Congreso Nacional de Control Automático 2013
Ensenada, Baja California, Mexico, Octubre 16-18, 2013

Sensitivity Parameter of a Microscopic Traffic Model

Oscar A. Rosas-Jaimes (oscar.rosasjaimes@yahoo.com)
Omar Luckie-Aguirre (omar_ luckie@hotmail.com)
José C. López Rivera (jclopezr@fi.uaemex.mx)
Autonomous University of the State of Mexico UAEMex
Cerro de Coatepec s/n, c.p. 50100, Toluca, México

Abstract— **Microscopic models are used in traffic analysis, road design and driving behavior studies due to they focus on individual agents of traffic, from which it is possible to observe interesting details about concerning phenomena.**

In this work we have coded a very simple microscopic traffic model through the car-following perspective (by Pipes), in order to study driving behavior in an urban environment from instrumented cars data.

From these data sets of leader-follower cars, a parameter identification scheme is performed in order to obtain calculations of a sensitivity value, which is related to the driver reactive character. This value is then related to the possible driver behavior performing a psychological relation.

Final results are compared and discussed and conclusions established.

Keywords: Microscopic traffic models, Parameter identification, Driving behavior.

I. INTRODUCTION

Population growth has had as one of its consequences a larger number of cars through the years. At the same time, this has resulted in shrinkages in road capacities, higher traffic jams and longer travel times. Increased costs and fewer spaces to construct new streets or highways have turned impractical in a bigger number of cases. These observations can be traced from fifty or more years ago (Isaksen and Payne, 1973; Lighthill and Whitham, 1955).

From the same number of years, to visualize road networks and their different subsystems as dynamical in order to optimize them and regulate them by analytical means have gained popularity (Drew, 1968; Payne and Thompson, 1974; Richards, 1956; Rothery, 1992), due to they focus on expanding the road infrastructure possibilities minimizing costs but maximizing allocations for vehicles.

Those system models have divided into two main approaches, being macroscopic traffic systems those which study traffic variables as continuous and aggregated quantities similar to a fluid behavior, and microscopic traffic systems those which focus on values of individual units of the traffic phenomena (May, 1990). In these latter models, cars and even drivers are subjected to be represented dynamically in their responses and tried to get analyzed in order to be approached to real behavior (Brackstone and MacDonald, 1999; Gazis and Edie, 1968; Lárraga et al., 2005; Weng and Wu, 2001). Most of these models have as a main assumption that cars move on a one-lane road. This feature includes the consequence that there are not overtakes among vehicles (even though some special conditions must be taken into account in order to model lane changes) being then known as car-following models.

These models' design has to do with driving task analysis, where three subtasks (Rothery, 1992) are considered:

1) Perception: The driver collects visual information, primarily from the motion of the car in the front (leader). Driver's car (follower) will be affected by information resulted by the perceived velocity, acceleration, space between vehicles, etcetera.
2) Decision making: The driver interprets the information obtained, relates with previous learned knowledge and develops strategies that are applied in order to keep a safe and practical movement.
3) Control: The experienced driver can perform management actions with skill and coordination, relying on information obtained previously.

Many of the key issues related to driving such as perception, decision making and control are in the area of "human factors" and the study of how human intelligence is related to information processing. The car-following models do not explicitly take all these factors, but in general it is possible to express them with the simple relation in Equation (1).

$$\text{Response} = \lambda \cdot \text{Stimulus} \qquad (1)$$

λ is a factor that measures sensitivity of the follower's reaction and can assume many forms and many specialists have been conducted their research in order to design and calibrate terms of this type (Brackstone and MacDonald, 1999; Chung et al., 2005; Kesting and Treiber, 2008).

The stimulus function consists chiefly on relative speed, distance among vehicles and acceleration. Depending on the precision searched, other factors can be entered on consideration, as drivers' perception on other leading vehicles (Helly, 1959), the time history of the relative speed (Lee, 1966) or the assumption that the sensitivity factor is rather a function of other involved variables (Gazis, Herman and Rothery, 1961).

For the purpose of this work, we consider, in the next section of this document, a simple microscopic model that includes a constant sensitivity factor λ, which calibration we analyze, in the respective part of this paper, from real data obtained by experiments conducted in cars driven in urban conditions. Results are shown and depicted by illustrative plots, and analysis are then elaborated, as for the calibration as for the behavioral implications that can outcome. At the end, we write down some conclusive remarks as well as describe some future work.

II. PIPE'S MICROSCOPIC MODEL

We are considering Pipe's microscopic traffic model (Pipes, 1953). This author observes that the stimulus for car movement is related to keep up with the leading vehicle and to avoid collisions. From the right side of Equation (1), the stimulus function is then a relation of the relative speeds between leader and follower.

$$\text{Stimulus} = v_l(t) - v_f(t) \tag{2}$$

where:

$v_l(t)$: Leader's velocity at time t
$v_f(t)$: Follower's velocity at time t

In turn, the response function at the left side of Equation (1) is linked to the follower vehicle acceleration, because this response is influenced by the change in the leader's vehicle speed. In other words, the follower will increase its velocity $v_f(t)$ if he/she perceives that the velocity of the leader $v_l(t)$ is bigger, but will decrease it if he/she perceives that it is smaller. These changes in follower's velocity are expressed as acceleration

$$\text{Response} = a_f(t) \tag{3}$$

Both sides of Equation (1), expressed respectively by Equations (2) and (3), are integrated by Equation (4) by means of a factor λ.

$$a_f(t) = \lambda[v_l(t) - v_f(t)] \tag{4}$$

(Chandler et al., 1958) have proposed to make a more realistic approach of Pipe's model through the inclusion of a time delay, representing the fraction of time in which the follower responds physiologically and psychologically, i.e. the amount of time in which the task of driving lasts to perform the three subtasks described in Section I. Due to acceleration is the time derivative of velocity, Equation (4) can then be re-written as Equation (5).

$$\frac{\partial v_f(t+\tau)}{\partial t} = \lambda\left[v_f(t) - v_l(t)\right] \tag{5}$$

For this model, the sensitivity factor λ is assumed to be constant, and it is physically interpreted as a measure of the follower's reaction with respect to the leader, i.e. for lower values of λ correspond less reactive followers than those with larger values, implying psychological aspects implicit in such a parameter, which range spans $\lambda \in [0, 1]$.

Even though the main advantage of Pipe's model is simplicity and enough understanding of the main physics involved in car-following phenomena, it is also easy to notice that there are some drawbacks that undermine accuracy. One of them is that the only stimulus taken into account is the relative speeds among cars.

It has been tested and probe (Chung et al., 2005) that drivers also consider a safety distance between bumps also to avoid collisions. Other inconsistency in model (5) is that the arithmetic difference between velocities can result in zero values, giving zero acceleration $a_f(t)$, which is not realistic either (Helly, 1959).

However, in spite of these troublesome points, this model can be considered good enough, useful in most of the cases and simple to manage. We have decided to make a calibration of its sensitivity factor λ in order to obtain local data and validate simulations of the regions connected to our community as a first approach in conducting a broad set of experiments related with the traffic in the central part of Mexico.

III. CALIBRATION METHODOLOGY

We conducted series of experiments to get speed data from pairs of vehicles. Table I shows features of 6 cars with their respective drivers that were included to perform related activities.

TABLE I: Vehicles driven and drivers data

Vehicle				Driver	
Car Company	Brand	Vehicle	Year	Gender	Age
Volkswagen	Jetta	1	2003	Male	52
		2	2004	Male	23
Nissan	Sentra	3	2008	Male	21
		4	2013	Female	43
Toyota	Yaris	5	2010	Male	40
		6	2010	Male	52

As can be observed, the selected cars were categorized in pairs, because we wanted to perform leader-follower runnings with as much similar as possible automobiles, in order to diminished the influence of each car specifications and leaving a bigger influence on the drivers' performance.

In that manner, vehicles 1 and 2 were driven in such a way that one of them played as leader and the other as follower for a first running, and then roles changed for a second running. The same activities were played by the other two pairs of cars.

Suitable OBD (On-Board Diagnostics) hardware and software were utilized in order to get velocity and other quantities from on board computer of every involved car.

Drivers were asked to drive their vehicles in a loop of approximately 2.5 km, which represent the University Campus perimeter (Figure 1). This is located in an urban area, where two sets of traffic lights and six bumps exist as part of this road circuit. Four of the six runnings (with vehicles 1-4) were performed on a Saturday morning, where moderate traffic influence in the surrounding streets was taken as part of the conditions of the experiment. Another pair of runnings with vehicles 5 and 6 was performed during Sunday low–volume traffic.

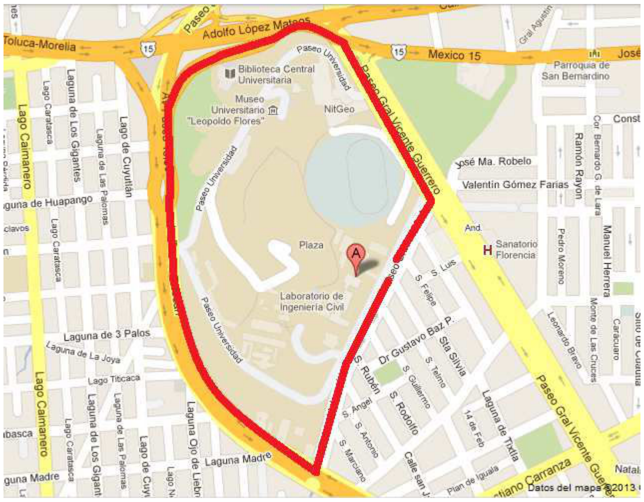

Fig. 1: UAEM Campus and loop performed in the set of experiments with cars

We stress drivers' performance above any other conditions as the main factor to take into account for our experiments. In fact, all of them were asked to drive as usual, with only two restrictions:

1) Followers should not overtake leaders.
2) Followers should not permit any external car succeeded in locate between them and leaders, except if safety was in risk.

IV. EXPERIMENTAL RESULTS

Six sampling circuits were performed outside the University Campus in the already described loop, organizing the runnings as Table II shows, where the identification numbers given to cars in Table I indicate the role as leader or as follower.

TABLE II: Organization of the runnings

Sampling Circuit	Vehicle Identification	Car Number Relationship	
		Leader	Follower
A	Jetta	1	2
B		2	1
C	Sentra	4	3
D		3	4
E	Yaris	6	5
F		5	6

Data obtained had to be processed and treated, i.e. a synchronization-type treatment had to be performed. Due to an operator accompanied to each driver in order to manage the software in each computer where data were captured, starting times to record data differ as well as stopping times. Watching for convenient and similar times between data sets, it is possible to establish analogous time series for all the pairs of vehicles for each running. Once identified, velocity data for the leader-follower pair has an aspect like those shown in the plots of Figure 2.

In the same figure it is possible to see that there is a shift-like behavior for all followers in relation with their respective leader for every sampling circuit, an expected result because of the not-overtaking condition. This aspect corresponds also with the intention of following the leader by the followers depicted by the speed profiles very similar among the two involved drivers. However, even though these resemblances are very close, they are not identical, which revels the followers' necessity to be in expectancy and to react to the behavior of the leaders' unknown intentions.

V. SENSITIVITY PARAMETER ESTIMATION

From the last data sets it is possible to perform an estimation of the sensitivity parameter λ. Model of Equation (5) can be written in a discrete approximation form like in (6).

$$\frac{v_f(t+\Delta t)-v_f(t)}{\Delta t} \approx \lambda\left[v_f(t)-v_l(t)\right] \qquad (6)$$

The left side of (6) is the derivative approximation for two very close sample points of the time series.

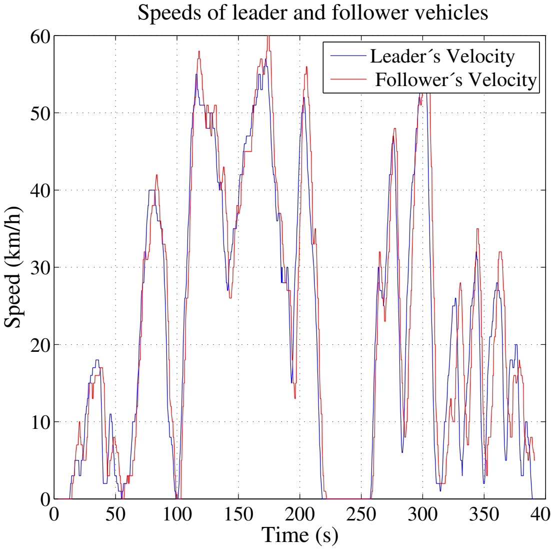

Fig. 2: Speed profile for running A as listed in Table II

Equation (6) has the additional advantage of having all its quantities known but one, and then it is convenient to work out the value of λ to obtain Equation (7)

$$\lambda \approx \frac{1}{v_f(t) - v_l(t)} \cdot \frac{v_f(t+\Delta t) - v_f(t)}{\Delta t} \tag{7}$$

By substituting leader and follower velocities for each case in Equation (7), estimations of λ are achieved.

These sets are not series of constant values for such a parameter. In many intervals these estimated values tend frequently to infinity because, as previously mentioned, $v_l(t) - v_f(t)$ some times tends to zero. There were also other calculations that resulted in finite values being out of the range $\lambda \in [0, 1]$. It was necessary for us to identify and to get rid of such values without losing the inherent signification of this parameter.

The remaining estimations were consistent enough to be suitable of calculation of their means. Table III shows the sensitivity parameter λ for each follower in his/her respective sampling circuit. Sampling times Δt are also included. Due to car's computer has different inner clock signals, those Δt values are distinct in each case.

TABLE III: Average value of the sensitivity parameter λ for each running.
Mean sample time values t are included for each case.

Sampling Running	Δt	λ [s^{-1}]
A	0.4300	0.56
B	0.4391	0.52
C	0.1899	0.75
D	0.1880	0.80
E	0.1858	0.78
F	0.1886	0.62

VI. SIMULATION

The main purpose to calibrate a parameter as λ has to do with the completion of having a model that can be used in simulations of real phenomena as close as possible to reality. Once achieving such an objective it is possible to estimate other useful quantities, such as times of travel, travel distances, levels of congestion and bottleneck places in a network.

Plots in Figure 3 depicts comparisons between speed profiles of followers against speed profiles obtained by calculation of model (5), with $\tau = 0$ and with the corresponding substitution of λ in A. Similar profiles were obtained for runnings B to E performed by pairs of cars in our experiments. For each follower we have run the respective simulation with λ.

VII. PSYCHO-PHYSIOLOGICAL ASPECTS

Sensitivity parameter is a measured of follower's reactivity to the actions of the leading vehicle being, as stated previously, bigger for higher values of λ. In other words, there is a value of this parameter for each driver. But it is also true that even for a specific individual this value can change depending on the level of fatigue or mood. In this manner, this quantity encloses also some psycho-physiological aspects of those drivers that generate them.

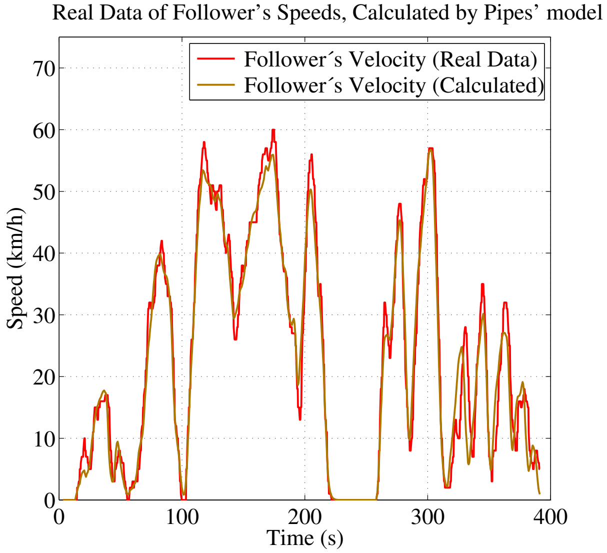

Fig. 3: Comparison between measured data of Running A and the calculation of Pipe's Model with λ = 0.5586

It is impossible to distinguish all different factors that affect the value of λ, but it is possible to use it as a junction among physical data and psycho-physiological ones. From speed profiles like those shown in Figure 3, and knowing the initial separation among pairs of cars for each running, it is possible to estimate the position of the cars by means of (8).

$$S(t) \approx \sum_{i=1}^{n} v_{fi}(\Delta t)_i \tag{8}$$

where:

$S(t)$: separation between centers of cars
v_{fi}: follower car velocity at the end of interval i
$(\Delta t)_i$: i-th sample time interval

As a consequence of expression (8), now it is possible to generate position profiles for each running as in Figure 4. With such data sets now we are able to calculate the relative separation of cars for each running, by subtracting follower's position from leader's position at time t. Table IV lists the average for such separations for each running.

Table IV also repeats λ values relative to each running. A close watching on Table IV shows that there is an inverse relation tendency among quantities in the last two columns, i.e. for bigger λ there exist smaller $s_l(t) - s_f(t)$ differences.

TABLE IV: Average value of separations between centers of cars for each running

Sampling running	$s_l(t) - -s_f(t)$ [m]	λ [s^{-1}]
A	43.38	0.56
B	43.72	0.52
C	19.28	0.75
D	11.98	0.80
E	44.74	0.78
F	53.40	0.62

This should not be a surprise. A direct way to measure reaction levels on drivers that follow other car in front of them is through the separation they permit to exist between both vehicles. Many authors (see for example (van Winsun, 1999; Chung et al., 2005)) report that this is a main factor to take into account not only to model human driving behavior, but in order to model microscopic traffic.

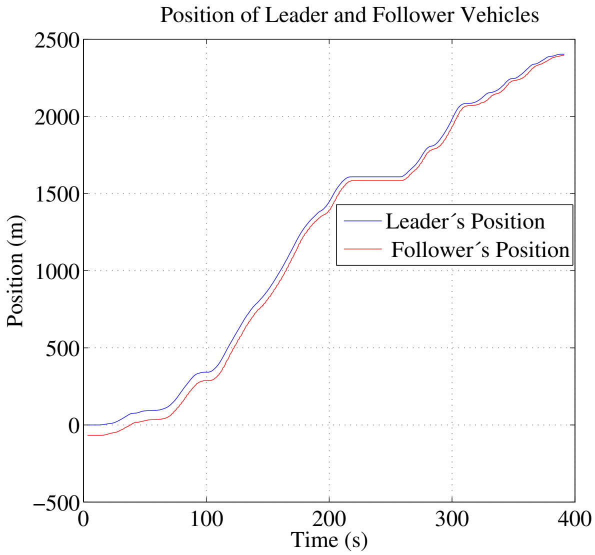

Fig. 4: Position profiles for Running A

VIII. CONCLUSIONS

A model is useful for performing simulations of real phenomena until necessary calibrations are performed. Such calibrations are carried on model's parameters that fit such a model into specific situations of application. We have obtained appropriate measuring data sets of vehicular speeds for leader-follower pairs in order to perform a calibration for a well-known car following model.

Different values of the sensitivity parameter λ were obtained in each running, and then they were substituted in proper programming codes in order to perform simulations in which the speed profiles from measured data of the followers were compared with those calculated in such simulations. The resulting plots show a very good fitting between both pair of points for each situation.

Such sensitivity values were obtained for different drivers, which reflect inherently psycho-physiological aspects in their driving behavior, which can be roughly related through this sensitivity parameter due to it is a mean to adjust the reactive response of a driver behind a leading vehicle for the proposed model.

In order to obtain an alternative way to probe this idea, position estimations were calculated from speed data. By proper mathematical expressions and knowing the initial separation between leader and follower vehicles for each running, it was possible to calculate instantaneous separations and then calculate a mean in each running, where small values of average separations correspond to higher values of the sensitivity parameter λ.

If we agree that smaller distances correspond with more reactive drivers, then we can conclude that all the values for λ reflect such a condition. However, it is noticeable that this observation is not meaning that the relation between parameter λ and the separation averages calculated can be related in a simple proportional relation. However, this is a matter of future work.

Pipes' model is simple to understand, to analyse and to manipulate. On opposition, it shows conditions that misrepresent real behavior. Other microscopic models can represent in a better way those situations where this model fails. Besides this is a matter for future work also, in this communication we have been able to establish a general frame to estimate parameters like λ that appear in such models.

IX. ACKNOWLEDGEMENTS

This project is supported by the Autonomous University of the State of Mexico, funding with register FE048/2012.

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