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On the Role of Warm-Up Detection in Multi-Level Traffic Simulations

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Abstract**—*The works proposed in this paper address the problem of the warm-up detection in the context of multi-level traffic simulations. Such phenomenon, called also "initialization Phase" is of a most importance since it defines the fluctuations which appear during the transient phase. The main characteristic of the warm-up phase is the state instability during the traffic flow simulation and its duration cannot be known in advance. The main objective consists in eliminating the warm-up phase by dynamically transforming macroscopic simulation to a microscopic one.*

Keywords**—*Intelligent transportation systems, dynamic hybrid simulation, warm-up roadtraffic, multi-agents system, multi-level models.*

I. INTRODUCTION

The congestion of a road network usually occurs when vehicle traffic increases and consequently causes an overall slowdown. Consequently, the congestion results in the degradation of quality of service when the number of users increases. It is therefore characterized by the high frequency of delays and bottlenecks during periods of heavy traffic or rush hours, that is to say when the infrastructure capacity becomes insufficient to regulate the flow. The problem is very common locally and periodically, and particularly in large cities.

The consequences of congestion are numerous and can be classified into three categories: economic, social and environmental.

TABLE I. The consequences of congestion.

Economic	Social	Environmental
Congestions block the arteries of road communication.	Frequent traffic jams are subject to stress, anxiety and nervousness problems, leading to an increased risk of accidents.	The increase in pollution that generates economic and ecological costs in exponential growth.
Because of the delays of people going to the workplace and, because of late deliveries of supplies or services.	The increase in energy consumption. In the current context of soaring oil prices, this generates a net decrease in the purchasing power of users.	

In order to improve traffic conditions without expanding the already existing infrastructures, computer simulations of road networks have been proposed. In fact, the final objective is to describe the behavior of the flow of traffic on the network. Therefore, a variety of simulation tools has been developed on the basis of these models so as to assist operators of road networks to ensure better traffic management.

Generally, there are two main sets of models: macroscopic models, which represent the flow of vehicles (in a highway system) in a global way. On the other hand, microscopic models describe the behavior of vehicles in a road network more accurately. There is also another type of model called mesoscopic, which uses explicit representations vehicles but they consider them as packets, their movements being governed by macroscopic models.

However, to simulate large road networks, it will be interesting to integrate these different representations in the same model as shown in Figure 1.

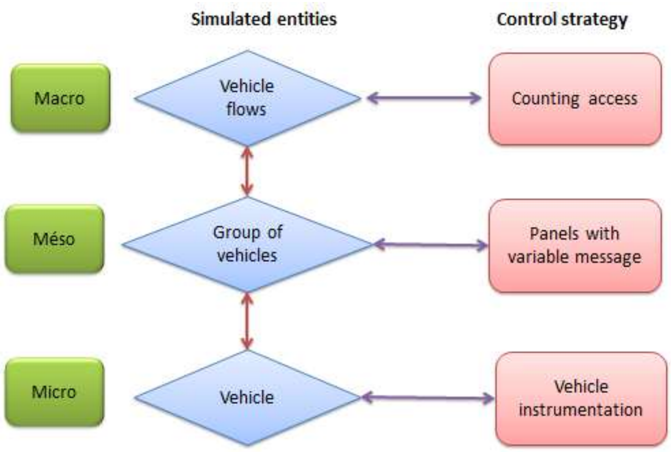

Fig 1. Simulation and hybrid control of traffic flows.

The previous figure represents respectively the interactions between vehicles, groups of vehicles sharing some properties (such as a neighbor position or the same destination) and finally vehicle flows. Each approach is useful in a particular context: the micro and meso models make it possible to simulate networks with a complex topology such as urban areas, while the macro models make it possible to develop control strategies to prevent congestions on highways.

In such approaches, the road network is divided into several parts. In each part, the traffic flow is simulated using its own model (micro, macro or meso). The overall coherence of the simulation is ensured by the interconnection between the various parts and the exchange of data such as the density, the speed and the average flow of the vehicles. These heterogeneous models are called hybrid models. They are "static": Each portion of the network is associated with a unique representation, which will not change during the simulation.

And as was mentioned at the beginning of this introduction, the many traffic problems such as traffic congestion and air pollution are mainly caused by the increase in traffic volume. In order to alleviate traffic congestion and improve network performance, there has been a great deal of interest in the analysis of the state of traffic and the spread of congestion.

However, static hybrid models cannot be used to adequately observe emerging phenomena such as formation and propagation of congestions. To overcome these limitations, we have developed an approach to allow the transition from a macroscopic presentation to a microscopic presentation.

We are interested in the latter which is more complex, because the passage from macro to micro will create an empty section that will be gradually filled with vehicles. This phase called "initial transition", or "warm-up" marks an unstable state, whose duration cannot be known in advance. Theoretically, there are several methods to detect a warm-up period, which differ according to the principle used, the simplicity of implementation and the precision.

The purpose of this paper is to present our approach on the importance of warming phase detection in a dynamic hybrid simulation, discussed in Section 1. Section 2 is devoted to methods for detecting a warm-up period. The implementation techniques used and the results are discussed in section 3. Finally, the conclusions and perspectives are given in section 4.

II. WARM-UP IN THE DYNAMIC HYBRID SIMULATION

A. *Dynamic Hybrid Simulation*

The simulation of large road networks requires to integrate different representations (macroscopic and microscopic) in the same model [1]. Because this hybrid approach allows [2]:

- To obtain quantitative and qualitative information on traffic conditions, using respectively macroscopic and microscopic simulation performances in the same simulation.
- To switch between these representations locally to meet the needs of the simulation, for example, to determine the source of a traffic jam, or to manage the computational as managing the CPU load.
- Explore dynamic routing algorithms traffic as part of the regulation of a flow network road or motorway traffic large. The principle is to establish a balance between all the choices of possible routes that may occur to users, so that we can minimize the risk of occurrence of congestion.

Switching from macro to micro goes through a transitional phase, where data traffic is unrealistic. The question that arise is how long is the duration of the warm-up?

To determine the start of the equilibrium phase, many methods have been proposed [3].We found around a total of 44 methods in the literature. Generally, these methods for estimating the warm-up period can be classified into four main categories (See Fig 2):

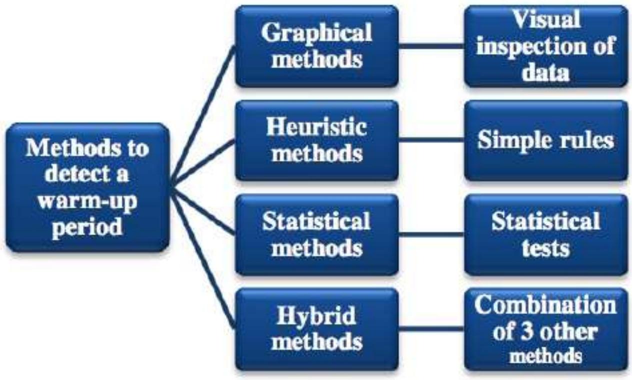

Fig. 2. Methods for detecting the warm-up period.

Several criteria were used to discuss the strengths and weaknesses of each class of these methods among which are: simplicity, ease of implementation, accuracy and parameter estimation. After a comparative study of different existing methods [4], it was concluded that the MSER-5 method was the simplest, and works well for longer run lengths.

It is important to underline that a similar work on dynamic hybrid simulation, has been described by Sewall et al [5]. Nevertheless, the statistical nature of the instantiation technique, which rapidly alternates the simulation type of a zone, will likely result in inconsistent vehicles - quantities and distributions will be relatively stable, but not actual positions.

Among the techniques discussed above, we have chosen the MSER-5 heuristic that adapts well to dynamic hybrid simulation models.

B. *Marginal Standard Error Rule (MSER)*

Let $\{x_1, x_2, \dots, x_n\}$ are the observation values of a simulation, the optimal setting (i) of the transitional period can be calculated as:

$$\boldsymbol{i = argmin_{0\leq i\ll n}\left\lfloor\frac{S^2}{n-i}\right\rfloor} \qquad (1)$$

In this formula, the value $\boldsymbol{S^2}$ is the variance of the sample of observed values:

$$\boldsymbol{S^2 = \frac{1}{n-i-1}\sum_{j=i+1}^{n}(x_j - \bar{x}_{n,i})^2} \qquad (2)$$

With:

$$\boldsymbol{\bar{x}_{n,i} = \frac{1}{n-i}\sum_{j=i+1}^{n}x_j} \qquad (3)$$

The rest of the series $\{x_1,x_2, \dots, x_n\}$ is assumed to be stationary, and the range of marginal minimum confidence is $mseri$ calculated from the formula:

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$$mseri = \left[\overline{x}_{n,i} - \frac{S^2}{n-i} \quad , \overline{x}_{n,i} + \frac{S^2}{n-i}\right] \quad (4)$$

If x_i is thefirst value which mseri is the minimum, we can take i as the parameter optimal for the initial transient.

C. Marginal Standard Error Rule-5 (MSER-5)

MSER as described above is a simple heuristic for resolving the initialization problem in steady-state simulation output analysis. This is done through selecting the truncation point that minimizes the half-length of the confidence interval about the truncated sample mean. The method was first proposed by White et al.[6] as the MCR (Marginal Confidence Rule). Modifications of this method were presented in White et al., [7], Franklin [8] and Spratt [9]

Spratt (1998) suggests MSER-5, where instead of using the raw data to calculate the MSER statistic; the raw data is batched into non-overlapping batches of size 5 and the batch means are used to calculate the MSER statistic.

Then, for the output sequence$\{Xi: i = 1 \ldots . N\}$ of size N, the batch means are calculated as: For $j = 1, \ldots, k = \left[\frac{N}{5}\right]$

$$Z_j = \frac{1}{5}\sum_{i=1}^{5} X_{5(j-1)+i} \quad (5)$$

From the Equation (5), the basic data items now are the batch means$\{Zj: j = 1 \ldots . k\}$. For any truncation point d, the grand average and the sample variance of the data are given respectively, by:

$$\overline{Z}(k,d) = \frac{1}{k-d}\sum_{j=d+1}^{k} Z_j \quad (6)$$

Therefore, a $100(1 - \alpha)$ % has the form

$$\overline{Z}(k,d) \pm z_{1-\alpha/2}\frac{S_Z(k,d)}{\sqrt{k-d}} \quad (7)$$

$$S_Z^2(k,d) = \frac{1}{k-d}\sum_{j=d+1}^{k}\left[Z_j - \overline{Z}(k,d)\right]^2 \quad (8)$$

Where $z1-\alpha/2$ denotes the $1-\alpha/2$quantile of the standard normal distribution. The statistic that MSER-5 tries to minimize is the half-length of the CI, since $z1-\alpha/2$ is a constant.

$$MSER5(k,d) = \frac{S_Z(k,d)}{\sqrt{k-d}} \quad (9)$$

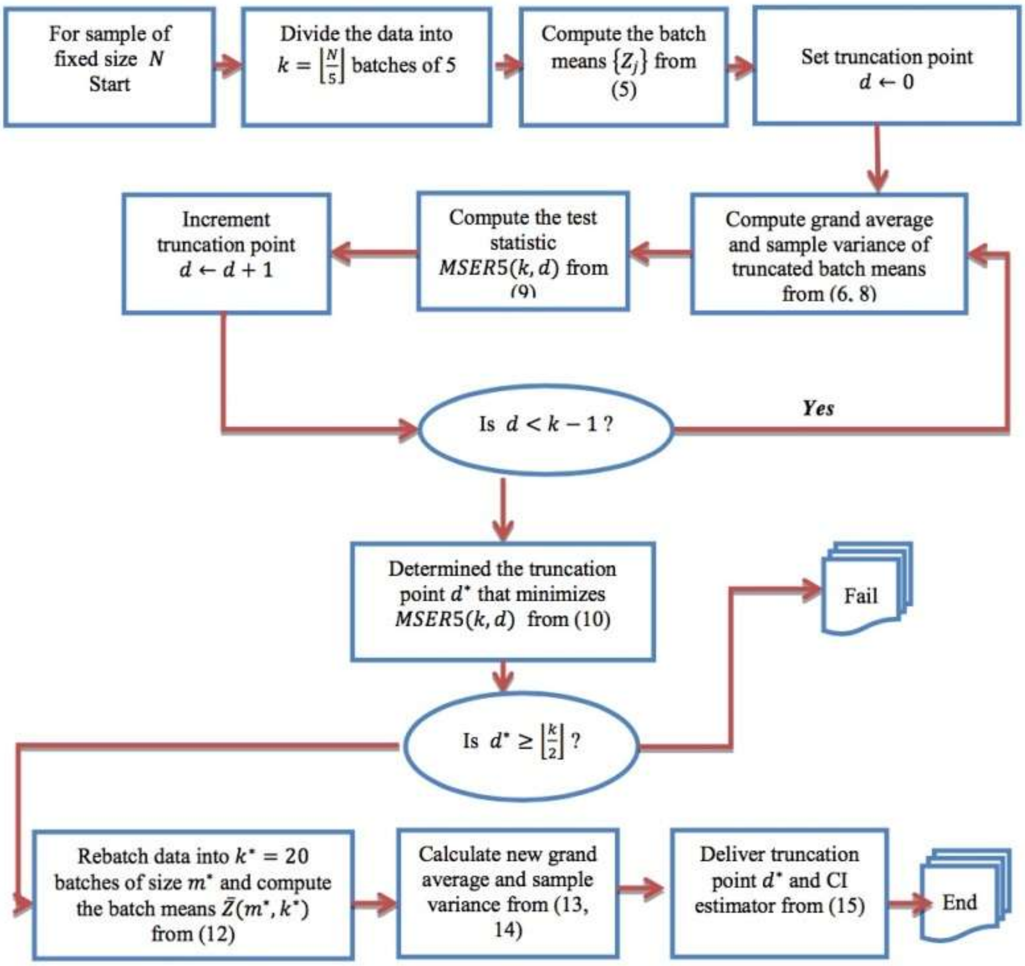

Fig. 3. Flow chart of MSER-5.

The optimal truncation point is defined as follows

$$d^* = \arg min \left(\frac{S_Z^2(k,d)}{k-d}\right) \quad 0 \le d < [\frac{k}{2}] \quad (10)$$

Nevertheless, if $d^* \geq \lfloor k/2 \rfloor$, then MSER-5 fails because of insufficient data.

In the case when $d^* < \lfloor k/2 \rfloor$, White et al., (1994), suggest the application of the classical method of no overlapping batch means (NBM) to the truncated sequence Zj: $j = d^* + 1 \ldots . k\}$. They suggest using "new" batches with the batch size:

$$m^* = \lfloor (k - d^*)/\, k^* \rfloor \qquad (11)$$

Therefore with the truncation point d^* and the new batch size m^*, the lth new batch mean is:

$$\bar{Z}_l(m^*, d^*) = \frac{1}{m^*}\sum_{j=1}^{k^*} Z_{d^*+(l-1)m^*+j} \qquad (12)$$

For $l = 1, \ldots, k^*$. And the corresponding grand average and sample variance of the new batch means are given by:

$$\bar{\bar{Z}}(k^*, m^*, d^*) = \frac{1}{k^*}\sum_{l=1}^{k^*} \bar{Z}_l(m^*, d^*) \qquad (13)$$

$$S_{\bar{Z}}^2(k^*, m^*, d^*) = \frac{1}{k^*-1}\sum_{l=1}^{k}[\bar{Z}_l(m^*, d^*) - \bar{\bar{Z}}(k^*, m^*, d^*)]^2 \qquad (14)$$

Finally, an approximate $100(1 - \alpha)$ % CI is:

$$\bar{Z}(k, d^*) \pm z_{1-\alpha/2, k^*-1} \frac{S_{\bar{Z}}(k^*, m^*, d^*)}{\sqrt{k^*}} \qquad (15)$$

Where$z_{1-\frac{\alpha}{2}, k^*-1}$ denotes $1 - \alpha/2$ quantile of Student's distribution with$(k^* - 1)$ degrees of freedom.

A graphical representation of the MSER-5 algorithm is given in Fig. 3.

III. WARM-UP DETECTION IN DYNAMIC HYBRID SIMULATION: EXPERIMENTS

The dynamic simulation of road traffic is considered an interesting tool for decision-making. It makes it possible to model and to return the operation of a section of road over a determined duration.

Its objective is to test and evaluate different development scenarios in order to compare their performance in terms of travel time; average speed, congestion ...).

We are interested in the transition from a macroscopic simulation to a microscopic simulation, and more precisely, we will treat the case of congestion.

The Congestion of a road network occurs when vehicle traffic causes an overall slowdown of it. This phenomenon is characterized by the appearance of bottlenecks during periods of heavy traffic.

In other words, congestion occurs when the density (in vehicle number / km / lane) is greater than the critical density.

Fig. 4. Congestion of road traffic.

A macroscopic presentation provides quantitative information on traffic, including average speed and free flow velocity. A significant difference between these values indicates the presence of traffic jams. Finding the area where bottling is located focuses on those where average speed is significantly lower than that of free flow.

The approach we adopted is based on the agent paradigm. And this choice is justified by the advantages that multi-agent systems offer for the development of this type of application such as:

- ✓ Adaptability: An agent can adapt his behavior to different situations based on his experiences.
- ✓ Communication: allows agents to coordinate and cooperate.
- ✓ Robustness: the failure of a single agent does not mean the failure of the entire system.
- ✓ Reliability: solving local problems.
- ✓ The rapidity: local processing of information, avoids the transfer of a large amount of data.

To briefly explain our approach, take the example of a section of macroscopic road.

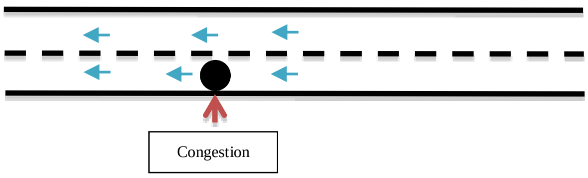

Fig. 5. Congestion.

In what follows, we will describe the roles of simulation agents:

1) Congestion detection: An agent will be responsible for detecting congestion. That is, during the simulation, it controls the density. If the latter is greater than the critical density, it is congestion.
2) Identification of the area: an agent will identify the area where there has been congestion, and also the agents that govern the operation of the model in the defined area.
3) In order to avoid interfering with the simulation, that is to say to avoid the interruption of the information feedback

between this delimited zone and the outside of this zone, it is necessary to instantiate an application dedicated to the detection warm-up.

4) Generation of a simulation model containing only the delimited zone: this model includes the agents that govern the simulation of this delimited zone and more precisely an agent that simulates what happens in the simulated zone and another that simulates what happens passes out of the simulated area.
5) Perform the warm-up calculation until it is complete. This agent executes the warm-up algorithm and the result of this execution is to determine the time t from which the system becomes stable.

Indeed, we performed the MSER-5 algorithm on real data from a site chosen to perform a first hybrid simulation from the A25 to the Chapel of Armentieres in France. The output data (time, speed and speed of vehicles ...) from the simulation are exported to a file. We were particularly interested in road traffic during the period from 16:00 to 16:30.

For example, the variation of the average traffic flow and the preheating period for the first experiment are shown in Fig. 6. The warm-up period in this example ended at the instant 55 seconds.

Performing a local warm-up allows for more accurate speed, density and vehicle flow.

6) Remove the old agent that manages the simulated zone.
7) Recovery of the new agents obtained after the warm-up and who will manage the simulated zone.
8) The integration of this new area to the simulation.

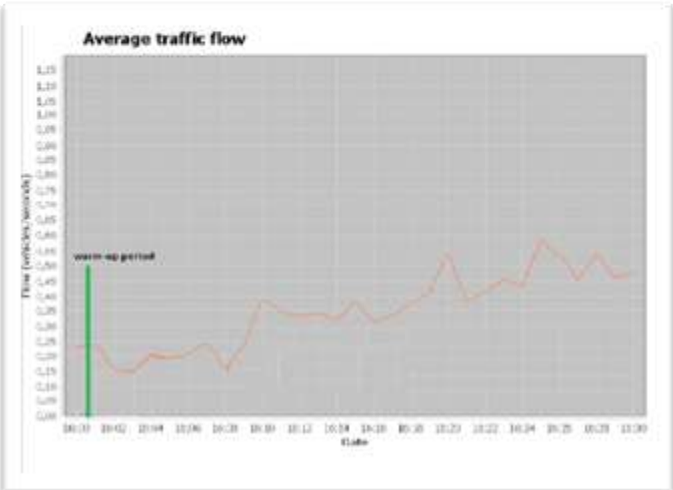

Fig. 6. The average traffic flow and the warm-up period (MSER-5).

IV. Conclusion

The purpose of this article was to present the importance of dynamic hybrid simulation, and primarily we addressed one of the most important issues called the "warm up" period. In this context, we have defined some of the existing algorithms and the method to determine its duration.

So we have our first approach to move dynamically from the macroscopic representation to the microscopic representation of the traffic flow in a simulation of hybrid traffic. In this article, the focus has been on the MSER-5 algorithm.

MSER-5 is not a specific model or data type and is therefore a very general method. It requires no parameter estimation and can work properly without user intervention. It has been shown that the robustness and efficiency of the majority of test datasets are very satisfactory. It is quick to implement and simple enough to understand. It is therefore an ideal candidate for automation and inclusion in an automated analysis system. It is important to emphasize that the purpose of this article is not to evaluate the equilibrium phase detection techniques, but to present our approach to move from a macroscopic presentation to a microscopic presentation using the notion of warm-up.

The integration of MSER-5 into a multi-level multi-agent simulator is being implemented. Other work will be oriented to define the rules of dynamic change from a macroscopic representation to a microscopic representation for several use cases such as: road accidents.

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