A model to estimate the throughput value for a transport network

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***Abstract*— During the last period, road traffic has become one of the most studied topics. The main problem in urban transport network is congestion. Congestion is due to a several factors such as infrastructure, the ratio of the large number of vehicles and road network capacity as well as traffic signals mode. For this reason, several models have been developed in order to estimate the throughput value for a street or intersection. In this paper, we propose a new model to estimate the throughput for node of the network. This analytical model is developed based on existing elements in queueing theory. The model takes into account an attenuation factor that describes the quality of street/connection between network nodes, more precisely it shows the traffic status in analyzed section (traffic jam or traffic fluently).**

***Keywords:* road traffic, queueing network, modeling, transport network.**

I. INTRODUCTION

Transport systems have always been an essential aspect of human civilization. In the last half of this century, the road traffic in large cities has become a major problem due to continue growth in the number of vehicles involved in traffic. For this reason, currently it investigates solutions to fluidize traffic in congested cities.

The congestion problem in road networks is quite complex. This involves a number of processes and elements that interact such as vehicles, driver behavior, street topology, traffic signals, etc. The phenomenon of traffic jams has negative effects on the quality of people's lives because it leads to queues, hence delays associated, reduced safety and increase of environmental pollution.

To solve this problem in an effective way it is necessary to apply models of plans and traffic control techniques at network level. The control techniques for traffic flows are generally adapted to road configuration. The objectives of these control techniques of traffic flow are to: use maximum capacity of existing infrastructure, reduce congestion and emissions in urban transport network and limit access in certain areas of network to avoid or limit the congestion.

In order to achieve these objectives, the research community has turned to the most modern technologies currently used, namely the modeling and simulation of traffic in urban transport network.

Modeling the traffic at the network transport level is an important element used to avoid congestion and bottlenecks in a system. In this way we obtain opportunities to improve traffic by offering alternatives to amending existing network.

In scientific literature there are several methods proposed for modeling the road traffic. The most common methods for modeling traffic in an urban transportation network are modeling the phenomenon of change of signals at traffic lights and traffic flow modeling using queues.

This paper proposes a new model to estimate the throughput value for a system/node in a transport network. Building this model was based on the idea that a transportation system can be modeled by a network of queues. The proposed model is designed based on the topology of a network transport, network that is influenced by the presence of one or more input sources. The novelty of this model is the definition of an attenuation factor that describes the quality of street/connection between network nodes, more precisely it shows the traffic status in analyzed section (traffic jam or traffic fluently).

Our further work will analyze the current state of research in this area. In Section 3, we will define the analytical model proposed and the common elements used in building the traffic model of queueing theory. Section 4 will show how to use the model and illustrate the application of this model for a certain section of traffic. The results and conclusions close this paper.

II. PREVIOUS WORK

A model is an abstraction of a real system. A queueing network model is a representation of a system using service centers and customers. It was originally applied to modeling of computer systems [1], where it obtained good results, and has spread to other real systems [2].

The existing research literature that deals with traffic issues is focused on the optimization and evaluation of transport systems. In [3], it is proposed an algorithm that allows you to identify the level of congestion of an intersection.

Other research examines analytical models based on queues in order to analyze traffic fluency. In [5], the author proposes a queue for each line of traffic in order to analyze the traffic from Lausanne city. In this way, every time the road capacity is changing, he adds or removes selected queue from transport network. The street network obtained is used to maximize the traffic light time in the intersection of the city. Later in [4], it is proposed the simulation of traffic networks with queues with finite capacity.

An excellent analysis of analytical models based on queues in signalized and not signalized intersections is offered by Heidemann in [6] [7].

Another way to model urban traffic in a set of intersections with an analytical model using a queueing network was proposed [8] [9]. Both are based on Expansion Method and try to define urban traffic as an extension of highway traffic.

More recently, in [10], it was tried to simulate a signalized intersection with multiple lanes of access. The author defines a queue for each sector of intersection and calculates performance indicators attached. In this way, the model determines if there are congestion situations and the time when they are likely to occur.

In another study, [11], it was proposed a model for intersections of a section of the urban network using service centers. This paper consists in applying a new analytical model based on service center in traffic simulation.

III. PROPOSED METHOD

The determination of a throughput model for a node in the traffic network started from the idea that a transport system can be modeled by a network of queues [12]. The network appears as a multitude of service centers (nodes, junctions) interconnected on the one hand, and on the other, connected with the outside [13].

To represent the topology of a network with all the interconnectivity requirements between nodes, it should consider the following:

•The network is defined by a graph in which nodes/ intersections are service centers.

•The arrival rate of the customer/vehicle in service centers *i* is λ_i .

•The network topology can be considered through its λ_i .

Each service center *j* contributes to create the flow of customers served in center *i* with a certain amount q_{ji} (transition probability matrix).

The arrival rate is determined as:

$$\lambda_i = \lambda \cdot q_{si} + \sum_{j=1}^{N} \lambda_j \cdot q_{ji}; i = \overline{1, N} . \quad (1)$$

Where:

q_{si} -is the transition probability matrix from input sources to network nodes, which describes the contribution of each input source to each node in the network. The input source is the one that generates the flow of customers in the system.

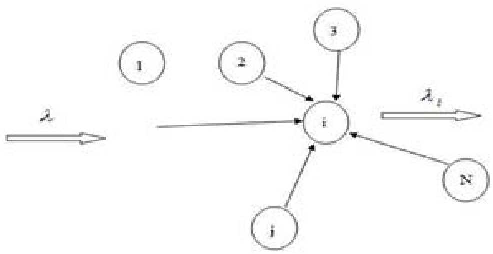

Figure 1. Configuration mode of the service centers.

Each service center can process a certain amount of customers/vehicles which pass through the respective service center. If we indicate by e_i the throughput of center *i* and we report the total flow of customers λ , that enter the system, we can note:

$$\lambda_i = e_i \cdot \lambda . \quad (2)$$

By replacing the throughput in the relationship is obtained:

$$e_i = q_{si} + \sum_{j=1}^{N} e_j \cdot q_{ji} . \quad (3)$$

This is the equation that expresses the network topology influence on the clients flow.

In this paper, we want to develop a new mathematical model to determinate the throughput for a node of the road network, which allows traffic quality improvement throughout the transportation system.

To achieve this, we will proceed to introduce in the equation, for determining the throughput, an attenuation factor, which modify the frequency of vehicles on the street / connection; the attenuation factor describes the quality of street/connection and will be denoted by R_{ij} .

The attenuation factor defined in this paper take, values in the range $[0,1]$.

In the case in which attenuation factor will have a value 0, then it indicates that the sector is traffic jam, and when the value of this factor will be 1, it indicates that the traffic is fluent in the analysis.

Thus, the equation for determining the throughput will be of the form:

$$e_i = q_{si} + \sum_{j=1}^{N} R_{ij} \cdot q_{ji} \cdot e_j ; i = \overline{1, N}; j = \overline{1, N} . \quad (4)$$

A. Method of determining the attenuation factor R

Since the attenuation factor should determine the performance of a transportation network, its value must take into account of the input and output flows of that network. For this reason we believe that a ratio between the output flow q_{out} and input flow q_{in} in a transport network express exactly performance of that network.

$$R_{ij} = \frac{q_{out}}{q_{in}} . \quad (5)$$

To determine exactly the calculation mode of this attenuation factor, we performed some measurements on a network sector which was randomly selected. These measurements were conducted on a 10 minutes period within 8 hours of analysis, where it was recorded the output flow (number of vehicles) and the input flow. In table I, it is shown the values obtained for this factor, which indicates the quality of analyzed sector.

Based on the obtained values of attenuation factor R_{ij} in each analyzed interval, we compute the average value of these values. The final result represents the quality of the analyzed sector.

TABLE I.
ATTENUATION FACTOR R_{ij}

Measuring range [h]	Input[no. cars]	Output[no. cars]	R
08:00-08:10	230	205	0,891304
09:00-09:10	170	147	0,864706
10:00-10:10	90	90	1
11:00-11:10	77	77	1
12:00-12:10	82	75	0,914634
13:00-13:10	112	90	0,803571
14:00-14:10	165	109	0,660606
15:00-15:10	130	125	0,961538

$$R_{ij} = \frac{1}{8}\sum_{k=1}^{N} R = 0.887045 \cdot \quad (6)$$

In next section will be performed some experiments to establish quality for selected road section. For tests, we will use the methods presented.

IV. EXPERIMENTS

To verify the proposed model to determinate the throughput for node of network, 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. [11].

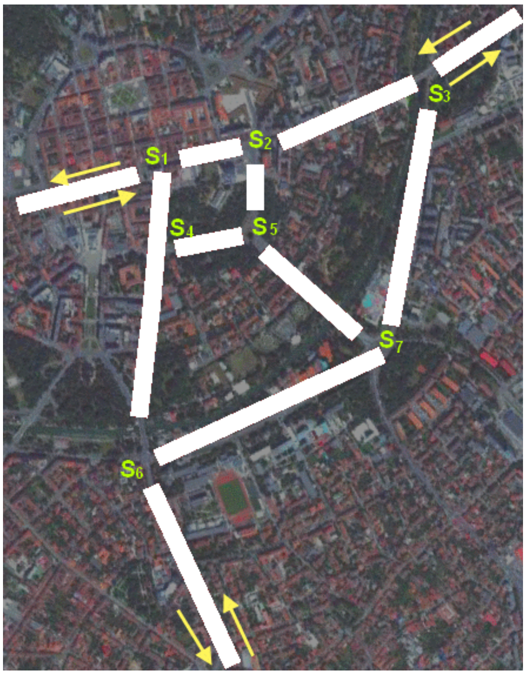

Figure 2. A road section of transport network.

In Figure 2, it is identified the road section that needs to be modeled. This road section is composed by:

•White lines – represent the traffic arteries that connect the junctions (nodes) of network

•Yellow lines – represent the inputs and outputs of road section considered

• $S_1 \ldots S_7$ - represent the junction of road section analyzed.

The specified elements contribute to the description of the physical structure of the existing road. To determine the throughput for each node of the network, the following should be defined:

• Contribution of each service center ($S_1 \ldots S_7$) to form the flow of vehicles in the network, more precisely transition probability matrix:

$$q_{ij} = \begin{bmatrix} 0 & 0.2 & 0 & 0.3 & 0 & 0.3 & 0 \\ 0.1 & 0 & 0.4 & 0 & 0.3 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 & 0 & 0.5 \\ 0.2 & 0 & 0 & 0 & 0.4 & 0.2 & 0 \\ 0 & 0.2 & 0 & 0.2 & 0 & 0 & 0.3 \\ 0.5 & 0 & 0 & 0.3 & 0 & 0 & 0.1 \\ 0 & 0 & 0.6 & 0 & 0.1 & 0.3 & 0 \end{bmatrix}$$

• Contribution of each input source in the network at each node; in the network is suggested by q_{si} . To simplify matters, it was considered that the inputs into the system are generated by one source.

$$q_{si} = \begin{bmatrix} 0.3 \\ 0 \\ 0.2 \\ 0 \\ 0 \\ 0.5 \\ 0 \end{bmatrix}$$

• Quality factor that characterizing the connections between nodes is R_{ij} .This describe the road condition in the analyzed sector of the network.

In the next step, are presented experiments which were performed to determine the throughput for all nodes contained in the transport network e_i . For each experiment, it was performed a new array for quality factor that characterize the connection that exists in network. The purpose of these experiments was to test the model in real conditions.

In table II, it is shown some of quality factor matrices that were used to test the throughput for all the nodes contained into the network and determine the values for them.

TABLE II.
NETWORK RESULTS R_{ij}

No.	R_{ij}	e_i
1	$\begin{bmatrix} 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 1 & 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 0 & 1 \\ 1 & 0 & 0 & 1 & 0 & 0 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \end{bmatrix}$	e_1= 1.2597 e_2 = 0.9850 e_3= 1.1606 e_4= 0.9352 e_5= 0.7640 e_6= 1.3482 e_7= 0.9443
2	$\begin{bmatrix} 0 & 0.5 & 0 & 0.5 & 0 & 0.5 & 0 \\ 0.5 & 0 & 0.5 & 0 & 0.5 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 & 0 & 0.5 \\ 0.5 & 0 & 0 & 0 & 0.5 & 0.5 & 0 \\ 0 & 0.5 & 0 & 0.5 & 0 & 0 & 0.5 \\ 0.5 & 0 & 0 & 0.5 & 0 & 0 & 0.5 \\ 0 & 0 & 0.5 & 0 & 0.5 & 0.5 & 0 \end{bmatrix}$	e_1= 0.4733 e_2= 0.1164 e_3= 0.2539 e_4= 0.1670 e_5= 0.0560 e_6= 0.6030 e_7= 0.1020
3	$\begin{bmatrix} 0 & 0.6 & 0 & 0.3 & 0 & 0.9 & 0 \\ 0.4 & 0 & 0.2 & 0 & 0.5 & 0 & 0 \\ 0 & 0.3 & 0 & 0 & 0 & 0 & 0.7 \\ 0.5 & 0 & 0 & 0 & 0.3 & 0.2 & 0 \\ 0 & 0.4 & 0 & 0.4 & 0 & 0 & 0.6 \\ 0.4 & 0 & 0 & 0.5 & 0 & 0 & 0.2 \\ 0 & 0 & 0.4 & 0 & 0.5 & 0.3 & 0 \end{bmatrix}$	e_1= 0.4443 e_2= 0.0908 e_3= 0.2313 e_4= 0.1380 e_5= 0.0352 e_6= 0.6345 e_7= 0.1000
4	$\begin{bmatrix} 0 & 0.8 & 0 & 0.4 & 0 & 0.5 & 0 \\ 0.5 & 0 & 0.3 & 0 & 0.8 & 0 & 0 \\ 0 & 0.6 & 0 & 0 & 0 & 0 & 0.7 \\ 0.6 & 0 & 0 & 0 & 1 & 0.5 & 0 \\ 0 & 0.8 & 0 & 0.9 & 0 & 0 & 0.3 \\ 0.4 & 0 & 0 & 0.3 & 0 & 0 & 0.5 \\ 0 & 0 & 0.8 & 0 & 0.4 & 0.6 & 0 \end{bmatrix}$	e_1= 0.4447 e_2= 0.1736 e_3= 0.2881 e_4=0.1258 e_5= 0.1004 e_6= 0.6045 e_7= 0.1401
5	$\begin{bmatrix} 0 & 0.8 & 0 & 0.6 & 0 & 0.7 & 0 \\ 0.5 & 0 & 0.8 & 0 & 0.7 & 0 & 0 \\ 0 & 0.7 & 0 & 0 & 0 & 0 & 0.9 \\ 0.4 & 0 & 0 & 0 & 0.9 & 0.6 & 0 \\ 0 & 0.5 & 0 & 0.7 & 0 & 0 & 0.9 \\ 0.4 & 0 & 0 & 0.6 & 0 & 0 & 0.7 \\ 0 & 0 & 0.5 & 0 & 0.5 & 0.7 & 0 \end{bmatrix}$	e_1= 0.4628 e_2= 0.2052 e_3= 0.3362 e_4= 0.2234 e_5= 0.1353 e_6= 0.6733 e_7=0.2349
6	$\begin{bmatrix} 0 & 0.1 & 0 & 0.1 & 0 & 0.1 & 0 \\ 0.1 & 0 & 0.1 & 0 & 0.1 & 0 & 0 \\ 0 & 0.1 & 0 & 0 & 0 & 0 & 0.1 \\ 0.1 & 0 & 0 & 0 & 0.1 & 0.1 & 0 \\ 0 & 0.1 & 0 & 0.1 & 0 & 0 & 0.1 \\ 0.1 & 0 & 0 & 0.1 & 0 & 0 & 0.1 \\ 0 & 0 & 0.1 & 0 & 0.1 & 0.1 & 0 \end{bmatrix}$	e_1= 0.3262 e_2= 0.0166 e_3= 0.2016 e_4= 0.0251 e_5= 0.0017 e_6= 0.5107 e_7= 0.0152

As it can be seen from Figure 3 in the first case when the quality factor is 1 for each connection (fluent traffic), the values obtained for the throughput of nodes reaches the maximum value.

In the second case, the quality index is reduced by half (the traffic fluency level is halved) and the values obtained for throughput is reduced more than 60%.

In the cases 3, 4, 5, we may be noticed that the values of quality index fluctuate from a connection to another connection (traffic varies from an area to another), which influences the traffic capacity and determines its variation.

In the last case, it is analyzed when quality index values is 0.1 for all the streets, more precisely the traffic is close to reaching the maximum congestion, then the throughput is reduced.

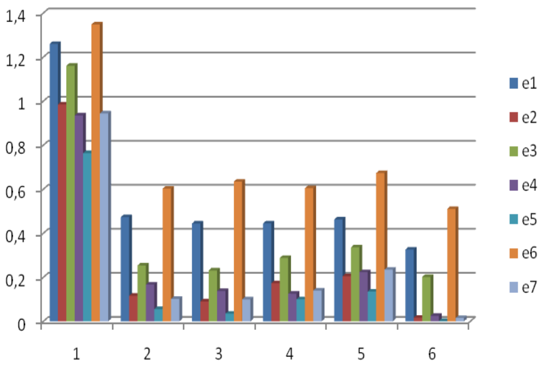

Figure 3. Graphic representation of the throughput for all the nodes contained in the network

V. CONCLUSIONS

In this paper, we propose a new model to estimate the throughput for a node of transport network. The purpose of this model is to analyze traffic on network level and to assess if the network is congested or not. The proposed model is developed based on existing elements in queueing theory.

As it was shown in the last section, we obtained different values for the throughput. This is due to variation of traffic quality in different areas of the transport network (traffic jam-fluently.)

The maximum capacity is obtained only if the quality index is 1. We can say that index enables the analysis of traffic network, and classifies it according to the level of congestion.

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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