MICRO SIMULATION OF CITY TRAFFIC FLOWS IN SUPPORT OF PREDICTIVE OPERATIONAL CONTROL

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ABSTRACT

This paper describes a new efficient microscopic traffic 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 model with the macroscopic character of measurement information provided by the installed telemetry system. On the microscopic level, the simulator evaluates for each vehicle the dynamically changing micro-environments which determine the feasibility of the intended movements of a given vehicle. At the same time, the turning movements at the road junctions are modelled macroscopically, through the probability density functions that can be related to the traffic flow measurements. The paper discuses how the combination of these two complementary features of the simulator affords accurate predictions of traffic flows through the adaptation of its parameters.

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 fluctuation 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 Probabilistic ADaptive SImulation Model (PADSIM), developed in the Department of Computing at The Nottingham Trent University, which is designed to be a tool for confidence limit analysis as well as to be embedded into existing traffic control systems. It offers a realistic vehicle simulation, probabilistic traffic flow description which is convenient for confidence limit analysis and is capable to accept incoming data from the real-time control system (traffic flow measurements, Split, Cycle and Offset for traffic lights etc.).

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 SCOOT, ACTS and PRODYN
- it implements horizontal queue 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 system (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,
- differentiation between the two types of feedback data:
  - -- traffic flow data (received from the telemetry system)
  - -- control feedback data(from the working control system)
- 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

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 parking etc.

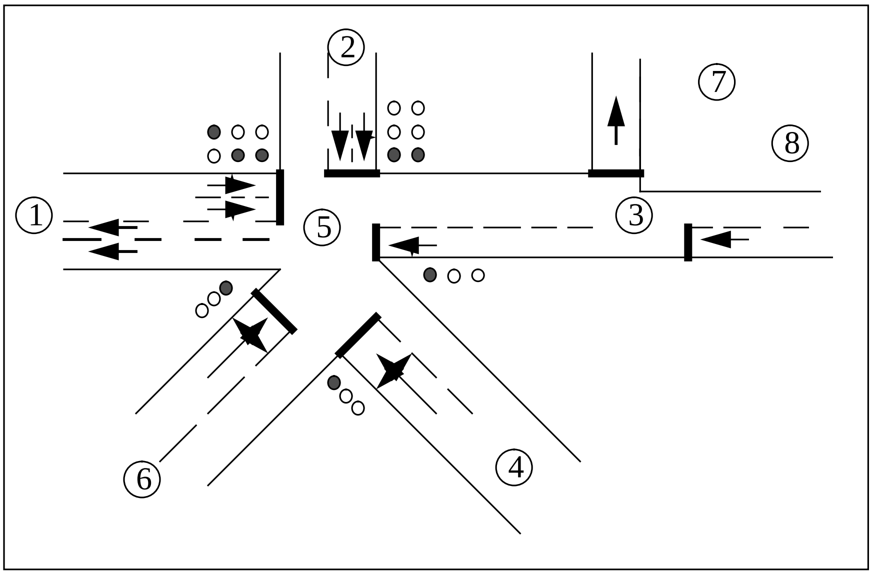


Figure 1.

Nodes: The nodes represent crossroads, road junctions or the boundary points of the simulated network. A node which delimits the boundary of the simulated network 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.
- 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 1. 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.

Road sections: Every section connects two Nodes. It can have one or two directions and several lanes in each direction. A section is described by giving the length of the connection in each direction (can be different), the number of lanes in each direction (can be varied according to demand), and the turning access from each lane of the section. Every direction in a section has an associated probability function describing the traffic flow in this direction. On the figure 1 there are 6 bi-directional sections: 1 - 5, 2 - 5, 3 - 5, 4 - 5, 6 - 5, 3 - 8, and 1 uni-directional section: 7 - 3. Consequently the network description includes 13 probability functions for the corresponding directions.

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.

Simulation - Main Principles

The simulation is performed via consecutive execution of procedures for every internal task of the simulator. The general structure of the simulator is outlined below in pseudocode:

```
Initializing Procedures;
main loop
  action = ChooseNextAction ();
  case
    action = Timing control:
      begin
        if SimulationType = Advance then
                DecreaseSimulationUnitDuration;
        if SimulationType = EndAdvance then
              RestoreSimulationUnitDuration;
        ModifyInternalSimulationTime;
      end;
    action = Vehicle generation:
      begin
        Incoming Vehicle Generation (from Boundary Nodes);
        Vehicle Generation from internal sections;
      end;
    action = Vehicle movement simulation:
      begin
        Section vehicle movement simulation;
        Cross-road vehicle movement simulation;
      end;
    action = Traffic lights simulation:
      begin
        Calculate new traffic lights state;
        Traffic lights simulation;
      end;
    action = Feedback data processing:
      begin
        Accept new traffic lights state;
        Measured traffic flow data processing;
        New turning movement percentages calculation;
      end;
endloop;
```

Main tasks performed by the simulator are:

- Timing control

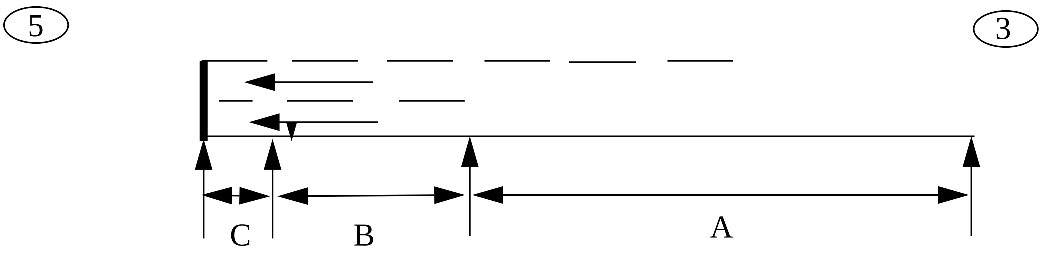
In order to accommodate the requirements of a decision support system the simulator has an in-built facility to step ahead of the real time thus producing a tool for "what-if" type of queries from the operator. This is implemented by the modification of the duration of the internal loop.

- Vehicle generation

There are two mechanisms for adding a vehicle to the existing traffic: generation of a vehicle at the Boundary Node or a re-activation of a parked vehicle. In the first case a vehicle is added at the Boundary Node according to a given probability function (this function describes how often and how many vehicles are joining the system. In the second case vehicles are generated at the mid-point of each section, again according to probability functions as specified for each section. These functions can assume negative values, which models the situation where parking exceeds re-activation. There is no route assigned to any of the vehicles. Once a car riches a Boundary Node it is removed from the simulation model.

- Section vehicle movement simulation

Every section is divided into three parts:



C -- waiting for traffic light
B -- joining appropriate lane
A -- moving in any lane

Figure 2.

-- 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. This speed has a random variation from the average speed in the connection. There is a collision detection check performed by the simulator and the speed of every vehicle is modified according to the space available for the movement.

-- 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 vehicles. This is an uncontrollable and widely varying parameter. In order to reflect this variability, the simulator provides means of specifying, in statistical terms, the lower and upper bound of the maximum number of vehicles crossing the junction. The simulator differentiates between two situations of a traffic progressing: in a "green wave" and from a standstill. A typical profile for the throughput of the crossroad is illustrated in figure 3, where Zone A corresponds to the "green wave" traffic and Zone B to the traffic that has been stopped and re-started. The volumes Ng^u, Ng^l, Ns^u and Ns^l marked on the diagram denote upper and lower limits for the maximum throughput for the two respective situations.

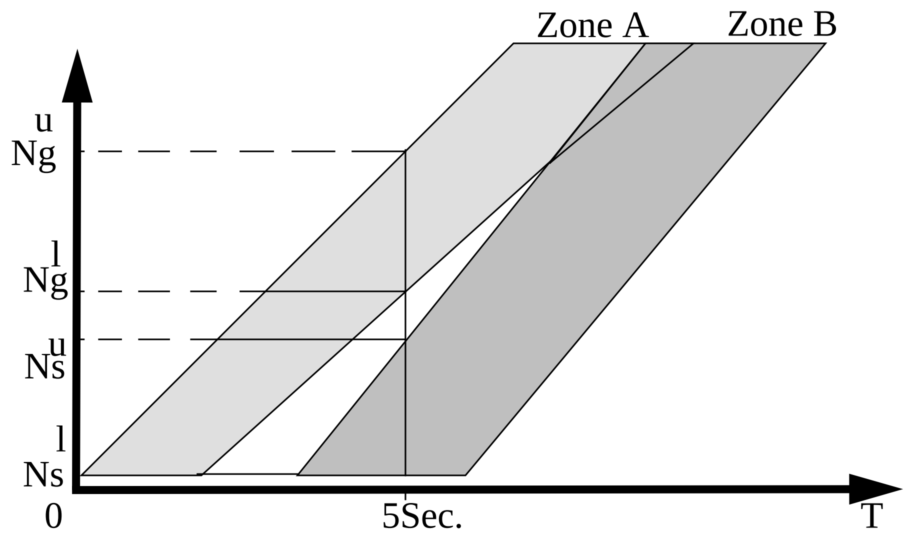


Figure 3.

- <u>Traffic lights simulation</u>

Traffic lights can be situated at some of the Nodes in the network. 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.

Traffic light simulation is performed once for one period of the internal time and if there are any modifications to the settings of the traffic lights. All the values of split, cycle and offset can be changed during the work of the simulator according to the control sequences issued by the real-time control system.

- <u>Turning movement rules</u>

When a vehicle enters part B of a road section the simulator assigns a turning movement

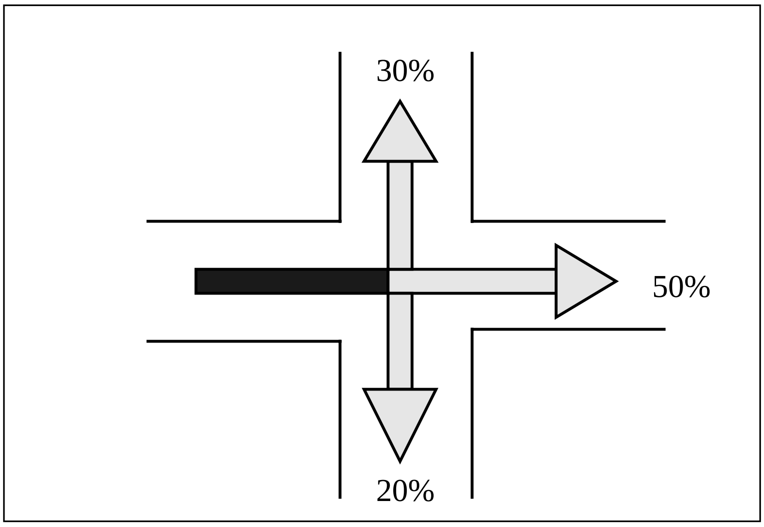


Figure 4.

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. From now on the vehicle will attempt to position itself in appropriate lane in order to implement this turn. After passing the crossroad and on entering the part A of the next section the vehicle has its turn label deleted. The next turn is assigned to this vehicle when it reaches part B of the new section.

- Feedback data processing

There are two kind of feedback data processed by the simulator: Traffic flow data from the telemetry system and control data from real-time traffic control system.

-- Data from real-time telemetry system

This data describes the current traffic flow at discrete locations in the traffic network. However, because of the nature of the measuring devices, the raw data collected through the transducers needs to be interpreted in the context of the specific traffic situation. The combination of the inaccuracies inherent to the measurement process and the inaccuracies of the subsequent interpretation leads to the data that has a relatively wide confidence limits. The simulation has, at present, in-built heuristics that attempt to relate the confidence limits of the real measurement data to the confidence limits of the simulation results. A more comprehensive interpretation of the measurement data will be possible through the state estimation process which is currently being developed.

-- Data from existing real-time traffic control system

This data describes the control sequences of the controlled traffic lights. The data is deterministic and the occasional error conditions are clearly identifiable. The only important consideration for the simulator is that it should be designed in such a manner, that any change in the traffic lights control parameters should be readily accepted. The proposed model satisfy this requirement and is capable to continue simulation with the new parameters.

- Statistical data processing is performed by the simulator according to a user specified cycle time (typically every 15 minutes). The simulator stores on the disk traffic flows in all directions for future use and future statistical processing. At the same time the simulator reads previously stored and processed statistical data. These processed data are used during the simulation to estimate the traffic trends in the context of the previously accumulated knowledge on traffic flows at co-related times (differentiation of the statistical data for the relevant stages of the modelling process).

In order to facilitate the case of use the PADSIM software has been equipped with a simple graphics based user interface.

The model is coded in ANSI C and is X11_Windows compliant, thus being highly portable.

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 based on the processing of probabilistic information associated with events and measurements in traffic systems in order to quantify the confidence limits on predictive simulation. The PADSIM model combines microsimulation of the vehicles with a statistical interpretation of macroscopic traffic flow measurements. The model is designed to be a tool for further confidence limit analysis of the real-time data, obtained from the existing traffic control systems.

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