Simulating the interaction of road users: A glance to complexity of Venezuelan traffic

Juan C. Correa\textsuperscript{1,}\textsuperscript{*}, Mario I. Caicedo\textsuperscript{3}, Ana L. C. Bazzan\textsuperscript{2} & Klaus Jaffe\textsuperscript{4}

\textsuperscript{1} Facultad de Psicología. Fundación Universitaria Konrad Lorenz. Colombia
\textsuperscript{2} Instituto de Informática. Universidade Federal do Rio Grande do Sul. Brazil
\textsuperscript{3} Departamento de Física. Universidad Simón Bolívar. Venezuela
\textsuperscript{4} Centro de Estudios Estratégicos. Universidad Simón Bolívar. Venezuela

Abstract

Automotive traffic is a classical example of a complex system, being the simplest case the homogeneous traffic where all vehicles are of the same kind, and using different means of transportation increases complexity due to different driving rules and interactions between each vehicle type. In particular, when motorcyclists drive in between the lanes of stopped or slow-moving vehicles. This later driving mode is a Venezuelan pervasive practice of mobilization that clearly jeopardizes road safety. Here, we developed a minimalist agent-based model to analyze the interaction of road users with and without motorcyclists on the way. The presence of motorcyclists dwindles significantly the frequency of lane changes of motorists while increasing their frequency of acceleration/deceleration maneuvers, without significantly affecting their average speed. That is, motorcyclist “corralled” motorists in their lanes limiting their ability to maneuver and increasing their acceleration noise. Comparison of the simulations with real traffic videos shows good agreement between model and observation. The implications of these results regarding road safety concerns about the interaction between motorists and motorcyclists are discussed.

1 Introduction

An almost worldwide practice of mobilization in urban traffic is known as “motorcycle lane-sharing”. This practice occurs when motorcyclists ride in between the lanes of stopped or slow-moving vehicles; an event observed in the so-called “heterogeneous traffic” in which different types of vehicles interact on the road (see Figure 1).

The practice of motorcycle lane-sharing has been studied with computer simulations. Lan and Chang \cite{1} simulated the moving behaviors of motorbikes

\textsuperscript{*}This author finished this work while being at Universidad Simón Bolívar in Caracas - Venezuela. His permanent affiliation is at Fundación Universitaria Konrad Lorenz in Bogotá - Colombia. E-mail: juanc.correa@konradlorenz.edu.co
in a mixed traffic with cars, and concluded that the maximum flow rates corresponded to a relative road occupancy (a proxy of density) of 17% to 30%. In another study, Lau and Chang [2] observed that the speed of motorcyclists was slightly higher than the motorists and that both maximum flow rates and critical speeds declined with an increase of maximum speed deviations. Lee [3] modeled six behaviors of motorcyclists (i.e., traveling alongside another vehicle, oblique following, filtering, moving to the head of a queue, swerving or weaving, and tailgating) and concluded that the presence of motorcycles enlarged the capacity of the road; b) the installation of a motorcycle’s dedicated lane on a road increased the maximum flow rate by around 20% because of the additional capacity of the motorcycle lane; c) the values of the “passenger car unit” (a metric used to assess heterogeneous traffic-flow rate) of motorcycles were considerably higher than the values of the passenger car unit of four-wheeled vehicles, since motorbikes are still able to progress by filtering when the movements of cars are constrained by density. Lan and his colleagues [4] simulated the interaction between motorists and motorcyclists and observed a larger deterioration of car flow as the number of motorcycles increased.

In Venezuela the use of motorcycles has dramatically increased as reflected in the rising sales of motorcycles during the last five years although dropping lately because of an acute economic and political crisis (see Figure 2). As a consequence, the practice of motorcycle lane-sharing has proliferated increasing road safety concerns [5]. Only in the first ten months of 2012 more than three daily fatalities of motorcyclists in road accidents were reported [6].

Our purpose in this work is to address the case of Venezuelan motorcyclists, who often ride in between other vehicles. We are interested in capturing the effect of such behavior on motorists’ behavior, if any. We tackle this problem through a minimalist agent-based model capturing the most basic interactions between road users. Agents’ rules were devised in order to mimic what any driver would observe when using a Venezuelan highway, i.e. extremely aggressive motorcyclists not afraid of driving between lanes at roughly 40 mph. The rest of the paper is organized as follows. Section 2 presents the procedure and results of empirical observations conducted in a Venezuelan highway. Section 3 describes the agent-based model. Section 4 presents the results of our simulation model and section 5 discusses the implications of our overall results.


2 Caracas traffic as it is

The reader can watch one of our observations in YouTube (http://youtu.be/QLCIqaXOQzY). This video shows the segment of “Francisco Fajardo Highway” in the south-west of Caracas where we observed the two types of traffic: homogeneous traffic where only motorists were on the road and heterogeneous traffic where motorcyclists and motorists used the road at the same time. Motorcyclists ride in between the left and the central lane of the road, while homogeneous traffic occurs between the central and the right lane where a motorcycle was rarely seen. The videos were recorded when traffic was high (7:00am - 8:00am and 17:00pm - 18:00pm) during working days.

The analysis of heterogeneous traffic flow required the use of the so-called passenger car unit (“PCU”) which is a proxy of density based on the idea of the physical occupation of the road that corresponds to each type of vehicle. The PCU values of cars and motorcycles have been empirically determined [3]: a 1 PCU represents a standard four-wheeled vehicle and 0.4 PCUs represent a standard motorcycle. These values were employed to estimate the heterogeneous traffic flow of our videos and found that this was on average 1.25 times higher than the homogeneous flow; indicating that the practice of motorcycle lane-sharing increases the physical capacity of the road by allowing a greater volume of heterogeneous traffic. The presence of motorcycles affected the frequency of lane-changing maneuvers and the speed of motorists. From the analysis of 20 videos we observed that motorists changed lanes $9.9 \pm 6.6$ times per minute (average ± standard deviation) in homogeneous traffic and $3.7 \pm 2.9$ times in heterogeneous traffic. The average speed of motorists proved to be quite similar in both situations ($9.95 \pm 2.6$ m/s in homogeneous traffic versus $9.9 \pm 2.2$ m/s in heterogeneous traffic). A Student’s t-test showed that the difference in lane changing frequency was statistically significant ($t = 18.05; df = 1; p < 0.01$), between both type of traffic, whereas that between the average speeds was not ($t = 1.02; df = 1; p > 0.1$).
3 A model of motorcycle lane-sharing

The model was implemented with “SeSAm” and is available for download at [http://www.openabm.org/model/3135/version/2/view](http://www.openabm.org/model/3135/version/2/view). The model simulates cars traveling on a two lane road with and without interacting with motorcyclists. The purpose of our model is to explore the effects of motorcycle lane-sharing on motorist’s behavior in order to answer the following questions: 1) What is the quantitative impact of motorcycle lane-sharing on the motorist’s behavior of lane-changing? 2) What is the quantitative impact of motorcycle lane-sharing on the frequency of acceleration and deceleration maneuvers performed by motorists? 3) What is the effect of motorcycle lane-sharing on the average speed of motorists? Our procedure of data collection includes the observation of average speed; the frequency of accelerations/deceleration maneuvers and the frequency of lane-changing maneuvers of motorists and motorcyclists. These metrics have been deemed relevant for traffic management and traffic safety [7, 8]. Our agent-based model reproduces the behavioral interaction between road users and allowed for quantitative and for visual qualitative presentation of the results.

The model comprises three agents: the road, the motorists and the motorcyclists. These agents interact in a non-toroidal 2-dimensional virtual environment, represented as a map with a coordinate system whose origin lies in the upper, left corner. The physical dimensions of this map were 40 meters of height by 400 meters of width. The physical dimensions of the road were equivalent to a two lane avenue with a length of 400 meters. The width of each lane was fixed to 4 meters. The total length of a single lane is constituted by 100 cells of 4 meters length by 4 meters width. We assume a maximum speed of 10 m/s. These features are common to the so-called “cellular automata models” where the road is divided as a grid and each cell behaves according to standard rules that allow the simulation of the macroscopic behavior of traffic (see for instance [9]). The cells of the top lane of the road were identified with the number one and the cells of the bottom lane were identified with the number two for allowing the motorists to change lanes according to the rules described in Table 1.

The road allowed the entrance of cars on the right edge of the way, inside a randomly selected lane and with a randomly selected preferred speed. The critical reader might be against this form of modeling arguing that traffic flow does not behave completely at random. Yet, this form of modeling has been done in previous simulations [10, 11], and it was not our purpose to study traffic flow transitions and its impact on mixed traffic. The physical dimensions of cars were set to 4.5 meters length by 1.7 meters width, resembling a “standard compact vehicle” in the real world and motorcycles were set to 2 meters length by 1 meter width, resembling a “standard street motorbike”. Regarding the driving behavior of motorists, we used the geometrical central point of the cells of the road to locate the position of cars “inside the lane” when entering to the road. Motorcycles were located at the bottom of the first lane which corresponds to the space in between cars (i.e., between lane 1 and lane 2). Motorcyclists could “switch lanes” but never traveled “inside” them. Motorists and motorcyclists decided their instantaneous behavior following the rules defined in the format of “if-then-else” decisions that are summarized in Table 2. We are keenly aware of the simplistic rules that we use to mimic the current behavior of motorists and motorcyclists. Yet, we justify this approach because it allows understand
Table 1: State variables of motorists and motorcyclists

| Name | Type of variable and default values | Description |
|------|------------------------------------|-------------|
| D    | Numeric (Direction = 180)          | Stands for direction (from east to west) |
| IS   | Numeric (5, 6, 7, 8, 8, 10)        | Stands for instantaneous speed in m/s |
| PS   | Numeric (5, 6, 7, 8, 9, 10)        | Stands for preferred speed in m/s |
| CL   | Numeric (1, 2)                     | Identifies the lane in which the vehicle is circulating at an instantaneous moment |
| P    | Position (Cartesian coordinates)   | Indicates the instantaneous position of a driver inside the road. |
| IFV  | List of entities                  | Enumerates in no specific order the list of in-front vehicles inside a radius of 25 meters from the instantaneous position of a vehicle. |
| FV   | List of entities                  | Enumerates in no specific order the list of following vehicles inside a radius of 25 meters from the instantaneous position of a vehicle. |
| VAL  | List of entities                  | Set that enumerates in no specific order the list of vehicles that are seen from the left rear view mirror |
| VAR  | List of entities                  | Set that enumerates in no specific order the list of vehicles that are seen from the right rear view mirror |

how simple rules interact to create the macroscopic behavior of traffic which is commonly analyzed in terms of macroscopic variables that do not consider the behavioral interactions among road users.
The model proceeds in discrete time steps and the road maintains a constant vehicular traffic flow by verifying the maximum number of cars that should be created for allowing their controlled entrance in either lane at the right edge of the map, and eliminating them when reaching the left edge of the road. This procedure is similar to previous simulations \[12, 10\] and this process iterates during 700 time steps for each simulation run. In the first 100 time steps no data is gathered in order to reach an invariant traffic flow (this is necessary for experimental control and it is not intended for mimicking “realistic” traffic flow transitions). Thus, data collection was done from \(t = 101\) until \(t = 700\). Once moving agents were created their state variables were processed in a random order within each time step. The motorists-motorcyclists ratio was kept constant at 2:1. Our experiment follows a completely randomized factorial design \[13\]. We manipulated traffic flow by creating five discrete levels of density (4, 8, 12, 16 and 20 cars on the road) in two types of traffic (homogeneous and heterogeneous). Both motorists and motorcyclists were allowed to drive with different preferred speeds as described in Table 1. The experimental setup used different combinations of density and traffic type, resulting in ten experimental situations. In order to make a tractable experiment, we limited the preferred speed of motorists and motorcyclists to 10 m/s. Data was summarized in a new database containing the motorists’ performance for each time step in 24 replications for each experimental situation.

| Name of the action                  | Check IF          | Then, do... (Else)                                                                 |
|-------------------------------------|-------------------|--------------------------------------------------------------------------------------|
| Accelerate                         | IS < PS           | Change speed by 1 m/s (Otherwise, if IS > PS, and change IS to PS)                  |
| Decelerate                          | IFV ≥ 1           | Change speed by 4 m/s (If IS < 0, set IS = 0)                                        |
| Switch to right lane                | CL = 2 IFV ≥ 1    | Adds 45 degrees to the value of D                                                   |
|                                     | VAR = 0           |                                                                                      |
| Enter into the right target lane    | D = 225 CL = 2    | Set D = 180 and set CL = 1                                                           |
| Switch to the left lane             | CL = 1 IFV ≥ 1    | Subtracts 45 degrees to the value of D                                               |
|                                     | VAL = 0           |                                                                                      |
| Enter into the left target lane     | D = 135 CL = 1    | Set D to 180 and set CL to 2                                                         |
| Keep speed                          | None of the previous rules met | Move according to IS , Set P and CL, Set the list of moving entities reflected in all rear view mirrors |

Table 2: Behavioral rule for motorists and motorcyclists
4 Results and validation of the model

The statistical distributions for the frequency of driving maneuvers as well as average speed of both motorists and motorcyclists are depicted in Figure 3. Note that acceleration/decelerations maneuvers of motorists increased when density increased in both traffic types, although they were performed less often in the homogeneous traffic condition ($F_{acceleration} = 1148.40; \text{df} = 4; p < 0.001$; $F_{deceleration} = 527.45; \text{df} = 4; p < 0.001$). The $95.8\%$ of the variance for motorists’ decelerations, and the $98.1\%$ of the variance for motorists’ accelerations were mainly accounted for by density ($\Omega^2_{acceleration} = 93.9\%; \Omega^2_{deceleration} = 88\%$) than by traffic type ($\Omega^2_{acceleration} = 0.7\%; \Omega^2_{deceleration} = 1.1\%$). The average speed of motorists dwindled while density increased, but motorcyclists kept their average speed regardless of density ($F_{speed} = 258.44; \text{df} = 4; p < 0.001$) and almost all of its statistical variance was accounted for by density ($\Omega^2 = 88.5\%$). Interestingly enough, the frequency of lane-changing maneuvers increased when density increased for both traffic types ($F_{lane-changing} = 89.64; \text{df} = 4; p < 0.001$), but motorists changed lanes four times more in the homogeneous traffic condition compared with the heterogeneous traffic, and motorcyclists changed lanes as frequent as motorists in the heterogeneous traffic condition. The larger part of the variance of lane-changing maneuvers was accounted for by the traffic type ($F = 534.82; \text{df} = 1; p < 0.001; \Omega^2 = 31.2\%$), the density ($F = 110.26; \text{df} = 4; p < 0.001; \Omega^2 = 30.6\%$) and the combination of these factors ($F = 89.64; \text{df} = 4; p < 0.001; \Omega^2 = 25.1\%$).

The validity of these results were assessed through a measure of agreement for interval or nominal multivariate observations “by different sets of judges” [14]. This measure, known as “iota” ($\iota$), indicates an agreement when a set of two or more observers have rated a sample of objects on several dimensions or variables. This measure can be interpreted in terms of expected and observed disagreement, calculated as average distances between judges’ observations, with a correction factor of agreement by chance. To estimate the agreement between the results of our model and the results of our observations, we created a unified table composed by data for relative differences between traffic types of the frequency of lane-changing maneuvers performed by virtual and real motorists as well as the difference of their average instantaneous speed, controlling for traffic density. This procedure is useful for validating “ordinal patterns” [15] between the two types of traffic. The agreement between the simulated results and the observed results proved to be highly significant ($\iota = 92.91\%$), as depicted in Figure 4.
Discussion

The effects of motorcycle lane-sharing on motorists’ behavior are consistent with Lee’s earlier results showing that heterogeneous traffic flow is higher than the homogeneous one [3]. In addition, our results complement previous findings described by Lan and colleagues [4] on the incentives for motorists to make lateral drifts and lane changes when sharing the lane with motorcyclists, showing that motorcycle lane-sharing “corrals” motorists into their lane reducing their frequency of lane changes while increases their frequency of acceleration/deceleration maneuvers. Also, the increase in acceleration and deceleration maneuvers increased acceleration noise (standard deviation of acceleration), which in turn affects the level of service of the roadway, and is also sometimes related to safety [16].

The above effects have to be combined with the fact that the average overall speed of motorists proved to be much more affected by traffic density than by the presence of motorcyclists on the road, which suggests that traffic accidents in heterogeneous traffic are not necessarily due to motorists’ speed, but to the maneuvers of both drivers and motorcyclists, which is consistent with previous...
simulations designed to analyze car accidents in homogeneous traffic [17] and earlier experiments on the interaction between motorists and motorcyclists in experimental settings [18].

Our study is by no means exhaustive on the observed complexities of Venezuelan traffic. Yet, we regard our model as one that illustrates how very simplistic rules for driving behavior can mimic traffic dynamics, without including very sophisticated features of simulation. Future works could include more detailed aspects of (un)safe driving behavior, such as the analysis of traffic accidents that are due to driving maneuvers, speed and their combination. As a final remark, we believe that our results may be significant for the research that aims studying the link between physical parameters of traffic and human behavior.

6 Acknowledgements

This research used resources of “Centro de Computo Científico del Grupo de Relatividad y Campos” of Universidad Simón Bolívar, Caracas – Venezuela. We are also indebted with Tess Roseng Carbonell for her assistance in reviewing preliminary versions of this manuscript.

References

[1] L. W. Lan and C.-W. Chang, “Motorbike’s moving behavior in mixed traffic: Particle-hopping model with cellular automata,” Journal of the Eastern Asia Society for Transportation Studies, vol. 5, pp. 23–37, 2003.

[2] L. W. Lan and C.-W. Chang, “Inhomogeneous Cellular Automata Modeling for Mixed Traffic with Cars and Motorcycles,” Journal of Advanced Transportation, vol. 39, no. 3, pp. 323–349, 2005.
[3] T.-C. Lee, *An Agent-Based Model to Simulate Motorcycle Behaviour in Mixed Traffic Flow*. PhD thesis, Imperial College: PhD Thesis, 2007.

[4] L. W. Lan, Y.-C. Chiou, Z.-S. Lin, and C.-C. Hsu, “Cellular automaton simulations for mixed traffic with erratic motorcycles’ behaviours,” *Physica A: Statistical Mechanics and its Applications*, vol. 389, pp. 2077—2089, may 2010.

[5] M. Wigan, “Motorcycles as full mode of transportation,” *Journal of the Transportation Research Board*, no. 1818, pp. 39–46, 2002.

[6] D. Figuera and K. J. Agar Angulo, “Primer estudio nacional de “accidentes” de motos en Venezuela,” tech. rep., AVEPAE, Caracas, 2012.

[7] A. Kesting, M. Treiber, and D. Helbing, “General Lane-Changing Model MOBIL for Car-Following Models,” *Transportation Research Record*, vol. 1999, pp. 86–94, jan 2007.

[8] J. A. Laval and C. F. Daganzo, “Lane-changing in traffic streams,” *Transportation Research Part B: Methodological*, vol. 40, pp. 251–264, mar 2006.

[9] X.-G. Li, B. Jia, Z.-Y. Gao, and R. Jiang, “A realistic two-lane cellular automata traffic model considering aggressive lane-changing behavior of fast vehicle,” *Physica A*, vol. 367, pp. 479–486, 2006.

[10] V. T. Arasan and R. Z. Koshy, “Methodology for modeling highly heterogeneous traffic flow,” *Journal of Transportation Engineering*, vol. 131, no. 7, pp. 544—551, 2005.

[11] K. Krishnamurthy and V. T. Arasan, “Effect of road width and traffic volume on vehicular interactions in heterogeneous traffic,” *Journal of Advanced Transportation*, vol. 48, no. 1, pp. 1–14, 2014.

[12] V. T. Arasan and G. Dhivya, “Simulation of highly heterogeneous traffic flow characteristics,” in *In Proceedings of the 24th European Conference on Modelling and Simulation*, (Kuala Lumpur, Malaysia), pp. 81—87, 2010.

[13] R. A. Fisher, *The design of experiments*. Edinburgh: Oliver and Boyd, 1935.

[14] H. Janson and U. Olsson, “A measure of agreement for interval or nominal multivariate observations by different sets of judges,” *Educational and Psychological Measurement*, vol. 64, no. 1, pp. 62–70, 2004.

[15] W. Thorngate and B. Edmonds, “Measuring simulation-observation fit: An introduction to ordinal pattern analysis,” *Journal of Artificial Societies and Social Simulation*, vol. 16, no. 2, p. http://jasss.soc.surrey.ac.uk/16/2/4.html, 2013.

[16] S. Boonsiripant, *Speed Profile Variation as a Surrogate Measure of Road Safety Based on GPS-Equipped Vehicle Data*. PhD dissertation, Georgia Institute of Technology, 2009.

[17] N. Moussa, “Car accidents in cellular automata models for one-lane traffic flow,” *Physical Review. E*, vol. 68, no. 3, p. 36127, 2003.
[18] A. D. Ohlhauser, S. Milloy, and J. K. Caird, “Driver responses to motorcycle and lead vehicle braking events: The effects of motorcycling experience and novice versus experienced drivers,” Transportation Research Part F: Traffic Psychology and Behaviour, vol. 14, pp. 472–483, sep 2011.