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Modelling and Simulation of Transportation Systems: a Scenario Planning Approach

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It is increasingly realized that building more roads does not solve the traffic congestion problem but actually makes it worse. Instead of adding capacity to our roads there should be an effort to find ways in order to enhance the level of service of the public transport mode especially with the use of technology, such as applying computer and information technology to transportation systems. Advanced technologies such as Intelligent Transportation Systems (ITS) provide a big opportunity for alleviating the traffic congestion problem. On the other hand, ITS technologies require though rigorous testing and evaluation, which can only be achieved with computer simulation modeling. This paper presents an overview on traffic simulation as well as the development process of a microscopic simulation model of a highly congested traffic network in Nicosia, Cyprus. The validated simulation model gives transportation planners and traffic managers the capability to test various Bus Rapid Transit scenario solutions involving the use of intelligent transportation systems prior to their implementation.

Key words: Modeling, Simulation, Transportation Systems, Bus Rapid Transit.

1 INTRODUCTION

Traffic congestion constitutes a complex dynamical problem. It comprises 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 one's 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 from 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 Bus Rapid Transit 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.

In particular, a microscopic simulation model for Strovolos Avenue, which is depicted in Figure 1, is developed, which is the main transport artery of the Strovolos Municipality. 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

Fig. 1 The Strovolos Avenue Traffic Network

base for similar projects to be carried out all over Cyprus.

2 TRAFFIC FLOW MODELING

The study of traffic flow [1], 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 develop a mathematical theory for traffic flow date back to the 1930s [2, 3], but even until today we do not have a satisfactory and general mathematical theory to describe real traffic flow conditions. This is because traffic phenomena are complex and nonlinear, depending on the interactions of a large number of vehicles. Moreover, vehicles do not interact simply by 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 speed/density [4] that are difficult, if even possible, to be accurately described with mathematical models. According to a state of the art report of the Transportation Research Board [5], mathematical models for traffic flow may be classified as: Traffic Stream Characteristics Models, Human Factor Models, Car Following Models, Continuum Flow Models, Macroscopic Flow Models, Traffic Impact Models, Unsignalized Intersection Models, Signalized Intersection Models and Traffic Simulation Models. Below we describe briefly each of the above categories.

Traffic stream characteristics [6] theory involves various mathematical models, which have been developed to characterize the relationships among the traffic stream variables of speed, flow, and concentration or density. Human factor modeling [7], deals with salient performance aspects of the human element in the context of the human-machine interactive system. These include perception-reaction time, control movement time, responses to: traffic control devices, movement of other vehicles, hazards in the roadway, and how different segments of the population differ in performance. Further, human factors theory deals with the kind of control performance that underlies steering, braking, and speed control. Human factors theory provides the basis for the development of Car following models. Car following models [8], examine the manner in which individual vehicles (and their drivers) follow one another. In general, they are developed from a stimulus-response relationship, where the response of successive drivers in the traffic stream is to accelerate or decelerate in proportion to the magnitude of the stimulus. Car following models recognize that traffic is made up of discrete particles or driver-vehicle units and it is the interactions between these units that determine driver behaviour, which affects speed-flow-density patterns. On the other hand, continuum models [9] are concerned more with the overall statistical behaviour of the traffic stream rather than with the interactions between the particles. Following the continuum model paradigm, macroscopic flow models [10], discard the microscopic view of traffic in terms of individual vehicles or individual system components (such as links or intersections) and adopt instead a macroscopic view of traffic in a network. Macroscopic Flow Models consider variables such as flow rate, speed of flow, density and ignore individual responses of vehicles. Traffic impact models [11] deal with traffic and safety, fuel consumption and air quality models. Traffic and safety models describe the relationship between traffic flow and accident frequency. Unsignalized intersection theory [12] deals with the gap acceptance theory and the headway distributions used in gap acceptance calculations. Traffic flow at signalized intersections [13] deals with the statistical theory of traffic flow, in order to provide estimates of delays and queues at isolated intersections, including the effect of upstream traffic signals. Traffic simulation modeling [14] deals with the traffic models that are embedded in simulation packages and the procedures that are being used for conducting simulation experiments.

In a two-level view the problem of modeling vehicle traffic flow, may be approached mathematically by two main scales of observation: the microscopic and the macroscopic levels. In the microscopic level 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 level we use the analogy with fluid dynamics models, where we have a system of partial differential equations which involves variables such density, speed, flow rate of traffic stream with respect to time and space. In such a configuration speed, flow, and density will be governed by the following partial differential equation [9].

$$\frac{\partial q}{\partial x}+\frac{\partial \rho}{\partial t}=g(x,t) \tag{1}$$

where q is the traffic flow, x is the displacement, ρ is the density and $g(x, t)$ is function for sources and sinks of traffic flow.

The microscopic model involves separate units with characteristics such as speed, acceleration and individual driver-vehicle interaction. Microscopic models may be classified in different types based on the so called car-following modelling approach. The car-following modelling approach implies that the driver adjusts his or her acceleration according to the conditions of leading vehicles. In these models the vehicle position is treated as a continuous function and each vehicle is governed by an ordinary differential equation that depends on speed and distance of the car in the front as shown in Eq. (2).

$$\ddot{x}_f(t)=\lambda\cdot\frac{\dot{x}_l(t)-\dot{x}_f(t)}{x_l(t)-x_f(t)} \tag{2}$$

Where x_f is the one-dimensional position of the following vehicle, x_l is the one-dimensional position of the leading vehicle, t is time, and λ is a sensitivity coefficient.

Another type of microscopic models are the Cellular Automata or vehicle-hopping models which differ from the car-following approach in that they are fully discrete time models. They consider the road as a string of cells which are either empty or occupied by one vehicle. One such model is the Stochastic Traffic Cellular Automata [15, 16].

Microscopic approaches are generally computationally intense, as each car has an ODE to be solved at each time step, and as the number of cars increases, so does the size of the system to be solved. Analytical mathematical microscopic models are difficult to evaluate but a remedy for this is the use of microscopic computer simulation. In such microscopic traffic models, vehicles are treated as discrete driver-vehicle units moving in a computer-simulated environment.

On the other hand, macroscopic models aim at studying traffic flow using a continuum approach, where it is assumed that the movement of individual vehicles exhibit many of the attributes of fluid motion. As a result, vehicle dynamics are treated as fluid dynamics. This idea provides an advantage since detailed interactions are overlooked, and the model's characteristics are shifted toward the more important parameters such as flow rate, concentration or traffic density, and average speed, all being functions of one-dimensional space and time. This class of models is represented by partial differential equations. Modeling vehicular traffic via macroscopic models is achieved using fluid flow theory in a continuum responding to local or non-local influences. The mathematical details of such models are less than those of the microscopic ones. The drawback of macroscopic modeling is the assumption that traffic flow behaves like fluid flow which is a rather harsh approximation of reality. Vehicles tend to interact among themselves and are sensitive to local traffic disturbances, phenomena which are not captured by macroscopic models. On the other hand, macroscopic models are suitable for studying large scale problems and are computationally less intense especially after approximating the partial differential equation with a discrete time finite order equation.

There exists also a third level of analysis the so called mesoscopic level, which is somewhere between the microscopic and the macroscopic levels. In a 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 at velocity v. This function, following methods of statistical mechanics, can be computed solving an integro-differential equation, like the Boltzmann Equation [17, 18].

The choice of the appropriate model depends on the level of detail required and the computing power available. As a result of advancements in computer technology in recent years, the trend today is towards utilising microscopic scale mathematical models, which incorporate human factors and car-following models as a driver-vehicle behaviour unit.

3 MICROSCOPIC TRAFFIC MODELING SOFTWARE

Microscopic simulation is a term used in traffic modelling and is typified by software packages such as VISSIM [19, 20, 21, 22], CORSIM [23, 24, 25, 26], AIMSUN [27, 28, 29, 30] and PARA-

MICS [31, 32, 33, 34]. Traffic simulation microscopic models simulate the behaviour of individual vehicles within a predefined road network and are used to predict the likely impact of changes in traffic patterns resulting from proposed commercial developments or road schemes. They are aiming to facilitate transportation consultants municipalities, government transportation authorities and public transportation companies. The traffic flow models used are discrete, stochastic, time step based microscopic models, with driver-vehicle units as single entities.

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 screenshot of the VISSIM graphical user interface is provided in Figure 2. The microscopic model depicted in the figure was developed in order to analyze traffic and evaluate the impact of various bus priority scenarios for a traffic network in Nicosia, Cyprus [35, 36].

In today's traffic simulation software, data such as network definition of roads and tracks, technical vehicle and behavioural driver specifications, car volumes and paths can be inserted in a graphical user interface mode. Values for acceleration maximum speed and desired speed distributions can be configured by the user to reflect local traffic conditions. Various vehicles types can also be defined. Further traffic control strategies and algorithms may be defined as well as interfaces may be build with well known urban traffic controllers. Below we present some of their main features CORSIM, PARAMICS, VISSIM, and AIMSUN, which were calibrated and validated in a number of traffic studies worldwide.

CORSIM, which stands for Corridor Microscopic Simulation is developed by Federal Highway Administration of United States. It has evolved from two separate traffic simulation programs NETSIM and FRESIM. NETSIM models arterials with signalised and unsignalised intersections, while FRESIM models uninterrupted freeways and urban highways.

In the case of VISSIM developed by PTV, the microscopic model consists of a psycho-physical car following model for longitudinal vehicle movement and a rule-based lane changing algorithm for lateral movements. The model is based on an urban and a freeway model which were developed by Wiedemann from the University of Karlsruhe. VISSIM is especially renowned for its signal control module, which by using a vehicle actuated programming language can model almost any traffic control logic. Further, VISSIM scores high on its ability to model public transportation systems.

AIMSUN was developed by TSS in order to simulate urban and interurban traffic networks. It is based on the car-following model of Gibbs. AIMSUN therefore is based on a collision avoidance car-following model. Traffic can be modelled via input flows and turning movements origin destination matrices and route choice models.

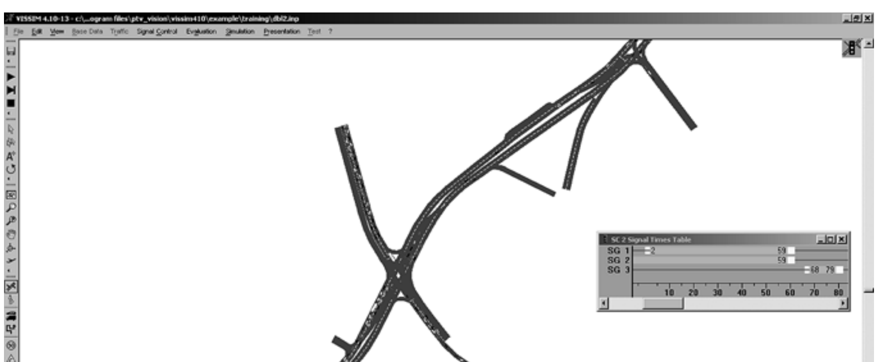

Fig. 2 The VISSIM Graphical user Interface Depicting Part of Strovolos Ave

PARAMICS which stands for Parallel Microscopic Simulation comprises of various modules which include a modeller, a processor, an analyser, a monitor, a converter and an estimator. PARAMICS is renowned for its visualization graphics and for its ability to model quite a diverse range of traffic scenarios.

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 [37]. 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 [38] who compared Corsim and Vissim as well as the work of Boxill and Yu [39] who compared the capabilities of Corsim, Aimsun and Paramics. It can be concluded from the various reviews that software modelers, which have comparative capabilities include VISSIM, AIMSUN, and PARAMICS.

In a more recent comparative study of microscopic car-following behaviour Panwai and Dia [40] evaluate AIMSUN, VISSIM and PARAMICS. They conclude that the accuracy of a traffic simulation system depends highly on the quality of its traffic flow model at its core, which consists of car following and lane-changing models. In the study the car-following behaviour for each simulator was compared to field data obtained from instrumented vehicles travelling on an urban road in Germany. The Error Metric on distance [41] performance indicator gave substantially better values for AIMSUN than those of VISSIM and PARAMICS. Further the Root Mean Square Error (RMSE) was substantially less for VISSIM and AIMSUN than the RMSE for PARAMICS. In another paper presented at the 9th TRB Conference on the Application of Transportation Planning Methods Choa et al. [42] concluded that although CORSIM provides the shortest traffic network setup time PARAMICS and VISSIM generated simulation results that better matched field observed conditions and traffic engineering principles.

4 THE PROBLEM OF TRAFFIC CONGESTION IN CYPRUS

In 2007 there were more than 600000 registered vehicles in Cyprus, a figure that approaches the number of people of the island and unfortunately puts Cyprus at the top of the world when it comes to number of vehicles per capita. 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 in the number of vehicles. The number of registered vehicles has increased from 100000 in 1980 to more than 600000 by the year 2007, which represent more than a 600% increase in 27 years.

In addition to the increased number of cars, the use of the bus transport mode has sharply fallen. From 13 million passengers during the year 1981 we are down to 3 million for the year 2007. This represents more than a 400% decrease in the use of the bus transport mode.

The traffic congestion problem situation will remain and even get worse, 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.

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 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.

5 THE PROPOSED TRAFFIC MODELING AND SIMULATION METHOD

As described in the previous sections traffic phenomena constitute a chaotic dynamical problem situation, which make traffic modelling and simulation a very complex, iterative and difficult process. In order to increase our chances for a successful simulation model the following methodology is proposed, which is applied for modeling the Strovolos Avenue traffic network as described in the next section.

The proposed traffic modeling and simulation method is based on the suggestions of Lieberman and Rathi [14]. As shown in Figure 3, the first step is to identify and clearly define the problem. Caution should be taken not to just deal with the symptoms of the problem but to find the real cause of the traffic congestion problem. The use of advanced modeling techniques such as system dynamics analysis may be incorporated here. Having defined the problem, together with specifying the problem's extent and significance, the next step is to define the model objectives. In other words the purpose of the simulation model to be developed should be specified. Again here caution should be taken to investigate whether the stated objectives would really solve the problem as well as to take into consideration any »side effects« that may occur as a result of specific proposed solutions.

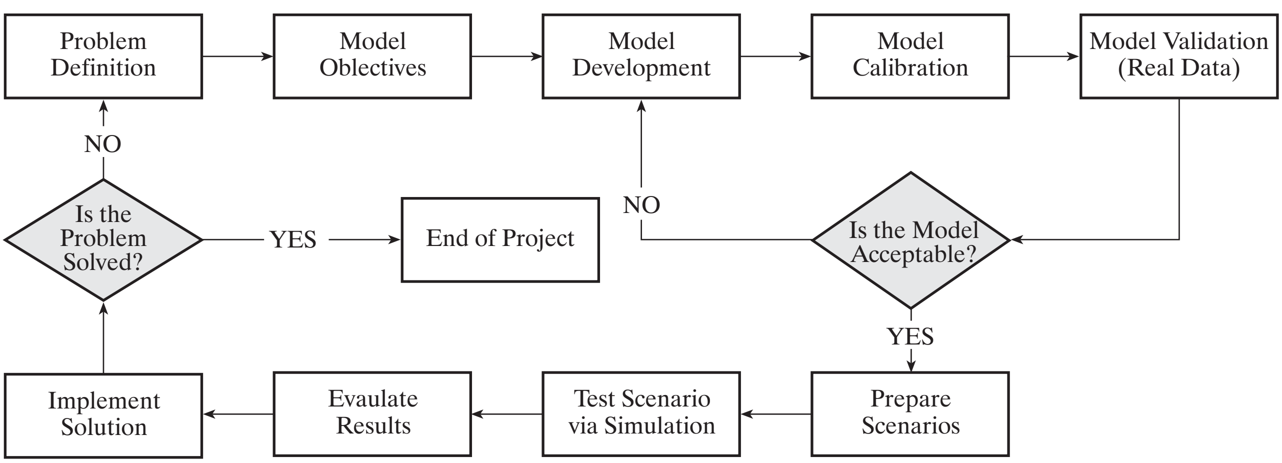

Fig. 3 The Proposed Traffic Modeling and Simulation Method

Next, we have the definition of the system to be studied. Here the major components of the system need to be identified as well as the boundary of the domain of the system needs to be defined. Further the interactions of the various components need to be analyzed. Finally, the necessary information to be used as input to the model has to be identified. Once the system to be studied is defined the next step would be the development of the model. Here, the level of complexity needed to satisfy the stated objectives should be identified. It might be for example that a macroscopic model would be adequate for the current problem. Therefore the model is to be classified and its inputs and outputs should be defined.

During model development an appropriate software modeler based on the model objectives should be selected. It is important therefore to carry out an assessment of a number of software for traffic simulation and investigate there capabilities and limitations. In case the selected model is not adequate for the model objectives then enhancements should be carried out with some further software development. In this event the flow of data within the model as well as some functions and processes of the model components need to be defined. Further, the calibration requirements need to be determined. Mathematical, logical and statistical algorithms of each inadequately represented (by the selected software modeller) system component with its activities and interactions should be developed. The logical structure for integrating these model components needs to be created to support the flow of data among them. Then the software development method should be selected as well as an appropriate programming language, user interface and the presentation format of model results. Finally, the design logic and all computational procedures should be documented and the software code should be developed and debugged.

The next step which partly belongs to the model development process is model calibration. Here the necessary data should be collected or acquired in order to calibrate the model. Then, this data should be introduced into the model. Further, especially for the case of software development enhancements it should be verified that the software executes in accordance with the design specifications. Model development and calibration are part of an iterative process as shown in Figure 3 that leads to validating the model. Model validation includes the collection or acquisition of data as well as reduction and organizing for purposes of validation. That is, gathered data should be reduced and structured in such a way so that they are in the same format as the data generated by the model. Further, validation criteria should be established stating the underlying hypotheses and selecting the statistical tests to be applied.

The iterative process of model development, calibration, verification and validation is completed once it is established that the model describes the real system at an acceptable level of accuracy over its entire domain of operation. Here, the use of statistical testing methods proves to be useful. In more detail the validation process may include experimental design development, identification of the causes for any failure to satisfy the validation tests and repairing the model accordingly. As differences between the model results and real world data emerge the developer must repair the model and then revalidate. In order to validate a traffic simulation model considerable skill and persistence are needed.

Once the model is validated, that is, it adequately represents the real system, then the simulation part of the method commences. This involves scenario preparation, testing the various scenarios via simulation, evaluation of the results and implementation of the emergent solution. Simulation tests should be viewed as performing rigorous statistical experiments. A prerequisite for the tests is that the simulation model is at a state where it properly represents the initial state of the current traffic environment. Further, the changing input conditions which describe the traffic environment need to be specified. For example, the distribution of traffic flows over the period of time where the experiments will be carried out need to be determined.

6 TRAFFIC MODELING AND SIMULATION OF STROVOLOS AVENUE

As shown in Figure 3, 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 so-

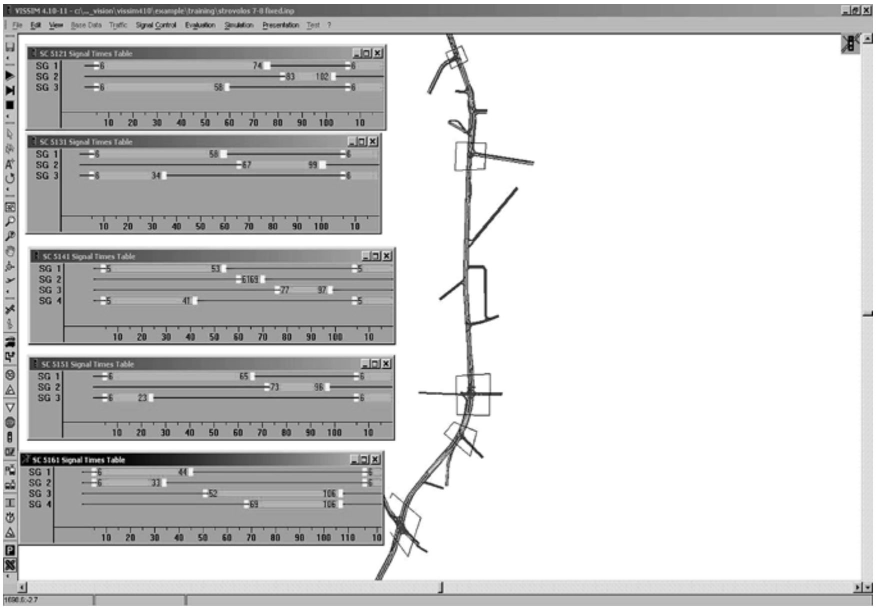

Fig. 4 The Simulation Model of Strovolos Avenue Traffic Network

lution 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 4 below. Strovolos Avenue is more than 3 kilometers long extending from the borders with Nicosia Municipality near the Presidential Palace to the borders with Lakatatmeia Municipality. Figure 4 also shows the signal times for the various signal groups at five main signalized intersections of Strovolos Avenue. 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 in terms of static data and dynamic data. Static data represents the roadway infrastructure. It includes 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.

Dynamic data is to be specified for traffic simulation applications. It includes traffic volumes including vehicle mix (e.g. truck, HOV percentage) for all links entering the network, locations of route decision points with routes, that is the 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 or keep-clear-areas, locations of stop signs, public transport routing, departure times and dwell times.

Having introduced the above static and dynamic data in our model, we enter 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

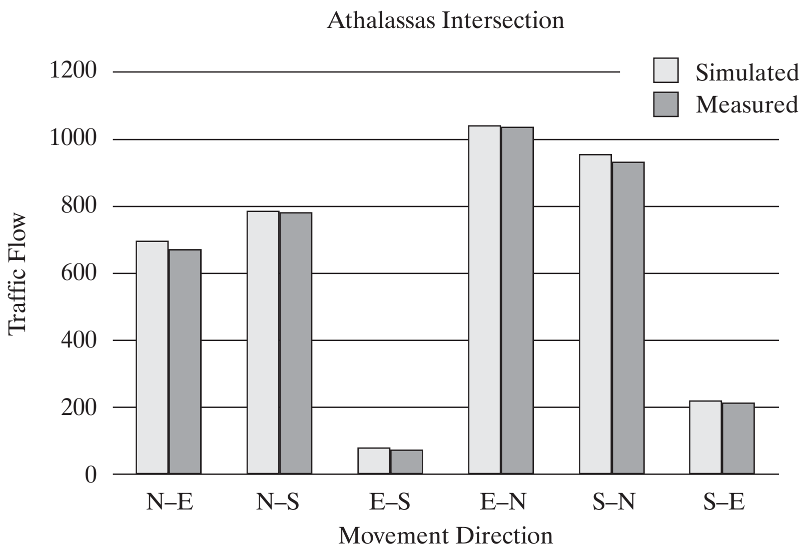

Fig. 5 Model Validation

position to present some optimistic results concerning the validity of our model.

Figure 5 shows the real Vs simulated traffic flows of the various vehicle movement directions of a central intersection of our traffic network, that of Athalassas-Strovolou (see also figure 4). As seen in the graph below the traffic flows of real measurements obtained and those of simulated results, are quite comparable. In certain intersections such as the one shown in Figure 4, the error ranges from only 1% to 3%. Further, our simulation model demonstrates the queues that we encounter in reality during the morning peak.

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 6 shows a screenshot of the simulated model as a bus has difficulty in exiting the bus bay to enter the main road.

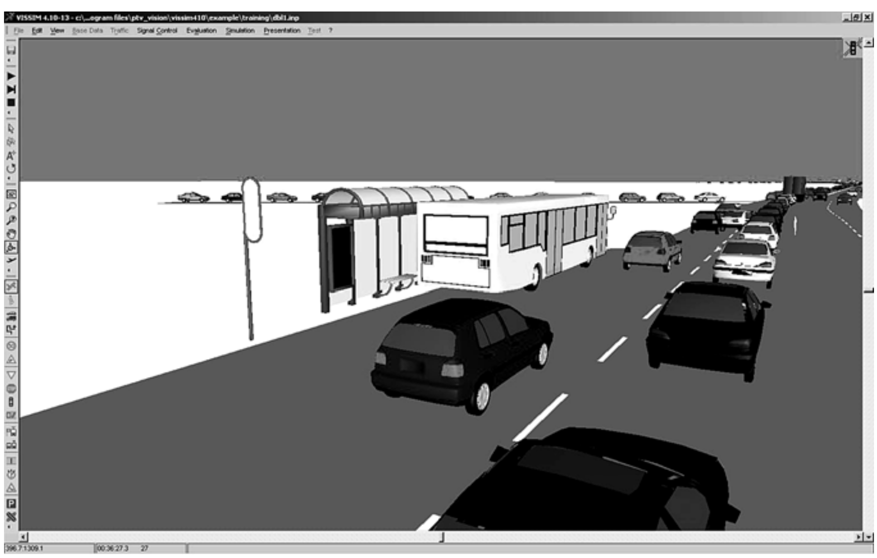

Fig. 6 A Snapshot of the Traffic Simulation Model

In summary the various scenarios to be evaluated utilizing the developed traffic simulation model include the following:

- Bus Lane with Restricted Use where dedicated bus lanes may be assigned during the peak traffic hours. In this scenario based on a review of Similar systems that have been implemented worldwide an examination of the use of High Occupancy Vehicle (HOV) lanes and issues such as traffic flow and safety of drivers and pedestrians will be investigated.
- Signal pre-emption. In the Signal Pre-emption System the bus is sensed, which is approaching the traffic signal and priority is given to the bus by extending the green phase. The system consists of detectors on the road that communicate with the traffic lights. Here Global Position Systems (GPS) may also be utilised.
- Extra Traffic Light. An extra traffic light with a special signal for buses may be installed 40–50 meters from the signalised intersection in order to hold the rest of the traffic behind and give priority to the bus. An extra traffic light may also be used for the easy access of the buses from the dedicated lanes to the main traffic stream. The extra traffic lights should be synchronized with the intersection traffic lights, which requires analysis of vehicle dynamics. Here bus dynamics will be analysed concerning acceleration and deceleration projections. Based on the bus dynamics analysis optimisation of the traffic flow will be carried out.

Finally, Safety analysis based on the above scenarios could be carried out, and the traffic flow effect on the traffic network could be assessed.

Initial results show that the attractive scenario of bus dedicated lanes could make things worse for all transport modes if not properly designed. By examining all possible options, and going through detailed traffic analysis via computer simulation experimentation a viable solution is derived where the measures of effectiveness of travel time, average speed and time delay show significant improvements for the bus transport mode while the impact to rest of traffic is kept to a minimum. In particular, the suggested solution involves a combination of central dedicated bus lanes with extra traffic lights. In fact simulation results for the bus transport mode show a reduction of total travel time by 27 %, increase average speed by 45 % and reduce delay time by 28 % [44]. All these improvements have almost no negative effects on the other modes of transport.

7 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 validation process shows that the model simulates traffic flows in various vehicle movement directions intersections with an average of 95 % accuracy.

Based on the validated microscopic simulation model alternative bus priority strategy scenarios involving dedicated bus lanes, signal preemption and bus advance areas are evaluated. Via computer simulation experimentation it was possible to develop a scenario solution, which reduces total travel time by 27 %, increase average speed by 45 % and reduce delay time by 28 % for the bus transport mode with almost no negative effects the rest of the traffic. Such simulation results allow transportation managers to measure the impact of their plans and test any viable solutions prior to implementation, which represents a significant step towards designing optimized traffic networks.

8 ACKNOWLEDGEMENTS

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Modeliranje i simulacija transportnih sustava: pristup planiranja scenarija. Postaje sve razvidnije da se izgradnjom novih cesta ne može riješiti problem prometne zagušenosti, već se čak može i povećati. Dakle, umjesto proširenja mreže cesta trebalo bi uložiti energiju u povećanje razine usluga javnog transporta, poglavito primjenom novih tehnologija kao što su računalna i informacijska tehnologija. Napredne tehnologije uključene u tzv. *Inteligentne transportne sustave* (ITS) pružaju velike mogućnosti za ublažavanje problema prometne zagušenosti. S druge strane, ITS tehnologije zahtijevaju rigorozne provjere i vrednovanja koja se jedino mogu provesti pomoću računalnih simulacija. U radu se daje pregled načina simulacije prometa te proces razvoja mikroskopskog simulacijskog modela jako zagušene prometne mreže u Nikoziji na Cipru. Vrednovani simulacijski model pruža planerima transporta i upraviteljima prometa mogućnost provjeravanja raznih rješenja scenarija brzog autobusnog prometa, uključujući primjenu inteligentnih prometnih sustava prije njihove implementacije.

Ključne riječi: modeliranje, simulacija, transportni sustavi, brzi autobusni promet

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