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Microscopic approach for the evaluation of an urban transport system in emergency conditions

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Abstract

The paper presents some traffic microscopic models and procedures for the analysis and management of a road transportation system, when an evacuation of a densely populated area has to be planned, due to a forthcoming calamitous event.
In the sphere of Dynamic Traffic Assignment (DTA), the microscopic approach allows a disaggregate analysis of each driver behaviour in terms of speed and acceleration and the simulation of queuing and lane-changing phenomena; but it needs high computation times for extended transportation networks analysis and large amount of data for the behavioural rules definition.

1 Introduction

The aim of this work is the analysis and the management of a road transportation system by means of traffic microscopic models and procedures, when the population evacuation of a urban area is necessary, because of the approximation of a calamitous event.
In such context, where temporary sovra-saturation phenomena of some transportation supply elements, queues formation and dispersion are present, methods and procedures for Dynamic Traffic Assignment (DTA) become necessary, which can have different models or specifications: pseudo dynamic [1], mesoscopic [2] or microscopic, presented in this paper.
Microsimulation procedures require the use of microscopic traffic flow models, path choice and assignment models. Microscopic traffic flow models belong to

two different classes:

- *link* models, that simulate the interactions among vehicles on each link of the network;
- *node* models, that simulate the interactions among vehicles on each node of the network (signlized and not-signalized intersections, merging and diverging areas, toll plaza areas, ...).

Link models can be divided in two categories: *car-following* models, that simulate the movement of each vehicle and the interaction with vehicles travelling dowstream on the same lane; *lane-changing* models, that simulate the interactions among vehicles travelling on different lanes.

Car-following models can be subdivided in two classes:

- *monoregime* models, based on the "stimulus-reaction" concept ([3], [4], [5], [6], [7], [8], [9], [11] [12], [13]), that describe vehicles interactions in the different flow regimes by means of one equation;
- *multiregime* models, based on the "stimulus-reaction" ([14], [15]) and "safety speed" concepts [16], that describe vehicles interactions in the different flow regimes by means of multiple equations.

Lane-changing models, depending of the manoeuvre to be simulated, can be classified as follows:

- *mandatory* ([17], [18], [19], [20], [21], [22]), when the driver must necessarily execute the lane-changing manoeuvre in order to reach the destination lane (es. merging manoeuvre, lane number reduction, etc.);
- *discretionary* ([19], [18], [23], [20]), when the driver performs the lane-changing manoeuvre in order to reach his desired speed.

Moreover, *lane-changing* models can be distinguished in: urban and extraurban; deterministic or stochastic, according to the nature of the variables.

Among *node* models, there are models for *signalized nodes* and models for *not-signlized nodes*.

Models for *signalized nodes* can be subdivided in: macrocospic, for an aggregate analysis of node performances [24] and microscopic, for a disaggregate analysis of node performances, simulating explicitly every driver behaviour. In the microsimulation procedures a virtual vehicle is located on the final section of the entering link during the red phase of the traffic light; the virtual vehicle is removed at the beginning of the green phase, reproducing the traffic light cycle ([25], [26], [19]).

Models *for not-signalized* nodes are based on the gap-acceptance model. Different gap-acceptance models have been developed ([27], [28], [29], [30], [20], [31]) according to the assumptions of the critical gap distribution. Federal HighWay Administration [20] proposed a methodology based on average critical gap for the estimation of delay and capacity at the intersection.

References of microscopic traffic flow models proposed in literature are presented in figure 1, according to the previous classification.

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- Link
  - Car-following
    - Monoregime (stimulus-response)
      - [3], [4], [5], [6], [7], [8], [9], [11] [12], [13]
    - Multiregime
      - Stimulus-response
        - [14], [15]
      - Safety speed
        - [16]
  - Lane-changing
    - Mandatory
      - [17], [18], [19], [20], [21], [22]
    - Discretionary
      - [19], [18], [23], [20]
- Node
  - Signalized
    - [25], [26], [19]
  - Not-signalized (gap-accepatance)
    - [27], [28], [29], [30], [20], [31]

Figure 1: Classification of microscopic traffic flow models.

The specification of *path choice* models requires the definition of the *path choice set* and the *path choice* models. The *path choice set* is generally defined in a behavioural way, in other words, selecting admissible paths according to behavioural rules of the driver. Paths inside the *path chice set* can be *variable* or *fixed*, if new paths can be periodically reconsidered from the drivers or not.
Path choice models [32], on *variable* or *fixed path choice set*, can be:

- *pre-trip*, when the driver chooses the path according to the origin, the destination and departure time, before starting the trip;
- *en-route*, when the driver modifies, during the trip, the path on the base of current traffic conditions on the network.

Among the path choice models, we can distinguish two types of models:

- *deterministi*c, if the driver chooses the path with the minimum cost;
- *stocahstic*, if the driver associates a probability to each path belonging to the *path choice set.*

The *en-route* choice implies that information concerning current traffic conditions on the network are available. Modeling driver reaction to the available information is part of ATMS/ATIS systems, not treated in this work.
Figure 2 shows a picture of path choice models, as previous classified.
The assignment model ([33], [34], [32]) provides path flows concerning drivers which departe from an origin, o, in a temporal interval, to reach the destination, d. Path flows depend on the demand flows from the origin, o, to the destination, d, which depart in the considered interval, and from the path choice probability, given the departure time and the o/d couple. From the path flows it is possible to obtain link flows for every time interval.

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- Variabile paths
  - Pre-trip
    - Deterministic (minimum path)
      - [26]
    - Stochastic
      - [35], [25], [36], [26]
  - En-route
    - Stochastic
      - [19]
- Fixed paths
  - Pre-trip
    - [37], [25]

Figure 2: Classification of path choice models.

Few literature concerning the analysis of a transportation system in emergency conditions is present. In [38], it is faced the definition of *path choice sets* for pedestrian evacuation in pubblic buildings, by means of a dynamic network loading model of demand flows on the network; in [39], evacuation times by means of a mesoscopic approach in the Vesuvio volcano area (Italy) are estimated; [40] and [1] present a pseudo dynamic approach for the demand management at departure time and distribution dimensions for the evacuation of population from an urban area; in [41] and [42], general models and procedures to be used in a "what if" and "what to" approach of road transportation network analisys in emergency conditions are described and classified.
The paper presentes microscopic models and procedures for the analysis and management of a road trasportation system in emergency conditions, when the transportation network is loaded by high and concentrated demand.
The paper is articulated in four sections. In section 2 some definitions and notations are introduced and the traffic microscopic model used is presented. Section 3 describes the microsimulation procedures. In section 4 the conclusions and the research perspectives are highlighted.

2 Models

2.1 Definitions and notations

The parameters of the *car-following* model used are:

- n, examined vehicle (user);
- $h_{n,a}(t)$, spatial headway at time t between vehicle n and leader vehicler n-1 travelling on the same lane of link a;
- $v_{n,a}(t)$, speed of vehicle n at time t on link a.

The *car-following* model is calibrated for each link a (or classes of links) of the network defining exogenously the following four macroscopic parameters:

- $v_{0,a}$, free speed;
- $v_{cr,a}$, speed at capacity;

- C_a, capacity;
- $K_{j,a}$, jam density.

The parameters of the gap-acceptance model at not-signalized nodes are the following:

- t', arrival time of vehicle at the node;
- T_n, maximum waiting time for the vehicle n starting from t', after which the vehicle starts the manoeuvre;
- $G_{n,}^{cr\prime}$, critical gap for vehicle n at time t';
- $G_{n,}^{cr}(t)$, critical gap for vehicle n at time t, between t' and T_n;
- G_n^b, value of critical gap if the vehicle executes a straight through manoeuvre and if the conflicting link, with higher prority, has a single lane;
- m, type of vehicle manoeuvre at the node (straight through, left turn, right turn);
- nl, number of opposing lanes for the vehicle to cross;
- $\Delta G_n(m,nl)$, increment of critical gap for vehicle n due to more articulated manoeuvre than straight through one (left turn, right turn) and when nl>1.

2.2 Used model

The traffic flow models used are proposed in [13] and [26].
The *link* model combines a *car-following* model and a *lane-changing* model able to simulate manoeuvres in discretionary and mandatory conditions.
The *car-following* model is a relationship between spatial headway $h_{n,a}(t)$ and speed $v_{n,a}(t)$ for each link a, whose equation is:

$$h_{n,a}(t) = \alpha_{1,a} + [\alpha_{2,a} / (v_{0,a} - v_{n,a}(t))] + \alpha_{3,a}\, v_{n,a}(t) \qquad (1)$$

where

$$\alpha_{2,a} = (1 / k_{j,a})[1 / (\beta_a + 1 / v_{0,a})] \qquad (2)$$

$$\alpha_{1,a} = \beta_a\, \alpha_{2,a} \qquad (3)$$

$$\alpha_{3,a}=[- \alpha_{1,a} + v_{0,a}/ C_a - (\alpha_{2,a} / (v_{0,a} - v_{cr,a}))]/v_{cr,a} \qquad (4)$$

$$\beta_a = (2\, v_{cr,a} - v_{0,a}) / (v_{0,a} - v_{cr,a})^2 \qquad (5)$$

with $\alpha_{1,a}$, $\alpha_{2,a}$ e $\alpha_{3,a}$ parameters to be calibrated for each link a, defining exougenously $v_{0,a}$, $v_{cr,a}$, C_a, $k_{j,a}$.
The *lane-changing* model is based on decisional rules and allows to simulate discretionary and mandatory manoeuvres. The latter depend on traffic conditions on the link, the former on the network geometry.
According to the model, a driver n evaluates the possibility to execute a discretionary lane-change if his desidered speed is greater than the speed of the leader vehicle n-1. The lane-change is executed after the evaluation and comparison of different potential speeds. The first speed is the one at which the

driver can travel along the current lane, the others are the speeds at which the driver can travel if he moves on adiacent lanes. The driver will reach the lane that allows him to travel at the highest speed among the potential ones. The lane-change, however, is conditioned from the availability of a sufficient gap on the destination lane.
The driver executes a mandatory lane-change if he is forced from the link geometry. The lane-changing manoeuvre is actuated gradually through the definition of a softwall and a hardwall. The softwall is a road section, from which the driver perceives the necessity to change lane, while the hardwall is a downstream road section, that can not be passed from the driver, because this would make impossible the lane-change execution and the achievement of the destination lane. When the driver is between the softwall and the hardwall, he is progressively forced to execute the manoeuvre.
The gap-acceptance model [31], based on the definition of critical gap for vehicle n at time t between t' and T_n, is deterministic and has the following equation:

$$G_n^{cr}(t) = G_n^{cr'} - G_n^{cr'}\,(t - t') / (T_n - t') \qquad (t' \le t \le T_n) \qquad (6)$$

where

$$G_n^{cr'} = G_n^{cr'}(m, nl) = G_n^{b} + \Delta G_n\,(m, nl) \qquad (7)$$

According to (7), the value of $G_n^{cr'}$ increases when the manoeuvre at the node is more articulated than the straight through one and the number of lanes of the conflicting link increases (nl>1). The value of $G_n^{cr}(t)$ linearly decreases from time t' until it goes to zero at time T_n, according to (6), in case the densities on the conflicting link are high and cause delay for vehicle in the execution of the desidered manoeuvre.
The *path choice* model operates on a *variable path choice* set and it is *pre-trip* and *deterministic.*

3 Procedures

The simulation of the evacuation from an urban area is carried out with the support of a microscopic software, called Integration [26].
It contains an algorithm where the *car-following* model (1) and the *lane-changing* model are combined toghether to represent the vehicular flow on links with multiple lanes, and the *gap-acceptance* model is able to manage conflicting vehicular flows at not-signalized nodes.
The algorithm operates according to the following steps:

- vehicles generation at the origins; if sufficient capacity exists on entering links vehicles enters into the network, otherwise vehicles wait to enter in virtual queues;
- each generated vehicle selects the path with the minimum travel time from the origin to the destination according to the current traffic conditions on the

network (pre-trip choice);
- the space-time traiectory of each vehicle from the origin to the destination comes out from the interaction with other vehicles on the links and at the nodes.

The vehicle advancing procedure on the links combines the *car-following* model (1) with the *lane-changing* model, according to the following scheme:

```
VEHICLE ADVANCING ON LINK
{
  IF (it is desiderable / necessary to change lane) THEN
        Apply lane-changing model;
  ELSE
        Apply car-following model;
  END
}
```

The gap-acceptance procedure at not-signalized nodes requires the specification of the conflicting links of the current one, with higher priority.
If it is not exougenously specified, the value of critical gap for the vehicle n, $G_n^{cr}(t)$, is obtained from the following procedure:

```
CRITICAL GAP AT TIME t
{
  t' = arrival time of the vehicle at the intersection;
  Tn = maximum waiting time of vehicle at the interserction;
  Gn^cr' = number_of_lanes_of_the_conflicting_link (sec) + Gn^b
     IF (right_turn) THEN
          Gn^cr' = Gn^cr' + 0.5 sec;
     ELSE IF (left_turn) THEN
          Gn^cr' = Gn^cr' + 1.0 sec;
   Gn^cr(t) = Gn^cr' - Gn^cr' (t - t') / (t'- Tn);
}
```

4. Conclusions and future work

The analysis and management of a road transportation system in emergency conditions is necessary for planning the evacuation of a popolated area due to the approximation of a calamitous event. In such context, in which temporary sovra-saturation phenomena of some transportation supply elements, queues formation and dissipation are present, methods and procedures for Dynamic Traffic Assignment (DTA) become necessary, which can have different models or specifications: pseudo dynamic, mesoscopic, microscopic.
In the paper microsimulation models and procedures for the analysis and management of a road transportation system in emergency conditions are presented. An application to a small town (Zafferana Etnea, Italy) is described in [43], where the road trasportation system is simulated for different configurations

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of supply (different number and location of assembly centers) and demand (different distributions among the assembly centers), according to a "what if" approach.

The microscopic approach allows a disaggregate analysis of each driver behaviour in terms of speed and acceleration and the simulation of queuing and lane-changing phenomena; but it needs high computation times for extended transportation networks analysis and large amount of data for the behavioural rules definition. So, it is suitable for detailed off-line analyses of evacuation phases from not extended areas (industrial areas, small/medium urban areas, ...), supporting transportation planning activities in emergency conditions. Moreover, it can support the calibration of link and node models, used in static and mesoscopic approaches, due to the high detailed representation of traffic phenomena. But, it is not suitable for real time analyses and for extended transportation networks analyses (large cities, metropolitan and sub regional areas, ..)

Future work concerns the the project of the departure time management at the origins and the application to microsimulation procedures to a more extended urban areas.

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