ON THE COMPUTER SIMULATION FOR TRAFFIC SYSTEMS

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ABSTRACT

In this paper, the significance of computer simulation for traffic systems is analyzed and both the relationship between traditional transportation systems and simulation technology and the relationship between Intelligent Transportation System (ITS) and simulation technology are discussed. The research interests and approaches of traffic simulation are reviewed in details and contemporary development and applications in this field are presented. Finally，several important future prospects in the traffic simulation based on digital computers are pointed out according to the recent research and development of modern computer simulation technology. The tendencies include virtual reality technology, network and system integration, parallel computing, object-oriented programming, discrete-event simulation, travel demand simulation and traffic control system simulation.

Keywords: Traffic Simulation; Virtual Reality; System Integration; Discrete-event Simulation; Object-oriented Programming

1. INTRODUCTION

Traffic simulation has been widely used in the fields of research, planning, decision-making, demonstration and development of traffic systems. With the development of computer technology, digital and visualized computer simulation is now the main manner in the modern traffic simulation. Generally speaking, simulation refers to dynamic representation of systems in the real world through establishing computer model and evolving the model over computers [1]. Moreover, simulation is an efficient and effective tool to evaluate Intelligent Transportation System (ITS) [2]. So far, traffic simulation based on computer technology has become one of the hot topics in traffic research and development. In this paper, only ground traffic simulations with dynamic behaviors are addressed without considering related issues in aviation and marine transportation.

Ground transportation, which implies efficient transfer of people and goods through physical road and street networks, is a fascinating problem. Traffic systems in ground transportation might be characterized by a number of features. Therefore, it is very difficult to analyze, control and optimize the traffic systems. The traffic systems normally contain wide physical areas and huge active participants. Nevertheless, the goals and objectives of diverse participants are not necessarily coincident with each other or with those of the system operator (system optimum vs. user optimum), and there are many system inputs including controls of the operator and the participants (such as the weather conditions, the number of users, etc.). In addition, road and street transportation systems are inherently dynamic and random in nature, that is, the features of the systems varies with nature time, locations, and considerable amount of randomness. The great number of active participants involving in the system means a great deal of simultaneous interactions.

It is obvious that transportation systems are typical man-machine systems, which indicates that the activities in the system include both human interaction, i.e. interaction among drivers and operators, and man-machine-interactions, i.e. drivers interaction with vehicles, traffic information and control system, and with physical roads and streets environment. In addition, the laws of interaction are not so precise in nature; the observations and reactions of drivers are governed by human perception instead of the technology based sensor and monitoring systems.

One can note that traffic systems are excellent and typical application environments for simulation based traffic research and planning. The analytical tools, although very important, are limited to subsystems and sub-problem levels.

The growth of urban automobile traffic has led to serious and worsening traffic congestion problems in most cities around the world. Since travel demand increases at a higher rate than that of improvement of road capacity, the situation will continue to deteriorate unless better traffic management strategies are implemented. One of the most attractive remedial measures for addressing the congestion problem is deploying Intelligent Transportation Systems.

Advanced technologies made it possible to develop more sophistical traffic management strategies, but it has been shown that advanced strategies do not always result in improved performance. While designing a particular traffic management system, many possible architectures and alternatives might be chosen. Evaluation is, therefore, an important element in the design process. Similarly, in assessing the impact of proposed changes to an existing traffic system, the analyst faces various "what if"questions.

If a traffic management system is already fully operational, field operation tests can be adopted to assess its performance and evaluate many practical aspects of the systems. However, field tests tend to be expensive, and as a result, typically few schemes can be tested. In addition, field test results depend on a lot of uncontrollable factors of environment, such as weather condition, travel demand and incidents, etc.

In recent years simulation has become a tool being commonly used to understand the characteristics of a traffic system and to select an appropriate design policy [2].

Reasons to apply computer simulation to traffic field are the same as in other simulation usages, which include the difficulties in analytical solving of a question at hand, the need to test, the evaluation and demonstration of a proposed action course before implementation, the research as well as the personnel training.

2. CLASSIFICATION OF TRAFFIC SIMULATION

Traffic simulation can be categorized into microscopic, mesoscopic and macroscopic ones. The traffic simulation can also be divided into continuous and discrete time approaches. According to different research and development purposes, traffic simulation might be subdivide into intersection, road section and network simulations. Special research interests in traffic simulation include the traffic safety and the effects of advanced traffic information and control systems. A newly emerged area is the demand estimation through microscopic simulation.

3. BRIEF REVIEW OF COMPUTER SIMULATION RESEARCH ON TRAFFIC SYSTEMS

In 1955, D. L. Gerlough's Ph. D. dissertation titled *Simulation of freeway traffic on a general-purpose discrete variable computer* indicated the start of computer simulation research on traffic systems. From that time, computer simulation has become a widely applicable tool in transportation engineering with a variety of applications from scientific research to planning, training and demonstration.

During the nearly 50-years long history, computer simulation in traffic analysis has been developed from a research tool of limited group of experts to a widely used technology in research, planning, demonstration and development of traffic systems. The elementary application areas of simulation mainly remained the same, but the applications have grown a lot in size and complexity. In 1990's demand analysis through simulation has emerged as a new topic. New programming techniques and R&D environments, such as object-oriented programming and virtual reality tools, are coming to common users. Integrated usages of several programs and applications of parallel computing and GIS databases are some of the latest research interests in traffic systems simulation. New ideas, like cellular automata and rule-based simulation with discrete variables, have also shown their powerful strength.

Forces behind this development are the advances in traffic theory, computer hardware technology and programming tools, development of general information infrastructure, as well as society demand on more detailed analysis of the consequences of traffic measures and plans. Graphic presentation of simulation appeared in late 1960's.

One of the oldest and most well known cases of simulation applications in theoretical research is the car-following analysis based on the GM models. In such models a differential equation governs the movement of each vehicle in the platoon under analysis. Car following, like the intersection analysis, is one of the basic questions of traffic flow theory and simulation, and still under active research after almost 40 years from the first trials.

The traditional simulation problem with practical orientation in road and street traffic analysis is related to questions of traffic flow, that is, to capacity and operational characteristics of facilities. Delays and queue lengths at intersections are a never-ending object of analysis and simulation studies with a newly grown international interest in roundabouts.

In the area of traffic signal control, the classic Webster's formula is an example of early usage of simulation with practical results. In this formula a simulation-based correction is added to an analytical delay formula derived from the queuing theory. Modern vehicle-actuated traffic signal controllers have added a new dimension to signal control simulation. In traditional fixed time signal control only the traffic was reacting to signals, now the signals are also reacting to traffic, and the analysis of controller reactions is rather important as the analysis of traffic itself. New solutions, like the connection of a real controller to the simulation system are used in the analysis.

Most urban transportation problems are network related. In networks, one has to combine different kinds of intersections (signalized and/or un-signalized) and links (arterial roads, motorways, and city streets). This makes the simulation quite complicated and the number of comprehensive simulation tools for network analysis is lacking in comparison to that of programs for isolated intersections and road sections. The most widely known package in this area is probably the American NETSIM since 1970's. Later examples of tools in this area are INTEGRATION and AIMSUN2, etc [3].

In lane traffic flow analysis, motorway simulation seems to be more common than the simulation of ordinary two-lane two-way traffic roads. One of the reasons is that in two-lane road environment the interactions between vehicles traveling in opposite directions have to be modeled. The platoon and overtaking are not only dependent on traffic situation but also on the road environment (sight distances, passing control). The problem is much more complicated than that in the motorway environment. Probably the most well known packages in this area are the Swedish VTI-model and the Australian TRARR, both of them are mainly developed in 1970's.

Most traffic system simulation applications today are based on the simulation of vehicle-vehicle interactions and are microscopic in nature. Traffic flow analysis is one of the few areas, where macroscopic (or continuous flow) simulation has also been used. Most of the well known macroscopic applications in this area originates from the late 1960's or early 1970's. The British TRANSYT-program is an example of macroscopic simulation of urban arterial signal control coordination and the American FREQ- and FREFLO-programs plus the corresponding German analysis tool are related to motorway applications. A mesoscopic approach with groups of vehicles is used in CONTRAM, a tool for analysis of street networks with signalized and non-signalized intersections.

An alternative investigation of system level simulation is to develop open environments in which several analysis tools can be adopted interactively to solve the problems. The selected tool at a specific stage is most suitable for the related issue. An example of this methodology is the FHWA TRAF-program family and the FHWA Traffic Management Laboratory, whose primary goal is to develop a distributed, real-time test-bed to simulate traffic conditions for Advanced Traffic Management Systems (ATMS). For example, a general graphical user interface has been developed for the TRAF-family programs. The cooperation among Finnish, Swedish and British partners around the Finnish HUTSIM program for an open traffic-modeling environment is another example of this kind of work that is still going on [7].

Traffic safety related issues are alternatively hard problems for simulation. In traditional simulation programs, the drivers are programmed to be able to avoid collisions. Some trials for analysis of conflict situations through simulation can be found, but a general approach to the problem and widely used safety simulation tools are still lacking. Traffic safety simulation belongs to the field of human-centered simulation where the perception-reaction system of drivers with all its weak points has to be described. This kind of approach is sometimes called nano-simulation in order to distinguish it from the traditional microscopic simulation.

On the other hand, safety aspects and human reactions in different traffic situations have been analyzed using driving simulation systems, in which the test subjects are exposed to artificial driving tasks in a simulated vehicle and traffic environment and the driver has to react to the given traffic. Nevertheless developments in virtual reality technology will increase the possibilities for realistic simulations.

A new application area is the simulation of applications and effects of telematic services in traffic. This is related to the simulation of traffic flow, and on the other hand, to the simulation of human behaviors and decision-making. Even the effects of totally human-free driving are tested in this area.

4. FUTURE RESEARCH TENDENCIES IN TRAFFIC SIMULATION

The development in traffic simulation from the early days in 1950's and 1960's has been tremendous, which is partly related to the development of computer technology and programming tools. On the other hand, the research in traffic and transportation engineering has also grown in the past 40-years. Simulation is now an everyday tool for practitioners and researchers in all fields of the profession.

In the following, some of the R&D trends in sight are briefly discussed. Most of these issues are related to microscopic simulation. It is, however, noteworthy that there is some quite interesting effort in the theoretical macroscopic models for fundamental traffic flow analysis, which give us new insight into the fundamental speed-flow-density relationships.

4.1 Virtual Reality

Virtual reality (VR) and its programming tools become in common use, especially in simulations where the driver reactions and behaviors must be considered in great detail. Traffic safety related simulation would therefore probably be an area that greatly benefits from VR technology. There is, of course, no reason why VR tools could not be used in more traditional simulation tasks, as well. In planning applications, VR provides new possibilities for the planning work, and demonstration of plans to decision-makers and public [8].

VR makes possible the combination of traditional driving simulators and traditional traffic flow simulation systems. In traditional driving simulator, the test driver has to react to the fixed traffic that he/she observes on the display. A more natural situation is achieved if the traffic also reacts to the test driver behavior, that is, the vehicle with the test driver becomes an interactive part of the simulated traffic flow [5].

4.2 System Integration

The traffic applications are growing in size and complexity, that is, we are moving from the quite well covered local or one-facility type of applications to network wide systems where several types of facilities are integrated into one system. Another trend that increases the need of computing power is the more and more precise description of the physical road and street environment, especially in local applications, such as in the simulation of intersections. In both these cases the use of graphic user interfaces and integration to GIS and CAD are a feasible approach [6].

4.3 Parallel Computing

TRANSIMS of US is an example of a network approach. The simulation of the traffic system of a whole city is based on massive use of parallel computing, which again is a feature that is coming more common in modern applications. Parallel computing can be achieved for example through simultaneous use of several microcomputers communicating through a local network.

4.4 Object-Oriented Programming

In addition to the parallel computing, the modern programming principles and methods have their effects on the simulation [9]. Object-oriented programming has been found very suitable in the description of the great amount of practically parallel interactions in traffic. Objects, or agents, can be programmed to interact in a very natural manner to set up accurate models of traffic flow behaviors.

4.5 Discrete Event Simulation

TRANSIMS is also an example of discrete event simulation. The traditional traffic flow descriptions are based on continuous speed and distance variables. TRANSIMS, in turn, adopts a discrete approach in which the road and street network is set up from elements that can accommodate only one vehicle at a time unit. In this cellular automata approach, the vehicles move forward by "jumping" from the present status to a new one according to rules that describe the driver behavior and maintain the basic laws of physics at present in vehicle movements [4].

4.6 Travel Demand Simulation

In recent years another new area of traffic simulation has emerged, namely simulation of travel demand. In the travel demand simulation, analytical convention has changed from aggregate gravity modeling to individual based disaggregate choice models. The question in this approach is to reproduce the trip pattern (the number, time of day, purpose, origin-destination pattern, modal split and use of routes) of the citizen population within an area by summing up the behaviors of individuals. Examples of this approach include the American SAMS and SMART, both of them are still under development. One of the most advanced modeling approaches, the American TRANSIMS, combines demand modeling and flow behavior on streets and roads thus try to describe the whole traffic system behavior in one simulation environment.

The simulation of travel demand is expected to grow up rapidly. The basic research in time-use studies and trip chaining of individuals combined with disaggregate modeling form a theoretical basis for this new methodology. Demand simulation will also adopt GIS databases and tools as the basic data input and demonstration of the results. The simulation approach will be useful not only in the analysis of peak hour traffic in congested urban areas but also in the planning of special low demand transport services like demand responsive public transport.

4.7 Traffic Control Systems Simulation

Simulation of control systems as a part of traffic operations is also becoming more and more crucial with the wide ongoing research in transport telematics. The new control systems interact with traffic, and thus both the control system reactions and the driver reactions must be described in a practical manner. An especially important feature in driver reactions is the route choice decision that must be treated dynamically. In the future, more and more simulation systems will be embedded in control systems to predict the state of traffic flow and the effects of alternative control measures.

5. CONCLUSION

Traffic simulation is a widely used technology in the research, planning, demonstration and development of traffic systems. It is also a fruitful application of computer simulation technology to transportation engineering field. In this paper, the significance of computer simulation for traffic systems is discussed and both the relationship between traditional systems and simulation technology and the relationship between ITS and simulation technology are analyzed. The research efforts in traffic simulation are reviewed in details and future possible R&D activities in this field are presented. Seven trends in traffic simulation are given out according to the recent research and development of computer simulation technology.

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