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TRAFFIC MODELING SOFTWARE FOR IVHS APPLICATIONS

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ABSTRACT

Intelligent Vehicle/Highway Systems (IVHS) is an an ambitious multi-year, multi-billion research/demonstration program which aims at improving the vehicle/highway system operation and management techniques for the post-interstate construction era. The main goal of the IVHS program, which will carry the Federal Highway Administration into the 21st century, is to develop the state of the art vehicle/highway management, information and control systems which will effectively combat congestion and succeed in providing an increased level of safety, mobility, driver convenience and environmental quality in both rural and urban areas.

This paper begins with an introduction of the framework of IVHS which has four major components: 1) Advanced Traffic Management System (ATMS); 2) Advanced Driver Information System (ADIS); 3) Commercial Vehicle Operations (CVO); and 4) Advanced Vehicle Control Systems (AVCS) and emphasizes the ATMS related research and development plans to support the realtime traffic management systems and control strategies.

This paper then reviews the state of art traffic engineering modeling software currently available from FHWA. The discussion centers around the TRAF system – a family of microscopic and macroscopic traffic simulation software models for surface streets, freeways, and corridor networks. The gap between the capabilities provided by the current traffic modelling software and the functional requirement of the IVHS traffic models are also addressed in the paper. The paper concludes by outlining the work that needs to be done in order to fully support the IVHS program.

1. INTRODUCTION

Sound transportation systems, which ensure the proper movement of people and goods, promote business, facilitate communication, and serve as the backbone for the social and economical development of any country. Over the last few years, however, demand for the use of transportation facilities in the U.S. has increased at a rate much higher than that which can be absorbed by current systems. This phenomena, coupled with the lack of public funding to construct new facilities and accommodate this additional demand, have been the major contributors to traffic congestion.

Mobility 2000 is an ad-hoc group representing public, private, and academic organizations which recognize the detrimental effects of traffic congestion. The thrust of this group has been to develop an action plan which combats congestion and guarantees short and long term mobility. Recognizing the economical impossibility of constructing new facilities to satisfy travel demand and the concern for the preservation of the environment, the Federal Highway Administration (FHWA) and Mobility 2000 have developed the concept of Intelligent Vehicle/Highway Systems (IVHS).

2. WHAT IS IVHS ?

IVHS is the formalization of a concept which maximizes the utilization of existing facilities by applying of state-of-the-art technology to traffic engineering. The overall objectives are to optimize the use of existing roadway systems, minimize the need for additional construction, and establish a sound operational system capable of adequately accommodating future demand.

To simplify its development and implementation, IVHS is broken into four major components: Advanced Traffic Management Systems (ATMS), Advanced Driver Information Systems (ADIS), Commercial Vehicle Operations (CVO), and Advanced Vehicle Control Systems (AVCS). These are briefly discussed below.

ATMS is the backbone of IVHS. It encompasses the development of surveillance system/s capable of monitoring the operational status of a roadway network, development of real-time, traffic-adaptive control system/s which, through the feedback provided by the surveillance system, adapt network control (traffic signals, freeway ramp meters, messages on electronic signs, etc.) for optimal performance, and the development of system operator support systems (expert systems, simulation models, etc.) to enable and facilitate real-time control and management of the network.

ADIS is the framework through which information is made available, not only to the driver, but to the general traveller. ADIS encompasses the development of in-vehicle route guidance systems (audio-visual system like electronic maps and highway advisory radio to enable route selection and optimization), the development of models which optimize network usage, the dissemination of information to travellers which allows for pre-trip and/or en-route planning (i.e., congested highways have affected bus schedules, HOV restrictions have been lifted, etc.) and the quantification of driver behavior to the extent of developing models which replicate how people select routes, how they react to highway incidents (divert?), and how they select the mode of travel.

From a conceptual standpoint, it is very difficult for the driver (an/or any motorist) to distinguish between ATMS and ADIS functions. Providing drivers and/or travellers with status reports on the performance of the network should be considered an ATMS function as it is only the dissemination of the data collected by the surveillance system (regardless if the information is made available through in-vehicle route guidance systems). On the other hand, if such data is complemented by advice on route selection, the function shifts from ATMS to ADIS. Although the distinction from a users' standpoint is trivial, they are very distinct functions from a design and development perspective.

CVO addresses the special needs of commercial traffic. It encompasses many of the ADIS aspects and enables dynamic fleet management. CVO also encompasses in-vehicle diagnostic systems, automated vehicle identification and certification, and driver performance systems. These systems will alert professional drivers of possible vehicle malfunctions, log arrivals at checkpoints and/or jurisdictional boundaries (for tax purposes), and measure driver performance (such as alerting a driver who is experiencing fatigue).

The ultimate goal of IVHS is to develop AVCS – a system where the driver no longer drives; the driver becomes a passenger. AVCS is developing the technology to " drive" a vehicle without human intervention on designated highways which are suitably instrumented. Examples of this technology include the use of radar for guidance within a lane and for sensing neighboring vehicles, automated braking systems, automated steering systems, systems which regulate vehicle speed and minimize the time separation (headway) of platooned vehicles, and others.

There are two major challenges in the development of these systems: integration and anticipation/forecasting. Integration will require the development of highly sophisticated and complex systems and interfaces which must break the hardware interface and compatibility problems. That is, these systems must be flexible enough to interact with different equipment therefore ensuring that costs are kept competitive. On the other hand, these systems must shy from being reactive – sense, analyze, react – and become proactive – sense, forecast, and implement prior to degradation.

Urgency in the development of these systems is of the outmost importance given that, if congestion continues to grow, there will be nothing we can do to ensure our future mobility. It should be recognized, however, that most of the technology needed to implement IVHS is already available. That is, many of the subsystems needed have been developed and, to a certain extent, have been implemented.

In the following sections, the discussion will focus on the modelling needs for ATMS.

3. MODELING NEEDS FOR THE ADVANCED TRAFFIC MANAGEMENT SYSTEM (ATMS)

More specifically, ATMS has been defined as a two part program. The first part is aimed at bringing traffic control systems in metropolitan areas across the U.S. up the state of the art. The second part is a research, development and demonstration program designed to further advance the state of the art, thus enabling ATMS to meet the following system requirements [Euler 1989]:

- Real-time and responsive system - ATMS must be responsive to traffic flow and work in real-time. The implemented traffic management strategy should link real-time traffic monitoring, short-term travel forecasting, and electronic route guidance to integrate highway control and traffic signal control into an integrated traffic management system. Data that are transferred to the control center should be current so that an effective strategy can be devised and implemented quickly.
- Provide route guidance information - collect and disseminate routine guidance to vehicles based on actual traffic conditions. These systems will also be able to predict the number and type of vehicles that will be on a particular road segment and could conceivably give special instructions to different classes of vehicles.
- Include surveillance and detection systems - Surveillance and detection are crucial in a traffic controls system. The surveillance and detection system could be a policeman at the corner or a smart set of detectors on the highway. In either case, a mechanism to transmit that information back to a central control center is required.
- Integrated system - ATMS must include both the management of freeways and alternate routes on surface arterials, thus providing a more effective and comprehensive system;
- Effective incident control management strategies - Incident management is crucial. However, before an incident can be managed, it must be detected and verified, and an appropriate response plan made. The response plan must integrate both on-freeway tactics (vehicle clearance and required maintenance), and diversion strategies (streets involved, changeable messages signs, radio broadcasts, and traffic signal timing during diversion).

In summary, ATMS's surveillance system identifies the presence of vehicles, locates disturbances in traffic flows, and identifies congestion points and accidents. Based on the traffic information collected, ATMS will permit real-time adjustment of traffic control systems, and variable signing to informs drivers about the status of the network [T.T.I 1990]. With intelligent traffic prediction algorithms, ATMS can also prevent traffic congestion by developing on-line traffic control measures based on anticipated degradation in the throughput of networks using current traffic volumes and Origin-Destination (OD) information. Ultimately, when in full integration with ADIS and CVO, ATMS can influence driver route choices by indicating alternate routes to be followed (in case of incidents) or by simply redistributing part of traffic to less congested routes during rush hours [U.S.D.O.T 1990]. The traffic control system function provided by ATMS includes both the signals on the surface streets and metering on freeway ramps.

Preliminary ATMS applications in selected corridors have proven to reduce delay and travel time, improve the productivity of commercial fleets, enhance highway safety, produce energy savings, and improve air quality. However, the full development and implementation of ATMS requires the availability of a comprehensive traffic modelling system.

4. REVIEW OF THE CURRENT TRAF SYSTEM

Historically, traffic simulation models had been constructed to simulate and analyze traffic operation problems for a certain type of roadway facility and at a preset level (micro- or macroscopic) of analysis and reporting detail. Of the some 104 computer models documented in the "Handbook of Computer Models for Traffic Operations Analysis" [Byrne et al. 1982], for example, they can be simply classified by the network geometrics into the following categories: intersection models, arterial models, urban network models, freeway models, and corridor models. Models within each category are only applicable to a single type of physical environment or roadway facility. This model development philosophy was driven by the computer power available at the time and the cost of using such models.

While the usefulness of these models cannot be overstated, in an ATMS or IVHS environment it is questionable that such an isolated treatment of an individual portion of the entire network is capable of providing a traffic management plan that is accurate and compatible with the rest of the non-modeled portions of the network. Today's congestion problems in urban areas are such that a comprehensive traffic management strategy encompassing the full range of measures for all affected facilities is required. Measures such as those that influence route and mode choice of trip makers are essential in the efficient operation of the existing roadway system as well as in the planning of future facility expansion. The ability to unite and unify the various categories of simulation models in an integrated, coherent manner is what led to the development of the TRAF systems.

The FHWA first conceived TRAF in the mid 1970's [Yedlin et al. 1988; Lieberman et al. 1987] and the development of the software continued through the 1980's [Radelat and Tiller 1981]. Even though the development for major modules under TRAF have been completed, FHWA continues upgrading and enhancing various modules to make sure that TRAF can keep pace with advances in traffic control systems and strategies.

The design philosophy of TRAF can be summarized as follows:

- Standardization of input/output format. TRAF should be a single source of traffic simulation program and the user need be concerned with only one set of documentation and one set of input and output format. This approach eliminates the confusion caused by the diversity of simulation modeling processes and formats. It also considerably reduce the effort required by the user to learn and apply the models.
- Integrated system modeling with varying subnetwork details. TRAF should be capable of representing traffic flow in large urban areas consisting of both surface streets and freeways. This requires TRAF to contain an integrated set of simulation submodels which, in aggregate, represent the traffic environment in adequate detail over the specified network. In addition, TRAF needs to be flexible in providing the user with a choice in the analysis detail (or precision) desired for each subnetwork.
- Automatic submodel or subnetwork interfacing. The partition of the entire analysis network into subnetworks for analysis by the submodels and their interfacing should be transparent to the use and be accomplished in one single computer run. As an example, spillbacks from a subnetwork should be preserved and properly simulated in the adjoining subnetworks.
- Traffic assignment capability. An equilibrium traffic assignment model with both user and system optimization capabilities should be incorporated to extend the TRAF package to transportation planners. This enables TRAF to internally translate the origin-destination data into link-specific turning percentages for simulation purpose. With the assignment model as part of the system, the users can easily examine the impact in the travel pattern from the changes is the transportation system such as road closure and detour due to maintenance and reconstruction.

- Reasonable demand on computer resources. TRAF should be operational on virtually any general purpose computer, preferably on microcomputers, and should optimize the efficiency of all computations.

It should be noted, however, that the design and development of TRAF was conceived for off-line applications. The system simulates at much less than real-time and, although most of the basic elements are present, a lot of development remains to be done.

4.1 System Architecture

The organization of the simulation modules within the TRAF system is illustrated in Figure 1. Each of the component models is grouped and listed as below:

Microscopic models:
FRESIM: freeway traffic simulator.
NETSIM: urban surface street network traffic simulator.

Macroscopic models:
FREFLO: freeway traffic simulator.
NETFLO: urban surface street network traffic simulator including Level 1 and Level 2 submodels.
TRAFFIC: equilibrium-based, static traffic assignment model.

Each TRAF components simulation model can be run independently as a stand-alone program or be applied to a specific subnetwork which is a partition of the entire network. The interface of adjoining subnetworks is accomplished by defining " Interface Nodes" which represent points at which vehicles leave one subnetwork and enter another. Associated with each interface node is a " Vehicle Holding Area" that stores vehicles exiting from one subnetwork until they are processed by the subnetwork receiving these vehicles. Continuity of flow from one subnetwork to another is preserved by the program logic, and any spillback occurred at one subnetwork will be carried over properly to another subnetwork. The program logic can also handle the vehicles transition from microscopic subnetwork to macroscopic subnetwork, and vice versa without an user intervention.

4.2 NETSIM

The NETSIM model [Rathi and Santiago 1989] is a microscopic, time-scanning traffic simulation for urban surface street network. To obtain satisfactory simulation results, the user is required to enter detailed traffic and network geometric information such as lane channelization, lane alignment, detector location, etc. During the simulation, the time-scanning logic moves each vehicle each second based on the car-following and lane-changing logic, and in response to traffic control devices and other condition which influence vehicle behavior such as the interference from the bus dwelling the pedestrians. NETSIM can generate detailed network-wide and link-specific Measures of Effectiveness (MOE) such as stops, delay, vehicle-miles, trips, etc. Bus route-specific MOE can also be generated if there is any bus route presented in the network.

4.3 FRESIM

The FRESIM model [JFT Associates 1990] is the latest addition to the TRAF system. It is a microscopic, time-scanning freeway simulation model which evolved from the INTRAS model [Wicks and Lieberman 1977]. FRESIM is capable of simulating very complicated freeway geometrics and operational characteristics which include the following:

- One to five through-lane freeway mainlines with one to three-lane ramps and one to three-lane freeway-to-freeway connectors.
- Variations in grades, radius of curvatures, and superelevation.
- Auxiliary lanes, lane additions and lane drops.
- Incidents and freeway blockages.
- Realistic lane changing model.
- Ramp metering - both clock time and traffic responsive.
- Comprehensive freeway surveillance system.
- Various vehicle types and driver types.
- Driver reaction to warning signs and upcoming geometric changes.

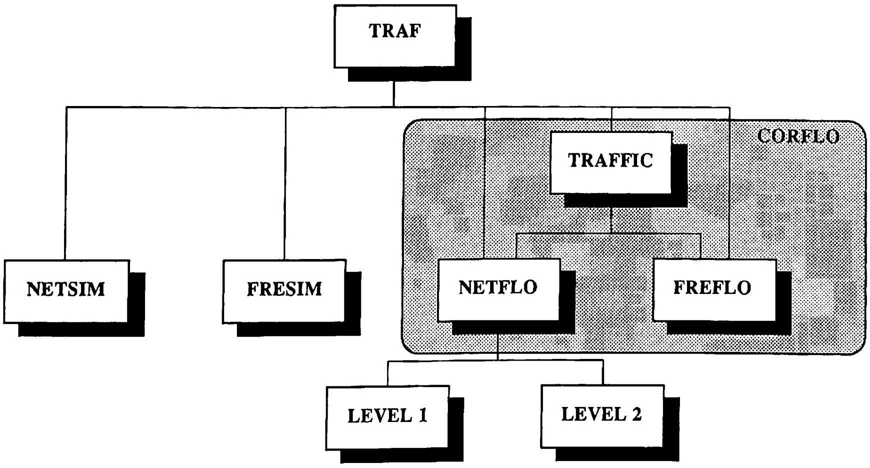

Figure 1. TRAF Structure Chart

4.4 NETFLO

There are two submodels in NETFLO to meet the needs for different precisions: the Level 1 and Level 2 submodels. Level 1 represents vehicles microscopically but process the traffic stream in an event-based fashion. Each vehicle is processed as infrequently as possible. The frequency depends on the condition that the subject vehicle will encounter immediately downstream. The less impedance encountered by a vehicle, in the form of queues and NO-GO signal indications, the fewer processing steps are required to move a vehicle a given distance. Each such processing step thus involves far less computing than for a microscopic model such as NETSIM.

The Level 2 submodel represents traffic stream in movement-specific histograms and the simulation time is defined in terms of time steps. Such representation preserves the platoon structure of the entire stream. For each turning movement on each link, five different histograms are use to differentiate among entry volumes, arrival volumes at the stop lines, service rates, queues, and actual discharge volumes. Vehicles except buses are not represented individually in this submodel. Buses are treated separately so that individual bus can be traced across the subnetwork boundary, thus route-specific MOE can be collected properly throughout the whole network.

4.5 FREFLO

The FREFLO model is a macroscopic simulation model for freeway traffic which is represented in terms of aggregate measures on each section of freeway. The aggregate measures used are flow rate, density, and space-mean speed within the freeway section. The model is based on a conservation equation and an equilibrium speed-density relationship with a dynamic speed equation. FREFLO can simulate disjoint freeway segments. Both the special purpose lane such as the HOV lanes and the regular lanes can be modeled. Incidents are represented as lane reduction or in the form of capacity restraint on the freeway section.

4.6 TRAFFIC

The equilibrium traffic assignment model [Sharaf-Eldien 1989] under TRAF is capable of assigning trip demand tables for a given network specification employing either a user-optimal or system-optimal equilibrium. The model is based on a variation of the Frank-Wolfe decomposition algorithm which can internally prove reliable estimate of turning movement service rate and link travel time, including differential turn penalties and intersection delay. It can be used independently to provide estimates of MOE impacts for a given trip table, or as an intermediate stop to produce the approach turning volumes to be simulated by other simulation models.

5. CURRENT AND FUTURE SOFTWARE MODELS NEEDS

As discussed above, a lot has been done, yet, a lot remains to be done. Some of the very basic simulation needs based on the current concept of IVHS include:

- Dynamic traffic assignment models.
- Real-time traffic responsive signal control logic
- Optimal route diversion models
- System operators' support systems
- Freeway-surface street integrated control
- "Generic" simulation engines capable of testing any new control logic
- Driver/traveller behavior models

A crucial activity is the development of simulation environments where the potential benefits from these technologies can be assessed. These includes benefits to users, developers, State and local agencies, etc.

For example, software can be used to simulate the effectiveness of an AVCS which continuously regulates the speed and position of all vehicles on it. Occupancy of lanes, spacing between vehicles, merging, and exiting would proceed in accordance with prescribed protocols. When a vehicle left the roadway, the driver would recover conventional control. In fact, given that a central computer would know each vehicle's immediate position and eventual destination, all vehicles on the automated highway could be directed in order to achieve some overall optimum such as maximum vehicle throughput. Disruptions in flow due to merging and lane changes could be minimized, and headway and lateral spacing between adjacent vehicles could be reduced to those levels needed for safe operation. From this simulation, one could assess the operational benefits of the system, the overall feasibility of the concept, and assess the technical merit of the system by demonstrating strengths and deficiencies.

6. SUMMARY

It should be apparent that the development and implementation of IVHS technology can only be done through the use of simulation and optimization models. The high cost in acquiring and installing the needed hardware on the roadways can only be undertaken if the economic feasibility of the project, both from an operational and economical standpoint, can be proven.

IVHS is the traffic engineer's response to congestion and will only become successful with the active participation from computer scientists, psychologists, statisticians, electrical engineers, and transportation professionals. We must pursue the aggressive development of automated systems, ensure that our transportation facilities are operating optimally, and introduce the necessary flexibility to accommodate future conditions. The social and economical well being of this country depends on it.

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