PARALEL SIMULATION OF CITY TRAFFIC FLOWS USING “PADSIM” (Probabilistic ADaptive SImulation Model)

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1. Introduction

During the last two decades significant research effort has been invested into development of various computer assisted traffic control schemes. The evolution of these control schemes reflected the changes in optimization criteria that evolved gradually in line with the accumulated operational experience. Early traffic control systems essentially performed static optimization of the maximum bandwidth of the “green waves” on specific routes in the city. This worked well on lightly or moderately loaded signalized arterials with few vehicles turning in from side roads. However, the optimization of a more complex city traffic required taking into account other performance indices such as the length of queues on traffic lights or the number of vehicle stops during a journey. More recent control systems use the on-line traffic flow data to modify the split/cycle/offset timing of the road junction lights in response to random fluctuations of traffic intensities. The projected developments of the traffic management systems of the 90's incorporate the inclusion of priority levels for various groups of users, road pricing, in-car route guidance systems, etc. As the control strategies grow in complexity, requiring expensive real-time measurements to maximize the road capacity, there is a need for the assessment of their effectiveness. While the test scenarios for the field trials of the early control systems, which were concerned with the average levels of performance, were relatively easy to design, the evaluation of the new control schemes is a much more demanding task since it requires extensive probabilistic studies that relate the controls and the random fluctuations of traffic flows.

The effectiveness of control systems depends on the accuracy of the modelling process and the prediction model. Several types of traffic models have been used with demand-responsive traffic control systems. In parallel with the development of new control systems, there have been developments of the simulation models aiming at a more realistic representation of vehicle states and their behavior. Early simulation models simulated vehicles as moving at constant speed, and queued them vertically at the stop line. An example of such a system is ACTS (Adaptive Control of Traffic Signals) which was first developed in 1983(Gartner, Kaltenbach 1983). PRODYN (Henry 1983) is an example of another centralized system for urban networks which uses similar traffic model. Because of the inherent inaccuracies, regarding the measure of the free space of the road, this type of models produce poor results in near congestion situations. Current simulation systems use a more realistic representation of vehicles and their state. For example PACKSIM (Grau and Barcelo 1992) is a simulation model which deals with packets of vehicles (macroscopic simulation), simulates horizontal queues as well as offers realistic representation of merging and give ways at intersections. Another example of an advanced simulation software is HUTSIM (Kosonen, Pursula 1990) which simulates and examines in detail the behavior of the traffic flow, but is designed only for one intersection, or multiple intersections controlled by one signal controller unit.

However, regardless of the sophistication of the simulators, it must be recognized that the simulation results can only be “correct” in a statistical sense. Consequently, if these results are to be used in the process of deriving the control decisions, the simulator must quantify the confidence limits on the results it produces. In other words, it must evaluate to which extent the discrepancy between the assumed and the actual traffic volumes and the random variation of drivers decisions, affects the accuracy of calculated traffic flows, journey times, average queue length etc.

This paper describes a new microscopic traffic flow simulator that is an essential component part of a predictive decision support system for operational control of a city traffic that is being developed at The Nottingham Trent University. The simulator reconciles a particle-oriented simulation model with probabilistic description of the traffic flow and relates them to the measurement information provided by the installed telemetry system. The simulator has been designed for the ease of a parallel processor implementation so that the growth of the physical system can be managed by system decomposition and parallel simulation of subsystems.

The Probabilistic ADaptive SImulation Model (PADSIM), developed at The Nottingham Trent University, has been designed to be a tool for both the Confidence Limit Analysis and to be embedded into existing traffic control systems. The PADSIM model represents a middle ground between the microscopic deterministic simulation, which is computationally intensive, and the macroscopic simulation which sacrifices the realism of individual vehicle simulation. It is capable of accepting incoming data from the real-time control system (traffic flow measurements, Split, Cycle and Offset for traffic lights etc.). The simulator achieves high computational performance by means of parallel simulation of the different parts of the traffic network, while requiring only a small amount of data to be exchanged between the subsystems

2. PADSIM environment.

The general processing environment of the PADSIM simulator is illustrated in Figure.1.

In order to achieve a high degree of correspondence between the simulated and the actual traffic states, the simulation software compares the calculated flows with the physical measurements and adaptively tunes its internal parameters to minimize any discrepancies. It should be noted that PADSIM simulation involves concurrent execution of two traffic network control tasks (such as SCOOT).The first one controls the physical road network

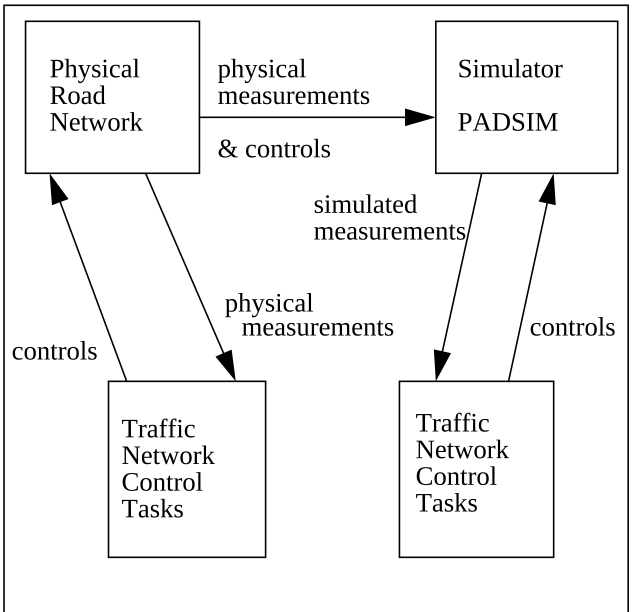

Figure 1. PADSIM simulator environment

and the second one controls the simulated network. Such arrangement allows the PADSIM simulation to run ahead of real time. The traffic network control task acting on simulated measurements provides control sequences which effectively anticipate traffic situations thus assisting an operator in making appropriate supervisory controls.

3. PADSIM approach

PADSIM shares some of its characteristic features with other modern simulation models and introduces some unique features, concerned with confidence limit analysis. PADSIM relates to the previous systems as follows:

- it provides microscopic simulation as in ACTS, PRODYN and HUTSIM.
- it implements horizontal queue estimation and simulation as in SCOOT and PACKSIM.
- it implements turning movement simulation as in PACKSIM.
- it provides feedback signal processing as in SCOOT and PACKSIM.
- it provides simulation of changeable speed of cars in the sections.

PADSIM is designed to be used with existing traffic control systems (such as SCOOT for example) and as a part of a decision support system. It's unique features in support of this role are:

- new probabilistic description of the traffic flows in the model.
  (Probabilistic description of car behavior in the streets and in cross-roads instead of a deterministic route assignment to the individual car)
- Reduced amount of information to be exchanged allows to split the traffic network into subparts and to simulate the different parts into UNIX environment on different machines using shared memory.
- differentiation between the two types of feedback data:
  -- traffic flow data (received from the telemetry system)
  The simulator relates these telemetry data to the internal probabilistic traffic flow description.
  -- control feedback data (from the working control system).
  The simulator reflects all the changes in the split, offset and cycle of the traffic lights.
- original interpretation of the statistical data (unknown-but-bounded uncertainty model).
- transition from macroscopic to microscopic car movement simulation as the vehicle progresses from the node to the road section.

4. Simulation Network modeling

For the purpose of the traffic network simulation, the physical network is modelled using three basic building blocks: road sections, nodes, and traffic lights. This model is then refined by means of inclusion of some additional information regarding the preferred routes, en-route parkings etc.

Nodes: The nodes represent crossroads, road junctions or the boundary points of the simulated network (or a part of it). A node which delimits the boundary of the simulated network (or a part of it) is labelled as a Boundary Node. The Boundary Node may have one or both of the following features:

- a random traffic generator representing incoming traffic flow from outside the simulated traffic network (or, alternatively, outgoing from the other part of the network).
- a “sink” property representing the traffic leaving the simulated network through this node. The remaining nodes are labelled as Transit Nodes and they are assumed to satisfy the criterion that the balance of traffic flows from the adjoining sections to these nodes is zero. Figure 2. illustrates a small network for which the nodes 1,2,4,6,7,8 are the Boundary Nodes, and nodes 3 and 5 are the Transit Nodes.

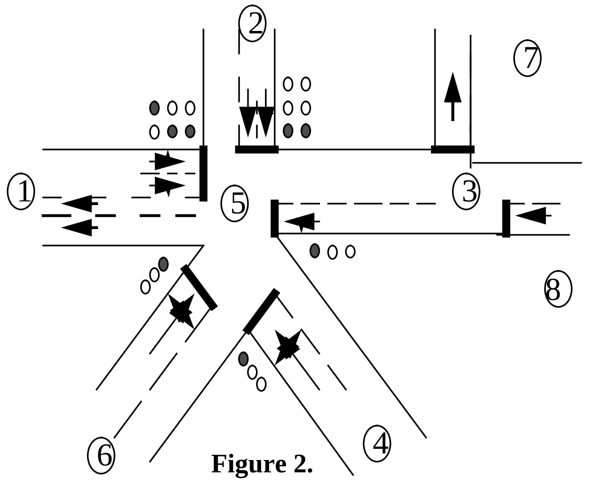

Figure 2.

Road sections: Every section connects two Nodes. It can have one or two directions and several lanes in each direction. The description of the section contains all the basic information the simulation might need such as: number of lanes, length, width, max. speed of the vehicles in the section, feasible turns from this section etc. In addition every direction in a section has an associated probability function describing the traffic flow in this direction.

Traffic lights: Every traffic light is associated with one or more lanes in a particular direction and have a number of corresponding parameters such as split, cycle and offset times specified for it.

5. PADSIM Simulation - Main Principles

The simulation is performed by executing sequentialy the component tasks of each of the two concurrent loops. The internal structure of the simulator is presented in Figure 3. The component tasks have been arranged into two concurrent loops. The first loop is concerned with adaptive identification of parameters characterizing traffic flows and the second loop is concerned with predictive simulation. The two loops are semi-independent in that they cycle with different rates.

The communication between the tasks of the two loops is implemented by means of shared memory with appropriate access locking mechanism.

- Traffic Data Collection

Data generated by vehicle presence detectors are compiled into statistically meaningful sets. The size of these sets, and the associated length of sampling time, are determined by the intensity of traffic, at a particular time of the day. All available information about traffic lights split, offset and cycle is also collected by this task.

- Correlation of meter readings

The accuracy of traffic system simulation depends critically on the knowledge of vehicle dynamics (acceleration/decceleration) and the knowledge of an origin-destination function for every vehicle. Yet, typically, no direct measurements of these entities are made during the normal operation of the network. This module attempts to extract the implicit information about origin-destinations of vehicles by statistically processing the road occupancy data, provided by the telemetry system. The module correlates the patterns of road occupancy on consecutive transducers and derives information about turning movements of the vehicles. The combination of all turning movements in the network provides an approximation of the origin-destination function. The accuracy of this approximation is quantified in statistical terms.

Similarly the acceleration/decceleration parameters are derived by measuring the time delay between the change of the signal light and the corresponding pulses from the road occupancy transducers activated by the vehicles that have re-started. In order to achieve statistically valid results these calculations are averaged over a period of time.

The origin-destination functions and the values of acceleration/ decceleration parameters are refined iteratively by comparing the results of simulation that are based on these parameters with the actual measurements carried out in the physical system. The parameters are stored in shared memory as illustrated in Figure 3.

- Calculation of “average” traffic volumes

The road occupancy meters provide instantaneous values of traffic volumes. However, the random nature of traffic flows (big variance) means that it is necessary to derive suitable functional description of traffic flows before the simulation can be attempted. This module averages the traffic flow measurements and attempts to filter-out the random component from the underlying trend. Since the underlying trend is time dependent, its evolution is modelled using Autoregresive Moving Average Model.

The resulting time function of generating/sinking of traffic is

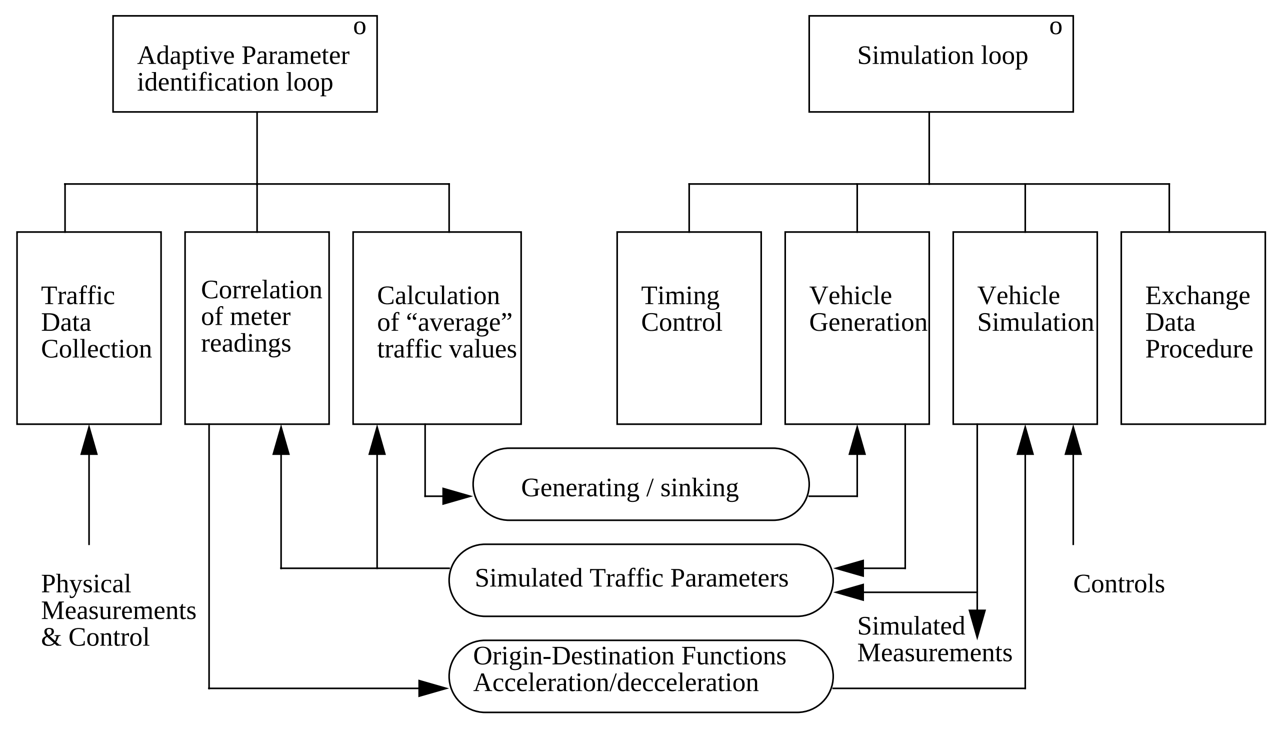

Figure. 3 Component Tasks of PADSIM Simulator

made available to the microsimulator through shared memory (Figure 3.).
The module also calculates the discrepancies between the physical and the simulated measurements and it refines the values of the generating/sinking parameters.

- Timing control

In order to accommodate the requirements of a decision support system the simulator has an in-built facility to step ahead of the real time thus producing a tool for "what-if" type of inquiries from the operator.

- Vehicle generation

Vehicles are generated at the boundary points of the simulated network according to the functions that were identified through statistical processing of road occupancy measurements. An additional component of "distributed" generation of vehicles has been included to account for the reactivation of parked vehicles or inflow of traffic from unmodelled junctions in the network.

- Vehicle simulation

-- Section vehicle movement simulation

Every section is divided into three parts:

--- part A is the part where all the vehicles in the current traffic flow are treated equally, they have no route, they have no knowledge about their next turn (yet). A vehicle can be positioned in any lane of the section according to the speed it has had assigned on entering the section.

--- part B is the part where the vehicle decides about the next turn (see turning movement rules). The simulator attempts to move each vehicle into appropriate lane and to progress it with an appropriate speed taking into account the collision detection rules and the speed activation rules as in part A.

--- part C is the part where the queue is formed. The vehicles are stationary until there is a permission for entering the crossroad (green light). The simulation of the movement in the queue is performed according to the rules which are appropriate for a given crossroad. The length of part C of the section varies according to size of the queue. The remainder of the section is divided between part B - 30%, and part A - 70%.

-- Crossroad vehicle movement simulation

The number of the vehicles traversing the crossroad is directly related to the dynamics of individual flows. The information provided by "Traffic Data Collection" procedure is used to calculate the current state of each traffic light.Traffic lights can be situated at some of the Nodes in the network and they are characterized by:

--- cycle time in seconds (time from one "green" signal to the next),

--- offset time (time difference between the local "green" signal and the "green" signal of the preceding traffic lights,

--- split of the cycle into "red", "amber" and "green" times.

-- Turning movement rules

When a vehicle enters part B of a road section the simulator assigns a turning movement to this particular vehicle. This assignment is performed according to the probability function characterizing the split of the traffic flow from the current section into the all adjoining sections at the next cross road.

- Exchange data processing is performed by the simulator once in every loop cycle and it involves storing information about sinking/generation of the vehicles in all boundary Nodes of the network (sub-networks).

6. "PADSIM"s Features for Parallel Network Simulation using distributed UNIX environment

Realistic urban traffic network consists typically of several hundreds of nodes and many thousands of vehicles. For example the Nottingham city traffic network required specification of 1150 nodes, 1330 road sections and is estimated to accommodate the movement of 15000 to 50000 vehicles depending on the time of the day.
The successful parallel simulation depends on:

- Proper spliting of the traffic network:
  - -- Node and road section renumbering
  - -- Decomposition optimization
- Successful coordination between several copies of the simulation software.
- Proper parallel distribution implementation.
- Successful description of the outgoing and incoming traffic flows for each subsystem.

This paper concentrates on the simulator's features which allow proper parallel work of several copies of the simulation program.

Nottingham Traffic Network Description

A comprehensive road map of Nottingham city has been created using "TEDI" editor (a software developed at The Polytechnic of Barcelona, Spain). The software maintains the data base for the whole city, and allows retrieval of user specified areas for simulation purposes. "TEDI" provides suitable numbering of the road sections and nodes allowing reading and using the same road section numbers and the same node numbers for different application programs.

Spliting Traffic Network

Every part of the traffic network can consist of any number of Road Sections, Nodes and traffic lights. It is recommended, that groups of road sections that share one control strategy (e.g. SCOOT area) should belong to the same subsystem of the network. The actual number of nodes and road sections in a subsystem is a result of an off-line optimization which balances physical size and the traffic volumes in all subnetworks. The

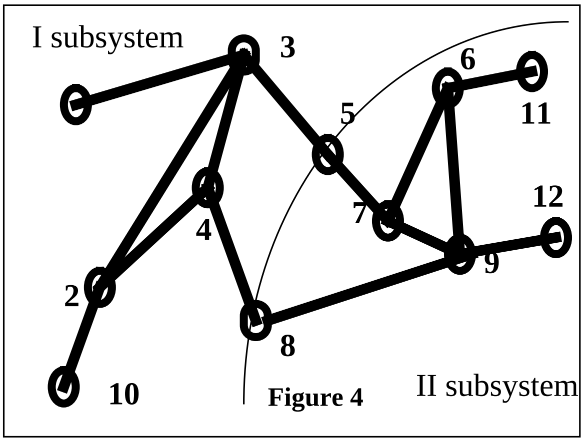

Figure 4

subnetworks are connected through "Boundary Nodes" (figure 4). For the example of Figure 4. the network is divided into two subsystems. The first subsystem consists of nodes 1, 2, 3, 4, 5, 8, 10 and the road sections between them, while subsystem 2 consists of nodes 5, 8, 6, 7, 9, 11, 12 and the road sections between them. Nodes 1, 10, 5 and 8 are Boundary Nodes for the first subnetwork, while 5, 8, 11, 12 are Boundary Nodes for the second subnetwork.

Parallel Simulation.

For the example system on Figure 4. two copies of the simulator program are started on two different machines. Each copy reads and renumbers the nodes and road sections of the corresponding subsystem and performs traffic flow simulations.

Distributed shared memory is used for dynamic data exchange and traffic flow coordination between the two copies of the simulator. The correct simulation needs all the data provided by the simulators to be consistent, which means that the value for the "sinking" feature for any particular boundary node (calculated as a result of the traffic flow simulation in that specific subsystem) should be equal to the value for the generating feature for the same node for the other subsystem (nodes 5 and 8 in the example):

F(5-->7) = F(3-->5)

F(5-->3) = F(7-->5)

F(8-->9) = F(4-->8)

F(8-->4) = F(9-->8)

The internal representation of the traffic flows (no route is assigned to the specific vehicle) does not require the simulator to track one particular vehicle through all subsystems of the whole traffic network, thus only the information for the "sinking" and generating of traffic at boundary nodes needs to be exchanged. The amount of this information is very small (four numbers for the example system of figure 4).

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6. Conclusion

Several types of traffic models have been used with demand-responsive traffic control systems. However, they all share a deterministic approach to the representation of traffic data. This paper introduces a new approach for parallel simulation based on the processing of probabilistic information associated with events and measurements in traffic systems. The PADSIM model combines microsimulation of the vehicles with a statistical interpretation of macroscopic traffic flow measurements.

Suitable traffic flow representation allows running several copies of the simulator simultaneously. There is no route assigned to the particular vehicle and consequently the requirement for data exchange between the concurrent copies of the simulator is low.

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