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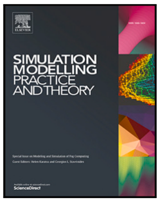

An agent-based platform to evaluate V2X routing road traffic scenarios

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ABSTRACT

Traffic congestion is a recurrent problem in both urban and non-urban road networks. It impacts several key issues such as higher overall gas consumption, vehicle emissions, and noise. Traffic information available on time to vehicles is a key element for helping to reduce these issues. Nowadays, modern vehicles produce information via its own sensors that can be communicated to other vehicles on the road. For example, average speed or fuel consumption or if it was applied the ABS due to slipping in the previous segment road. This information could be exchanged between vehicles on road to help them in their driving decisions. This is known as V2V communication capability. When this information can be exchanged also with Infrastructure elements of the road, it is known as V2X communication. Current approaches for simulators in the context of V2X communication are devoted to the design and evaluation of the wireless technologies suitable for the efficient exchange of information, they are not designed to deal with the usage that drivers can do with the traffic information exchanged. In this paper, an agent based model is presented to test the importance of traffic information exchange for reducing traffic congestion. In this model, vehicles can use no communication, vehicles to vehicle (V2V) or vehicle to infrastructure (V2I) communications. The functional architecture of the proposed model is structured in several layers including the road network knowledge model, the road traffic model and the interaction protocols. The model allows the creation of different traffic scenarios, based on traffic flow, type of vehicles, etc. Results drawn from the executions of diverse traffic scenarios show the relevance that information exchange (via V2I and V2V communications) has to calculate efficient itineraries in real-time, and thus, reducing the overall consequences of traffic congestion.

1. Introduction

Traffic congestion has a deep impact in economic, social and environmental areas. It can be seen as a resource problem where vehicles have conflicting intentions and need coordination in order to use effectively the different parts of the road network [1]. Since there is no central authority that dictates how vehicles should travel, each vehicle behaves independently according to its own criteria. This selfish behavior makes coordination a difficult task. Therefore, the more information available about the traffic environment (vehicles, road, traffic parameters, etc.), the better the overall traffic management coordination can emerge.

In the last two decades significant advances in Intelligent Transport Systems (ITS) have been made to improve congestion, traffic flow and road safety. Due to the wide availability of wireless communication, internet and artificial intelligence technologies the concept of connected vehicles and cooperative systems [2–5] is one of the hottest topics of research and innovation. A connected

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vehicle can be generally described as a vehicle capable of sending/receiving external information through any digital communication channel: WIFI, Bluetooth, 4G/5G...

The relevance of connected vehicles and cooperative systems is evidenced in several research initiatives, such as the development of the EU strategy to achieve connected and autonomous mobility. In the period 2014–2020, the EU funded €300 M in the development of intelligent and autonomous vehicles and up to €450 M in CEF (Connecting Europe Facilities) actions to achieve the digitization of transport. Moreover, the wide availability of connected vehicles is expected to grow fast and large economic benefits are expected with revenues exceeding €620 billion by 2025 for the EU automotive industry and €180 billion for the EU electronic sector [6].

Connected vehicles circulating on the road network form a Vehicle Ad Hoc Network (VANET) [7]. Depending on the communication architecture used, the VANET network can be categorized as V2V, where vehicles communicate with each other; V2I, where they communicate with the infrastructure or V2X where they communicate either with the infrastructure, other vehicles, or any other system.

In a classic V2I architecture that infrastructure consists of elements managed by a traffic authority: road side measure equipments, Variable Message Signs (VMS), red lights, etc. However, the emergence of Internet of Things (IoT) and *Smartcities* has made possible to exchange information between whatever connected device in the city and the road traffic elements. Thus, other related information such as parking spaces or closures due to road works are also available for traffic management to improve the traffic behavior and to avoid congestion.

The evaluation of VANET systems in real traffic scenarios has severe drawbacks due to several reasons: the selfish behavior of the drivers, the complexity of the overall traffic behavior, the great variability in unexpected events (e.g. wind, rain, accidents, potholes on roads and dismissed of drivers, and so on) that can affect to traffic behavior, accurate performance communications protocol efficiency, and to get reproducible results. Thus, the handy approach for the design, analysis, and evaluation of VANET models is to use simulators. Agent based modeling is a natural way to address the developing of traffic simulators, because each of the agents involved in traffic can be individually modeled and then, individual and collective behavior can be observed and analyzed. In this paper, a new open-source agent-based model to test how different communication modes, V2V and/or V2I, impact on the election of different routing traffic scenarios is presented.

The rest of this paper is organized as follows. In Section 2, other related works regarding traffic tools to simulate VANET traffic systems are analyzed. Then, in Section 3, the main aspects of the new proposed platform are highlighted. Section 4 shows the overall process to perform a test in the new platform. In Section 5 several traffic scenarios for a real road network are described and modeled. Next, in Section 6. results obtained from the previously described traffic scenarios are analyzed. Finally, conclusions are drawn.

2. Simulation and agent-based modeling in transportation domain

There are several commercial and open-source simulators for VANET. Most of them support V2X communication on traffic connecting two different simulators, one to deal with physical properties issues of communication (as NetSim [8], Omnet++ [9] or NS-3 [10]) and another for the road traffic mobility issues (such as the wide used open-source SUMO [11] or Aimsun 2 [12], a commercial microsimulator). Popular examples of these systems are: NetSim, a semicommercial tool that manages the simulation for the wireless network communications among traffic elements, and interfaces with SUMO to model the road traffic conditions; Veins [13], an open-source framework for building vehicular network simulations by combining the parallel execution of Omnet++ and SUMO; and ezCar2X [14], an open-source framework for developing applications for networking vehicles and evaluate them in a real world setting combining NS-3 and SUMO, among others, simulators.

Therefore, these simulators provide complete and in-depth data for such VANET simulations, from detailed data on the underlying architecture of the network being used to the movement of vehicles on the roads. However, if the goal is to focus the V2X experimentation on how to modify the behavior of each vehicle due to the continuous exchange of information without taking into account the physical and transport aspects of the network protocol used, this is not easy to achieve with this combination of simulators. This goal requires a simulator that provides a flexible way to address both individual and collective behavior with emphasis on what to do with the exchanged information, leaving aside the physical and transport properties of the network protocol and considering only the functional aspects of the network protocol, that is, how the information is communicated appropriately to be interpreted by its recipients.

Multi-agent systems are a modeling paradigm that supports the development of systems in which individual and collective behavior can be expressed and analyzed. Several examples of multi-agent approaches applied to ITS can be found in [15–18]. These approaches have in common that they are ad-hoc programming solutions, in the sense that they were been programmed from scratch (maybe using some kind of middleware software for communications, such as JADE [19]). Therefore, they provide useful solutions to the concise traffic problem for which they were developed, but they are usually hard to reuse for other different traffic problems.

However, there are available several multi-purpose frameworks for developing agent-based models that provide easiness for programming, analysis, verification and maintainability. Netlogo is a multi-agent programmable modeling framework that provides these features. In Netlogo, the modeler can express individual and ongoing behaviors of the involved agents. The programming language embedded in Netlogo makes agent-based models easy to read, develop, and extend.

Several traffic models have been developed in Netlogo that are, in some way, related to the one presented here. In [20], the model analyzes road safety in heterogeneous traffic flow combining autonomous and non-autonomous vehicles in rural roads. [21]

presents a new A* search algorithm for congestion avoidance. The main idea is to check, in each roundabout, the state of the next direction, and if necessary to force the agents to perform a parallel search for another path using A* algorithm. However, the model is not suitable for generalization to other traffic scenarios and VANET features are not allowed. In [22], an agent-based modeling framework has been developed to evaluate the impact of V2V and V2I technology in a two-lane highway work zone scenario from a microscopic traffic perspective. The framework is integrated with R and RNetLogo to simulate drivers behavior. However, the agent-based model exposed in this paper is more advanced. It can be easily adapted to more traffic and V2X communication scenarios. Also, it can be programmed with more advanced dynamic routing decisions (e.g. using both macroscopic and microscopic data).

3. The proposed agent-based platform

This platform extends the architecture developed in [18]. In this previous multi-agent architecture communications were done by vehicles and elements of the infrastructure. Then, vehicles and infrastructure exchanged information to determine the current traffic status and each vehicle determined dynamically the best itinerary for reach its final destination in the road network. The new features introduced are: the addition of V2V communication models, more types of vehicles (including passengers cars and trucks); improving of the traffic management core estimator; addition of a new routing algorithm, the possibility to introduce traffic incidents on the road network and, due to a change in the programming framework and programming language used, a friendlier way for users/modelers to experience and incorporate more new features.

This new platform is structured in several layers including: (a) a knowledge model consisting of a road network model, traffic model and communication model, (b) a traffic management core model to estimate traffic flow and (c) a set of interaction protocols to manage V2X communications.

3.1. Road network model

The road network model follows the road knowledge model proposed in [18]. It is based on three main elements: nodes, segments and steps. Nodes represent those points on a road where there is an intersection, incorporation or exit lane, or a bifurcation (from now on we call all those types of points intersections) Segments represent one-way sections of a road connecting nodes. A road is modeled as a sequence of node-segment pairs. The road network is modeled as a weighted multigraph.

Segments are composed of steps. Each segment is virtually split into a list of steps (at least 1). All steps in the same segment have the same static characteristics (number of lanes, capacity, maximum allowed speed, etc.).

The network model uses two different types of agents. Agent Nodes are created to model the intersections and directed links agents are created to model the road segments and steps. There are another two types of agents for modeling the two types of vehicles that can circulate on this network model: passenger cars agents and Heavy Good Vehicles (HGV) agents. Each type of vehicle, and each vehicle in each type, has its traffic behavior properties and features, e.g. its maximum speed reachable, or the comfortable driving speed.

3.2. The traffic flow estimator

The traffic estimator determines the real-time traffic status in a macroscopic approach using the linear relationship between speed and density. The macroscopic model of Greenshield [23] is applied to every step in a segment. This model is adapted to steps by the equation:

$$S_i = S_{free_j}(1 - \frac{D_i}{D_{step}}) \tag{1}$$

where S_i and D_i are, respectively, the estimated speed and the density at step i of a segment j. S_{free_j} is the free flow speed for segment j and D_{step} is the step density. It is observed that when density becomes zero, speed approaches segment free flow speed. The level of Service (LoS) is also used to define the traffic estimation. LoS relates the quality of traffic service to a given flow rate, following the definition described in the Highway Capacity Manual [24]. It consists of six qualitative values, from A to F, where A is the best quality of service, i.e. vehicles can circulate up to its maximum preferred speed according to the maximum speed of the segment, while F represents the worst quality of service, in which vehicles on the segment suffer frequent Stops-&-Go situations due to a traffic congestion.

To improve the determination of density, a heavy-vehicle adjustment factor, f_{hv}, has been introduced to calculate the flow rate. f_{hv} is based on [24] and is obtained using Eq. (2):

$$f_{hv} = \frac{1}{1 + (P_T(E_T - 1))} \tag{2}$$

where P_T is the proportion of trucks in the traffic stream and E_T is the passenger-car equivalent for trucks.

Thus, the equivalent flow rate, I_{eq}, in equivalent passenger-car units, is calculated by Eq. (3):

$$I_{eq} = \frac{I}{f_{hv}} \tag{3}$$

where I is the current flow rate.

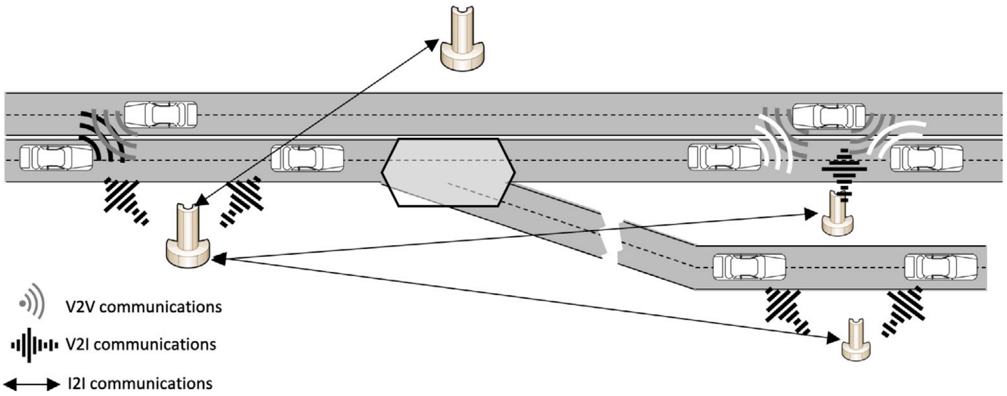


Fig. 1. Example of communications. Different types of communication have been modeled and implemented: V2V, V2I and I2I.

3.3. Communications: V2I and V2V protocols

The communication model describes how the agents communicate with each other. The proposed model implements two possibilities: V2I and V2V (see Fig. 1). The interaction protocols used in the system have been defined following the interaction protocols defined by FIPA [25]. V2I communication protocols allow the communication between vehicles and infrastructure, mainly installed in road network segments. These V2I protocols are:

- Register-segment. It follows a FIPA Request interaction protocol. It is used by a vehicle to ask for subscribing to the list of vehicles currently circulating on the segment that it is beginning to use. The message sent to the segment contains this information: unique identification tag, current location and speed. The segment responds with the current traffic values.
- Deregister-segment. It follows a FIPA Inform interaction protocol. A vehicle informs the segment where it is circulating that it is leaving it.
- Segment-Vehicle-Inform-traffic-status. It follows a FIPA Inform interaction protocol. A segment communicates to the current vehicles circulating on it that some dynamic traffic properties have changed (e.g. LOS, speed, etc.)
- Segment-Segment-Inform-traffic-status. It follows a FIPA Inform interaction protocol. This interaction is similar to the previous one (Vehicle-Inform-traffic-status) but it is used by a segment to inform others about its dynamic traffic properties.
- Vehicle-segment-traffic-status. It follows a FIPA Request interaction protocol. Vehicles need to know the traffic status to determine their routes. So, a vehicle may ask one or more segments about its current traffic status. Then, the segment agents answer back with the requested information.
- Segment-Vehicle-inform-incident. It follows a FIPA Inform interaction protocol. This protocol is used by an upstream segment to inform about an incident to the current vehicles in the segment.
- Segment-Segment-inform-incident. It follows a FIPA Inform interaction protocol. This interaction is similar to the previous one, but the segment informs others about an incident.

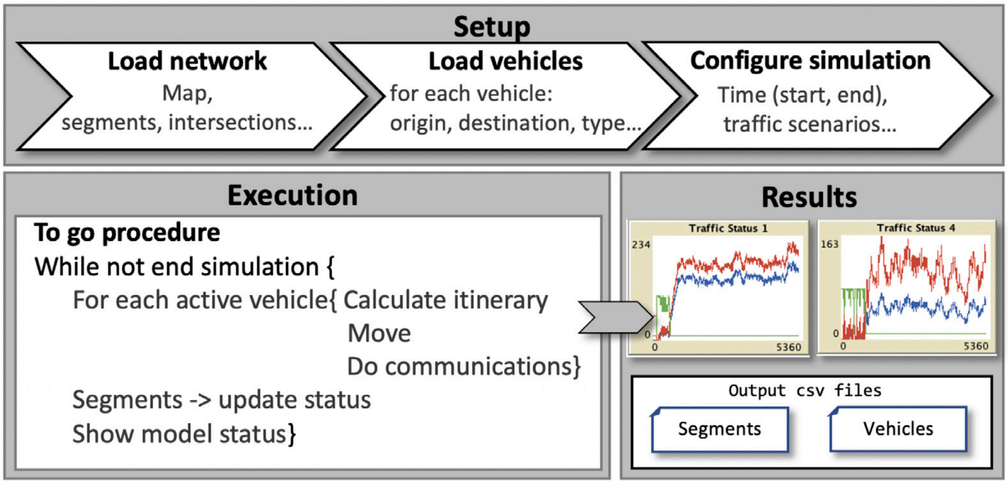
The V2V communication protocols are:

- Vehicle-Vehicle-segment-status. It follows a FIPA Request interaction protocol. A vehicle asks another vehicle about the traffic status in the segment where the receiving vehicle is currently moving.
- Vehicle-Vehicle-network-status. It follows a FIPA Request interaction protocol. A vehicle asks another vehicle about the network traffic status in the segments where the receiving vehicle has been previously circulating.
- Vehicle-Vehicle-downstream-status. It follows a FIPA Request interaction protocol. A vehicle asks another vehicle about the traffic status in the sender downstream segments.
- Vehicle-Vehicle-alarm-incident. It follows a FIPA Inform interaction protocol. A vehicle sends the information it has about an incident in a segment to other vehicles.

3.4. Routing algorithms

There are five types of algorithms for vehicles to select how to complete their routes.

- Shortest: the itinerary is based on the minimum distance between the origin and the destination.
- Fastest: the itinerary is based on the minimum time to reach the destination from the origin given its speed and the maximum allowed speed in every segment. No information related to current traffic is used at any time.
- StartSmart: this algorithm is similar to the previous one, *Fastest*, but it uses the current traffic status of the segments to calculate the itinerary at the beginning of the trip. Once this itinerary is calculated the vehicle follows it without hesitation.



```
To go procedure
While not end simulation {
    For each active vehicle{ Calculate itinerary
                             Move
                             Do communications}
    Segments -> update status
    Show model status}
```

Fig. 2. Runtime phases. In the setup phase, the road network is loaded and scenarios are selected: vehicles with their characteristics, type of communications, incidents, etc. Once the scenario is defined, the execution begins. During the execution, the traffic status evolution is shown in the Netlogo interface. After the execution, all information is stored in two files to analyze the data.

- V2VSmart: this algorithm is only used if V2V communications are available. This algorithm, as *StartSmart* does, calculates the itinerary using the current traffic status only at the beginning of the trip. However, a new itinerary calculation is done if the vehicle receives a *Vehicle-Vehicle-alarm-incident* message that affects its current itinerary.
- DynamicSmart: Vehicles using this algorithm re-calculate the fastest itinerary each time it reaches an intersection. It uses the current traffic status of the traffic network to calculate the best route. To deploy this algorithm, the vehicle needs to exchange information with other vehicles or segments to know the traffic status in each time period.

A vehicle cannot change the routing algorithm used during the simulation.

3.5. *Configuration parameters*

Different traffic scenarios can be tested by tuning several parameters:

- Peak and valley hour. How many vehicles represent the peak and valley hours in a road network.
- Percentage of vehicles in the simulation for each type of the routing algorithm and each type of vehicle (passenger car or HGV).
- Communications: V2V or V2I. The traffic status in real-time can be calculated using V2V, V2I or both types of communications. In V2V, vehicles forecast the traffic status only with the information provided by other vehicles whilst in V2I communications vehicles only communicate with the infrastructure.
- Equivalent flow rate. The impact of HGV can be analyzed using Eqs. (1) and (2). Using this option, traffic parameters are calculated with the percentage of HGVs and the number of passenger cars by HGV unit.
- Incidents. A decrease in the capacity of one or more segments can be forced externally to simulate an incident.

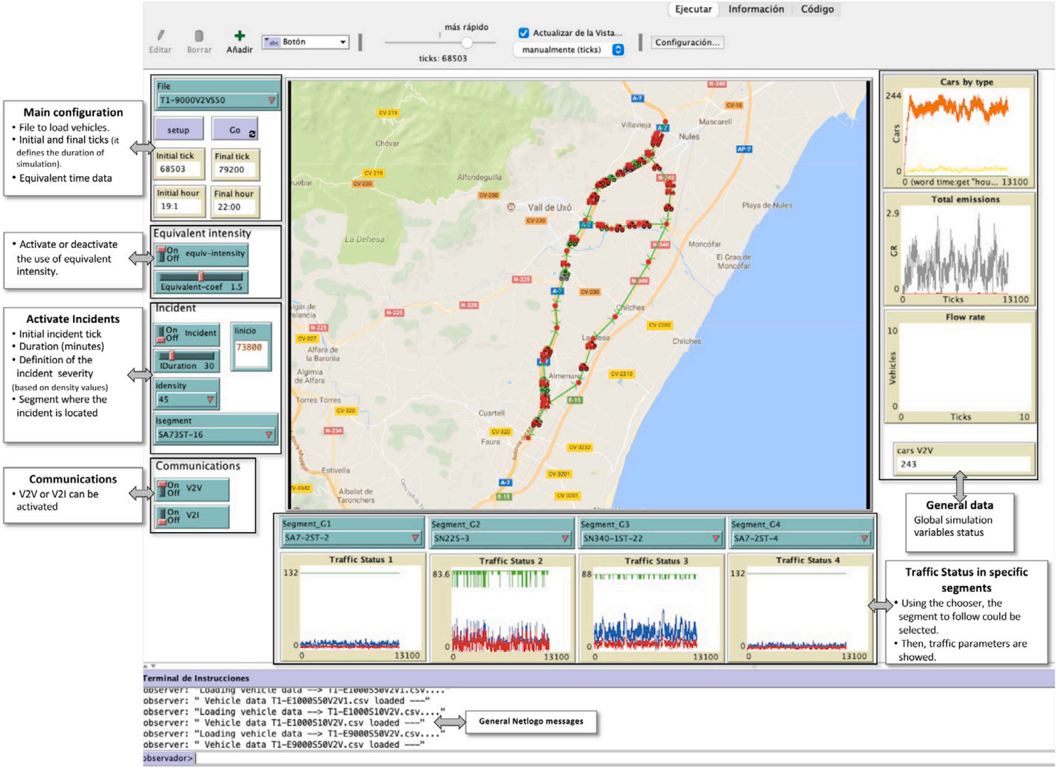
4. Runtime

The platform has been programmed in Netlogo [26]. Netlogo is a framework and programming environment for developing, validating and evaluating complex agent-based models. It is widely used in domains as sociology, economics, biology, systems dynamics and many more.

A test in the platform proposed in this paper involves three phases: setup, execution, and results (see Fig. 2). In the setup phase, the overall characteristics of the test are defined and initialized: start and end time, the road network creation, type of communications, incidents, etc. Then, vehicles are loaded from a specific *csv* file. Each row in this file represents data for a vehicle: start time, maximum speed, current drive speed, origin, destination, passenger car or HGV, and its routing algorithm.

Once the setup process has been finalized, the execution phase can start. This execution develops by attending to updates of vehicles and segments.

- When a vehicle enters the simulation, it calculates the path from the origin to its destination, depending on its own routing algorithm. If the car uses the DynamicSmart algorithm, it communicates with the segments and/or other vehicles (depending on the configuration of the communications) to know the traffic status in downstream segments. Furthermore, if V2I communications are activated vehicles exchange their own information with segments.



File: T1-9000V2VS50

Initial tick: 68503

Final tick: 79200

Initial hour: 19:1

Final hour: 22:00

ticks: 68503

Equivalent-coef 1.5

IDuration 30

Iinicio: 73800

idensity: 45

Isegment: SA73ST-16

Segment_G1: SA7-2ST-2

Segment_G2: SN225-3

Segment_G3: SN340-1ST-22

Segment_G4: SA7-2ST-4

cars V2V: 243

Main configuration
- File to load vehicles.
- Initial and final ticks (it defines the duration of simulation).
- Equivalent time data

- Activate or deactivate the use of equivalent intensity.

Activate Incidents
- Initial incident tick
- Duration (minutes)
- Definition of the incident severity (based on density values)
- Segment where the incident is located

Communications
- V2V or V2I can be activated

General data
Global simulation variables status

Traffic Status in specific segments
- Using the chooser, the segment to follow could be selected.
- Then, traffic parameters are showed.

```
observer: "Loading vehicle data --> T1-E1000S50V2V1.csv...."
observer: " Vehicle data T1-E1000S50V2V1.csv loaded ---"
observer: "Loading vehicle data --> T1-E1000S10V2V.csv...."
observer: " Vehicle data T1-E1000S10V2V.csv loaded ---"
observer: "Loading vehicle data --> T1-E9000S50V2V.csv...."
observer: " Vehicle data T1-E9000S50V2V.csv loaded ---"
observador>
```

General Netlogo messages

Fig. 3. Platform user Interface. In the left part, the simulation scenarios can be selected. The simulation evolution can be followed via the road network map and the different graphs. In these graphs, the user can choose the segments to be monitored.

- Segments continuously update their status (current segment speed, traffic flow, density…). They also may communicate, if communications are allowed in the test, traffic data with other segments and/or vehicles.

During the execution phase, several graphs are showed in the user interface. These graphs dynamically monitor the simulation: number of types of agents, the flow rate in main segments, etc.

When the execution ends, the result phase starts. Data collected from the simulation are written in two *csv* files:

- Vehicles file. It contains the information of all vehicles in the simulation. For each vehicle, the file has a row containing: vehicle id, origin, destination, the start time, driving travel time used to reach the destination, and type of routing algorithm used.
- Steps file. This file contains the information of all steps in all segments for every minute of the simulation. For each step and minute, the file has a row containing: step id, time, flow rate, equivalent flow rate, density, and LoS, numbers of vehicles classified by type (passenger car/HGV).

4.1. Platform user interface

The interface developed (see Fig. 3) allow users to choose the features of the traffic scenario desired:

- The road network map is loaded by default.
- The vehicle flow rate is loaded using the *csv* file commented in Fig. 2. The file to be loaded can be chosen from the interface.
- The use of equivalent flow rate can be activated or not. The value for the equivalence coefficient can be modified to test the importance of HGV.
- The activation of an incident can be selected or not. After activating the incident option, some parameters have to be defined: (1) the time when the incident begins, (2) its duration, (3) the step where it is located and (4) the density produced by this incident in the segment to which the step belongs.
- Type of communication. V2V, V2I or any combination of communication can be selected.

Furthermore, the interface has several graphs in which ongoing values of some traffic variables on different segments are shown.

5. A real network example

A test-bed has been created modeling a real network. The idea is to test and analyze the behavior of the simulator in the context of the main goals proposed in this paper. The road network models an area of a Spanish road network, the A-7 motorway in the Community of Valencia, (the road network is the one shown in Fig. 3). This road network is part of the Trans-European Road Network (TERN).

The modeled part covers 50 km. and includes 3 main roads: A-7, N-340 and N-225. The maximum legal speed is 120 km/h for A-7 motorway and 90 km/h for N-340 and N-225 National Roads. In this area, there are several industrial areas with a high percentage of HGV movements. This road network is modeled using 16 segments and 96 steps.

Several traffic scenarios have been developed to analyze the behavior of the model. These scenarios cover different combinations of the traffic parameters described in Section 3.5. Scenario election can be chosen from the simulator interface. Traffic flow and percentage of HGV for each scenario have been adjusted to the Average Annual Daily Traffic (AADT) of this road network, according to the data available by DGT [27] and the traffic map of the Spanish Ministry of Transport [28]. Traffic flow has been classified in:

- Normal traffic (Valley hour). In this scenario, traffic flow tends to be 1.400 vehicles per hour. The traffic is usually not congested although some punctual congestion may occur at certain times.
- High-load traffic (Peak hour). This scenario increases the flow rate to simulate peak hours. The traffic flow tends to be 1.900 vehicles per hour.

According to the AADT information, the percentage of HGV is, respectively, 21%, 19%, and 15% for the A-7, the N-225, and the N-340.

6. Results

To analyze the model behavior, different tests have been planned and executed. Each test is composed of different traffic scenarios.

In all scenarios, values for origin and destination intersections, the usual desired speed to travel, and the time of departure are always the same for each vehicle. The rest of the parameters for each vehicle have values related to the features of the scenario to test. Also, in each scenario, vehicles not following dynamic routing algorithms follow, in similar proportions, one of the other previously described in the routing algorithms subsection.

The period analyzed is from 20:00 to 21:00. However, the simulations are executed from 19:00 to 22:00 h considering warm-up and warm-down periods in the execution of the model.

6.1. Routing algorithms and flow rate: Peak vs Valley hour

Despite the breakthrough of on-board ITS and the overall availability of third-party routing tools, e.g. mobile applications, not all drivers use them always when driving. This is the reason because it has been chosen two extreme values for vehicles following dynamic routing algorithms. Fig. 4 shows the results of traffic flow for two configurations of smart dynamic routing vehicles (10% vs 90%) in a segment of N-225 road. Both graphs show the equivalent flow rate and the number of smart dynamic routing vehicles.

The top graph corresponds with the valley hour. When the total traffic is composed of 90% of smart dynamic routing vehicles, N-225 road is more used. In the opposite case, i.e., when the total traffic is composed of only 10% of smart dynamic routing vehicles, N-225 is less used. The bottom graph corresponds with the peak hour. The number of dynamic smart vehicles in the 90% scenario driving on the N-225 decreases with respect to the behavior in the valley hour.

The reason for this behavior is related to the flow rate in peak hours. This flow rate supposes an increase in density, which involves a decrease of LoS and speed in N-225. Thus, dynamic smart routing vehicles avoid these segments to reach their destinations.

6.2. Behavior in case of an incident

Incidents produce a decrease in road network capacity, so LoS, speed, and density are also affected. In order to analyze the model behavior, an incident has been simulated in the road network. It is located on the A-7 motorway, in the Barcelona direction (see Fig. 5). The incident begins at 20:30 and has a duration of 10 min. It increases the LoS in the segment to reach level F (worst quality of service).

Fig. 6 shows two graphs with the evaluation of traffic flow for two scenarios: 90% and 10% of smart dynamic routing vehicles of the total traffic. The top graph shows the results of the two scenarios in the A-7 segment, whilst the bottom graph shows them in the N-340.

In the A-7 traffic flow for both scenarios has a similar behavior until 20:30. Then, once the incident begins, a change is observed. With 10% smart dynamic routing vehicles, traffic flow follows the same trend. But, with 90% of dynamic smart vehicles, traffic flow decreases significantly. This is due because a huge number of vehicles (90% of them) know about the incident and the traffic status it provokes. Therefore, these vehicles modify their routes to avoid that congestion. This behavior is confirmed in N-340 traffic flow, where from 20:30, traffic flow with 90% dynamic smart vehicles is increased due to the vehicles that have changed their routes to use now this N-340 instead of the A-7.

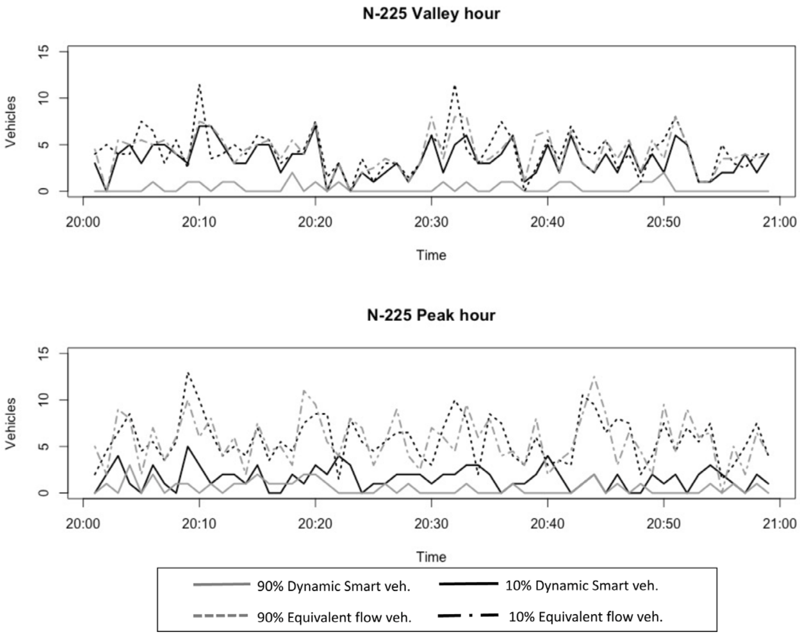


Fig. 4. Impact of % of dynamic smart routing vehicles in peak or valley hour in N-225 national road. Top graph shows flow rate of dynamic smart vehicles in valley hour whilst bottom graph shows flow rate in peak hour. Dotted lines represent the equivalent flow rate. Solid lanes represent the number of dynamic smart vehicles.

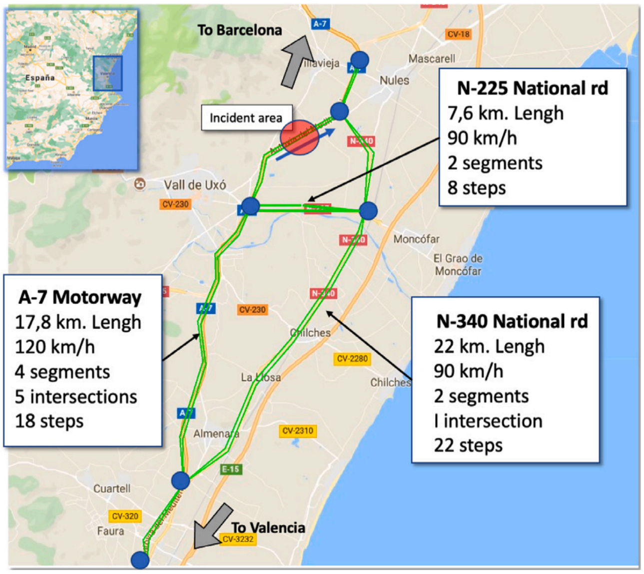


Fig. 5. Road network with an incident on the A-7 motorway and the alternative roads that can be used to avoid it.

6.3. Behavior in case of V2V/V2I

In this test, the use of V2V communications focused on the *Vehicle-Vehicle-alarm-incident* interaction protocol, is analyzed. An incident is produced in the same location as in the previous test, (A-7 motorway, in Barcelona direction).

The incident increases the LoS in the segment to reach level *F* and it also begins at 20:30, but now, it has a duration of 25 min. In the traffic scenario V2V communications are activated.

Fig. 7 presents a comparison of equivalent traffic flow evolution. The two top graphs show these values for the A-7, meanwhile the two bottom graphs show these values for the N-340. In left graphs V2V communications are activated, while in right graphs

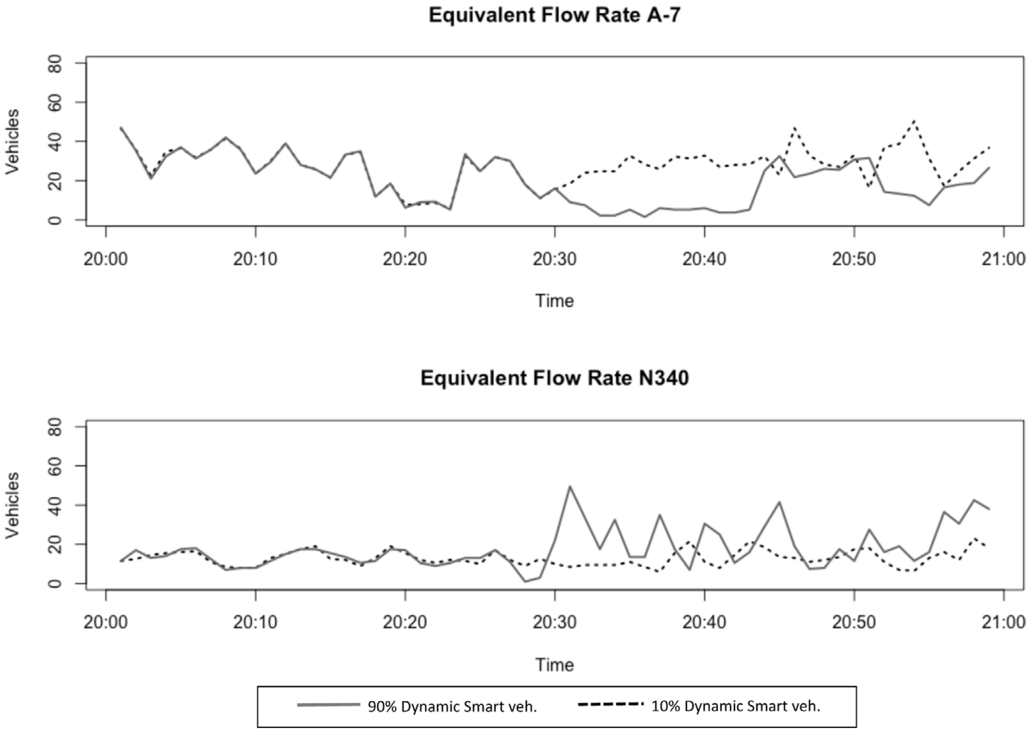


Fig. 6. Incident graph. Evolution of flow rate with an incident provoked in A-7 motorway. With 10% of smart dynamic routing vehicles, traffic flow does not vary, however, with 90% of smart dynamic routing vehicles, there is a significant amount of traffic using the N-340 as an alternative route while that incident is active.

V2V are deactivated. To have a threshold of how traffic behaves, a time series has been included for a traffic situation with no accident, nor V2V communications, and with only 10% of dynamic smart vehicles (dotted line).

In the A-7 motorway, the incident produces a considerable decrease in equivalent flow rate in all traffic scenarios (independently of the percentage of dynamic or V2V smart routing vehicles) in comparison with the normal situation (dotted line). However, in scenarios with only V2I communications, (top right graph), the low values of equivalent flow rate with V2V communications (top left graph) are only reached with a high percentage of dynamic smart routing vehicles (90%).

This situation is also evidenced on N-340 national Road. With V2V communications the equivalent flow rate is increased in all traffic scenarios (down left graph), meanwhile, in V2I communications these high values of equivalent flow rate are only reached with a high percentage of dynamic smart vehicles (down right graph). Thus, these experiments show that real-time information available via V2V communications plays an important role to improve routing decisions.

7. Conclusions

This paper describes a new open source agent-based model for testing different road traffic scenarios in the context of V2X communication. As a road traffic simulator, the behavior of the vehicles in this work is approached with a mathematical formula, that in the overall view provides satisfactory and useful results. However, in the real world not all the vehicles always follow this formula. This is what happens in all traffic simulators. This model consists of several layers dealing with the road network knowledge model, the road traffic model and the interaction protocols. These interaction protocols allow vehicles to exchange traffic information with other vehicles or with the road network infrastructure (V2X communication). Using this information, a vehicle can choose its best route to its destination, usually using the less congested route available in terms of time to reach its destination.

Different traffic scenarios can be built and simulated with this model. A scenario tunes its features by giving values for traffic flow, type of vehicles (passenger car, truck), equivalent flow rate, traffic incidents characteristics, and the type of communications available. Using this model, a real road network has been introduced and analyzed concerning several traffic scenarios. Real traffic data has been used to feed the simulations. The goal of this analysis was to show how the use of communications and dynamic routing help to reduce the time to travel, so reducing the overall traffic congestion. Results are positive when analyzing traffic data of key segments for the available routes on the road network selected.

The model has been built using one of the most prevalent tools for developing agent-based models, the Netlogo platform. With Netlogo, models are usually easy to read, maintain and update. These were also properties that we wanted to provide for the proposed model. Despite the expressiveness of the programming language provided by Netlogo, the application of the proposed

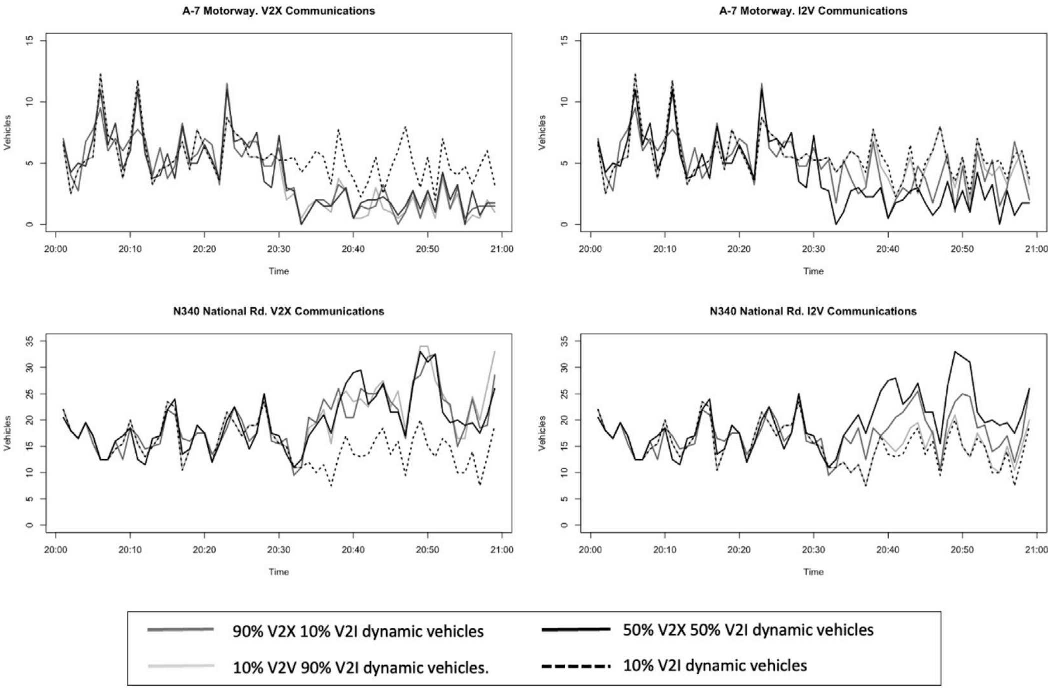


Fig. 7. Comparison of equivalent traffic flow evolution in A-7 motorway and N-340 National Road with and without V2V communications.

work to other road networks is possible, but not direct. To facilitate this application we are currently developing libraries to extend the Netlogo programming language to support GIS integration with OpenStreetMap and spatial databases such as PostGIS.

The initial hypothesis of this work is that the underlying network communication technology is suitable and reliable. This means that the information exchanged between vehicles is available in a timely manner. With the ongoing work and research being developed in the field of the wireless communication, this initial hypothesis will be achieved.

Data availability

Data will be made available on request.

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