applied sciences

MDPI

Article

Human and Environmental Factors Analysis in Traffic Using Agent-Based Simulation

Ariadna Claudia Moreno [1], Mailyn Moreno [2], Cynthia Porras [3] and Juan Pavón [4,*]

[1] Escuela Superior de Ingeniería Mecánica y Eléctrica, Unidad Culhuacán, Instituto Politécnico Nacional, Ciudad de México 04440, Mexico
[2] Centro de Investigación en Computación, Instituto Politécnico Nacional, Ciudad de México 07738, Mexico
[3] Facultad de Ingeniería Informática, Universidad Tecnológica de La Habana "José Antonio Echeverría", La Habana 19390, Cuba
[4] Instituto de Tecnología del Conocimiento, Universidad Complutense de Madrid, 28040 Madrid, Spain
* Correspondence: jpavon@fdi.ucm.es

Abstract: Traffic congestion is a frequent problem on most urban roads. This may be due to incorrect configuration of traffic signals but planning analysis should also include a study of human behavior, which, often imprudent, contributes to traffic congestion. The aim of this paper is to analyze the influence of human factors and their reaction to the environment on the impact of traffic performance through waiting time. For this purpose, an agent-based simulation is developed to represent the autonomous and social behavior of road users. The waiting of vehicles at signals is modeled on the basis of a queuing system. Simulations and experiments are based on the analysis of the age of the people and the condition of the pavement. Results show that people's age is the most important factor influencing their behavior on the road. It is also shown external factors that also affect driver response and thus signal impact, such as the condition of the pavement. Finally, traffic performance, measured by waiting time, depends strongly on the behavior of people facing signals, according to their characteristics and factors present in the environment.

Keywords: agent-based simulation; human behaviors; urban traffic; queuing model

check for updates

Citation: Moreno, A.C.; Moreno, M.; Porras, C.; Pavón, J. Human and Environmental Factors Analysis in Traffic Using Agent-Based Simulation. *Appl. Sci.* **2023**, *13*, 3499. https://doi.org/10.3390/app13063499

Academic Editors: Xue Yang and Luliang Tang

Received: 16 January 2023
Revised: 3 March 2023
Accepted: 8 March 2023
Published: 9 March 2023

1. Introduction

Problems related to traffic management are among the most frequently discussed in countries all around the world. Such problems include traffic accidents and congestion [1]. Traffic congestion refers to long queues of vehicles waiting for the activation of a traffic signal or for other vehicles. This situation can cause environmental pollution by excessive expulsion of gases into the atmosphere, fuel consumption and noise pollution [2]. In addition to environmental damage, it causes a delay in the routine and work activities of drivers and pedestrians [1].

The occurrence of unfortunate traffic situations is often caused by imprudent human behavior [3]. Human performance is a determining factor in the traffic scenario [3]. Road users decide whether or not to obey the signals, the travel speed, and whether or not to commit infractions; therefore, the evaluation of traffic configurations must consider human behavior [4]. Characteristics such as age, gender, or driving experience have been shown to be determinants of a person's behavior on the road [5,6]. In addition, other external elements can affect people's decisions, including road pavement [7] and weather [8,9]. The effect of these external factors will vary according to the main characteristics of the person. Therefore, in addition to analyzing how the person behaves on the road, it is also necessary to evaluate their reaction to events such as driving on a bad road or the occurrence of rain or fog.

Because of the number of factors that influence the results of a configuration, and the economic and labor costs of a counterproductive placement, they should be simulated prior to installation [10]. A technique that has proven to be effective in the evaluation of traffic configurations is agent-based simulation [11]. Intelligent agents offer advantages in modeling human behavior because they are autonomous, reactive, proactive and socially skilled [4]. Through simulation, it is possible to obtain—with a degree of certainty—the performance of such a signal configuration once in operation.

There are many metrics to evaluate the performance of a configuration: the number of accidents, the number of violations, and the waiting time of the simulation. Since the number of accidents, violations and the volume of vehicles directly influences the time that each vehicle delays within the simulated traffic region, it was decided to use the waiting time as an evaluation metric in this paper [12]. Therefore, to represent waiting situations that are generated on the road, queuing systems are used [13], where vehicles and people are customers waiting for the signal activation service.

Although the literature reviewed models various characteristics of people and their influence on traffic, there is no association between the different factors that confluence on the road, which can be human, vehicle or external, based on the human response to each of these factors.

The approach in this paper is novel in addressing human factors in an agent-based simulation model of urban traffic. Note that with agents it is possible to model different behaviors for traffic users, so they do not act all uniformly, but some variations can be specified, such as drivers not always respecting norms and signals on the road, or certain disabilities for pedestrians. The external elements modeled are weather, pavement, the technical condition of the vehicle and animals on the road. The experiments are based on the age of the traffic users, and in addition, the age-dependent reaction to pavement conditions. Thus, the relationship between various types of factors on the road, both human and environmental, will be also shown. The main contribution of the paper is given by the integration between the characteristics of traffic users and the external elements to evaluate their behaviors and reactions. The model can be easily extended to include new characteristics and human behaviors that are considered of interest for the analysis of signal configurations.

The rest of the paper is structured as follows. Section 2 contains a review of the literature, presenting studies with similar purposes and justifying research decisions based on the state of the art. In Section 3, the simulation model is presented, with the description of agents and their relationships. In addition, the generalities of the queuing system that represents the signal waiting times and the background of the simulation software are presented. Then, Section 4 describes the experiments performed and the results obtained. Section 5 discusses the results and compares them with previous research. Finally, Section 6 presents the conclusions and future work of this research.

2. Related Works

Several simulation models have been recently developed for the traffic phenomenon [11]. In [14], an agent-based simulation model is developed to evaluate the behavior of pedestrians crossing in front of automated vehicles, considering their personal characteristics. A study of the characteristics of drivers that can lead to driving errors resulting in accidents is presented in [15]. In a similar approach, in [16] drivers are profiled in order to know their potential behavior based on their characteristics. In [17], a microscopic traffic simulation, including vehicles and pedestrians, is proposed to evaluate in a virtual environment the behaviors of real traffic.

The characteristics of pedestrians and drivers that are considered in the literature are: age [14,15,17,18], driving experience [15,16,19], reaction to events [16,17], gender [15], education level [15], social interaction [20] and mental model [16]. From the literature reviewed it can be estimated that the main human factors to be taken into account are age and driving experience [**?**].

Furthermore, in addition to simulation models, many frameworks have been developed that simulate traffic with an agent-based architecture including human factors [11].

MATISSE 3.0 [22] allows simulation of the interactions between vehicles and various traffic controllers. This framework represents autonomous and non-autonomous vehicles; for non-autonomous vehicles, there is a driver-agent that controls the speed and circle-of-influence of the vehicle and maintains a certain level of distraction. SUMO is a traffic simulation framework widely used for the representation of road behavior [23]. Agent-based functionality has been incorporated to simulate human behavior such as the selection of the best routes [24], the deviation of traffic due to natural phenomenon [25] or to obtain the impact of human actions on road safety [26]. MatSim framework allows the representation of intermodal transport, which indicates how to get from one point to another in different types of transport. The simulations include human factors such as age, employment status, education level, or possession of public transport tickets [18]. New functionalities and features are systematically added to Matsim to make it more realistic and powerful [18].

Among the proposals, different behaviors are evaluated: waiting time [27**?** –29], travel time [31], signal timing [33**?**], vehicle-pedestrian relation [14] or traffic safety [15,16,20]. Most of the proposals that analyze the waiting time, use queuing theory to represent it. The use of queuing theory in traffic representation offers advantages because there is an exact equivalence between the components of a queuing system and the traffic elements, it allows modeling the entry and exit of vehicles in a traffic network, and the model is flexible to add other traffic performance measures such as accidents and violations in addition to the basic queuing performance measures [14,15].

3. Materials and Methods

The presented model is an agent-based simulation to represent traffic actors and their relationships. Within the agents that compose the model, elements of the environment and human factors will be presented. As part of this simulation, a queuing system is integrated to represent the waiting time of the agents with the signals.

3.1. Agent-Based Simulation Model

The objective of the simulation is to leverage the autonomous and proactive nature of intelligent agents to mimic the actions of road users. The following list briefly describes the factors modeled in the simulation that potentially influence the agents:

- Pavement condition: Pavement deterioration, the presence of potholes and accumulated precipitation generate increasing capacity restrictions and increase congestion [7]. Wet roads also become dangerous even if they do not have potholes, as rain may cause vehicles to slide and thus collide.
- Ambient sensation: Rain, humidity and fog affect the driver's visibility conditions, and windshields blur internally and make it difficult to detect vehicles and people on the road. Pneumatic tires lose adherence and the wheel slip on the water with little contact with the pavement [34]. The extreme heat also makes drivers feel uncomfortable.
- Animals on the road: There are numerous homeless animals that are run over or injured by vehicles. For drivers, it is also a danger because when trying to save these animals, they realize abrupt and hurried turns that can end in a collapse or an accident [35].
- Lane overtaking: This phenomenon occurs when a vehicle, either by driver's rush, provocation or recklessness, tries to pass in front of the vehicle preceding it on the road. This maneuver, if performed incorrectly, can cause accidents [36].
- Vehicle characteristics: The color, size and technical condition of the vehicle influence the driver's actions on the road. In addition, damage or breakage on the road would cause an exceptional waiting situation, until the vehicle is fixed or trailed [37].
- Person characteristics: Age, gender, disabilities, years of driving experience, mood, stress, sobriety and driving comfort of a person determine their decisions on the road [3,38].

For every execution of the simulation, all these factors will be present, varying only in the obtaining of reports, where statistics of those selected for evaluation will be shown. By including all these factors the state space of the simulation increases. For this reason, the values associated with each factor are treated in a discretized form, which minimizes the number of possible combinations. However, it is necessary to evaluate them because this combination of factors was not found in the literature reviewed. The presented simulation supports the representation of all the described factors in maps with a finite number of intersections.

The simulation represents each actor in traffic as an agent. Road users and the above-mentioned time-varying factors are modeled. In the simulation, there are static agents, which are part of the environment and provide information to other agents for their operation, such as the map and the queuing model. Other agents also belong to the environment but have variable behavior in the simulation, such as the pavement, the weather and the traffic lights. Finally, there are the agents that model the people including the vehicle, the driver and the pedestrians.

A description of how each non-static agent performs is given below:

- Traffic light agent: Traffic lights work as simple reactive agents. They wait until a light has timed out and then activate the next light. There will be a traffic light phase for each access road to the traffic light, and each phase will have a set of available exit roads [4]. Traffic lights are the most hierarchical signals in the simulation.
- Driver agent: Drivers are created randomly based on values for age, gender, experience on the road (years of driving experience), mood and a level of distraction, which may influence the behavior of the driving vehicle. The age and experience can determine their corresponding "Risk Level", which is used to establish the violation and accident probabilities of those drivers [39].
- Vehicle agent: The vehicles trace their trajectory from their arrival to the destination using Dijkstra's algorithm [40]. These agents can collide, commit infractions and overtake other vehicle agents based on probabilities. They are driven by drivers, and the characteristics of these, combined with their color, size and technical conditions determine the probability of the events associated with them [39].
- Pedestrian agent: Pedestrians follow an established route when they are created. They may be generated from a vehicle and may have simple disabilities such as visual, motor or hearing impairments. Pedestrians have energy that is depleted as they walk. They can be chatting or talking while they walk [39].
- Pavement agent: The behavior is based on improving or worsening its ability to circulate vehicles. Before starting the simulation, an initial state is configured, which may change during the simulation. When drivers are about to drive on a road, the first step is to check its condition and then modify their speed to protect the vehicle from damage and breakage [7].
- Weather agent: The environmental conditions considered for the simulation are temperature, humidity, time of day and precipitation. The update of the observed variables is displayed by the environment at each step of the simulation and the vehicles are notified accordingly to moderate their speed considering the environmental state at each moment [7].

To represent the simulation model, the agents, their tasks, responsibilities and purposes, diagrams of the agent-oriented methodology, built with the INGENIAS software, IDK 2.7 [41,42], are used. Figure 1 shows a static view of the agents and their respective responsibilities and purposes. A dynamic view of the agent-based model is shown in Figure 2. The static view places all agents within the model with their purposes and responsibilities. The dynamic view relates these agents, showing, in addition, all the tasks of the simulation with their responsible and participants.

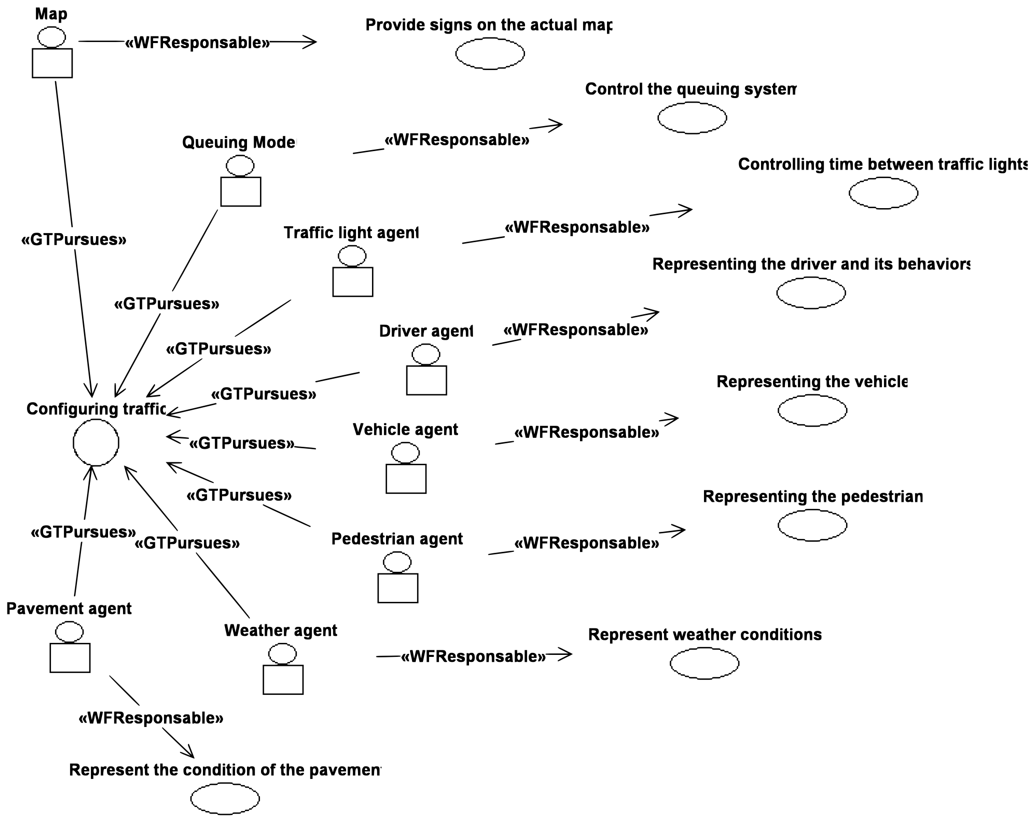

Figure 1. Static view of the agents present in the model: responsibilities and purposes.

In addition to the described agents, there are other entities that represent the remaining signals on the road -shown in order of importance on the road-: Stop, Yield and Speed Control signals. These do not have any associated behavior, they are only placed on the road at the beginning of the simulation and the users must respond to them. The location of the signals is obtained from OpenStreetMap [43] or placed by the expert in charge of the simulation.

Vehicles should only obey one signal at a time, as there is only one signal at each corner of the simulated map. To place a new signal on a corner that already has one, it can only be superior in type, eliminating the previous signal.

From the previous descriptions, the following basic rules of the simulation model can be obtained. All rules are based on probabilities posted by traffic staff:

- Vehicles proceed according to the status of the traffic light and other signals.
- Vehicles may commit infractions.
- Vehicles may overtake lanes.
- Vehicles avoid obstacles.
- Vehicles may break down while driving.
- Vehicles behave according to the characteristics of their driver.
- Vehicles behave according to the characteristics of the environment.
- Vehicles behave according to the characteristics of the pavement.
- There is a probability for pedestrians to stop and talk to other pedestrians.
- There is a probability for pedestrians to black out due to lack of energy.
- Disabled pedestrians will only cross the street at corners and with assistance.
- There is a probability for vehicles to drop off passengers.
- There is a probability for vehicles to pick up passengers.

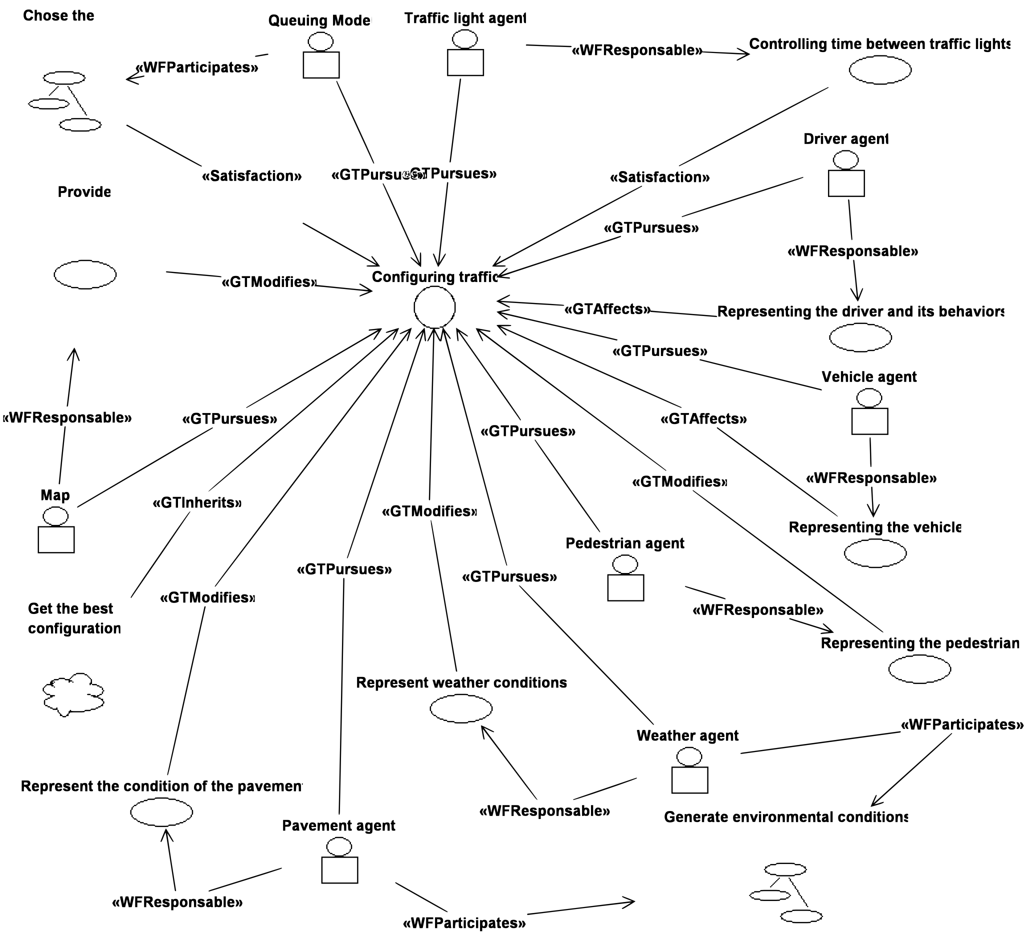

Figure 2. Dynamic view of the agents present in the model: relationships between agents, model tasks, responsible persons and participants.

3.2. Mathematical Model of Simulation Using Queuing System

The waiting time of vehicles at signals is modeled using queuing theory, where the customers are the vehicles, and the service provided is the activation of the signal to allow them to pass [44].

A queuing system is denoted by $(A|B|C : D|E|F)$ representation. Table 1 shows the representation of the queuing systems used in our model, which is based on the analysis at [28].

Table 1. Components of a queuing system and their representation in traffic.

Notation	Description	Values
A	Arrival distribution	Markovian (M)
B	Service distribution	Markovian (M)/General (G)
C	Number of servers	Lanes of the streets
D	Service discipline	FCFS (First Come, First Serve)
E	Maximum number of customers	Infinite
F	Customers source	Streets of the map

Service distribution has two possible values as there are two types of stations: traffic lights and stop signs. Stop signs have exponential distribution [28], so the model for these stations will be $(M/M/s)$. Traffic lights follow a general distribution [45] and the model will be $(M/G/s)$.

Table 2 shows the list of groups and parameters used by the model. It is also presented where each data set is obtained for the evaluation of the simulation and queuing systems [44]. The results that are generated by the simulation are random, while those set by the analyst are based on his knowledge of the traffic in the area. All model parameters are configurable so that it is usable by traffic staff. They have the responsibility to set some parameters and will also have the possibility to edit the ones obtained from the providers.

Table 2. Model parameters used by the queuing system to compute the waiting time at each service station.

Parameter Group	Parameter Name	Parameters Provider
Queuing Model	Average arrival rate Average service rate Variance of service time Utilization factor	Authors Measurements [1]
Map	Street Type Surface condition Width Maximum Allowed Speed	OpenStreetMap [2]
Vehicles	Type Technical condition Vehicle length	Set by traffic analyst
People	Age Sex Knowledge of the area Years of experience	Generated by simulator
Weather	Temperature Humidity Rain	OpenWeatherMap [3]
Probabilities	Red Light Violation Stop Violation Obstacles	Set by traffic analyst
Traffic	Minimum traffic light cycle Maximum traffic light cycle Standard speed of people Speeds by T_v and T_s Distance between vehicles	Set by traffic analyst

[1] https://github.com/amoreno98/simulation-model-data/tree/main/Measurements (accessed on 25 February 2022); [2] https://openstreetmap.org/ (accessed on 28 February 2022); [3] https://openweathermap.org/ (accessed on 28 February 2022).

Figure 3 illustrates how the relationship between the parameters behaves from a bottom up view of the parameters.

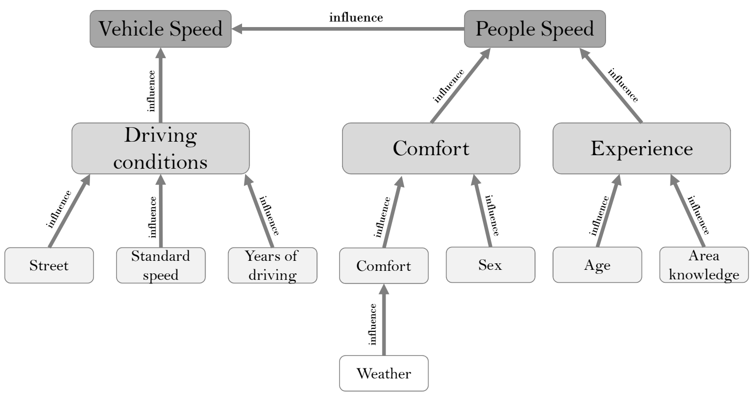

Figure 3. Leveled representation of model parameters and their relationships.

Human, vehicle and external parameters and factors compose the modifiers that affect vehicle and pedestrian travel speed. This speed serves as a determinant for the waiting time of the system, which is also affected by the waiting time for a crosswalk. The pedestrian waiting time also depends on the number of violations committed. Speed influences, whether driving or walking, through the following equation:

$$V_v = [\frac{V_e + V_s}{2} + Var_{CF-S_p}] \times Var_{G_p-K_p} \times Var_{U_s-E_v-X_p} \tag{1}$$

where,

V_e is the defined standard speed, -it has a different value for pedestrians and vehicles-,

V_s is the maximum allowable speed for vehicles,

Var_{CF-S_p} is the variation according to climate and gender,

$Var_{G_p-K_p}$ is the variation according to age and area knowledge, and

$Var_{U_s-E_v-X_p}$ is the variation according to the pavement, years of driving and condition of the vehicle.

In the case of pedestrians, for Equation (1), V_s has value 0 and $Var_{U_s-E_v-X_p}$ has value 1. Each variation is calculated with the following equations:

$$Var_{CF-S_p} = 0.01 \times (CF - 70)^2 + (1.5 - S_p) \tag{2}$$

$$Var_{G_p-K_p} = \frac{35}{G_p} \times \frac{3}{K_p} \tag{3}$$

$$Var_{U_s-E_v-X_p} = \frac{3}{U_s + E_v + X_p} \tag{4}$$

Several of the parameters mentioned in the model description are used in these equations. CF represents the comfort experienced by people facing the weather, obtained from the multiplication of ITH (Temperature-Humidity Index) and the millimeters of rainfall. The S_p, G_p and K_p are the sex, age and area knowledge of the person, respectively. $The U_s$ is the condition of the pavement, E_v the condition of the vehicle and X_p the driver's years of experience.

The total waiting time of the simulation will be calculated by the following Equation (5):

$$W = W_t + W_s + PA \tag{5}$$

where W_t is the waiting time at traffic lights, W_s is the waiting time at other signals and PA is the waiting time due to pedestrian and animal crossing.

A complete description of the mathematical model associated with the waiting time can be found in [44] and in Supplementary Material (https://github.com/amoreno98/simulation-model-data (accessed on 25 February 2022)).

3.3. Simulation Software Tool

The simulation is executed in simulation software developed by the authors. It contemplates the whole process from the capture of the map data to the analysis of the results obtained by the simulation. Figure 4 shows the diagram of the tool's activities (https://github.com/amoreno98/simulation-model-data/blob/main/simulation.rar (accessed on 25 February 2022)).

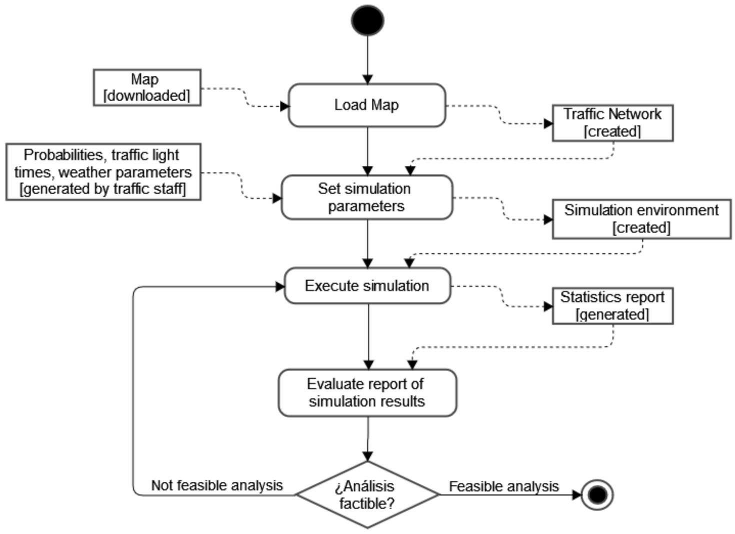

Figure 4. Activities Diagram of Simulation Software.

The general idea of this software is to provide a support tool for traffic authorities, where they can configure the traffic conditions they want to simulate. After each simulation, a report is generated with data of interest, such as the number of accidents, number of violations, and number of vehicles simulated, among other results. The simulation can be executed as many times as required until a satisfactory result is obtained, which can be installed in real time on the road. A complete description of each phase of the software can be found at [4].

4. Simulation Case Study

To illustrate and evaluate the agent-based simulation model, an experiment with four instances (agent configurations) has been performed. Each instance has been executed with 50 simulations corresponding to 6 h of traffic each (Each second of simulation is equivalent to 72 s of traffic. The 6-h executions required 5 min each). The objective is to show the influence of variation of the human factors on the model. For this purpose, we focus on two elements that influence human behavior: the age of pedestrians and drivers and their reactions to pavement conditions. Age was selected because it is the most important factor found in the literature review. In addition, the reaction to the pavement is evaluated because it is a key issue in the configuration of signals in Cuba due to the condition of the streets.

The influence of these two factors on violations committed, traffic speed and the resulting waiting time at the traffic intersection will be shown. Moreover, previous state-of-the-art scenarios that only include pedestrians or drivers exclusively are modeled. The results are compared to show the influence of both factors simultaneously.

4.1. Instances Description

Figure 5 shows the street and signal distribution for the four instances analyzed, which are taken from real streets in the town of Plaza, Havana, Cuba. The instances were chosen because of the variability in the distribution of the existing signals.

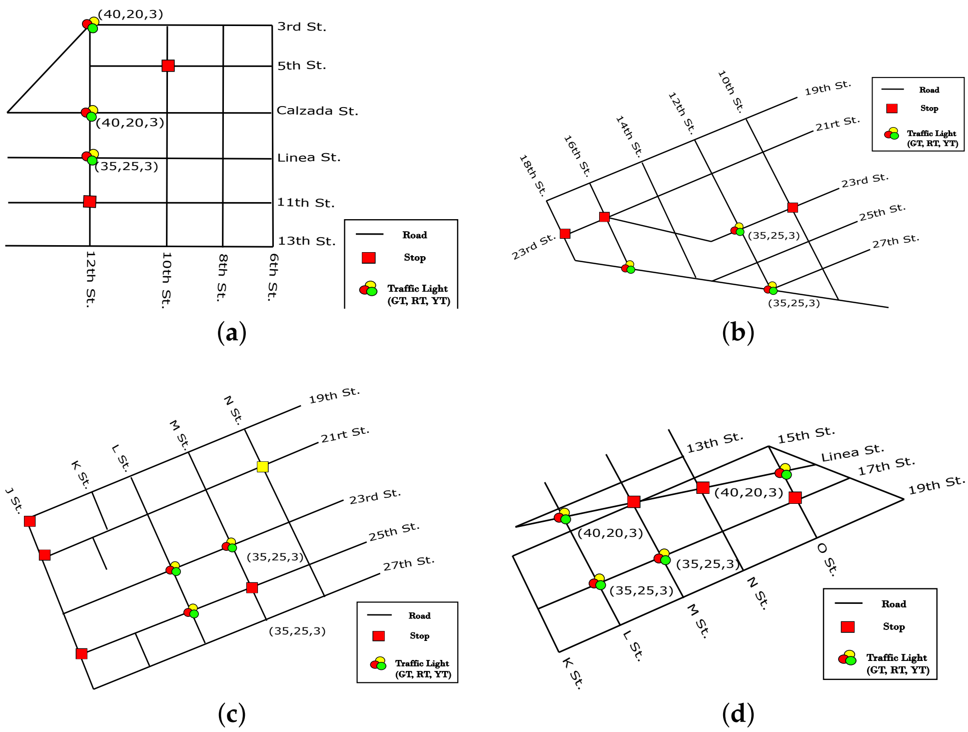

Figure 5. Experiment instances: (**a**) Linea St. & 12th St. (**b**) 23th St. & 12th St. (**c**) 23th St. & L St. (**d**) Linea St. & L St.

Each instance is evaluated with four different age configurations. Figure 6 shows the percentage relation of the number of people in the simulation for each age range. The first distribution contains a uniform proportion of each age group. The next configurations consist of a majority presence of young people, adults and elderly people, respectively.

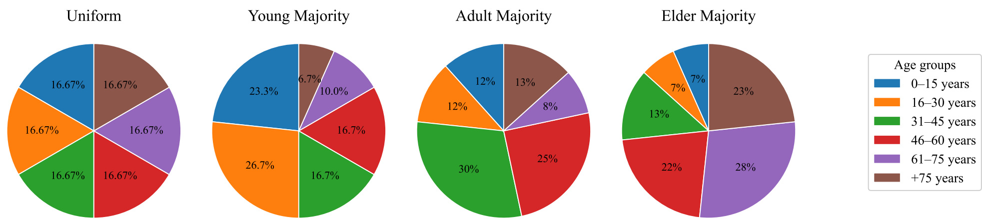

Figure 6. Simulated age distributions based on the number of people in each age group.

Similarly, every instance evaluates four configurations corresponding to the pavement condition. Figure 7 shows the percentage relation of the number of streets in the simulation for each pavement condition. In this case, a first uniform distribution is also conceived. The following represent the majority presence of streets in good, regular and bad condition, respectively.

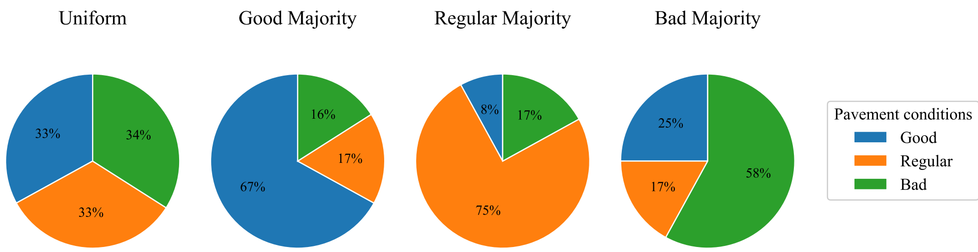

Figure 7. Simulated pavement condition distributions according to the street properties in each instance.

4.2. Experiments Conducted

The first analysis performed corresponds to the violations committed during the simulation. Figure 8 shows the results for each instance, aggregated across repetitions, separating driver and pedestrian violations.

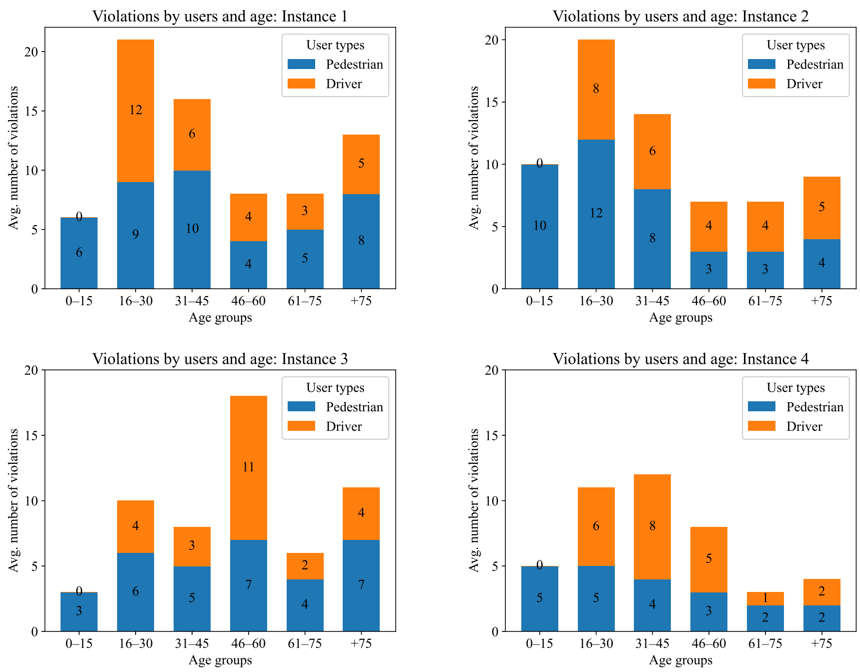

Figure 8. Average of total violations committed by instance and user type.

The simulation includes violations related to signal disobedience, improper passing, unauthorized parking for drivers, or improper crossings for pedestrians. For novice drivers—less than two years of driving—they can be caused by ignorance of traffic regulations. For experienced drivers, the main cause is recklessness and excessive confidence on the road.

Road users between 0 and 15 years old and only interact as pedestrians since they do not have a driving license. For this reason, only pedestrian infractions are included in this group.

Note that the age groups with more violations committed are from 16 to 60 years old. In most cases, there are more violations by drivers of vehicles. This is due to the fact that they have a privileged position on the road, while pedestrians, who are more vulnerable, take care of their safety and obey signals to a greater extent.

Instance 3 does not follow the same behavior as any of the other instances. Here, the highest number of violations were committed in the 46–60 age group. These violations were mostly improper overtaking by drivers and improper crossing by pedestrians. This is due to the fact of 75% of the simulated agents were familiar with the area where they were driving. This element mainly affects this age group, which is the one experiencing the most confidence on the road and committing violations for this reason. This result is unexpected for the experiment since knowledge of the area was not included in the analysis.

It is also observed, although to a lesser extent, that for the older age group, the number of violations increases again, mainly due to the deteriorating health of the elderly. Visual or motor problems may cause violations even if the individual did not intend to disobey.

Speeding can also be found as part of the violations. The second analysis corresponds to the average speeds of pedestrians and drivers according to age and pavement condition. Figure 9 shows pedestrian speeds, average across repetitions, for each of the instances. Age distributions with a majority of young, adults, and elderly people are used to analyze speed behavior in relation to the increase in the average age of the simulation. In this case, pavement condition is not considered because pedestrians travel on sidewalks.

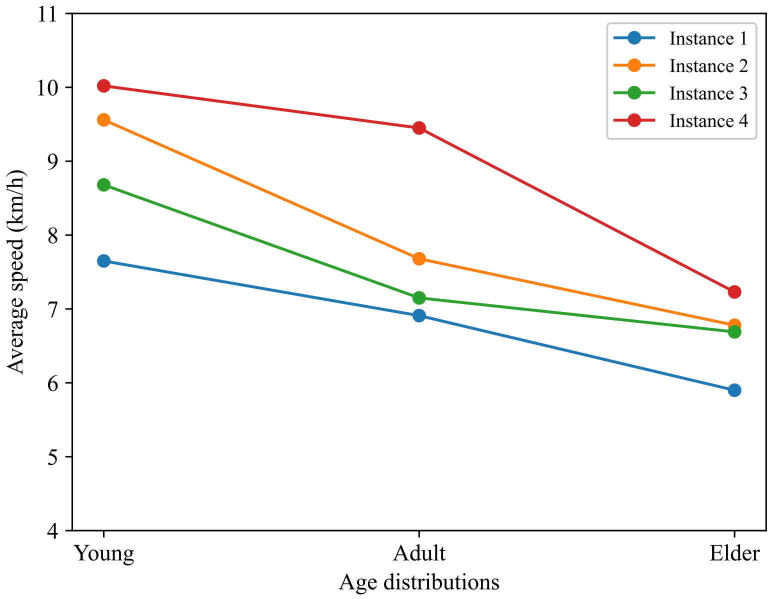

Figure 9. Pedestrian average speed by age.

Simulation speed with a majority of elderly people is considerably lower in all cases than the speed for the prevalence of young people. In general, young people walk faster; the elderly, due to motor problems, move very slowly and the adults maintain an average speed that varies according to their mental situation, such as discomfort, stress, grief, etc. It is remarkable that in Instance 4 this generality is not followed because the adult distribution is very similar to one of the young people. This is due to the fact that in the simulated area, despite the presence of several signs, there are walking areas such as parks and roads with little traffic, so pedestrians should not moderate their speed.

In Instances 2 and 3, the speed of the elderly decreases to a lesser degree because in the area of 23rd St., being very busy and dangerous, there are no pedestrians over 75 years of age, who are the ones who move more slowly, and therefore the average speed increases in the absence of them.

In addition to the factors examined for pedestrian speed, the condition of the pavement can also influence the behavior of people. For this purpose, the speed of vehicles is analyzed. The analysis of vehicle speed is shown in Figure 10.

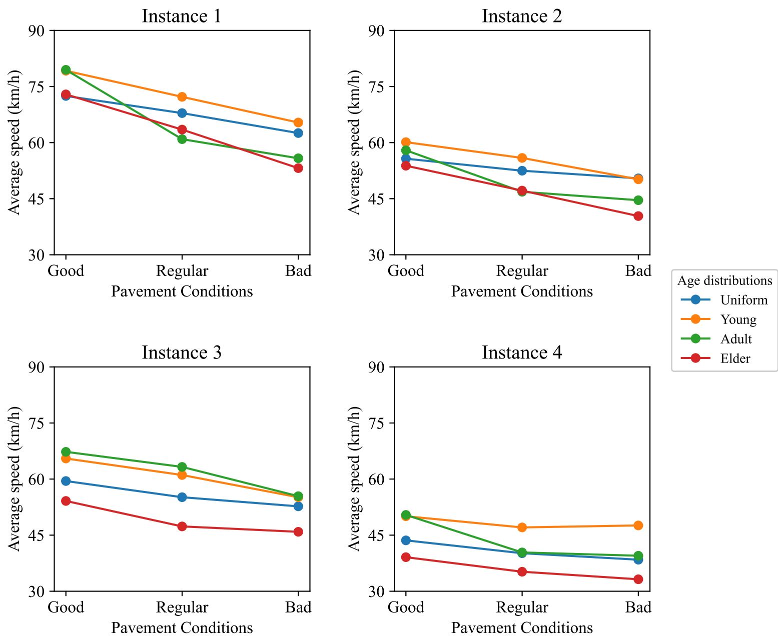

Figure 10. Vehicle average speed by age and pavement conditions.

There is a general tendency to decrease speed as pavement conditions worsen. This is because driving at high speeds on roads in poor condition can cause technical damage to vehicles. In most instances, there is a considerable speed decrease in the distribution of adults, since people between 30 and 60 years of age are generally the owners of the vehicles and those who are more careful with them.

Similar to the analysis of pedestrians, it is observed that as people's age increases, their speed on the road, whether walking or driving, decreases. The speed of Instance 1 is observed to be considerably higher than the others, and this was also the instance with the highest number of violations in the ages of 16 and 30 years, so speeding is related to violations of speed limits.

There is an unexpected contrast between pedestrian (Figure 9) and vehicle (Figure 10) speed for each instance. Instance 1 had the lowest pedestrian speed and is shown as the one with the highest vehicle speed, while Instance 4 has the opposite. For crowded areas with higher vehicle speeds, pedestrians are more cautious and this is reflected in these results.

Finally, the last traffic performance measure analyzed is the waiting time experienced by vehicles during the simulation, as the principal metric to measure the congestion in the traffic. Figure 11 shows the comparison of the waiting times. Results from uniform pavement distribution are used, for measuring the impact of age on this aspect.

The scenario proposed in this paper is shown in Figure 11a. There is an inversely proportional relation between vehicle speed (Figure 10) and waiting time (Figure 11). In this graph, it can be observed for Instance 4, which had the lowest vehicle speed and the highest waiting time; while in Instance 1 the opposite occurs highest vehicle speed and lowest waiting time.

In terms of age, the longest waiting time is obtained for adults, who show greater caution compared to young people and better health status compared to the elderly. This caution translates into obedience to signals and therefore longer waiting times at them. The young and the elderly always look lower because of disobedience, distraction or physical impediments, they wait less at the signals or for other vehicles. In the particular case of young people, traveling at a very high speed decreases the possibility of being stopped by a signal.

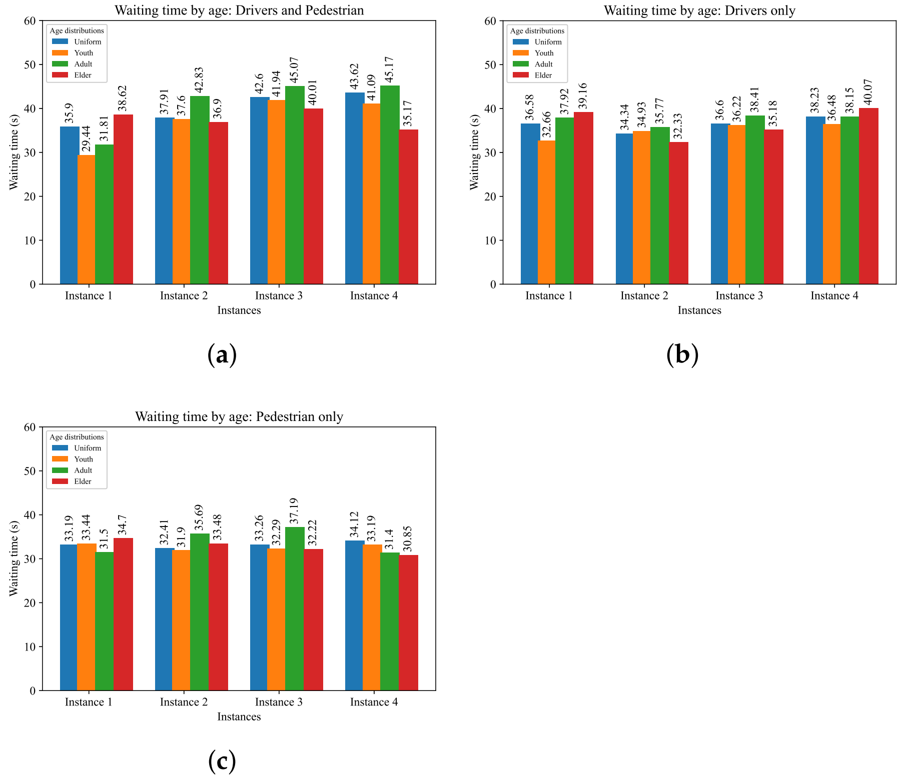

Figure 11. Average waiting time by scenarios: (**a**) Drivers and pedestrian. (**b**) Drivers only. (**c**) Pedestrian only.

Instance 1 behaves in a particular pattern, where the waiting time increases and the elderly exceeds the other age distributions. This is due to the presence of 5 consecutive signals for the plus traveled line—L St. to take Linea St.—in that instance, which affects the elderly who spend some time reacting to the signals, delaying the acceleration and inevitably will have to stop at the next signal.

After executing the simulation with the factors included in this research, we adapted it to imitate other models presented. The drivers-only scenario, Figure 11b, may correspond to models such as [15,16], where only driver characteristics are evaluated; while the pedestrian-only scenario, Figure 11c, would simulate models such as [14], which only consider pedestrian characteristics. Compared with state-of-the-art scenarios it is evident that pedestrian behavior has a lower influence than driver behavior, since in the simulations with only pedestrians, the waiting times for both age distributions are similar. When there are only drivers, the general trend seen in Figure 11a is maintained.

The waiting time on the road can also be due to several waiting factors. Figure 12 shows a distribution of this average waiting time for each of the instances. The main waiting factor is traffic lights, with over half of the time spent in most instances. Then, the time spent waiting at other signals and by pedestrians is similar. These last factors are not less present in the simulations, but the drivers of vehicles consider them of less importance and do not obey the corresponding waiting time.

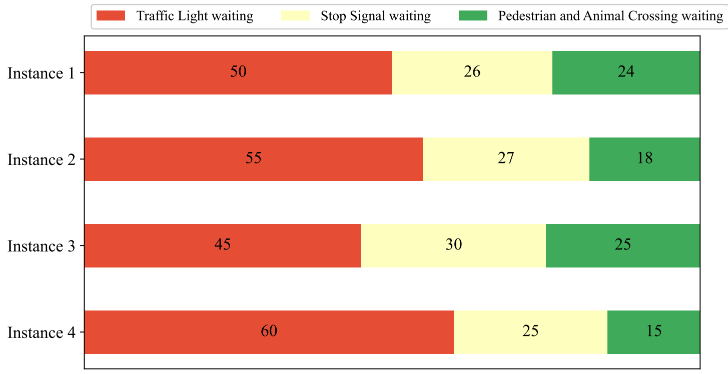

Figure 12. Waiting time distribution by signal cause.

5. Discussion and Analysis of the Contribution with Respect to the State of the Art

The agent-based simulation allows the representation of traffic based on the analysis of a wide set of factors: human and vehicle characteristics, weather, pavement and animals on the road. In addition, it represents the situations of waiting at signals and obstructions on the road as a queuing system. The model can obtain its parameters from external systems or be configured by the traffic analyst interacting with the simulation tool.

Previous research has developed other simulation models to represent traffic. An advantage of the proposed model over some of this research is the use of agent-based simulation. Due to the complexity of modeling social behaviors, this type of simulation offers better results due to the autonomous, proactive and social nature of the agents. Although, there are other agent-based models for traffic modeling [33,46**?**], they do not include simultaneously the actions of drivers and pedestrians.

Among the models studied are interactions of parameters that influence traffic, but are always oriented to a particular type of parameter. For instance, in [3] they studied the human factors that have a greater influence on traffic accidents and showed that the most influential is driver distraction, although they may include other factors such as age, gender, and familiarity with the road. These factors are all considered in our model.

In [34] the simulations performed to demonstrate the impact that weather conditions have on the behavior of the vehicular flow. They also incorporate some behaviors of the vehicles as part of the simulation and the interactions between them. These behaviors are also included in the model presented. On the other hand, the authors of [7] present an integration between several external parameters such as pavement and weather. The importance of these and their influence on traffic is demonstrated. However, it is not possible to have a realistic approach to the road if human behavior is not observed.

Finally, in addition to the parameters included in the simulation model, we have developed a detailed system based on queuing theory, which represents, in the form of a mathematical model, the traffic performance and quantifies the interactions and influences of the incorporated factors. This is considered an advantage with respect to the simulation models previously developed since in addition to determining the influence of the factors, it allows quantitatively establishing comparisons and priorities among them.

The limitations of this research are the fact that it has been only applied to experimentation with instances belonging to Cuba since the simulation model is based on Cuban traffic laws. In future versions of the simulation tool, the parameters associated with the laws should be configurable in order to eliminate this limitation. On the other hand, future studies should experiment with larger instances, which could include a wider region of the map or entire cities.

6. Conclusions and Future Work

Simulation models to analyze traffic dynamics have been widely used to optimize their performance. Our approach combines the flexibility that provides agent-based modeling with the formalism of queuing theory in order to determine the influence of the human factor on traffic. The vehicular flow performance is obtained from the evaluation of the model using a queuing system, which is able to give sense to the time consumed by the vehicles in their transit along the road.

This is illustrated in this paper with a case study to analyze the influence of certain aspects such as the age of drivers and pedestrians, proving to be an influential factor in their decisions. In addition, pavement is used as an additional factor, demonstrating that traffic performance is also influenced by environmental factors. The results show that the increase in the age of people on the road slows traffic flow, decreases the number of violations, and generally increases waiting time. In addition, with age also comes an increase in drivers' caution on poorly maintained roads.

On the other hand, results were also obtained that were not expected within the design of the experiments and are therefore valuable. The influence of the human factor "knowledge of the area", was shown in the analysis of the number of violations, where people with zone expertise are overconfident and commit more infractions. From the experiments, an inverse proportionality relationship between waiting time and vehicle speed was obtained, and also between the average speed of vehicles and pedestrians. These relationships are valuable because they allow for predicting the behavior of one of the factors with prior knowledge of the other.

Finally, an expected result is verified: the distribution of waiting time confirmed that the main waiting element is the traffic lights, which is why it is necessary to insist on an adequate configuration of their timing.

As part of the forthcoming work, experiments will be applied to other factors present in the simulation, such as gender, distractions on the road or the technical condition of the vehicles. The analysis of the degree of influence of each factor will provide further conclusions and it will be possible to arrive at rules for the configuration process.

After evaluating all the factors already included, the simulation model will be extended to new behaviors, such as alcohol consumption, stress or more severe disabilities. The inclusion of new factors can be used to analyze different types of configurations that contribute to better traffic performance, as well as to evaluate the simulation with other existing metrics. Another important feature to further work is the size of the instances so that the simulation allows us to have a more general view of human behavior in regions or entire cities.

The results obtained and the new work proposals will help in the conception of a complete traffic control tool. A tool that reproduces the presented simulation model will support signal configuration by evaluating real signaling plans. Therefore, the appropriate configuration for the data provided to the model can be obtained.

Supplementary Materials: The following supporting information can be downloaded at: https://github.com/amoreno98/simulation-model-data (accessed on 25 February 2022).

Author Contributions: Conceptualization, M.M. and J.P.; methodology, M.M. and C.P.; software, A.C.M.; validation, A.C.M.; investigation, A.C.M. and M.M.; resources, M.M. and J.P.; data curation, A.C.M.; writing—original draft preparation, A.C.M.; writing—review and editing, C.P. and J.P.; visualization, A.C.M.; supervision, C.P.; project administration, M.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data presented in this study are available in https://github.com/amoreno98/simulation-model-data/blob/main (accessed on 25 February 2023).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Sangaradasse, P.; Eswari, S. Importance of traffic and transportation plan in the context of land use planning for cities—A review. *Int. J. Appl. Eng. Res.* **2019**, *14*, 2275–2281.
2. Afrin, T.; Yodo, N. A Survey of Road Traffic Congestion Measures towards a Sustainable and Resilient Transportation System. *Sustainability* **2020**, *12*, 4660. [CrossRef]
3. Bucsuházy, K.; Matuchová, E.; Zuvala, R.; Moravcová, P.; Kostíková, M.; Mikulec, R. Human factors contributing to the road traffic accident occurrence. *Transp. Res. Procedia* **2020**, *45*, 555–561. [CrossRef]
4. Román, A.M.; Espino, M.M.; Fraga, D.B. Herramienta de simulación para evaluar configuraciones semafóricas. *Rev. Cuba. Transform. Digit.* **2021**, *2*, 102–114.
5. Li, W.; Zhang, H.; Huang, Z.; Li, C. Human-Vehicle Intersection Traffic Lights Timing Optimization Research. *J. Adv. Transp.* **2022**, *2022*. [CrossRef]
6. Shin, J.; Sunwoo, M. Vehicle Speed Prediction Using a Markov Chain with Speed Constraints. *IEEE Trans. Intell. Transp. Syst.* **2019**, *20*, 3201–3211. [CrossRef]
7. Llopis-Castelló, D.; García-Segura, T.; Montalbán-Domingo, L.; Sanz-Benlloch, A.; Pellicer, E. Influence of pavement structure, traffic, and weather on urban flexible pavement deterioration. *Sustainability* **2020**, *12*, 9717. [CrossRef]
8. Ozerova, O.; Lytvynenko, S.; Sushchenko, R.; Zapara, Y.; Ovchar, P.; Lavrushchenko, Y. Factors influencing the modelling of transport flow dynamics in cities. *C. R. L'Academie Bulg. Des Sci.* **2022**, *75*, 259–265. [CrossRef]
9. Al-Jameel, H.A.; Kadhim, A.J. Rural traffic characteristics using field data and the developed simulation model. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *888*. [CrossRef]
10. Qadri, S.S.S.M.; Gökçe, M.A.; Öner, E. State-of-art review of traffic signal control methods: challenges and opportunities. *Eur. Transp. Res. Rev.* **2020**, *12*, 55. [CrossRef]
11. Nguyen, J.; Powers, S.T.; Urquhart, N.; Farrenkopf, T.; Guckert, M. An overview of agent-based traffic simulators. *Transp. Res. Interdiscip. Perspect.* **2021**, *12*, 100486. [CrossRef]
12. Mauro, R.; Guerrieri, M.; Pompigna, A. A Quick Criterion for Calculating Waiting Phenomena at Intersections. *Lect. Notes Civ. Eng.* **2021**, *153*, 81–93. [CrossRef]
13. Jacyna, M.; Żak, J.; Gołębiowski, P. The Use of the Queueing Theory for the Analysis of Transport Processes. *Logist. Transp.* **2019**, *41*. [CrossRef]
14. Razmi Rad, S.; Homem de Almeida Correia, G.; Hagenzieker, M. Pedestrians road crossing behaviour in front of automated vehicles: Results from a pedestrian simulation experiment using agent-based modelling. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *69*, 101–119. [CrossRef]
15. Papantoniou, P.; Yannis, G.; Christofa, E. Which factors lead to driving errors? A structural equation model analysis through a driving simulator experiment. *IATSS Res.* **2019**, *43*, 44–50. [CrossRef]
16. Witt, M.; Kompaa, K.; Wang, L.; Kates, R.; Mai, M.; Prokop, G. Driver profiling a Data-based identification of driver behavior dimensions and affecting driver characteristics for multi-agent traffic simulation. *Transp. Res. Part F Traffic Psychol. Behav.* **2019**, *64*, 361–376. [CrossRef]
17. Hasan, M.; Perez, D.; Shen, Y.; Yang, H. Distributed Microscopic Traffic Simulation with Human-in-the-Loop Enabled by Virtual Reality Technologies. *Adv. Eng. Softw.* **2021**, *154*, 102985. [CrossRef]
18. Müller, J.; Straub, M.; Richter, G.; Rudloff, C. Integration of Different Mobility Behaviors and Intermodal Trips in MATSim. *Sustainability* **2022**, *14*, 428. [CrossRef]
19. Han, W.; Zhao, J. Driver behaviour and traffic accident involvement among professional urban bus drivers in China. *Transp. Res. Part F Traffic Psychol. Behav.* **2020**, *74*, 184–197. [CrossRef]
20. Fujii, H.; Uchida, H.; Yamada, T.; Yoshimura, S. Mixed Traffic Simulation of Cars and Pedestrians for Transportation Policy Assessment. In *Crowd Dynamics, Volume 2: Theory, Models, and Applications*; Springer International Publishing: Cham, Switzerland, 2020; pp. 199–222. [CrossRef]

32. McCartt, A.T.; Mayhew, D.R.; Braitman, K.A.; Ferguson, S.A.; Simpson, H.M. Effects of Age and Experience on Young Driver Crashes: Review of Recent Literature. *Traffic Inj. Prev.* **2009**, *10*, 209–219. [CrossRef]

22. Torabi, B.; Al-Zinati, M.; Wenkstern, R. MATISSE 3.0: A large-scale multi-agent simulation system for intelligent transportation systems. In *Advances in Practical Applications of Agents, Multi-Agents Systems and Complexity: The PAAMS Collection*; Springer International Publishing: Berlin/Heidelberg, Germany, 2018; pp. 357–360. [CrossRef]
23. Barbecho Bautista, P.; Urquiza Aguiar, L.; Aguilar Igartua, M. How does the traffic behavior change by using SUMO traffic generation tools. *Comput. Commun.* **2022**, *181*, 1–13. [CrossRef]
24. Li, Y.; Tang, J.; Zhao, H.; Luo, R. Reinforcement Learning Method with Dynamic Learning Rate for Real-Time Route Guidance Based on SUMO. In Proceedings of the 2022 17th International Conference on Control, Automation, Robotics and Vision (ICARCV), Singapore, 11–13 December 2022; pp. 820–824. [CrossRef]
25. Shamim Akhter, M.; Ahsan, N.; Quaderi, S.J.S.; Al Forhad, M.A.; Sumit, S.H.; Rahman, M.R. A SUMO based simulation framework for intelligent traffic management system. *J. Traffic Logist. Eng.* **2020**, *8*. [CrossRef]

26. Karbasi, A.; O'Hern, S. Investigating the Impact of Connected and Automated Vehicles on Signalized and Unsignalized Intersections Safety in Mixed Traffic. *Future Transp.* **2022**, *2*, 24–40. [CrossRef]
27. Harahap, E.; Darmawan, D.; Fajar, Y.; Ceha, R.; Rachmiatie, A. Modeling and simulation of queue waiting time at traffic light intersection. *J. Phys. Conf. Ser.* **2019**, *1188*, 012001. [CrossRef]
28. Gunes, F.; Bayrakli, S.; Zaim, A.H. Flow Characteristics of Traffic Flow at Signalized Intersections and Performance Comparison using Queueing Theory. In Proceedings of the 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), Istanbul, Turkey, 22–24 October 2020; pp. 1–9. [CrossRef]
29. Keyvan-Ekbatani, M.; Carlson, R.C.; Knoop, V.L.; Papageorgiou, M. Optimizing distribution of metered traffic flow in perimeter control: Queue and delay balancing approaches. *Control. Eng. Pract.* **2021**, *110*, 104762. [CrossRef]
32. Zhao, B.; Kumar, K.; Casey, G.; Soga, K. Agent-Based Model (ABM) for City-Scale Traffic Simulation: A Case Study on San Francisco. In *International Conference on Smart Infrastructure and Construction 2019 (ICSIC)*; ICE Publishing: London, UK, 2019; pp. 203–212. [CrossRef]
31. de Souza, F.; Verbas, O.; Auld, J. Mesoscopic Traffic Flow Model for Agent-Based Simulation. *Procedia Comput. Sci.* **2019**, *151*, 858–863. [CrossRef]
32. Xu, M.; An, K.; Vu, L.H.; Ye, Z.; Feng, J.; Chen, E. Optimizing multi-agent based urban traffic signal control system. *J. Intell. Transp. Syst.* **2019**, *23*, 357–369. [CrossRef]
33. Jin, J.; Ma, X. A Multi-Objective Agent-Based Control Approach With Application in Intelligent Traffic Signal System. *IEEE Trans. Intell. Transp. Syst.* **2019**, *20*, 3900–3912. [CrossRef]
34. Chen, C.; Zhao, X.; Liu, H.; Ren, G.; Zhang, Y.; Liu, X. Assessing the influence of adverse weather on traffic flow characteristics using a driving simulator and VISSIM. *Sustainability* **2019**, *11*, 830. [CrossRef]
35. de Ramos, J.E.L.; Mareschal, P.; Closs, G.A.; Maqueda, A.R.; Galeano, S.E.; de Florenciano, M.D.P.; Cristaldo, L.D.; Recalde, N.N.; de Benítez, M.A.; Benítez, G. Reducción de animales en las calles de la ciudad de Concepción dentro de un marco ético, equitativo y transparente. *Investigaciones y Estudios-UNA* **2022**, *13*, 29–35. [CrossRef]
36. Mo, C.; Li, Y.; Zheng, L. Simulation and analysis on overtaking safety assistance system based on vehicle-to-vehicle communication. *Automot. Innov.* **2018**, *1*, 158–166. [CrossRef]
37. Gao, C.; Xu, J.; Jia, X.; Dong, Y.; Ru, H. Influence of large vehicles on the speed of expressway traffic flow. *Adv. Civ. Eng.* **2020**, *2020*. [CrossRef]
38. Chernyaev, I.; Oleshchenko, E.; Danilov, I. Methods for continuous monitoring of compliance of vehicles' technical condition with safety requirements during operation. *Transp. Res. Procedia* **2020**, *50*, 77–85. [CrossRef]
39. Moreno Román, A.; Moreno Espino, M.; Mariño, A. Factor humano en el tráfico: Simulación Basada en Agentes. In Proceedings of the VI Conferencia Internacional en Ciencias Computacionales e Informáticas (CICCI), Havana, Cuba, 21–25 March 2022.
40. Sedeño-Noda, A.; Colebrook, M. A biobjective Dijkstra algorithm. *Eur. J. Oper. Res.* **2019**, *276*, 106–118. [CrossRef]
41. Pavón, J.; Gómez-Sanz, J. Agent oriented software engineering with INGENIAS. In Proceedings of the Multi-Agent Systems and Applications III: 3rd International Central and Eastern European Conference on Multi-Agent Systems, CEEMAS 2003, Prague, Czech Republic, 16–18 June 2003; pp. 394–403. [CrossRef]
42. Gómez-Sanz, J.J.; Fernández, C.R.; Arroyo, J. Model driven development and simulations with the INGENIAS agent framework. *Simul. Model. Pract. Theory* **2010**, *18*, 1468–1482. [CrossRef]
43. Vargas-Munoz, J.E.; Srivastava, S.; Tuia, D.; Falcão, A.X. OpenStreetMap: Challenges and Opportunities in Machine Learning and Remote Sensing. *IEEE Geosci. Remote Sens. Mag.* **2021**, *9*, 184–199. [CrossRef]
44. Moreno Román, A.C.; Moreno Espino, M.; Porras, C.; Pavón, J. Modelling Urban Traffic Configuration with the Influence of Human Factors. In Proceedings of the Advances in Artificial Intelligence–IBERAMIA 2022: 17th Ibero-American Conference on AI, Cartagena de Indias, Colombia, 23–25 November 2022; Springer International Publishing: Cham, Switzerland, 2022; pp. 53–64. [CrossRef]
45. Kasatkina, E.V.; Vavilova, D.D. Mathematical modeling and optimization of traffic flows. *J. Physics Conf. Ser.* **2021**, *2134*, 012002. [CrossRef]
46. Zhang, H.; Feng, S.; Liu, C.; Ding, Y.; Zhu, Y.; Zhou, Z.; Zhang, W.; Yu, Y.; Jin, H.; Li, Z. CityFlow: A Multi-Agent Reinforcement Learning Environment for Large Scale City Traffic Scenario. In Proceedings of the The World Wide Web Conference (WWW'19), San Francisco, CA, USA, 13–17 May 2019; Association for Computing Machinery: New York, NY, USA, 2019; pp. 3620–3624. [CrossRef]