Computer Simulation for Transportation Planning and Traffic Management: a Case Study Systems Approach

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Abstract: - Traffic congestion is increasing world-wide as a result of increased motorization, urbanization, population growth and changes in population density. Congestion reduces utilization of the transportation infrastructure and increases travel time, air pollution and fuel consumption. Computer simulation can play a significant corrective role for designing effective traffic networks and managing transportation systems in today's highly congested cities. This paper presents the microscopic simulation model development of a major highly congested traffic network of Nicosia, Cyprus. The validated simulation model gives transportation planners and traffic managers the capability to test various scenario solutions involving the use of intelligent transportation systems prior to their implementation. Further, this paper demonstrates a wider spectrum of understanding on the principles of traffic flow theory and how a traffic flow simulation model is developed and utilized for effective transportation planning.

Key-Words: - Traffic Simulation, Transportation Planning, Traffic Management, Systems Approach, Computer Simulation, Traffic Engineering

1 Introduction

Traffic congestion constitutes a complex dynamical problem. It comprises of many complex processes, and incorporates many elements interacting with each other such as vehicles, driver behaviors, road geometry, traffic signs and so on. In such a complex problem situation a computer simulation approach can be very effective by providing evaluations for various traffic conditions. It can help policy-makers understand and analyze traffic, assess current problems and propose plausible solutions. Traffic simulation can support transportation planning, and traffic management decision making, for a long-term sustainable urban development. The new solutions and techniques can effectively be tested in a "virtual reality" environment, in the comfort of ones office, without disrupting the road traffic or having to leave for field trials. Effective traffic management and control strategies though, require up-to-date valid simulation test results.

This paper presents the current progress and lessons learned towards the modeling and simulation of an urban traffic network. The work presented in this paper is part of the Trafbus research project, partially funded by the Cyprus Research Promotion Foundation. The Trafbus research project is concerned with the modeling, simulation and analysis of traffic flow for a major traffic network in Nicosia, Cyprus. Further, the use of automatic and adaptive control systems are to be evaluated and tested in a simulated environment for increasing the level of service of the bus transport mode and optimizing traffic flow.

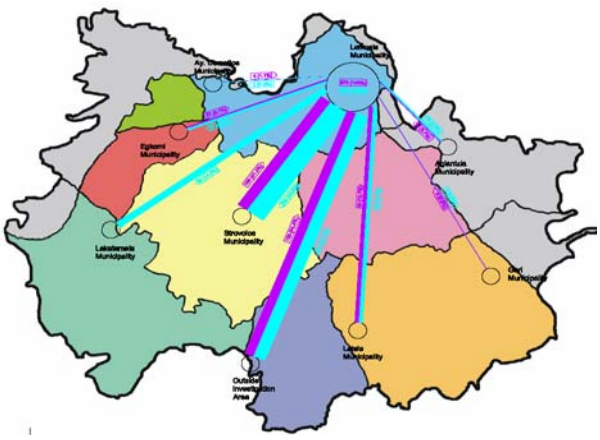

Fig. 1: Traffic Flows between Nicosia and the Surrounding Municipalities (source: Ministry of Communications and Works, Cyprus)

In particular, a simulation model for Strovolos Avenue is developed, which is the main transport artery of the Strovolos Municipality. As shown in the map of the various municipalities of Nicosia in Figure 1 above, Strovolos exhibits the highest traffic flows as compared with the other regions. Further, Strovolos Avenue serves as the connector between Nicosia and a large and heavily populated area of urban and rural communities including Strovolos which is the largest municipal area, Lakatameia, Tseri, Deftera and others. Based on the simulation model of Strovolos Avenue presented in this paper various scenarios of microscopic models of traffic flow including "dedicated bus lanes" and Bus Rapid Transit (BRT) Systems, are to be studied using computer simulation for the purpose of designing a more effective and safer traffic network. The Trafbus research project represents a pioneering work for Cyprus, and the experiences gained from the modeling and simulation of Strovolos Avenue will serve as a knowledge base for similar projects to be carried out all over Cyprus.

2 The Problem of Traffic Congestion in Cyprus

In 2005 there were more than 500,000 registered vehicles in Cyprus, a figure that approaches the number of people of the island. As a result, travel times are increasing and traffic congestion becomes an everyday reality. On a daily basis we are confronted with rush hours, road accidents, air pollution and driver-stress, causing an increasing number of economic, social and environmental problems.

Some of the causes of the current traffic congestion situation include the rapid economic development in Cyprus as well as the concentration of population in urban communities. Further, people are turning away from using the bus and use their own private car for daily transportation. As a result, Cyprus cities have serious traffic congestion problems in main arterials such as Strovolos Avenue, and at signalized intersections.

According to a recent traffic survey carried out by the local newspaper “Politis” the average resident of Nicosia (the Capital of Cyprus) drives for 1 hour and 40 minutes per day for relatively small distances. Further, 76% of the survey respondents declare they have never used the bus. The promising finding was that 57% declare they would use the bus if its quality of service was better.

Even though the Public Works Department of the Ministry of Communications and Works builds more and more roads in order to meet capacity demands the traffic congestion problem becomes worse. And the reason is that we use more and more cars for our everyday transportation.

In the last three decades there was an unprecedented increase the number of vehicles driven in Cyprus. The number of registered vehicles has increased from 100,000 in 1980 to more than 500,000 by the year 2004, which represent more than a 500% increase in 20 years. In addition to the increased number of cars, there are major problems facing the bus transport mode. From 13 million passengers during the year 1981 we are down to 3 million for the year 2004. This represents more than a 400% decrease in the bus transport use. Bus passengers are sharply decreasing at the same time as the urban population is increasing. Further, at the same time interval the number registered vehicles are increasing.

The traffic congestion problem situation will remain, unless the traffic flow trends and needs are understood and analyzed for deriving effective solutions. Traffic congestion constitutes a highly complex dynamical problem, which consists of a combination of factors such as the lack of a modern public transport system, the dependence on the private car, the town structure and the urban environment, the radial road system and the incomplete primary road infrastructure [1].

The assumption held by most policy makers, city planners, and transportation officials is that traffic volume is exogenous in that traffic volume is growing as population grows and local economy develops. Building roads therefore should keep travel time at low levels but also can serve special interests of particular businesses which would be eager to satisfy the personal interest of the policy maker. However traffic volume is not exogenous, that is road building does not alleviate traffic congestion. The number of cars in a particular region is a major determinant of traffic volume. Total traffic volume therefore equals to the number of vehicles in the region multiplied by the distance traveled of each vehicle per day. In turn the distance traveled per day for each vehicle is equal to the number of trips multiplied by the length of each trip. The number of trips per day and the average trip length are not constant but depend on the level of traffic congestion. People will take additional trips if the traffic is light while they would stick to the necessary trips when the traffic is heavy. Further, the number of vehicles in the region is not constant but varies with respect to the population multiplied by the number of cars per person. Furthermore the number of vehicles per person or business is not constant but depends on the attractiveness of driving, which depends on the level of traffic congestion.

Realizing that by building more roads the traffic congestion problem would even get worse, the Government of Cyprus and particularly the Ministry of Communications and Works aim for a more modern transport policy. The policy involves restraining the use of private cars, the enhancement of the urban bus transport system and betterment of its level of service, the promotion of alternative means of transport such as the bicycle, and the construction of a modern urban road network.

There is a need for advanced mathematical methods and models in order to analyze the dynamicity and chaotic behavior involved in the traffic congestion problem situation. The following section describes the development of traffic flow theories, which aim to analyze the traffic congestion problem.

3 Traffic Flow Theory

The mathematical study of traffic flow, and in particular vehicular traffic flow, is carried out with the aim of understanding and assisting in the prevention and remedy of traffic congestion problems. The first attempts to give a mathematical theory of traffic flow are dated back to the 1930s [2, 3], but even until today we still do not have a satisfactory and general mathematical theory to be applied in real traffic flow conditions.

This is because traffic phenomena are complex and nonlinear, depending on the interactions of a large number of vehicles and traffic control rules. Moreover, vehicles do not interact simply following the laws of physics, but are also influenced by the psychological reactions of human drivers. As a result we observe chaotic phenomena such as cluster formation and backward propagating shockwaves of vehicle density [4]. Further, large fluctuations in measured quantities such as the velocity of vehicles occur depending on the traffic conditions.

According to the state of the art report on traffic flow theory published by the Transportation Research Board (TRB) mathematical models for traffic flow may be classified as: Traffic Stream Characteristics Models [5], Human Factor Models [6], Car Following Models [7], Continuum Flow Models [8], Macroscopic Flow Models [9], Traffic Impact Models [10], Unsignalized Intersection Models [11], Signalized Intersection Models [12] and Traffic Simulation Models [13].

Traffic simulation modeling [13], deals with the traffic models that are embedded in simulation packages and the procedures that are being used for conducting simulation experiments. Further, traffic flow simulation should be viewed from the perspective of incorporating the use of automatic control systems in the modeling process [14]. In an interesting discrete event traffic flow model Chien et al [15] design analyze and simulate a macroscopic traffic density controller for an automated highway system for optimizing traffic density.

From another perspective, the problem of traffic flow may be approached mathematically in mainly three ways, corresponding to the three main scales of observation, microscopic, macroscopic, and mesoscopic. In a microscopic scale every vehicle is considered as an individual, and therefore for every vehicle we have an equation, that is usually an ordinary differential equation. In a macroscopic scale we use the analogy with fluid dynamics models, where we have a system of partial differential equations which examines properties such as the density of vehicles or their mean velocity. In mesoscopic or kinetic scale, which is an intermediate level, we define a function f(t,x,v) which expresses the probability of having a vehicle at time t in position x which runs with velocity v. This function, following methods of statistical mechanics, can be computed solving an integro-differential equation, like the Boltzmann Equation.

The choice of the appropriate model depends on the level of detail required and the computing power available. As a result of the advent in computer technology today the trend is towards utilizing microscopic scale mathematical models, which utilize human factors and car following models according to the above classification. Traffic simulation software modelers exist corresponding to the above three scales as discussed in the next section.

4 Traffic Simulation Software

Traffic simulation software modelers combine in a single package multiple traffic flow mathematical models and therefore make it possible to combine the current knowledge on traffic theory when analyzing a traffic congestion problem. A comprehensive review of simulation models of traffic flow was conducted by the Institute for Transport Studies at the University of Leeds as part of the SMARTEST Project a collaborative project to develop micro-simulation tools to help solve road traffic management problems. The study compared the capabilities of more than 50 simulation packages. The results are available on the internet at http://www.its.leeds.ac.uk/projects/smartest. Other significant reviews of traffic simulation software include the work of Bloomberg and Dale [16] who compared Corsim and Vissim as well as the work of Boxill and Yu [17] who compared the capabilities of Corsim, Integration, Aimsun and Paramics.

It can be concluded from the various reviews that software modelers, which have comparative capabilities include Vissim, Corsim, Paramics and Aimsun. For our study Vissim was chosen which can be utilized as a simulation tool for the design of traffic actuated control systems. It is a part of PTV Vision Suite which includes Visum, a macroscopic simulation software tool. Vissim is a microscopic tool, since it employs individual vehicle modeling. It has many applications, but it is mainly used to analyze traffic of various alternative road designs which include both urban and highway configurations. Further, Vissim is capable of modeling various vehicle types such as cars, buses, light and heavy rail, trucks, bicyclists and pedestrians.

Major areas of application of Vissim are in transit signal priority studies, and intersection design and operations [17]. Other applications include the development of vehicle actuated signal control strategies and evaluation of different traffic network layouts involving public transport, which is the main subject of the model developed in this paper. The traffic flow model in Vissim is a discrete, stochastic, time step based, microscopic model with driver-vehicle-units as single entities. The modeler incorporates a psycho-physical car following model for longitudinal vehicle movement and a rule-based algorithm for lateral movements. Vissim was developed during the 1970s, in the University of Karlsruhe in Germany. It is based on the model of Wiedemann [18, 19]. The basic idea of the Wiedemann model is the assumption that a driver can be in one of four driving modes: the free driving mode, the approaching mode, the following mode and danger or brake mode. Further, stochastic distributions of speed and spacing thresholds replicate individual driver behaviour characteristics. The model has been calibrated and validated [18, 20] through multiple field measurements in Germany and other countries.

5 Traffic Modeling and Simulation of the Traffic Network

The first step of the proposed approach is to identify and define the problem. In our case the symptoms of the problem which are attributed to traffic congestion manifest themselves as increasing travel times. Even though the Public Works Department builds more and more roads the traffic congestion problem becomes worse. And the reason is that we use more and more cars for our everyday transportation as explained earlier.

The main causes for the problem of traffic congestion in Nicosia consist of the increasing number of vehicles and the decreasing use of the bus transportation system. Therefore the long term solution to the problem is to turn around the situation that is to decrease the number of vehicles and increase the public transportation occupancy.

The question then becomes how do we change our bus transportation system and make it more attractive. This is what we aim to investigate in the Trafbus project concentrating on providing a faster and better quality level of service for our bus passengers. The objective therefore in our modeling and simulation method is to examine various scenarios such as dedicated bus lanes and Bus Rapid Transit Systems that would provide a better level of service for the bus transportation system. Meanwhile, we need to anticipate and assess any side effects of to the rest of the transportation system.

Based on the stated model objectives, the development of a simulation model of Strovolos Avenue, which is to be used as a test workbench, is carried out. Strovolos Avenue consists of many traffic parameters that need to be taken into account. These include traffic control signals, priority rules, routing decisions, pedestrian crossings, signalized and unsignalised intersections and so on. A helicopter view of Strovolos Avenue simulation model is depicted in Figure 2 below.

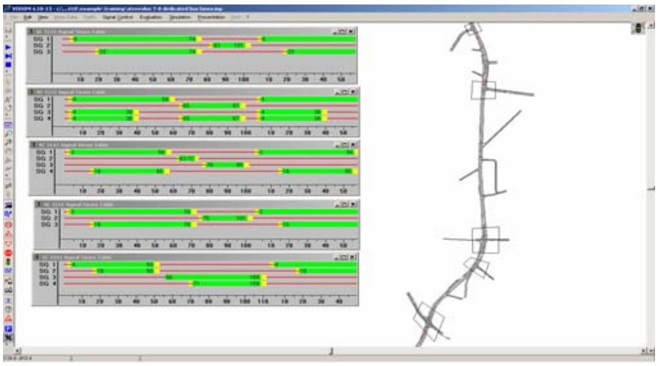

Fig 2: The Simulation Model of Strovolos Avenue Traffic Network

Strovolos Avenue is more than 3 kilometers long extending from the boarders with Nicosia Municipality near the Presidential Palace to the boarders with Lakatatmeia Municipality (see also Figure 1). Figure 2 also shows the signal times for the various signal groups at five main signalized intersections of Strovolos Avenue. Specifically, SC5121 depicts the signal changes of the northern intersection, that of Arch. Kyprianou – Stovolou, SC5131 corresponds to the signalized intersection of Athalassas Ave – Strovolos Ave, SC5141 shows the signal changes of Pericleous/Chryseleousis – Strovolou intersection, which includes a pedestrian crossing, SC5151 depicts the signal changes of Athinon – Strovolou intersection, and SC5161 shows the signal changes of Alexandroupoleos – Strovolou intersection. The depicted signal phases correspond to the traffic peak of the morning hours.

The various traffic data that we need to incorporate in our model may be classified it terms of static data and dynamic data. Static data represents the roadway infrastructure. This data is required for both simulation and testing of a traffic actuated signal control logic. Static data includes also links, which are directional roadway segments with a specified number of lanes, with start and end points as well as optional intermediate points. Further, static data includes connectors between links, which are used to model turnings, lane drops and lane gains, locations and length of transit stops, position of signal heads/stop lines including a reference to the associated signal group, and positions and length of detectors and locations of transit call points

Dynamic data is to be specified for traffic simulation applications. It includes traffic volumes including vehicle mix (e.g. truck percentage) for all links entering the network, locations of route decision points with routes (link sequences to be followed), differentiated by time and vehicle classification, priority rules (right-of-way) to model unsignalized intersections, permissive turns at signalized junctions and yellow boxes (keep-clear-areas), locations of stop signs, public transport routing, departure times and dwell times.

Having introduced most of the above static and dynamic data in our model, currently we are in the iterative process, which consists of model development calibration and validation of the model. Going through several iterations in developing the model, we are in a position to present some optimistic results concerning the validity of our model. A snapshot of the simulation model is seen in Figure 3 below, which depicts a central signalised intersection with a pedestrian crossing (Pericleous/Chryseleousis – Strovolos Ave.).

Fig. 3: A Central Signalised Intersection of the Simulated Traffic Network.

Figure 3 above shows the real Vs simulated traffic flows of the various vehicle movement directions for the above central intersection of our traffic network, that of Perikleous, Chryseleousis, Strovolou. As seen in the graph below the traffic flows of real measurements obtained recently (21/03/06) and those of simulated results, are quite comparable. In fact we get an average error in traffic flow of 10% for all directions. In certain directions as shown in Figure 4 below the error ranges from only 2% to 5%.

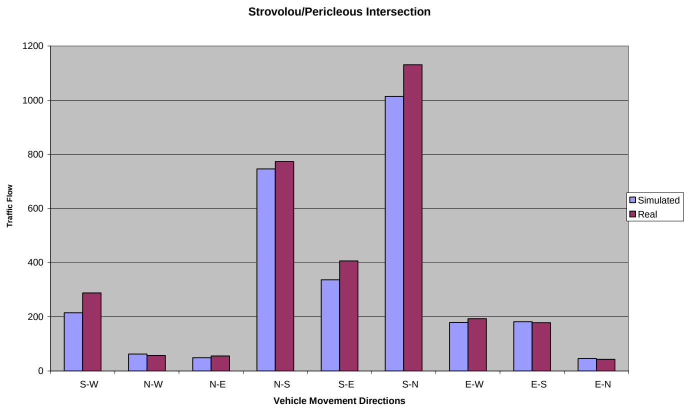

Fig. 4: Traffic Simulation Model Validation

Further, our simulation model demonstrates the queues that we encounter in reality and especially the one at Athalassas Ave intersection where there is no exclusive right turn lane. This is the main queue that a driver will encounter while going north towards the centre of Nicosia between 7:00 and 8:00 o'clock in the morning.

Having completed the iterative process of model development, calibration and validation, next comes the preparation of scenarios, testing and evaluation of the results. Figure 5 below shows a screenshot of the simulated model of the dedicated bus lane scenario. The screenshot shows a bus moving free through Strovolos Ave going towards the centre of Nicosia, while private cars have to wait in a long queue as a large section of the left hand side lane is made exclusively for buses during the morning peak hours. The dedicated bus lane scenario shown in Figure 5 refers to the section of Strovolos Ave between Pericleous/Chryseleousis-Stovolou intersection (SC5141) and Athalassas – Strovolou (SC5131) (see Figure 2). The referred section is 653 meters long and the dedicated bus lane amounts to 375 meters long. The simulated results show that travel times for buses are halved from 300 seconds on average to 150 seconds during the peak hour from 7:00 to 8:00 o'clock in the morning. Further, the simulation output shows that as a result of the dedicated bus lane there is an increase in the travel times of private cars from 300 seconds to 350 seconds on average.

At the moment we are in the process of discussing various measures for reducing the impact of the dedicated bus lanes to private cars and the rest of the traffic. One scenario that emerges is the reconfiguration of the traffic signal control strategy downstream the dedicated bus lane to give more green time to the vehicles on Strovolos Ave going towards the Nicosia Centre.

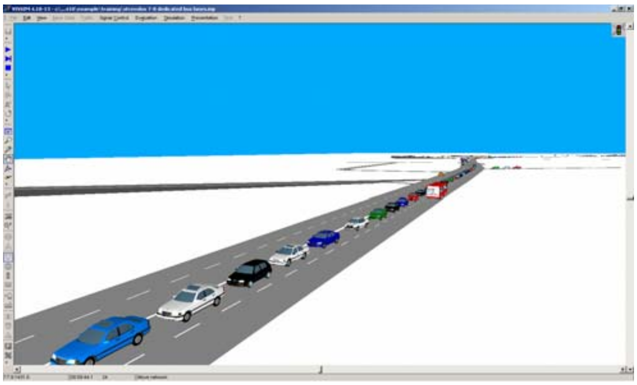

Fig. 5: A Dedicated Bus Lane Scenario

5 Conclusions

Computer simulation proves to be a very powerful tool for analyzing complex dynamical problems such as traffic congestions. This paper provides an overview of the current state of research regarding traffic simulation. Further, an approach to modeling and simulating traffic networks is proposed and implemented.

The proposed approach goes through various stages, which include problem identification, model objectives, model development, model calibration, model validation, scenario preparation, simulation experiments and simulated results evaluation. The proposed approach is applied in the case of developing a microscopic traffic simulation model for the Strovolos Avenue (Nicosia, Cyprus), traffic network. The preliminary validation process shows that the model simulates traffic flows in various vehicle movement directions intersections with an average of 90% accuracy.

Based on the validated microscopic simulation model various scenarios which will take the form of simulation tests will be carried out. Currently, we are in the stage of testing the effect of dedicated bus lanes during the morning peak hours. Preliminary simulation results show that travel times for buses are halved while travel times of private cars increase by 16% for a highly congested part of the traffic network. Such significant simulation results would allow transportation managers to measure the impact of their plans to the rest of the traffic network and test any viable solutions prior to implementation.

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