A Real-Time Information Processing Algorithm for the Evaluation and Implementation of ATMS Strategies

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Abstract

One component of the overall Intelligent Vehicle Highway System (IVHS) is the Advanced Traffic Management System (ATMS). An ATMS functions as the central nervous system of the overall transportation system, receiving and combining inputs from a variety of standard (on-street loops, operator-inputs) and advanced technology (image processing, in-vehicle probes) sources. Evaluation of ATMS strategies involves simulation of large systems of traffic actuated controllers and, ultimately, development of dynamic "real-time" optimization strategies. In general, existing simulation and optimization tools were developed for "off-line" analysis and typically impose restrictions on the types of signal control systems which can be simulated. This paper focuses on development of a "real-time" information processing algorithm, based on a macroscopic, platoon-based model of traffic flow, for the evaluation of systems of coordinated and uncoordinated traffic actuated controllers.

1. Introduction

An Advanced Traffic Management System (ATMS) comprises one component of the overall Intelligent Vehicle Highway Systems (IVHS) approach integrating advanced surveillance, communications, computers and other high-technologies with the goal of improving mobility, safety, and productivity of transportation systems (Euler, 1991.) Six characteristics differentiate ATMS from other existing traffic management systems (Mobility 2000, 1990):

(1) An ATMS works in real time,
(2) An ATMS responds to changes in traffic flow,
(3) An ATMS includes areawide surveillance and detection systems,
(4) An ATMS integrates management of various functions including transportation information, demand management, freeway ramp metering, and arterial signal control,
(5) An ATMS implies collaborative action on the part of the transportation management agencies and jurisdictions involved, and
(6) An ATMS includes rapid response incident-management strategies.

An ATMS functions as the central nervous system of the overall transportation system, receiving and combining inputs from a variety of standard (on-street loops, operator-inputs) and advanced-technology (image-processing, in-vehicle probes) sources. Using these inputs, an ATMS performs a variety of tasks including incident detection, delay computation, and alternate route determination. Results of these analyses are output to the operator of the system, and more importantly to the users of the system through several techniques including changeable message signs (CMS), highway advisory radio (HAR), pretrip planning services (origin-based video terminals), and in-vehicle navigation systems. Another important function of the ATMS is the capability to monitor and fine-tune traffic control parameters at urban intersections (allocation of green between traffic movements and time-offsets between intersections) and freeway on-ramps (metering rates.)

Traditional traffic control strategies at their most advanced stages of implementation have been represented as a control systems feedback (closed) loop consisting of the following steps (ITE, 1985):

(1) Monitoring of traffic flows and signal operation,
(2) Calculation of system performance measures,
(3) Selection of an alternate control plan from a set of predetermined control plans,
(4) Implementation of the selected plan, and
(5) Verification of correct implementation.

Only recently have systems providing the capability of "real-time" monitoring of signal operation come into widespread use. Technology for monitoring traffic volumes, specifically vehicle turning volumes, is still in its infancy. Calculation of system measures of performance and evaluation of alternate control plans is performed using any of a number of readily available simulation programs and occurs on an off-line basis.

Internal implementation (i.e., software and data structure design) of conventional traffic analysis packages, related specifically to the manner in which vehicles and signal timings are processed, preclude their effective use as tools in the study of the dynamic effects of "real-time" control parameter adjustments on traffic flow. In general, existing traffic analysis programs model the traffic system as part of the control systems model used in existing closed loop traffic control systems described above, computing system performance and optimal signal settings using measures aggregated over the entire study period. Cycle by cycle variations in traffic volumes are ignored. Dynamic modifications to signal control parameters (e.g., fine-tuning of splits and offsets on a cycle-by-cycle basis) and their resulting impacts on traffic flow and progression may not be analyzed using existing packages.

This paper documents an ongoing research project concerned with the specification and development of a simulation model that captures the dynamic aspects of traffic control parameter adjustment and the related impacts on urban arterial traffic flow. An ATMS may be considered as a "black box" connected to the "real-world" only through a series of inputs (local intersection and areawide detectors) and outputs (traffic signal displays and messages to system users.) The simulation model under development will mirror the response of the "real-world" to ATMS changes in inputs and outputs. This model is intended to be an integral part of the development of an overall ATMS adaptive traffic control system, capable of evaluating dynamic adjustments to a signal control plan and selecting optimal courses of action.

2. Background

Existing urban street traffic models may be classified using several model traits. One method of classification differentiates between *simulation* models (i.e., those which simply compute vehicle and system measures of effectiveness (MOE) based on a given set of inputs (intersection and network geometries, traffic volumes and signal control parameters) and *optimization* models (i.e., those which attempt to compute optimal signal timing parameters (phase sequences, green splits and offsets) for a given set of inputs.) Popular simulation models include TRAF-NETSIM (FHWA, 1989), TRANSYT-7F (Wallace et.al., 1988) and PASSER-II (Chang et.al., 1988.) TRANSYT-7F and PASSER-II also provide capabilities to optimize traffic signal green splits and offsets. PASSER-II provides the additional capability of selecting the optimal phase sequence.

Another principal grouping differentiates between *microscopic* and *macroscopic* models of traffic flow. A microscopic model performs MOE calculations by simulating the interactions between individual vehicles and between vehicles and intersection signal timings. Conversely, a macroscopic model calculates vehicle and system MOEs by aggregating the individual vehicles into platoons or, alternatively, modeling vehicle movement using fluid flow-density models. TRAF-NETSIM is a microscopic simulation model, tracking every vehicle in the traffic network, while TRANSYT-7F and PASSER II are based on aggregate models of traffic flow and delay. In general, microscopic models tend towards *time-scan* simulation of traffic flow where vehicles are moved at prespecified time-intervals (usually one-second increments) for the entire study period (ranging from 15 minutes to one hour). PASSER-II uses hourly traffic flows and corresponding delay relationships to compute MOEs for a specific study period (usually one hour.) TRANSYT-7F models platoon flows at a series of time-steps (usually one to three seconds) over two traffic signal cycles (usually two to four minutes); results are then scaled to provide MOEs for the study period.

Advantages and disadvantages may be associated with each modeling approach. While microscopic models tend to produce realistic dynamic responses to incidents and compute realistic measures of effectiveness, these models must track and compute individual vehicle characteristics at each simulation timestep; microscopic simulations of even modestly sized traffic networks tend to be computationally intensive and require large amounts of core storage. Application of these models in evaluation of realistic traffic networks would be prohibitive. Conversely, macroscopic models require significantly less computing resources, allowing rapid simulation of the traffic system. Existing macroscopic models, however, tend to be insensitive to cycle-by-cycle variations in traffic flow and do not allow cycle-by-cycle variations in signal timing parameters.

3. Proposed Methodology

The approach considered in this research involves implementation of a platoon-based, macroscopic, time-scan model of traffic flow in a form consistent with the desirable features discussed in the previous sections. Rather than model individual vehicles, groups of vehicles (platoons) form the basis of evaluation. The following sections describe the pertinent features of the proposed methodology.

3.1 Network Representation

The physical traffic network is represented as a series of connecting intersections. Intersections are connected by

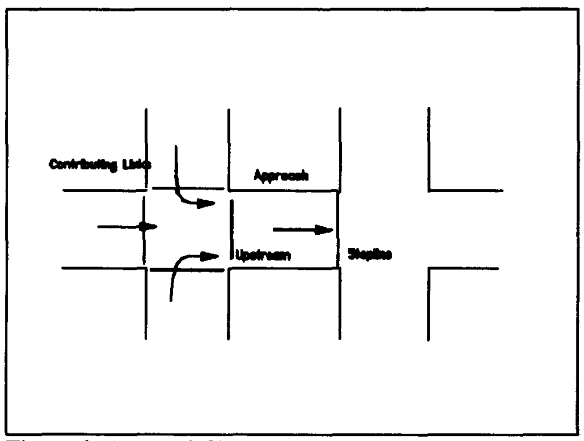

Figure 1: Approach Terms

approaches. Each approach has an upstream end and a downstream (stopline) end. Each intersection consists of one or more stoplines. Each approach is assigned a series of contributing approaches (stoplines) that "feed" the upstream end of the approach. Figure 1 graphically presents some of the relationships between the terms.Individual approach stoplines are represented as groups of traffic movements (links). Traffic signal phases are also represented as groups of links. Timing characteristics (minimum green, extension, maximum extension, yellow, all-red, pedestrian walk and pedestrian clearance) are associated with each signal phase.

3.2 Traffic Flow Representation

Interactions between vehicles and signal timings proceeds on a time-step basis; at each time-step, flows on all approaches in the system are evaluated. Flows at the upstream portion of each link are computed separately from the flows at the stopline. The relationship between upstream and stopline flows is described using platoon dispersion, and is discussed below. The upstream flow of any approach is simply the combination of the contributing approach stopline flows and the traffic signal phases moving during the current time step. For links with standing queues, the saturation flow (maximum flow rate) is assigned to the discharge flow; for stoplines without queues, the upstream flow rate is equal to the contributing approach stopline flow. The upstream flow for each approach is further constrained by the back of any standing queues. As the stopline queue grows and nears the upstream end of the approach, the flow assigned to the upstream end is slightly reduced; when the back of queue reaches the upstream end of the approach, no vehicles are allowed to enter the upstream end approach, resulting in spillback at the contributing stoplines and building of queues along the contributing approaches.

Traffic flows are transferred from the upstream end of each approach to the stopline through a process known as "platoon dispersion". Based on empirical observations, Robertson (1969) proposes a simple model of platoon dispersion. This model may be written as:

$$Q_{t+T} = F.q_t + [(1 - F).Q_{t+T-1}]$$

where

- Q_n is the downstream flow at timestep n,
- q_n is the upstream flow at timestep n,
- T is 0.8 times the cruise travel time on the link, expressed in terms of timesteps,
- F is a smoothing factor, calculated as $1/(1 + \alpha T)$,
- α is a platoon dispersion factor.

This model of platoon dispersion has been implemented in TRANSYT-7F and has been tested extensively under a variety of traffic conditions (Axhausen and Korling, 1987.)

3.3 Traffic Controller Representation

Traffic controllers are represented as sequences of phases. Each signal phase is represented as a collection of moving stopline links and a set of signal timing parameters. Pretimed controllers operate independent of the actual flow rates on the moving links. As the simulation proceeds, vehicles on alternate links are allowed to "move" by assigning the saturation flow rate to those links and zero to the non-moving links; this flow is defined as the "go" flow. The discharge flow rate at any stopline is simply the minimum of the input flow and "go" flow. Actuated controllers (both single and dual ring) operate in conjunction with the flow rates on the moving links themselves. If the flow rate is high enough (based on the extension time of the controller) the green is extended. If the flow rate is below the extension threshold, the currently moving phase is terminated and the next phase is serviced. Flow rates are obtained from detectors placed within the approach at specified distances behind the stopline.

3.4 Measures of Effectiveness

Measures of effectiveness (MOE) provide a means of comparison between alternatives. Standard MOEs include degree of saturation, maximum back of queue and numbers of stops. Uniform delay (delay due to arrivals on red or at the back of the queue) and random delay (delay due to congestion) are calculated using a modified form of Webster's equation (Webster, 1956) which is the same delay model used in TRANSYT-7F (Wallace et.al., 1988.) These measures may be computed on a time step basis; moving averages of various periods may be accumulated. Levels of service (a ranking of intersection performance ranging from "A" to "F", "A" being best) are determined for all intersections following methods prescribed in Chapter 9 of the Highway Capacity Manual (TRB, 1985); route and arterial levels of service are determined from methods prescribed in Chapter 11.

3.5 Discussion

The proposed methodology shares many characteristics with TRANSYT-7F including delay computations and the platoon dispersion model. TRANSYT-7F has received widespread acceptance as a valuable tool to assist the engineer in improving signal timings. There are two distinguishing differences between the proposed model and TRANSYT-7F: relaxation of the common cycle length constraint and explicit consideration of approach capacity based on backs-of-queue.

The common cycle length constraint arises from the manner in which flow pattern and MOE calculations are implemented. Memory conservation was an important programming consideration when Robertson coded the original TRANSYT in 1968. If all intersections were restricted to the same cycle length (and simulation step size), the traffic controller logic would be simplified (reducing program complexity and thus program size), and the memory used to store the temporary timestep by timestep flow rate patterns could be reused (reducing demands on core storage). As computer memory is now less of a constraint, the proposed methodology computes flows and delays in a time-scan fashion and retains the intermim time step measures of performance on a link by link basis for later MOE calculation (as moving averages.) Thus, each intersection is no longer restricted operate on its own cycle length. This relaxation allows explicit representation of traffic-actuated controllers within the program. Additionally, evaluations of sub-systems of controllers operating at alternate cycle lengths may be performed.

Explicit consideration of backs of queues (in relation to overall approach length) provides a realistic representation of spillback across approaches and ensures proper operation under heavily congested conditions. The proposed methodology implements these considerations as an additional constraint during calculation of the "go" flow (the logic is described in 3.2 above).

4. Implementation

Initial testing of the proposed time-scan processing algorithm and back-of-queue constraints was performed with the existing framework of the TRANSYT-7F program (Release 6.4). New data structures were developed and the core simulation routine of TRANSYT-7F (SUBROUTINE SUBPT) was recoded. MOE and platoon dispersion calculations were likewise modified to reflect changes in internal storage. The initial testing of the proposed methodologies included investigations of convergence and stability with the intent of demonstrating that the proposed methodology will replicate TRANSYT-7F outputs when similar assumptions (common cycle lengths, uncongested conditions) are applied. Further investigations studying the effects of relaxation of these constraints, as well as implementation of dual-ring traffic actuated controller and traffic detector logics requires that the proposed methodology be coded within an entirely new framework.

5. Results and Conclusions

The proposed algorithm was tested on a simple grid network consisting of 6 intersections, 10 approaches, and 67 traffic movements (links). A network schematic is presented in Figure 2. Signal timings in the network ranged from simple 2-phase sequences to actuated 8-phase sequences (6-phase estimated.)

Simulation outputs from the proposed algorithm were compared with outputs generated by TRANSYT-7F (Release 6.4). Measures of effectiveness for the proposed algorithm were computed for the preceding 60 time-steps (the number and size of the time steps were selected to match between programs). Figure 3 presents a plot of the percent difference (in overall performance index) between the proposed model and TRANSYT-7F versus simulation time. Because the proposed methodology performs a time-scan simulation, a period of initialization was required to completely fill the network (and the corresponding MOE arrays.) After approximately three cycles (180 time steps) of simulation in the proposed methodology, outputs from both program matched exactly; the flows and MOEs of the proposed methodology converged to those of the original TRANSYT-7F program (and the corresponding performance indexes converge). Additional simulation time provided to the proposed algorithm does not produce any changes in the MOEs as computed for the prior 60 time-steps, demonstrating that the simulation is stable over time.

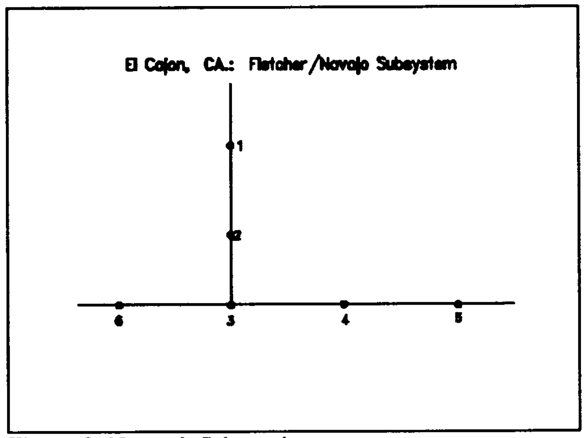

Figure 2: Network Schematic

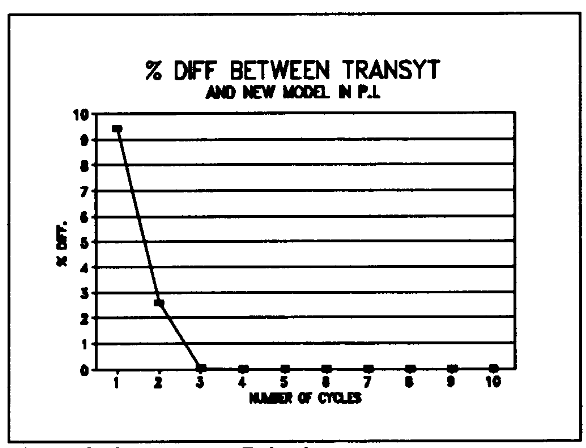

Figure 3: Convergence Behavior

Further investigations into the queuing and spillback behavior of the proposed methodology are ongoing. Preliminary findings demonstrate the desired behaviors; investigations into the dynamic properties of the queues (rates of growth and dissipation) being performed.

6. Acknowledgements

This research is sponsored by the California Department of Transportation, University of California Transportation Center and the UC Irvine Institute of Transportation Studies. Their support is gratefully acknowledged.

7. References

Axhausen, K. and H. Korling (1987). "Some Measurements of Robertson's Platoon Dispersion Factor" in Transportation Research Record 1112. Transportation Research Board, Washington, D.C.

Chang, E., et.al, (1988). PASSER II-87 Users Guide. Texas Transportation Institute, Texas A&M University, College Station.

Euler, G. (1991). "Intelligent Vehicle-Highway Systems" in Pine, J.L.(ed). Transportation and Traffic Engineering Handbook, Fourth Edition. Prentice Hall, New Jersey.

Federal Highway Administration (1989). TRAF-NETSIM Users Guide. U.S. Department of Transportation Office of Traffic Operations, Washington, D.C.

Institute of Transportation Engineers (1985). Traffic Control Systems Handbook. Institute of Transportation Engineers, Washington, D.C.

Mobility 2000 (1990). Final Report of the Working Group on Advanced Traffic Management Systems, February.

Robertson, D.I. (1969). TRANSYT: A Traffic Network Study Tool. Transport and Road Research Laboratory, Crowthorn, Berkshire, England.

Transportation Research Board (1985). Highway Capacity Manual. Special Report 209. Transportation Research Board, Washington, D.C.

Wallace, C., et.al (1988). TRANSYT-7F Users Guide. University of Florida Transportation Research Center, Gainesville.

Webster, F.V. (1956). Traffic Signal Settings. Road Research Technical Report, No. 39, London.