics results of performance indices as follows:

Number of customers - It can be seen in Fig. 4 and Fig. 5 that the number of customers keeps a constant value through the simulation in station $S_{2,4,5,7}$ (These are no entry stations). If we analyze the case in which the number of customers varies between to 100% to 250%, then the results are similar. This is due to the limited number of vehicles which pass through the intersection in a interval time.

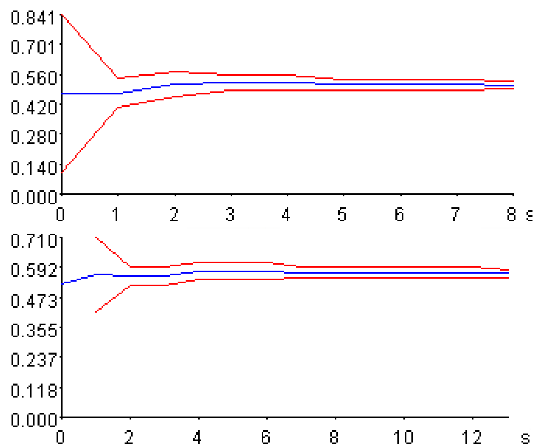

Figure 4. Number of customers for S_2 and S_4

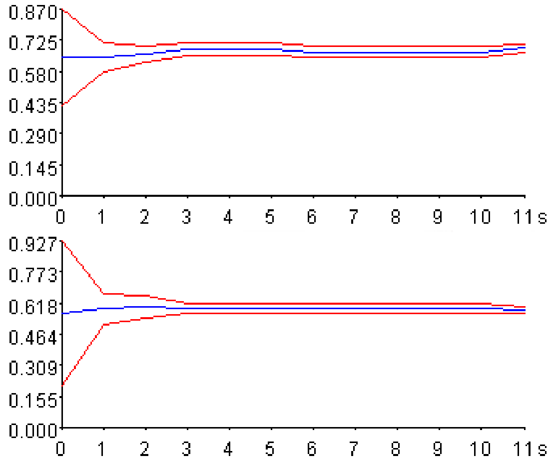

Figure 5. Number of customers for S_5 and S_7

For the input station ($S_{1,3,6}$), the simulation could not determine if the number of customers is constant on an interval. (It has an upward trend in time.) (Fig 6).

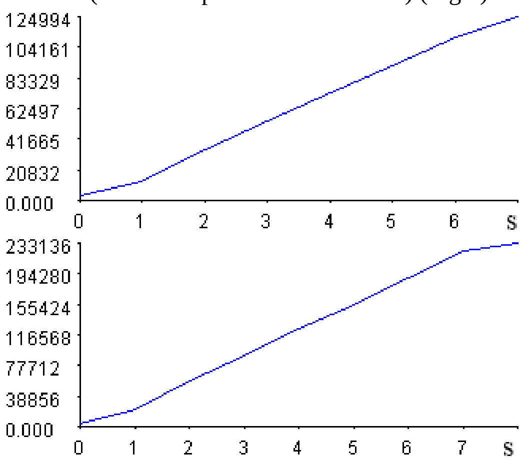

Figure 6. Number of customers for S_1 and S_3

Utilization - same as in a previous simulation, the utilization level of intersections $S_{1,3,6}$ are the maximum (saturation threshold). Rest of intersection presents a correct operation Fig. 7 and Fig. 8.

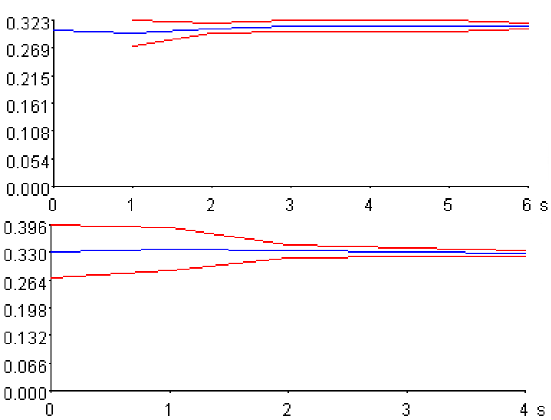

Figure 7. Utilization for S_2 and S_4

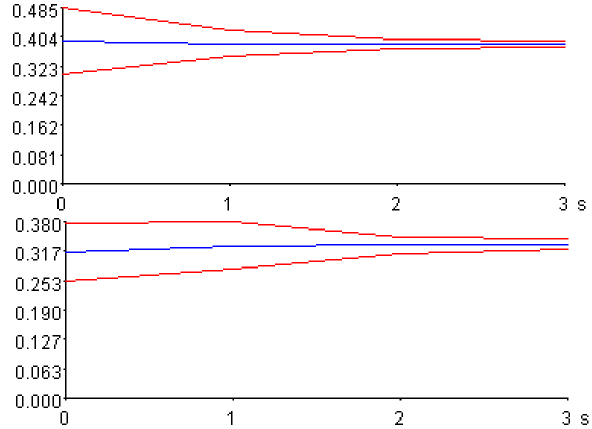

Figure 8. Utilization for S_5 and S_7

If we consider that at the station S_1 are executed upgrading works which imply a reduction of service time (Table III.), then the utilization reached a normal operation. Fig. 9

TABLE III. SERVICE TIME FOR INTERSECTION S_1

Intersection	**Auto**	**Bus**	**Bicycle**
S_1	1.42	1.81	6.17

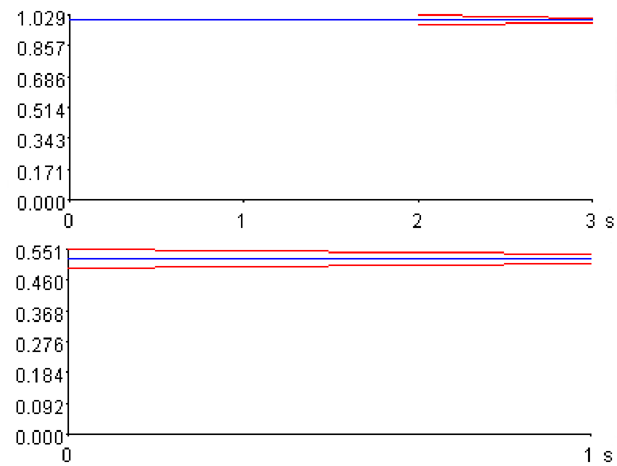

Figure 9. Utilization for S_1 before and after service time modification

For this case, we can check if the station S_1 can resist (is not saturate) even if the arrival rate of vehicles increases to 250% (What-if analysis when arrival rate is between to 100% to 250%). From Fig. 10, we can see if that the arrival rate increases to 200% then the station S_1 is saturated.

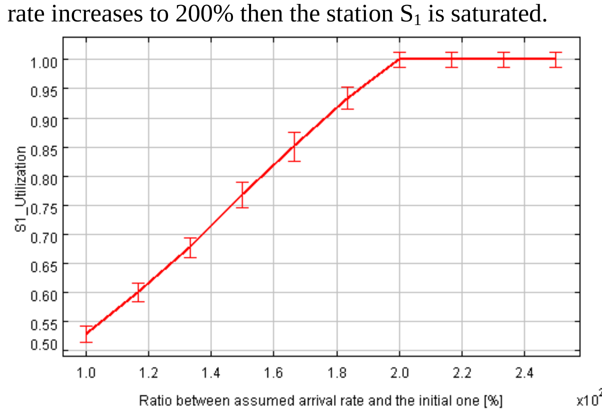

Figure 10. Saturation of S_1 during What-If analysis

The final analysis realized for this example presents changes of the throughput in station S_1 for its upgrading case (shown above). In Fig. 11, it can be observed a growing up to 50% of this value (from 2.4 vehicles /s to 3.1 vehicles /s).

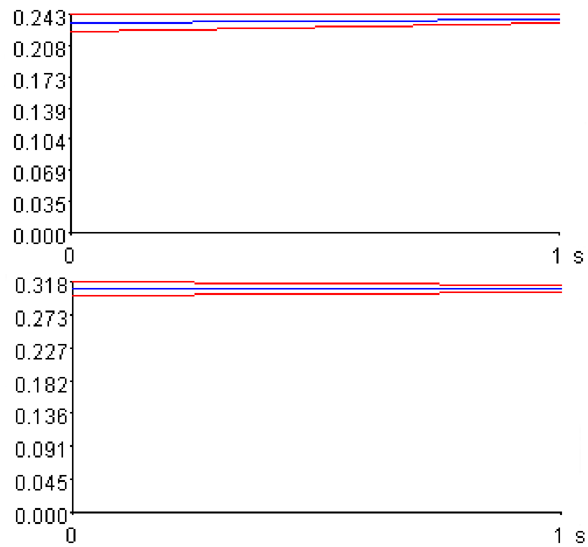

Figure 11. Growing of throughput with 50% for S_1

IV. CONCLUSIONS

In this paper, we propose a new model to simulate the traffic in a section of the urban network. The model is developed on the basis of the elements existing in the queuing theory and suggests the modeling of a junction by a service center. This unique approach in this area allows that all the junctions of the road to be treated in a uniform way.

The parameters which characterize a junction are introduced in a statistical model based on real measurements. Once the model created, it can be easily simulated in a JMT environment for obtaining the performance that characterizes the model.

As noted in Section 3, the modification of parameters of intersections (upgrade / change traffic light) is easily seen in changes of performance index values.

Another advantage of the proposed model is the possibility of using the "*What if*" analysis (variation of parameter for a certain interval). This analysis provides a new perspective into the model function in special conditions (peak traffic, congestion, etc).

We conclude that the model proposed by the authors is easy to use and opens the way to new possible research due to the performance offered.

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