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A New Car-Following Model: As Stochastic Process using Multi Agent System

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Abstract

In recent years, the research in topic of car-following has become an increased importance in traffic engineering and safety driving. Various theories attempt to describe the vehicular traffic flow process and the interaction between adjacent vehicles in the same lane. In this paper we present a new model for car-following models, which integrates some real-life factors that need to be considered, such as the random reaction time of each car. Our architecture is based on the combination of Multi-Agent Systems (MAS) and a stochastic model to capture the randomness of individual agent (car). which are able to react according to the real situation of the network. The obtained results illustrate that using the randomness in the reaction of agents enhance greatly the performance of simulation

Keywords: Car-Following Model, Stochastic Process , Multi Agent System, Traffic Engineering, Microscopic Simulation

Introduction

During the last years there has been expressed considerable interest in the study of various theories try to describe the vehicular traffic flow process. One class of such theories, called car-following models, the idea of Car following models assume that there is a correlation between vehicles and each driver controls a car under the stimuli from the preceding car, which can be expressed by the function of distance or velocity of two successive cars.

Car following models theories describe how one vehicle follows another vehicle and how a driver reacts to the changes in the relative positions and velocity of the vehicle ahead [1]. Various models were formulated to represent behaviors between leader and following car like Pipes [2], Forbes, General Motors [4] and Optimal velocity [4].

One aspect of interest in car following is reaction time. In the mathematical analysis, the reaction time and the response of each vehicle to the stimulus of the leader has been considered as a random process. In general Human react to a many different stimuli of different modalities. Reaction time is defined as interval of time between application of stimulus and the subsequent behavioral response.

Therefore, the main objective of the research is to develop a new car following model with MAS [8][9] combining the notion of theoretical mathematic model [5], especially the random process in the reaction time of each vehicle, and the main characteristics[11][12][13]of the Multi-agent System.

In this paper, in order to improve the accuracy of simulators, therefore the accuracy of the results obtained, a new hybrid approach is proposed to improve the effectiveness of the simulation. The structure of this paper is divided into six sections; the first section provides general overview microscopic simulation software [10][14]. The second section describes the new architecture. Section three presents the stochastic distribution and the interaction model. And Proposed following car algorithm presented in section five. The experimental results are presented and discussed in Section four. Finally, Section five concludes the paper.

Car-Following Models

Car-following models, explain the processes how a pair of vehicles interact in the traffic stream. There are various models have been studied in the literature of the car-following behaviors [1,2,3,4…]. These models are divided into three main types: Safety distance or collision avoidance models (CA)[4], Psycho-physical models and Action-points models .

A. Action-points models

The concept of car following was first proposed by Pipes (1953) [3] According to Pipe's “A good rule for following another vehicle at a safe distance is to allow yourself at least the length of a car between your vehicle and the vehicle ahead for every ten miles per hour of speed at which you are traveling», however the limit of this model is that minimum safe distance headway increases linearly with speed and length of car. In 1958

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Chandler [4] proposed a new model wish improve a relationship between vehicle speed and reaction time by a factor of sensitivity based on response time.

Response (t + τ) = sensitivity × Stimulus (t) (1.2)

Or

$$\frac{dv_n(t)}{dt} = \lambda \left(V \left(v_{n+1}(t) \right) - v_n(t) \right) \quad (2.2)$$

With

$\lambda = T^{-1}$, τ reaction time, $v_{n+1}(t)$ the speed of the vehicle n +1 at time t and $v_n(t)$ the speed of the vehicle n at time t.

To develop the limiting cases of this equation, Gazis [] in 1959 developed a new equation which expresses the stimulus in function of the distance between vehicle n and n+1

$$\frac{dv_n(t)}{dt} = \lambda \left(V_n(t)\right)^m \left(\frac{\left(v_{n+1}(t)\right) - v_n(t)}{\left(\left(x_{n+1}(t)\right) - x_n(t)\right)^l} \right) \quad (3.2)$$

Where l and m are parameters of the model. Models of this type are known under the name of type models GHR (Gazis, Herman and Rothery).

B. Psycho-physical models

The first models in this approach were introduced by Michaels [5] and Wiedemann [4].According to Wiedemann, on the road there are two types of conduct

- Free driving: when the driver's behavior is not influenced by that of its leader
- driving under constraint when the driver has to adapt to the behavior of its leader.

The next point in the development of these models came through a series of perception-based experiments conducted in the early seventies, by researchers such as Evans and Rothery (1973).

C. Collision avoidance models

This model was developed by Kometan []. It models the inter-vehicular distance to avoid collision between the vehicle and no vehicle in front:

$$d_s(t - \tau) = \alpha v_{n+1}^2(t - \tau) + \beta 1 v_n^2(t) + \beta v_n(t) + b_0 \quad (4.2)$$

with:

τ is the response time of the driver, ds inter-safe distance, $v_{n+1}(t)$ the speed of the vehicle n +1 at time t and $v_n(t)$ the speed of the vehicle n at time t. The set of parameters α, β, β1 and b_0 are constants to be calibrated.

In the same vein Gipps ([2], [3]), has developed a model in which the vehicle speed to achieve the desired speed and decelerate to avoid a collision when they try to maintain the desired speed. This type of model is often easy to calibrate and produces realistic results ([]It is used in micro-and software SISTEM CarSim [] McDONALD [].

$$V_a(n, t + \tau) = V(n,t) + 2.5 a(n) \tau \times \left(1 - \frac{V(n,t)}{V^*(n)}\right) \sqrt{0.025 + \frac{V(n,t)}{V^*(n)}} \quad (5.2)$$

- V (n, t) is the vehicle speed at the instant t n, * V (n) is the desired vehicle speed for the current section n, a (n) is the maximum acceleration of the vehicle n, τ: is the reaction time (not equal to the simulation).

The speed is also influenced by the characteristics of the vehicle and the limitations imposed by the leader vehicle.

$$V_b(n, t + \tau) = d(n)\tau + \sqrt{d^2(n)\tau^2 - d(n)\left(2x(n-1,t) - s(n-1) - x(n,t) - V(n,t)\tau - \frac{V^2(n-1,t)}{d'(n-1)}\right)} \quad (6.2)$$

d(n)<0 is the maximum deceleration desired by vehicle n, x(n,t) is position of vehicle n at time t, x(n-1,t) is position of preceding vehicle n-1 at time t, s(n-1) is the effective length of vehicle n-1 and d'(n-1) is estimation of desired deceleration.

Multi-Agent Architecture Description

In traffic simulation, two processes can be distinguished. First of all, the initialing process is composed of modules responsible of starting the simulation. The second process or the main process is, in the case of proposed architecture, comprised of multiple interacting intelligent agents.

The main process consists of a distribution model which is used to define the affectation method in the network. The interaction model is used to regulate the interactions between the agents.

In design of this architecture, the aim was to explicitly build a distributed and decentralized solution, where each agent performs its own task. The resulting architecture will then capitalize on effective use of distribution to avoid bottlenecks and achieve scalability with an increase in a number of transactions.

The architecture is schematically depicted in Fig. 1 which shows the architectural components. The Main Agent (**MA**), which is the main element of this architecture, serves to distribute the Execution Agents (**EAs**) – vehicles - in the network following the distribution model and supports these agents to locate all required resources designed by Zone Agent (**ZA**). This latter present the ground in which the **(EAs)** interact among each other according to the interaction model.

ZA is the agent responsible of building network from a database that contains all the elements necessary to build a network (roads, crossroads ...). Besides, during the simulation, it provides all information about the positions of **EA**s to the Control Agent (**CA**).

CA is designed to build a re-active and persistent architecture. This agent records the evolution of architecture caused by changes of existing resources in the interaction database which discern the change in the behaviors of the **EAs**.

In the proposed approach, **CA** collect all information of the execution agents. Thus, the accumulated information could be shared between agents, increasing overall efficiency of the system. During registration, the **MA** aims to retrieve **EAs**' characteristics in the interaction database. Hence, **EAs** update their knowledge about the other agents. This process of update is decided according to the collected information by the **CA**.

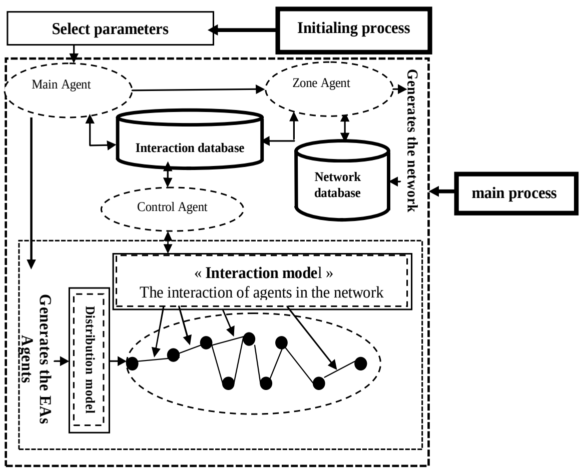

Figure 1. Architecture of MAS2RT :sheds light on the links between all agents and models of the architecture. In order to simplify the simulation, the use of execution agents is limited to vehicle.

Proposed Car Following Algorithm

A. Entry lane model

The vehicles are distributed randomly [17] [16]on the network according to the distribution model defined for each junction of the network. The vehicles react to the information concerning their next action [15]. Models differ according to the various answers to the key questions: What is the nature of the adequate action ? To what stimulus it does react? and how to measure the characteristics of the other agents?[18][19] The first and simplest model correspond to the case when the response is represented by the acceleration or deceleration of the vehicle.

In what follows, we use simplified notations and situations to be enhanced later. indexes j and k nominate considered j being the last introduced one in the ;vehicles A .section of networkcceleration is supposed a positive parameter "a" and deceleration a negative parameter "d".

Every vehicle k moving in the road is modeled as an agent, which has its own entry time T_{0k}, position x_{Tk} at time $T>T_{0k}$, speed V_{0k} at T_{0k}, speed V_{Tk} at $T> T_{0k}$, and acceleration a>0 or deceleration d<0. To reduce algorithm complexity, we drop the "T" index, x_{Tk} will be noted x_k meaning the actual position of vehicle k, so $x_k = x_{Tk}$ or $x_{T-1,k}$ depending if the position of k has been changed in the algorithm or not yet. Same for V_k, …

The algorithm generates the entry time T_{0k} of vehicle k, however k can't get in the network until road is free, i.e $\min\{x_f-x_k;\ x_f>x_k\ \&\ x_f<x_s\ \&\ f<k\}>\alpha.\beta.V_k$. Otherwise, k will be delayed and T_{0k} incremented to stay being the effective entry time of k. Here α is a determined parameter. We take α=2 in our simulations, so that, when started, vehicle k doesn't reach and hit him leader. While β is just a fixed parameter for correspondence between meters and pixels. When in the network, k will react to leading vehicle, if any, designed by k_p (if none, δ_k=0).

When in the network, k will react to leading vehicle, if any, designed by k_p (if none, δ_k=0).

$\Delta x_k = x_{k_p} - x_k$; is the distance between k and k_p;

$\Delta V_k = v_{k_p} - v_k$, is the difference between speed of k and k_p

if k and k_p are not too close ($\Delta X_k > \alpha.V_k$) and $\Delta V_k < 0$ ($V_{k_p} > V_k$) k has to accelerate. Model of Gips and al. [19] simplifier to:

$$V_k = V_k + 2.5a\left(1-\frac{V_k}{V_{em}}\right)\sqrt{0.025+\frac{V_k}{V_{em}}} \qquad (3.1)$$

if k and k_p are too close ($\Delta X_k < \alpha.V_k$) and $\Delta V_k < 0$ ($V_{k_p} < V_k$) k to decelerate. Models of Gips and al. [19] simplifier to:

$$V_k = d + \sqrt{d^2 - d\left[2\left(X_{k_p} - s_{k_p} - X_k\right) - V_k - \frac{V_{k_p}^2}{d'}\right]} \qquad (3.2)$$

Where s_k is the effective length of vehicle k, maintained constant in our simulations (s=2.7).Otherwise, k will continue with the same speed.Then k progress in the network: X_k becomes $X_k + V_k$
The speed V is expressed in pixels per second (p/s); T is in seconds (s) and X in pixels (p).

B. Reaction time model

The parameters of distribution of reaction time differ depending of the sensitivity of driver's; drivers expect to have to adjust their velocity to the preceding cars very often. And thus they react quite rapidly if a weak acceleration is required. However, the distribution of vehicles reaction time follows arbitrary patterns which make it impossible to predict the reaction time of vehicles against a stimulus. Thus, considering sequence (T_n), n ≥ 0 in which T presents the time of reaction of vehicles against a stimulus of leader vehicle[16]. Therefore, the sequence (T_n) n ≥ 0 is random variables in R+. The stimulus may be composed of the speed of the vehicle, relative speeds, distance headway etc, and hence, it is not a single variable, but a function and can

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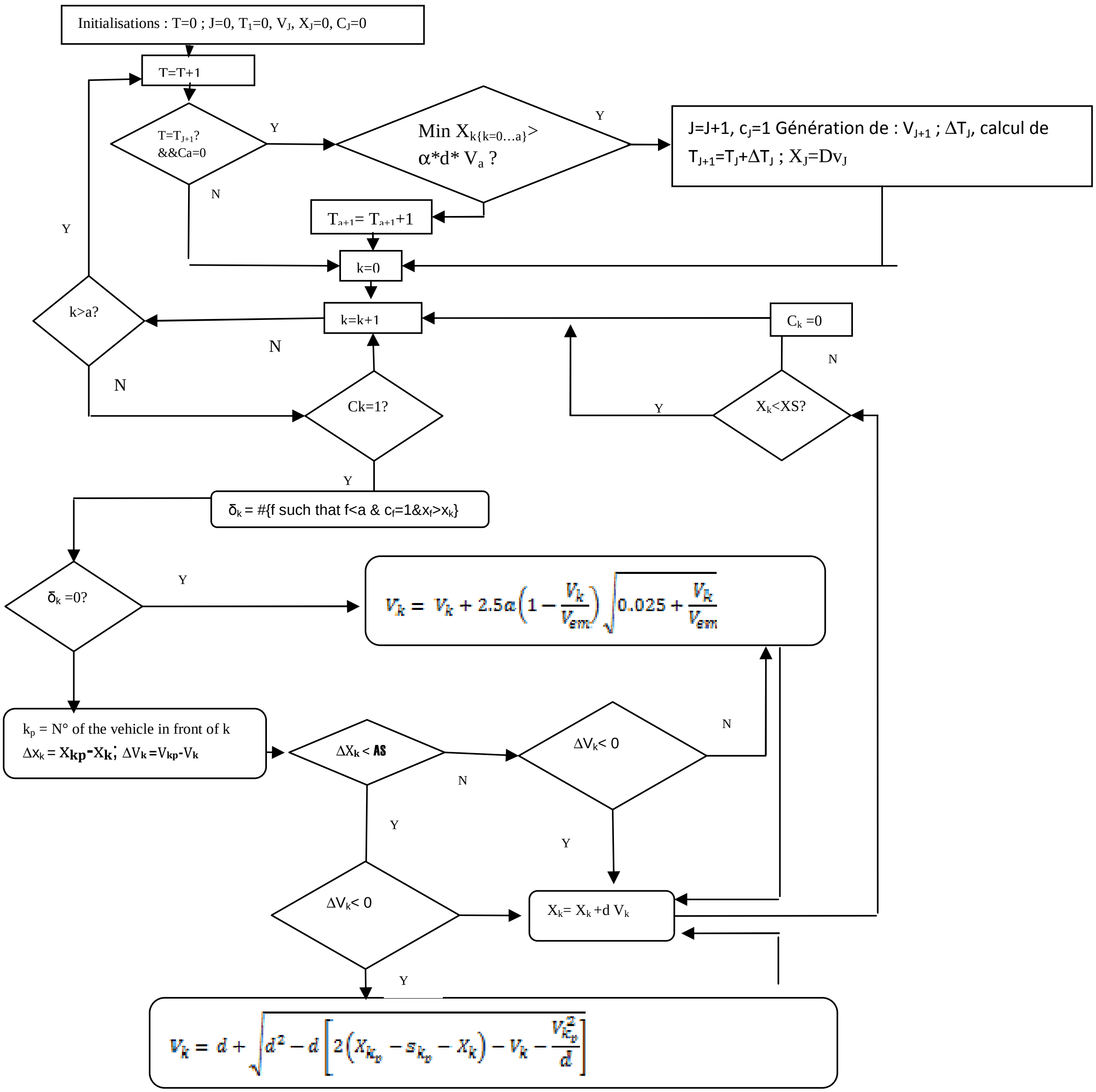
be represented as normal distribution [6][7] with a mean of μ second and a standard deviation of σ² second is given by:

$$f(x,\mu,\sigma^2)=\frac{1}{\sigma\sqrt{2\Pi}}\;e^{-\frac{1}{2}\left(\frac{X-\mu}{\sigma}\right)^2},\quad -\infty<x<\infty \tag{4.1}$$



$$V_k = V_k + 2.5a\left(1-\frac{V_k}{V_{em}}\right)\sqrt{0.025+\frac{V_k}{V_{em}}}$$

$$V_k = d+\sqrt{d^2-d\left[2\left(X_{k_p}-s_{k_p}-X_k\right)-V_k-\frac{V_{k_p}^2}{d}\right]}$$

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kp = N° Vehicle front k ; Δxk= xkp-xk= the distance between k and kp ; ck=1 if k in the circuit else 0; Δvk=Vkp-VK= difference between the speeds of kp and k; XS=output of the circuit; AS:self distance ;V is expressed in m/s; and T is in s.
Where VK(t) is the speed of vehicle k at time t (m/s); ak is the maximum desired acceleration rate of vehicle k (m/s); T is the driver's reaction time (s); and Vk is the desired speed of vehicle k or the vehicle-specific free-flow speed (m/s). Where: d(k) (< 0) is the maximum deceleration desired by vehicle k; x (k, t) is position of vehicle k at time t; x (k-1, t) is position of preceding vehicle (k-1) at time t; s (k-1) is the effective length of vehicle (k-1); d' (k-1) is an estimation of vehicle (k-1) desired deceleration.

Correspondence between pixels and meters are made to assure correspondence between our section network on the computer and the real network through a fixed parameter β. For example, for a screen with 1200 pixel per line, and a section of 1.2 km, and when we choose β=1, then a vehicle with speed V=72km/h=72/3.6 m/s=20m/s=20 p/s, will take 60s to go over that screen. The architecture below resume all that algorithm.

Simulation and Validation

In this section, in order to assess the performance of the proposed hybrid algorithm, series of simulations are conducted to illustrate that the proposed distribution model and interaction model can improve the microscopic traffic simulation.

The first column shows the time in seconds. Column 2, 3, and 4 shows the acceleration, velocity and distance of the leader vehicle. Column 5,6, and 7 shows the acceleration, velocity and distance of the follower vehicle.

Table 1: Car-following results

Time	Position vehicule k	Speed vehicule k	Position vehicule k+1	Speed vehicule k+1
1	1.7573973267085796	33.334204408194346	2.3333420440819435	30.734204408194344
2	2.0692393707905232	33.78420440819435	2.671184088163887	31.184204408194343
3	2.3810814148724666	34.234204408194344	3.0135261322458304	31.184204408194343
4	2.69742345895441	34.68420440819435	3.360368176327774	31.634204408194343
5	3.0182655030363534	35.13420440819435	3.711710220409717	32.084204408194346
6	3.348107547118297	35.584204408194346	4.067552264491661	32.984204408194344
7	3.6824495912002404	36.03420440819435	4.427894308573604	33.43420440819435
8	4.021291635282184	36.48420440819435	4.792736352655548	33.88420440819434
9	4.360133679364127	36.93420440819435	5.162078396737492	33.88420440819434
10	4.70347572344607	37.38420440819435	5.535920440819435	34.334204408194346
11	5.055817767528014	37.83420440819435	5.9142624849013785	35.234204408194344
12	5.412659811609958	38.28420440819435	6.297104528983322	35.68420440819435
13	5.769501855691901	38.73420440819435	6.684446573065266	35.68420440819435
14	6.1353438997738445	39.184204408194354	7.07628861714721	36.584204408194346
15	6.505685943855788	39.63420440819435	7.472630661229153	37.03420440819435
16	6.8805279879377315	40.08420440819435	7.873472705311096	37.48420440819435
17	7.255370032019675	40.534204408194356	8.278814749393039	37.48420440819435
18	7.634712076101619	40.98420440819435	8.688656793474982	37.93420440819435
19	8.018554120183563	33.434204408194354	9.102998837556925	31.38420440819435
20	8.406896164265506	33.88420440819435	9.521840881638868	31.83420440819435
21	8.79973820834745	34.33420440819435	9.945182925720811	32.28420440819435
22	9.201580252429393	35.784204408194356	10.373024969802755	34.184204408194354

23	9.603422296511336	38.23420440819435	10.805367013884698	35.184204408194354
24	10.00976434059328	40.684204408194354	11.242209057966642	40.63420440819435
25	10.420606384675224	44.13420440819436	11.683551102048586	41.08420440819435
26	10.835948428757169	44.58420440819435	12.12939314613053	41.534204408194356
27	11.255790472839113	45.034204408194356	12.579735190212475	41.98420440819435
28	11.680132516921056	45.48420440819436	13.034577234294417	42.434204408194354
29	12.108974561002999	45.934204408194354	13.49391927837636	42.88420440819436
30	12.542316605084942	46.38420440819436	13.957761322458303	43.33420440819435

The earliest car-following models considered the difference in speeds between the leader and the follower as the stimulus. And the reaction time disturbed randomly. It was assumed that every driver tends to move with the same speed as that of the corresponding leading vehicle. According to such models, the driving strategy is to follow the leader and, therefore, such car-following models are collectively referred to as the follow the leader model.

Conclusion

This work discussed the randomly distributed simulation of the road traffic. It described the main aspects of the general computer simulation and the specific features of the computer simulation in the field of road traffic. The first section introduced the topic. The second section provided a general description of the Microscopic traffic modeling software The third section proposed Multi-Agent architecture proceeded with the description of the main issues of the distribution model and the interaction model as well as the stochastic distribution model. The obtained results in section six proved the effectiveness of the new model and its relevance to reality.

This research does by no means intend to provide a general or a comprehensive study of the issue; it is just an attempt to shed light on microscopic traffic simulation by adding new dimensions and layers of study. The final results of the this paper proved its efficiency and applicability in real life.

We present two sets of experimental results. Our first set of experiments examines the Average Speed of the vehicles in a section of the road; the second one evaluates the average wait time of cars in the entry of the section road.

Shows simulation results for different levels of traffic volume (30%, 60%, and 90% of the capacity). Up to the 60% level, traffic was smooth and there were no long queues at all. In the 90% level, we note that average wait time increases but the average speed of vehicles in upstream remains balanced

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