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***Abstract*—A VOIR**

***Keywords*-Traffic-responsive signal control, stabilizing policy, fixed-time control, max-pressure control, semi-actuated, fully actuated, ACSLite controllers, store and forward queueing model, discrete-event simulation, Monte Carlo simulation, network performance evaluation.**

I. Introduction

A network of signalized intersections is modelled as a network of controlled queues, with a separate queue per movement or phase. These are point queues of a limited storage capacity for this study. Vehicles enter the network at entry links in a Poisson stream with specified demand rate, make turns at intersections with fixed probabilities and leave the network when reach an exit link. Network evolution is modelled as a controlled store-and-forward (SF) queueing network. At any time, a control policy actuates a stage, i.e. a set of simultaneous movements, for a duration of time.The actuation of a movement causes the corresponding queue to be served.

The large literature on signal control policies is reviewed in [**?**], [**?**], [**?**], [**?**]. Each study proposes an intuitively appealing policy, supported by an illustrative simulation, since mathematical analysis of a store-and-forward queuing network with blocking seems impossible. However, it seems not to be known whether a particular fixed-timed control will stabilise the network, i.e., bounded mean queue length. That answer is obtained by Theorem 3, Ecrire cite Varayia, fichier . bib. Different control schemes are compared in this paper in the context of the arterial network near the I-15 freeway in San Diego, CA, shown in Fig.1. Theoretical properties referred in paper encore ajouter cite varaiya 2013, are verified via simulation implementations. More precisely, different versions of Max-Pressure (MP) decentralised policies (all employing only current local information of the adjacent intersection links) are studied and compared with Fixed-Timed (FT) and other adaptive controls such as Fully Actuated (FA), Fully Actuated with max green (FA-MG) etc.

PEUT ETRE PRESENTER CHAQUE SECTION

II. Single Intersection Model

Each intersection is comprised of the related intersection node $n \in \mathcal{N}$ like node 37612 in Figure 1 and a collection of directed links, $l \in \mathcal{L}_{all}$.

There exist three types of links: entry links, (link $741 \in \mathcal{L}_{entry}$), exit links, (link $742 \in \mathcal{L}_{exit}$) and internal links

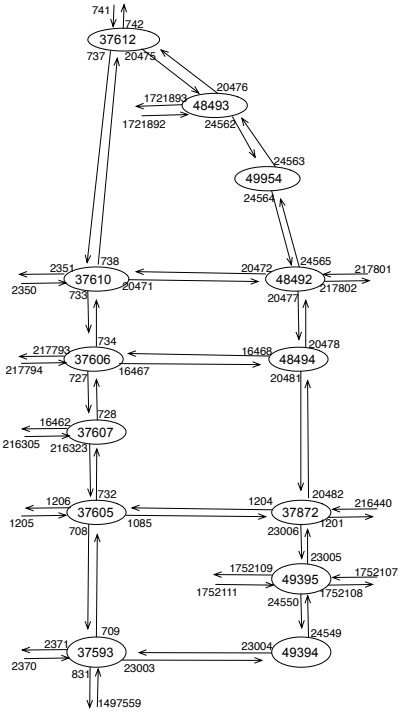

Figure 1. Study network near I-15 San Diego, CA

(link $737 \in \mathcal{L}$). An entry link $l \in \mathcal{L}_{entry}$ is an input link to an intersection node, an exit link $l \in \mathcal{L}_{exit}$ is an output link from an intersection node while an internal link $l \in \mathcal{L}$ in input link to an intersection and output link from another intersection.

A *phase* (l, m) is am

III. SF-Feasible demands

IV. ".Q"

A. System Modelling

A major factor to establish in a Discrete Event Simulation technique is the definition of the set $\{(E_i, P_i)\}_{i=1,\ldots,N}$ where E_i is the set of event types and P_i the corresponding procedure for the event treatment. The occurrence of an event modifies the system state according to the associated procedure, and it may also trigger future events. A trusting

equilibrium should be defined between the nature and number of the modelled events influencing the reliability of the model. Designing a complex structure will involve complicated simulation results difficult to analyse and understand. Conversely, a very simplified model will lead to unrealistic situations diminishing the simulator entrust. Despite all the difficulties, the development of the ".Q" simulator is made without the use of any particular simulation environment. Amongst other advantages, the master of the entire framework is achieved as well the ability of a direct access to the system functionalities depending upon the requirements of the study.

In the following, the description of the employed event types forming the network evolution according to the ".Q" model is presented. Events are related to the system entities: vehicles, traffic controls and the network (comprised of signalised and non-signalised intersection nodes, their corresponding input and output links and the vehicle queues modelled according to the related *phases* to each link). Vehicles travel in a network and events are supposed to take place at the network nodes and queues only.

1) Vehicle events
   - Vehicle Appears At An Entry Link: When a vehicle appears at an entry link of the network. At this time the vehicle is already situated at the appropriate queue according to its next destination.
   - Vehicle Ends Its Hold Time: When a store and forward model is selected to be studied, vehicles should remain in their queue during a minimum period of time. At this moment the vehicle in question has accomplished the store and forward condition and if all the departure constraints are verified the vehicle can leave the queue.
   - Vehicle Departs A Queue: When a vehicle leaves its queue and heads towards its next destination node.
   - Vehicle Arrives At A Queue: When a vehicle joins the end of the queue corresponding to its next destination.

   The previously presented vehicle events are distinguished for the signalised and non-signalised intersection nodes.
2) Intersection traffic control events
   - Decision for the Next intersection control: At this moment the selection of the next stage (case of a feedback policy) or a sequence of stages (open loop controls) to actuate is accomplished. Within this event amongst others the control starting time and its associated duration are defined. This decision should be completed before the end of the currently employed control.
   - New Intersection Control: From this time, a previously decided a control starts ruling the network.

B. Sequence of Events

The occurrence of an event modifies the system state according to the related procedure and may also create new events of any type and nature. In Figure 2 nodes represent the different event types and edges indicate the (possible, when a doted line is employed) generation of an event.

- Type 1: appearance of a new vehicle in a signalised network node.
  - The edge starting and pointing at the same event indicates that the realisation of this event will generate a new event of the same type. The new created event corresponds to the next vehicle appearance at the same entry link of the current event.
  - The edge heading towards the event of type 6 depicts the generation of an event of type *Vehicle Ends Its Hold Time* corresponding to the time at which the vehicle will have achieved its store and forward constraint (whenever the later one exists).
  - A new vehicle appearance explicitly modifies the link flow. In case of controls depending upon the current value of the vehicle flow (e.g. Fully actuated control etc.) and since a new vehicle appearance explicitly modifies the link flow, an event of type *Decision for the Next intersection control* may be generated in order to update the control decision. This justifies the edge starting from this event and pointing towards node 2.
  - When the employed traffic control decision is revised according to the variations of the vehicle flow, an event of type 2 will be generating in order to examine if the actuated stage has to be updated
- Type 2: decision for the next intersection control
  - A stage has just been selected for ruling the intersection. For controls with a predefined or limited actuation period, this decision should be updated before the end of their duration. In this case an event of the same type 2 should be initiated charged for updating the intersection control.
  - An event of type 2 causes the creation of an *New Intersection Control* event (type 3) representing the employment of the new intersection stage, action indicated in the graph by an edge originated at node 2 and pointing towards node 3.
- Type 3: a new stage is applied to the intersection
  - From this time, the same or different phases are actuated. When queues are actuated (case of non red clearance matrices), new vehicle departures (not previously initiated, case of controls without limited actuation duration such as Fully Actuated etc.) are going to be planned. Consequently an

event of type 3 may generate future events of type 4.

- Type 4: vehicle leaves a signalised queue.
  - At present, the related vehicle heads towards its next destination node, thus an event related to the vehicle arrival at the appropriate queue should be created. As the vehicle may join a signalised or a non-signalised queue, events of type 5 or 11 may be created, indicating the vehicle arrival at the queue, according to the type of the destination node.
  - The state of the queue from which the vehicle left is equally updated and the examination of other vehicle departures is realised. Whenever other vehicles can also leave, an event of type 4 should be created corresponding to their departure (edge starting and ending at/to node 4). The new potential departures may concern the queue from which the vehicle left as well other queues bringing vehicles at this queue. The later concerns the case when the corresponding links are of a limited capacity.
- Type 5: vehicle arrives at a signalised queue
  - Similarly to the vehicle appearance event, when a vehicle joins an empty queue, an event of type 6 will be generated, indicating when the vehicle will have completed its hold time in the queue, constrained imposed by the store and forward condition, (edge originated at node 5 and joining node 6).
  - For traffic controls revised according to the vehicle flow values, the arrival of a vehicle at a queue may cause the creation of an event of type 2 examining whether the current intersection control should be reviewed or not, (existence of an edge originated at node 5 and pointing at node 2).
- Type 6: vehicle achieve its hold constraint imposed by a store and forward model (case of a signalised intersection).
  - If all the departure constraints are verified the related vehicle will be able to leave the queue. Consequently an event of type *Vehicle Departs A Queue* will be created, action indicated by an edge originated at node 6 and heading towards node 4.
- Type 7: flow variations
  - This event deals with the case when flow parameters (such as demand, turing probabilities, travel times etc.) vary within the time. In the case of more than one variations, this event will cause a future event of the same type (edge starting and ending at node 7) corresponding to the next flow modification. THIS EVENT SHOULD BE UPDATED FOR THE CURRENT VERSION OF THE SIM
- Type 8: vehicle appearance, at a non-signalised intersection.
  - Similarly to the event of type 1, the next vehicle appearance at the related entry link should be defined, action corresponding by an edge from node 8 heading towards the same node.
  - In the case of a store and forward model and whenever the vehicle joins an empty non-siganlised queue, an event of type 9 will be generated, (edge from node 11 towards node 9), occurring when the vehicle hold time in queue will be accomplished.

  Similarly to the event of type 1, this event category indicates a vehicle appearance, to a non-signalised intersection. However, since no control is associated with the non-signalised intersections, there is no question of revising the control decision.
- Type 9: vehicle ceases its store and forward hold time in a non-signalised queue.
  - equivalently to type 6, if all conditions are satisfied for the vehicle departure, when this last one is located at an non-signalised intersection node, the vehicle leaves. In this case an event of type 10 should be generated indicating the completion of the vehicle departure.
- Type 10: as for events of type 5, this category deals with vehicle departures from an non-signalised intersection.
  - At this time the vehicle travels to its next destination node thus an arrival event is required representing the situation of the vehicle joining the related to its destination queue. This event will be either of type 5 or 11, (existence of edges from node 10 towards nodes 5 and 11), according to whether it arrives a signalised or non-signalised intersection node.
  - By the time the first positioned vehicle leaves, the departure of the following vehicles will have to be examined. As a result, an event of the same type 10 will be created in order to check whether other vehicles can depart.
- Type 11: vehicle joins a non-signalised intersection queue
  - As for the events of type 5, when a vehicle joins an empty non-signalised queue, an event of type 9 will be created indicating the accomplishment of the store and forward constraint.

Remarque

1) The vehicle departure events concern one or more vehicles according to the number of the vehicles which can leave the queue simultaneously. This number depends upon the saturation flow.
2) Events of types $6, 11$ corresponding to a store a forward model impose vehicles a minimum hold duration

at queues. If a simple forward model is desired to be studied, the vehicle hold time at queues will have to be initialised at one.

3) Events related to non-signalised intersections need to be updated to the current version of the ".Q" handling control requiring sensor information.

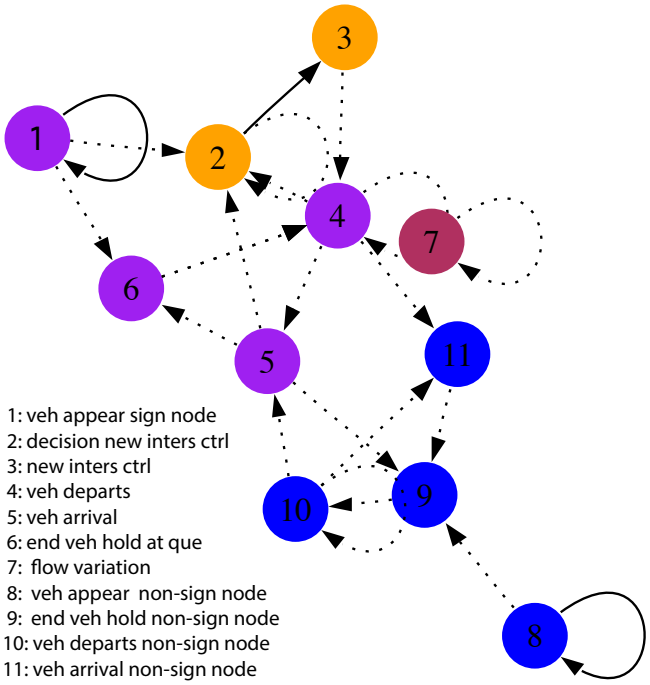

Figure 2. Sequence of the ".Q" events

V. FT Control

VI. MP Control

VII. FA Control

VIII. FA Max Green Control

IX. FA Max Min Green Control

X. ACSLite Control