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# Neural networks for local monitoring of traffic magnetic sensors

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**Abstract**

A real-time traffic incident detection algorithm is proposed and applied to the monitoring of a complex road junction in the city of Nancy in France. This algorithm has the potential to provide local monitoring of traffic sensors. Our approach is based on macroscopic traffic flow models, and more precisely on the flow-density relationship. Once this relation is extracted from real traffic data, an admissible region is defined in the flow-density space. Then, the classification properties of neural networks are used to design the monitoring network, which detects and isolates the incidents that disturb the traffic, when the measured data are out of the admissible region. A hierarchical scheme to deal with incidents in large-scale networks is developed as well.


*Keywords:* Traffic modeling; Traffic monitoring; Feed-forward neural networks; Supervision; Petri nets

## 1. Introduction

Congestion in urban networks is an everyday disturbance that becomes very wasteful in resources, mainly in terms of traffic delays, air pollution and safety conditions. In many cases, the cause of this congestion is due to traffic incidents such as accidents, vehicle breakdowns and slow moving vehicles (Zhang, 1995). However, by monitoring traffic it may be possible to detect such incidents and reduce their impacts by operational actions.

The goal of this work is to propose a model-based method for traffic monitoring. The principle of such monitoring algorithm is to detect and isolate incidents when the system's behavior is different from the one of a reference model (Isermann, 1984). In the context of macroscopic traffic models, our contribution is to adapt flow-density relationships, also called fundamental diagrams (FDs), for monitoring purpose. Because their abilities to perform real-time applications, neural networks (NNs) are well adapted for this kind of problems.

Section 2 of this paper presents an introduction to the traffic flow representations. Section 3 gives a description of the real system that was used as a test area and Section 4 presents the results of traffic flow modeling. In this section (Section 4), the parameters of STRADA flow-density relationship are estimated, by means of the least-squares algorithm, then feed-forward networks are investigated for to extract other flow-density relationships from real data. Performances of learning algorithms are also discussed according to the considered system and comparisons between the obtained results are carried out in order to select the reference model for monitoring purpose. Let us note that STRADA flow-density relationship is selected for the comparisons because it has been shown that STRADA is suitable for both urban highway and complex junctions (Buisson, 1996). In Section 5, the neural implementation of the proposed monitoring function is described and Petri Net supervisors, which monitor the temporal and spatial propagation of incidents in large-scale networks, are developed. Finally, the proposed approach is applied to a complex road junction in Section 6.

## 2. Traffic modeling

Traffic models are generally composed of three strongly connected sub-models: network representation,

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assignment model and flow model (Buisson, 1996; Bell & Iida, 1997). The network representation contains the description of the arcs or sections (number of ways, maximal speed, etc.) and the nodes or crossroads (traffic signal cycles, geometry of the crossroads, etc.). The assignment models describe the way in which the traffic is distributed between the arcs of the network. Such models are based on origin–destination–path incidence matrices, and on the evaluation of cost functions. They are used to determine the paths that will be chosen by the vehicle drivers. At least, flow models describe the queues and the circulation of vehicle flows through the network.

During the two last decades, three classes of traffic flow models have been developed. The microscopic models, like the car-following and the cellular automate models (Nagel, 1998; Ozaki, 1993), constitute the first class. These models consider vehicles individually and calculate the new speed and the new position of each vehicle from its old speed and the distance to the downstream vehicle. Mesoscopic models consider packets of vehicles that have the same destination. These models calculate the speeds of each packet along the axes of the network according to the average density on the section of the considered packet (Leonard, Gower, & Taylor, 1989; Jayakrishnan, Mahmassani, & Hu, 1994). Finally, macroscopic models consider the traffic as a compressible fluid that circulates on the links of the network (Leutzbach, 1988; Lightill & Whitham, 1955). This approach, based on the hydrodynamic theory, assembles both first- and second-order models.

The first-order macroscopic approach assumes that traffic is described for each link $(L_m)_{m=1,\dots,p}$, in terms of average speed $v_m$, rate of flow $q_m$ and density $d_m$ according to:

- the vehicle conservation equation:

$$\frac{\partial q_m(x,t)}{\partial x} + \frac{\partial d_m(x,t)}{\partial t} = 0, \quad m = 1,\dots,p, \tag{1}$$

- the dimensional consistency relation:

$$q_m(x,t) = d_m(x,t)\cdot v_m(x,t), \quad m = 1,\dots,p, \tag{2}$$

- the fundamental relationship:

$$q_m = F(d_m(x,t)), \quad m = 1,\dots,p, \tag{3}$$

where the variable $x$ stands for the spatial measure on the considered link, $t$ stands for the time and $F$ is a non-linear function.

Let us notice that the difference between first- and second-order traffic models stems only from the order of the conservation equation. In fact, some terms that take into account the reaction time of drivers have been introduced by second-order models (Payne, 1971; Papageorgiou, Blosseville, & Hadj-Salem, 1990) to improve the modeling accuracy of first-order ones (Papageorgiou, 1998).

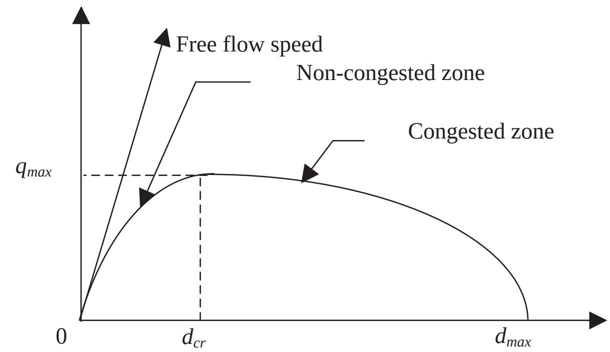


Fig. 1. STRADA FD.

On the other hand, the shape of the FD is a subject of several discussions and still is the principal difference between all the existing traffic models. Because these FDs are either deduced from empirical hypothesis or derived from microscopic considerations, several mathematical structures have been proposed to describe them. For example, INTEGRATION FD is composed of two polynomial curves (Van Aerde, 1995). STRADA FD is composed of two parabolic curves (Buisson, Lebacque, Lesort, & Mongeot, 1996). SIMAUT FD is composed of a polynomial curve of degree 3 and a line (Morin, 1984). At last, META FD is an exponential curve (Papageorgiou et al., 1990). Nevertheless, all the proposed diagrams have the same properties as that shown in Fig. 1.

The left part of the curve ($d < d_{cr}$) corresponds to the fluid state of circulation: the flow increases with the density up to its critical value $d_{cr}$. The level of flow $q_{max}$ corresponding to this density expresses the capacity of the infrastructure. Beyond this critical point, if the density continues to increase, the flow starts to regress and the circulation becomes congested.

According to relation (2), the speed corresponding to any point of the FD is given by the slope of the line connecting the origin to the considered point. Hence, when the density lies between zero and its maximal value $d_{max}$, the speed goes from its maximum value called free-speed to zero.

Let us also take notice that each flow corresponds to two densities and also to two speeds. The higher one refers to fluid circulation, and the lower one refers to congested situation.

## 3. Description of the real considered system

Let us consider a part of a network in the city of Nancy in France as an example. This system, equipped with 15 magnetic loops that are used for traffic