Simulation of Traffic Systems - An Overview

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ABSTRACT

During its more than forty years long history computer simulation in traffic analysis has developed from a research tool of limited group of experts to a widely used technology in the research, planning, demonstration and development of traffic systems. The five driving forces behind this development are the advances in traffic theory, in computer hardware technology and in programming tools, the development of the general information infrastructure, and the society's demand for more detailed analysis of the consequences of traffic measures and plans. The basic application areas of simulation have mainly remained the same, but the applications have grown in size and complexity. In the 1990's demand analysis through simulation has emerged as a new application area. New programming techniques and environments, like object-oriented programming and virtual reality tools are coming to common use. Integrated use of several programs and the applications of parallel computing and GIS databases are some of the latest trends in traffic systems simulation. New ideas, like cellular automata and rule-based simulation with discrete variables have also proven their strength.

KEYWORDS: transportation, simulators, virtual reality, discrete simulation, object-oriented

1. Introduction

In general, simulation is defined as dynamic representation of some part of the real world achieved by building a computer model and moving it through time (Drew 1968). Computer models are widely used in traffic and transportation system analysis, but only those with dynamic approach are in the focus of this paper. The use of computer simulation started when D.L. Gerlough published his dissertation: "Simulation of freeway traffic on a general-purpose discrete variable computer" at the University of California, Los Angeles, in 1955 (Kallberg 1971). From those times, computer simulation has become a widely used tool in transportation engineering with a variety of applications from scientific research to planning, training and demonstration.

The five driving forces behind this development are the advances in traffic theory, in computer hardware technology and in programming tools, the development of the general information infrastructure, and the society's demand for more detailed analysis of the consequences of traffic measures and plans. An example demonstrating the great advances in hardware and software technology is presented in Figure 1.

Figure 1 Graphic presentation of simulation results in late 60's (Sagen 1967).

In the following, I will try to give an overall view of the development, present use and future directions of simulation in road traffic planning and research. The great number of advanced simulation applications in railroad, air and maritime transportation are excluded in this connection.

2. Traffic as a simulation object

Road transportation, that is, efficient movement of people and goods through physical road and street networks is a fascinating problem. Traffic systems are characterised by a number of features that make them hard to analyze, control and optimise. The systems often cover wide physical areas, the number of active participants is high, the goals and objectives of the participants are not necessarily parallel with each other or with those of the system operator (system optimum vs. user optimum), and there are many system inputs that are outside the control of the operator and the participants (the weather conditions, the number of users, etc.).

In addition, road and street transportation systems are inherently dynamic in nature, that is, the number of units in the system varies according to the time, and with a considerable amount of randomness. The great number of active participants at present at the same time in the system means a great number of simultaneous interactions.

Transportation systems are typical man-machine systems, that is, the activities in the system include both human interaction (interaction between driver-vehicle-elements) and man-machine-interactions (driver interaction with the vehicle, with the traffic information and control system and with the physical road and street environment). In addition, the laws of interaction are approximate in
nature; the observations and reactions of drivers are governed by human perception and not by technology based sensor and monitoring systems (Figure 2).

In all, traffic systems are an excellent application environment for simulation based research and planning techniques, an application area where the use of analytical tools, though very important, is limited to subsystem and subproblem level.

The reasons to use simulation in the field of traffic are the same as in all simulation; the problems in analytical solving of the question at hand, the need to test, evaluate and demonstrate a proposed course of action before implementation, to make research (to learn) and to train people.

3. Areas and approaches in traffic simulation

The applications of traffic simulation programs can be classified in several ways. Some basic classifications are the division between microscopic, mesoscopic and macroscopic, and between continuous and discrete time approach. According to the problem area we can separate intersection, road section and network simulations. Special areas are traffic safety and the effects of advanced traffic information and control systems. A newly emerged area is that of demand estimation through microscopic simulation.

One of the oldest and most well known cases of the use of simulation in theoretical research is the car-following analysis based on the GM models. In these models a differential equation governs the movement of each vehicle in the platoon under analysis (Gerlough and Huber 1975). Car-following, like the intersection analysis, is one of the basic questions of traffic flow theory and simulation, and still under active analysis after almost 40 years from the first trials (McDonald et al. 1998).

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 (Webster and Cobbe 1966) is an example of early use of simulation with practical results. In this formula a simulation-based correction is added to an analytical delay formula derived by the use of 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 quite as important as the analysis of traffic itself. New solutions, like the connection of a real controller to the simulation system (Kosonen and Pursula 1991) are used in the analysis.

Most urban transportation problems are network related. In networks, one has to combine different kinds of intersections (signalized, unsignalized) and links (arterial roads, motorways, city streets). This makes the simulation quite complicated and the number of comprehensive simulation tools for network analysis is quite small 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 from the 1970's (Byrne et al. 1982). Later examples of tools in this area are e.g. INTEGRATION and AIMSUN2 (Algers et al. 1997).

In link traffic flow analysis motorway simulation seems to be more common than simulation of ordinary two-lane two-way traffic roads. One of the reasons here is that in two-lane road environment the interactions between vehicles travelling in opposite directions have to be modelled. The platooning and overtaking are not only dependent on traffic situation but also on the road environment (sight distances, passing control). This way the problem is much more complicated than in the motorway environment. Probably the most well known programs in this area are the Swedish VTI-model (Algers et al. 1996) and the Australian TRARR (Hoban et al. 1991), both basically developed in the 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 in use. Most of the well known macroscopic applications in this area originate from the late 1960's or the early 1970's. The British TRANSYT-program (Byrne et al. 1982) is an example of macroscopic simulation of urban arterial signal control coordination and the American FREQ- and FREFLO-programs (Byrne et al. 1982; Payne 1971) plus the corresponding German analysis tool (Cremer 1979) are related to motorway applications. A mesoscopic approach with groups of vehicles is used in CONTRAM (Leonard et al. 1978), a tool for analysis of street
networks with signalized and non-signalized intersections.

Traffic safety related questions have been quite a hard problem for simulation. In traditional simulation programs the drivers are programmed to avoid collisions. Thus, they do not exist. Some trials for analysis of conflict situations through simulation can be found (Karhu 1975; Sayed 1997), but a general approach to the problem and widely used safety simulation tools are still missing. Traffic safety simulation belongs to the field of human centred simulation where the perception-reaction system of drivers with all its weak points has to be described. This kind of approach is sometimes called nanosimulation in order to separate it from the traditional microscopic simulation.

On the other hand, safety aspects and human reactions in different traffic situations have for long been analyzed using driving simulation systems, where 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 (Moisio 1973). Here the developments in virtual reality technology will increase the possibilities for realistic simulations (Laakko 1998; SNRA et al. 1998).

A new application area is the simulation of the use and effects of telematic services in traffic. This is on the other hand related to the simulation of traffic flow, and on the other hand to the simulation of human behaviour and decision-making (Algers et al. 1997). Even the effects of totally human-free driving are tested in this area.

In recent years another new area of traffic simulation has emerged, namely simulation of travel demand. This is an area, where the analytical tradition has gone from aggregate gravity modelling to individual based disaggregate choice models. In demand simulation the question 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 behaviour of the individuals. Examples of this approach are the American SAMS and SMART, both still under development (Spear 1996). One of the most advanced modelling approaches, the American TRANSIMS, combines demand modelling and flow behaviour on the streets and roads thus trying to describe the whole traffic system behaviour in one simulation environment (Smith et al. 1995).

4. Trends in traffic simulation

The development in traffic simulation from the early days in the 1950's and 1960's has been tremendous. This, of course, 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 advanced during this 40-year period. Simulation is now an everyday tool for practitioners and researchers in all fields of the profession.

In the following, some of the development trends in sight are shortly discussed. Most of these trends are related to microscopic simulation. It is, however, noteworthy that there are some quite interesting new developments in the theoretical macroscopic models for fundamental traffic flow analysis, which give new insight to the fundamental speed-flow-density relationships (Helbing et al. 1997).

The applications are growing in size, that is, we are moving from the quite well covered local or one facility type applications to network wide systems where several types of facilities are integrated in 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, like in simulation of intersections. In both these cases the use of graphic user interfaces and integration to GIS and CAD systems (Etches et al.) are a feasible approach.

The American TRANSIMS development work 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 (Nagel and Schleicher 1994), which again is a feature that is coming more common in modern applications (Argile et al. 1996). Parallel computing can be achieved for example through simultaneous use of several microcomputers communicating through a local network (Argile et al. 1996).

In addition to the parallel computing, the modern programming principles and methods have their effect on the simulation. 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 way to produce accurate models of traffic flow behaviour (Kosonen 1996).

TRANSIMS is an example of still another change in the approach. The traditional traffic flow descriptions are based on continuous speed and distance variables. TRANSIMS, in turn, uses a discrete approach where the road and street network is build from elements that can accommodate only one vehicle at a time unit. In this cellular automata approach the vehicles move by "jumping" from the present element to a new one (Nagel 1996; Brilon and Wu 1998) according to rules that describe the driver behaviour and maintain the basic laws of physics at present in vehicle movements (Figure 3).

Another way of looking at the need for system level simulations is to develop open environments where several analysis tools can be used interactively to solve the problems each one of them is most suitable. An example of this is the FHWA TRAF-program family and the FHWA Traffic Management Laboratory, whose primary goal is the development of a distributed, real-time testbed to simulate traffic conditions for Advanced Traffic Management Systems (FHWA 1994). For example, a common graphical user interface has been developed for the TRAF-family programs. The cooperation of Finnish, Swedish and British partners around the Finnish HUTSIM program for an open traffic modelling environment (Kosonen 1996) is another example of this kind of work that is going on (Figure 4).

In traffic flow simulation rule based approaches, like in HUTSIM and TRANSIMS, are coming more and more common. In this kind of framework the use of fuzzy logic to describe the human perception can easily be used, and there are several applications of fuzzy car-following models available (Kikuchi and Chakroborty 1992; Rekersbrink 1995; Wu et al. 1998).
Simulation of control systems as a part of traffic operations is also coming more and more important 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 true way. 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 are embedded in control systems for the anticipation of the state of traffic flow and the effects of alternative control measures.

Virtual reality systems and programming tools become in common use, especially in simulations where the driver reactions and behaviour must be analyzed in great detail. Traffic safety related simulation will therefore probably be an area that greatly benefits from VR technology. There is, of course, no reason why VR could not be used in more traditional simulation tasks, as well. In planning applications VR gives new possibilities for the planning work, and for the demonstration of plans to decision-makers and public (Brummer et al. 1998).

The combination of traditional driving simulators and traditional traffic flow simulation systems becomes possible through virtual reality techniques. In traditional driving simulator the test driver has to react to the fixed traffic that he/she sees on the display. A more natural situation is achieved if the traffic also reacts to the test driver behaviour, that is, the vehicle with the test driver comes an interactive part of the simulated traffic flow.

The simulation of travel demand will grow up rapidly. The basic research in time-use studies and trip chaining of individuals combined with disaggregate modelling form a theoretical basis for this new methodology. Demand simulation will also use GIS databases and tools for 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.

References


