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THEORY OF NETWORK RELATED RESEARCH OF VEHICLES DYNAMICS IN URBAN ENVIRONMENT

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ABSTRACT

Transport and vehicles have great impact on peoples' life every day. Continuous increase in traffic on the roads is leading to serious issues with congestion, safety and impact on the environment. This is especially emphasized in urban areas. Networks theoryhas been and is very interesting approach studying of vehicle dynamics in urban areas which can help addressing number of said issues. This research has also added regionaldimension which could help development and introducing ITS in similar environment. In this, early stage of research, the initial results showed that the approach of presenting road infrastructure as network (graph) in vehicle simulations proves to be good and opens opportunities for deeper research.

KEYWORDS: network, vehicle dynamics, simulation model, ITS.

1. INTRODUCTION

Nowadays every bigger city is faced with the traffic congestion problem. The introduction of intelligent transport systems (ITS) can significantly improve the traffic flow, especially in urban areas. However, ITS are a wide research area, as the EU Directive 2010/40/EU defines: intelligent transport systems are systems in which information and communication technologies are applied in the field of road transport, including infrastructure, vehicles and users, and in traffic management and mobility management, as well as for interfaces with other modes of transport [1]. With the raised awareness of the constant increase in the number of vehicles worldwide many studies have been made, which resulted in development of useful tools such as traffic or driving simulators. The aim of all of them is improving safety and level of service, reducing emissions, maintaining control strategies, and responding promptly to emergency situations. The Laboratory of Transportation Engineering at the Helsinki University of Technology has developed a micro-simulation system – HUTSIM which has been in couple research projects and it was proven as solid basis for traffic information and monitoring purposes [2]. Later MITSIMLab was developed within the MIT Intelligent Transportation Systems (ITS) Program. MITSIMLab is a microsimulation laboratory for analysis and design of dynamic traffic management systems that consists of two main components: a Traffic Management System (TMS) that simulates the generation of route guidance and the operation of traffic signals and signs, and a microscopic traffic simulator (MITSIM) that models individual vehicle movements over a network and drivers route decisions and response to traffic controls [3]. MitsimLab (also as HUTSIM) is not centered around the actual vehicle simulation, but rather on the simulation of advanced dynamic traffic management systems.

On the other side, because the abovementioned simulators have not included the vehicle dynamic behavior, some researchers to solve the problem with traffic congestion have proposed omni-directional vehicle [4]. This research was focused on developing vehicle dynamic model for an omni-directional road vehicle for high velocity conditions, transferring loads and the effect of traction and braking. Considering many years of research of vehicle dynamics, every driver assistance system, stability control system, fuel economy and vehicle emissions, as well as traffic congestion solutions are based on vehicles' longitudinal and lateral dynamic behavior [5, 6, 7]. These days the research and simulation of vehicle dynamics is facilitated by advanced technology and informatics. As the automotive engineering became multidisciplinary and network approach is used in many scientific areas, there are opportunities for integrated analysis of vehicle dynamics. Networks are proven as very useful tool or mean in presenting connections or interactions between parts of a system in computer, biological and social sciences, but also in transportation and distribution research fields [8]. In mathematics network (graph) is a set of points, named vertices or nodes, connected with links, which are named edges or arcs. In road network, crossroads and dead ends of roads are represented by nodes, connected by links which represent the roads itself or road segments. This type of road representation [9] can be used for an integrated analysis of vehicle dynamics in urban conditions. Although for more complex analysis the network can include segments and lines as it is done in [3].

2. RESEARCH OBJECTIVE

Networks, meaning graphs are proven powerful tool presenting the scheme of connections or interaction between the components in a system. Yet there is moderate number of research work of the structure and function of transportation network, such as airline routes, road and rail networks [8]. Road and rail networks mostly have been studied in terms of interconnection of economics and their physical structure, in spatial representation of system environment, etc. The number of researches like [2, 3] where road representation as network is used for testing or improving of traffic flow or also for vehicle dynamic testing still has to be increased.

Considering the current directions of researchers and industry for autonomous (or cooperative) motion of vehicles and implementation of ITS technologies, the aim of this research is to explore the possibilities for analysis of vehicle dynamics at urban road network i.e. at Skopje's roads presented as a graph. The objective of the integrated analysis of vehicle behavior in urban conditions is in order to improve the safety and to"green"the transport. This approach of implementing road network in modeling and simulation of vehicle dynamics, especially in urban conditions could open possibilities for extension of the research done in [10]. In addition, it can be used for research of regional challenges in terms of ITS development.

3. RESEARCH APPROACH AND SIMULATION MODEL

First step in this approach was better understanding of networks, their characteristics and presentation. The second step was looking for tools i.e. software used to operate with networks. A complete road network of Skopje was downloaded by the open source OpenStreetMap [9]. Specifically exploring the possibilities, software was sought in which the network can be imported and used and at the same time the software to be suitable for creation and simulation of vehicle model. From vehicles' studying perspective MATLAB is an excellent tool for their mathematical representation and simulation, but in terms of the networks it needed a slight adjustment. The MATLAB Toolbox Matlog was developed at North Carolina State University [11]. The toolbox contains functions for solving problems as facility location, freight transport, vehicle routing, networks, geocoding, etc. So the goal to start up with was to create simple vehicle model which is going to be driven in the network of Skopje.

The network is presented with matrices. One matrix presents the vertices with their position in 2D graph and has four columns: first column are vertex indices, second x-coordinates, third y-coordinates and fourth by 1 and 0 shows if there is a traffic light on that vertex (1) or not (0).

$$Vertices = \begin{bmatrix} & \cdots & \\ 583 & 11917.51 & 6159.8810 \\ 584 & 4311.931 & 6432.0160 \\ 585 & 5980.857 & 5909.9891 \\ & \cdots & \end{bmatrix}$$

The links between vertices are presented with other matrix with three columns: first column gives the starting vertex and second the end vertex.

$$Links = \begin{bmatrix} & \cdots & \\ 59 & 87 & 1 \\ 59 & 48 & 1 \\ 60 & 8023 & 2 \\ & \cdots & \end{bmatrix}$$

Third column gives the weight of that link, which is calculated as:

$$link\ weight = road\ category\{1,2,3\} \cdot number\ of\ lanes$$

The road network of Skopje is given in Figure 1.

With creation of the adjacency matrix and using the Dijkstra algorithm shortest path between any two vertices is calculated. This would be the path that vehicle would be driving on. Another issue was the lack of data about the working cycle of the traffic lights, so one was created for this experiment. The number of traffic lights on the route is known when the path is chosen. One light cycle lasts 80 seconds from which 40 seconds – green light, 5(x2) seconds – yellow and 30 seconds – red light. The first traffic light starts at a random light color and every subsequent traffic light is moved by 60 seconds from the light color of the first. The matrix of the traffic lights has as many columns as there are traffic lights on the route plus one for the end vertex where vehicle has to stop. Below is shown an example of traffic light matrix (route 911-11459):

$$Tsem = \begin{vmatrix} 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 4 & 3 & 1 & 1 & 4 & 1 & 1 & 4 & 3 & 1 \\ 1 & 3 & 2 & 1 & 1 & 2 & 1 & 1 & 3 & 1 \end{vmatrix}$$

$$\begin{vmatrix} 1 & 3 & 2 & 1 & 1 & 2 & 1 & 1 & 3 & 1 \\ 1 & 3 & 2 & 1 & 1 & 2 & 1 & 1 & 3 & 1 \\ 1 & 3 & 2 & 1 & 1 & 2 & 1 & 1 & 3 & 1 \end{vmatrix}$$

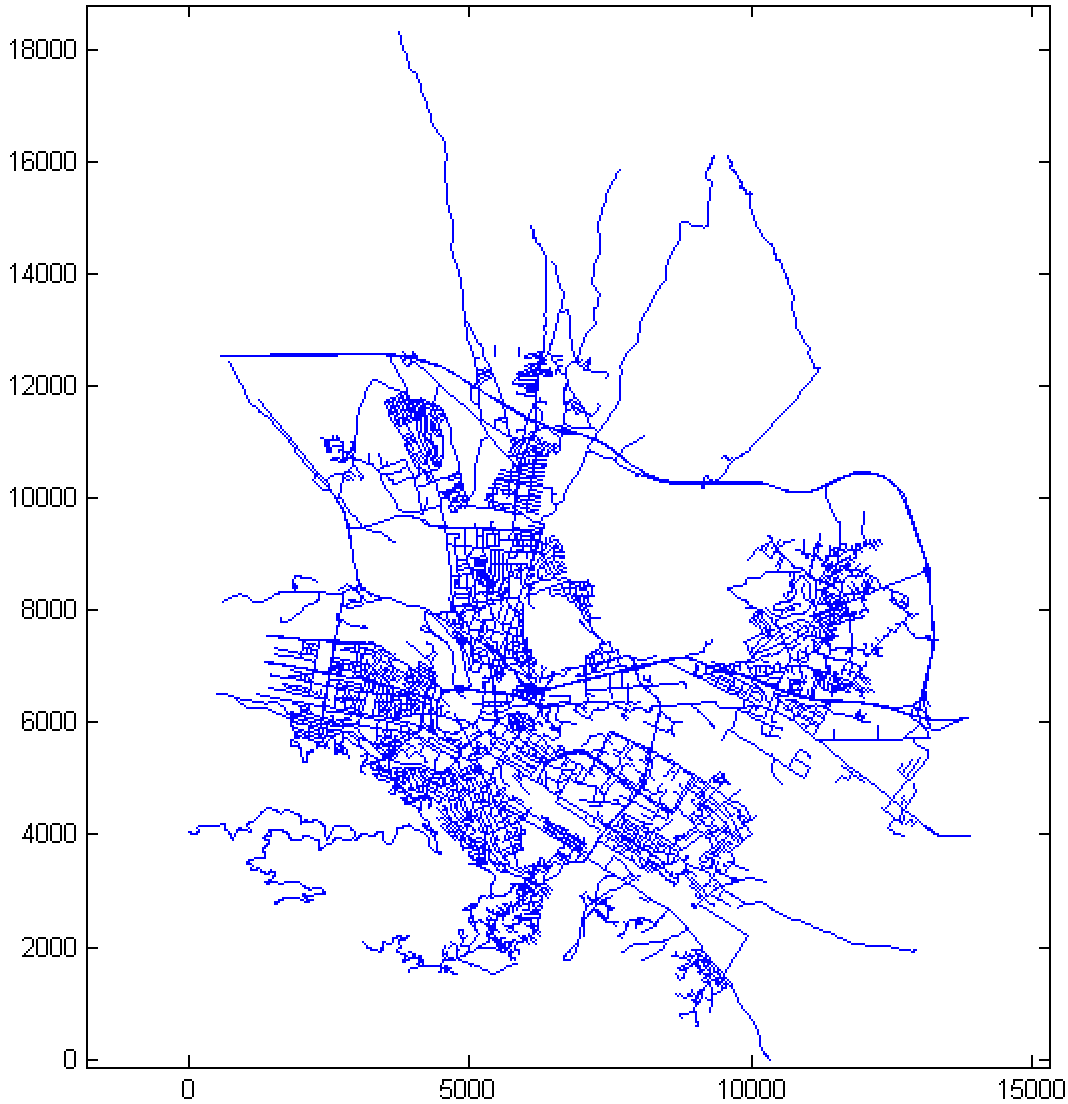

Figure 1. Skopje road network

The vehicle model is simpleacceleration/deceleration model. Vehicle starts moving and accelerating with 2m/s^2 until reaches velocity of 16.67m/s (60 km/h), which is the limit velocity in urban areas and then continues to move with constant velocity i.e.

$v = v_0 + a \cdot \Delta t$where$\Delta t$ is the time step.

If $v \geq 16.67 m/s$ then $v = 16.67 m/s = const.$

While vehicle accelerates the traveled distance is calculated $s = s_p + \frac{a \cdot \Delta t^2}{2}$ and if $v = const$, $s = s_p + v \cdot \Delta t$.

When vehicle approaches the traffic light, if it is at a distance of 45m or less and the light is red the vehicle starts decelerating with deceleration rate depending on the distance to the traffic light i.e.

$$a_d = \frac{v^2}{2 \cdot (D - s)}$$

where D is the distance from the starting point to the traffic light. So, the velocity is decreasing $v = v_p - a_d \cdot \Delta t$ and the traveled distance is $s = s_p + \left(v \cdot \Delta t - \frac{a_d \cdot \Delta t^2}{2}\right)$. When the traffic light changes the vehicle starts moving again and so on, until it reaches the final destination.

4. FIRST RESULTS AND DISCUSSION

Time step of the simulation is 0.1 seconds, while the number of steps or the simulation time depends on the chosen route and on the state of the traffic lights. In addition, on Figures 2, 3 and 4 are given the results from one simulation on randomly chosen route. The route shown on Figure 2 is from vertex 911 to vertex 11459 with total length of 4468.7 meters with nine traffic lights on it. The position of starting point is marked with green and the final point is marked with “x”. The red asterisks show the position of the traffic lights.

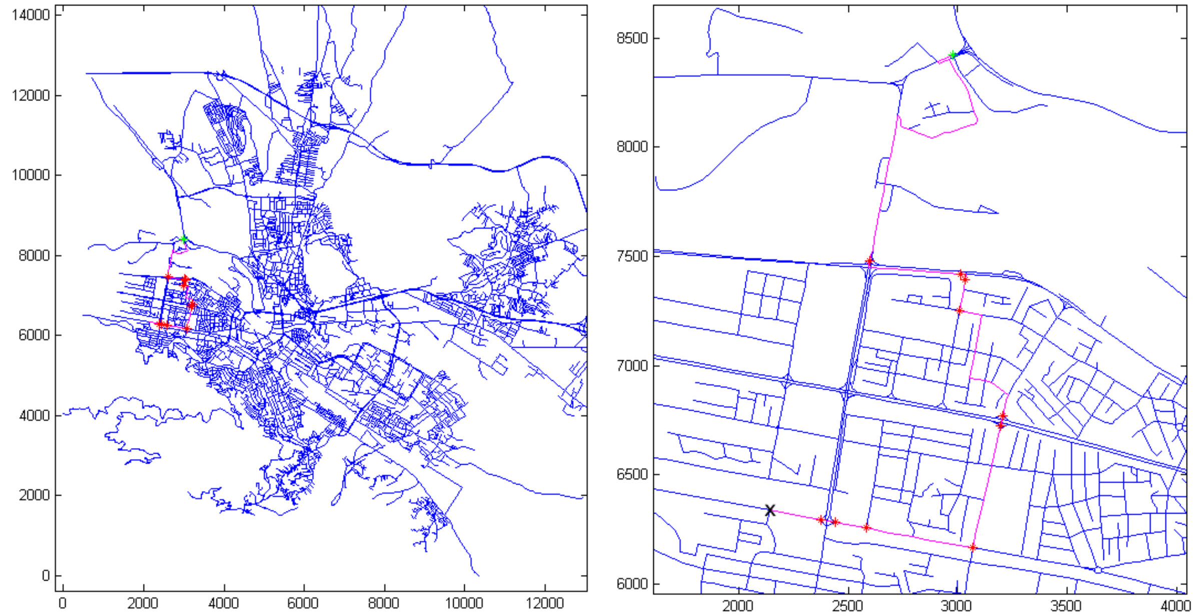

Figure 2. Route from 911 to 11459

The total time of simulation was 328.6 seconds. Given the limitations like single vehicle on the road and maximum velocity of 60km/h, the travel time is in reasonable boundaries in terms of total traveled distance. The average velocity is 47km/h. The velocity changes are given on Figure 3 and the traveled distance on Figure 4.

As can be seen from the Figures 3 and 4 vehicle stopped on a red light at the first traffic light and waited for 27.5 seconds until the light changed. Before the third traffic light the vehicle begins decelerating, but because the light changed when the vehicle was at a distance of 13 meters it started accelerating again. At the fourth traffic light the situation is similar with the previous; vehicle nearly stops when the light is changed. The other traffic lights were not red when the vehicle passed them. The last deceleration begins at a distance of 42.7 meters from the final destination.

5. CONCLUSIONS AND FURTHER RESEARCH

From the results to the extent to which the research work is done, it can be summarized that if the simulation is repeated for the same route, the results will not be the same, as is the case in real conditions. The simulation time and the velocity diagram will be different because of the different traffic lights’ state. In real urban conditions the state and frequency of light changing depends on what time of the day is, and also on the type of road where it serves, which is not taken into account in this initial research.

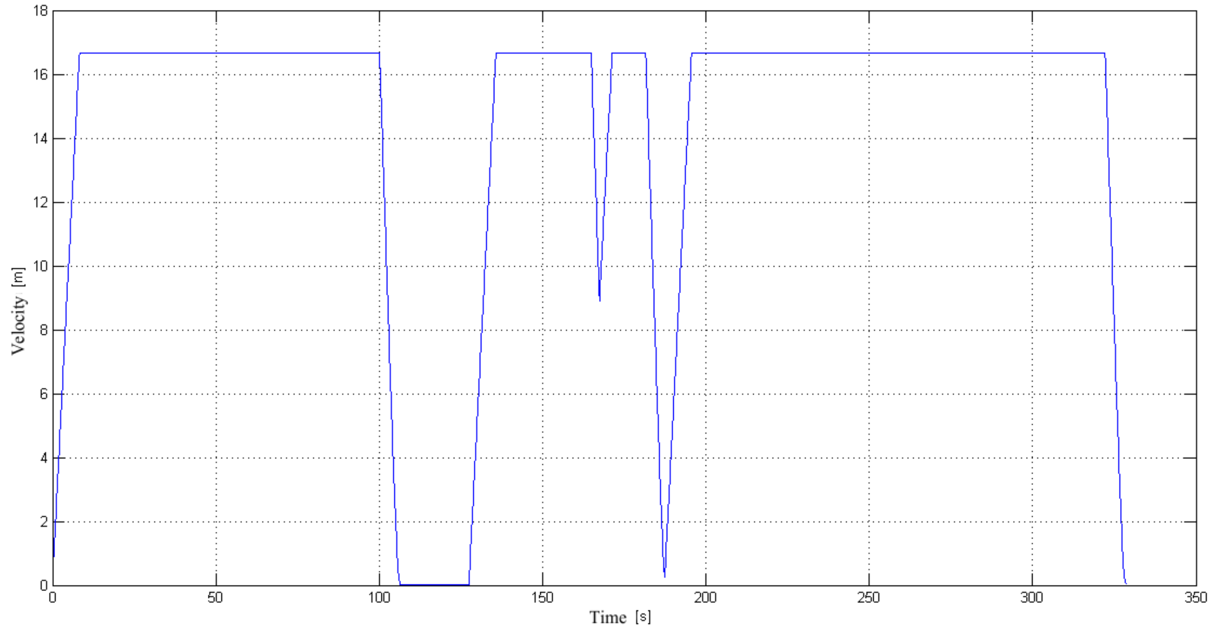

Figure 3. Velocity changes of the vehicle model

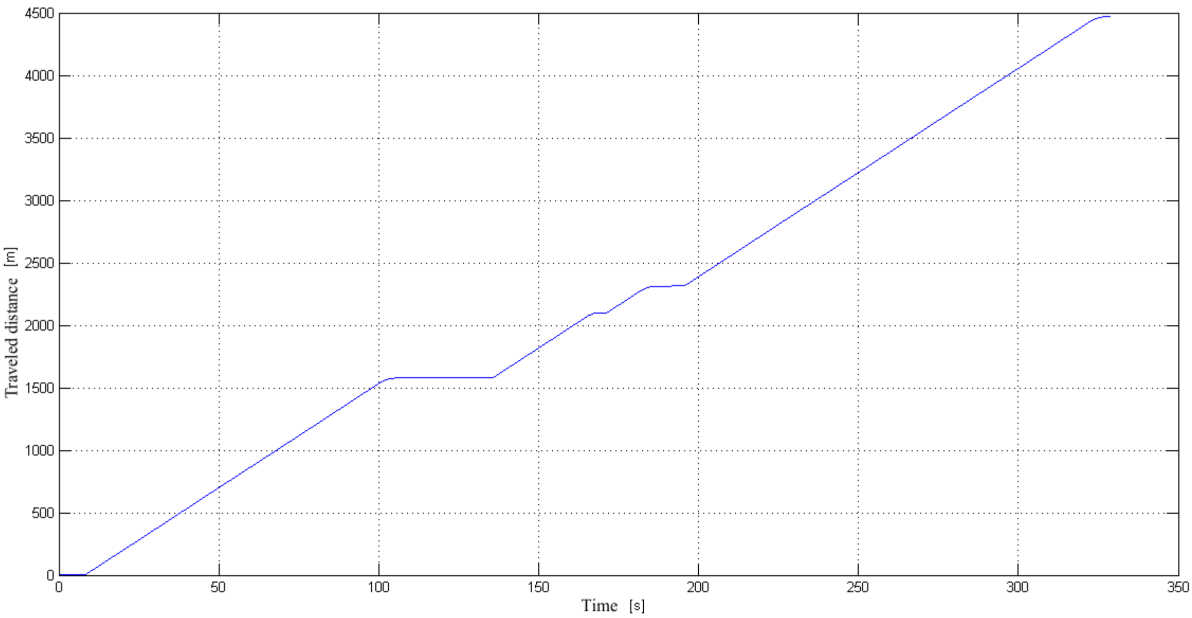

Figure 4. Traveled distance on the route 911-11459

The vehicle model, as said, is very simple and represents only the vehicle longitudinal dynamic. With exploring the possibilities of upgrading and including the lateral dynamic to the model, vehicle stability within any route in the network could be tested.

The network as a tool can be also used in traffic flow testing with multiple vehicles in simulation, on regionally known roads where traffic congestion happens at critical times of the day.

If the network could be upgraded with information about the number of lanes and the radius of curvatures it could be used for testing the line changing maneuver or overtaking another vehicle, again including the stability of the vehicle.

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