A Vehicular Traffic Simulator Model for Evaluating *Electrical Vehicle*s (EVs) Performances in a Configurable Mobility Scenario

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Abstract: Nowadays *Electrical Mobility* (EM) is one of the most interesting topics in vehicular environment. With the increasing adoption of EV an appropriate management of hybrid traffic could be a key factor to drastically reduce environmental pollution and to enhance road safety. EVs were slowly becoming a reality in everyday life. A novel mobility model which takes into account their characteristics become necessary for describing the key factors that influence EM and its performances. Moreover, it is important to build a real world close scenario by using a novel ad-hoc simulator that implements modules which are able to capture EV behaviors. Therefore, remarkable contributions to the mobility model introduced in the simulator are: a slope factor that influence users' speed and behavior as well as vehicle consumption, a *Kinetic Energy Recovery System* (KERS) emulation for EV to better simulate vehicles' battery life and integrated module for communication issues which will be able to allow *Vehicular Ad-Hoc Network* (VANET) protocol integration. In this way, a deep analysis on different vehicles distribution ratio has been done as well as their impact on the overall scenario. Results are shown in the dedicated section.

1 INTRODUCTION

According to recent researches the number of EV sold in the last years has increased of 200%. One of the most adverse factor for the users against the use of EV is the difficulty of finding charge stations inside the city, battery duration and the significant amount of time that a full-charge needs. The number and position of these kinds of vehicle can have a great impact on the traffic dynamics and should be taken into account. This will allow us to better understand distribution of traffic flows and their dynamics. To better analyze these kinds of scenario an ad-hoc simulator has been written in the Java language. Classic vehicular simulators have been improved and refined for many years but they do not take into account some characteristics that highly influence EVs and the use of their battery packs to move. For these reasons, in this paper we propose some enhancement to the simulation model to better depict new scenarios with a remarkable number of vehicles that use electricity to move in the urban and sub-urban areas. One of the factors that most influence battery lifetime of vehicles is the road gradient. This factor does not only influence EV but also fuel engine vehicle and should be taken into account when simulating vehicles flows inside an urban scenario. Also some improvement to extend EV battery lifetime has been developed through years and have been adopted lately by automotive companies. One big improvement is the use of regenerative braking that is capable of transforming part of the kinetic energy that is dissipated as heat in reusable energy that can replenish vehicle battery. In this simulator some innovative concepts have been developed to have more accurate results:

- Influence of slope on energy consumptions
- A KERS module for regenerative braking

The slope module takes into account street slope calculating a slope coefficient that influences vehicles speed and consumption as well as driver behavior. The KERS module is used to better simulate vehicles battery life. Every time a vehicle with KERS equipped brakes some of the kinetic energy of the deceleration is recovered end reused to increase battery life span.

This work is organized as follows:

- In Section II a brief introduction and the status of the art on simulating vehicles are presented pointing out major differences
- Section III consists of a detailed description of the simulator. The mobility model used in simula-

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tions is explained exhaustively together with the new modules that take into account the street gradient and the regenerative braking.

- In Section IV simulation results are presented
- In Section V Conclusions and future activities are presented at last.

2 RELATED WORKS

Lately one of the most requested features for a traffic urban simulator is the possibility to work on real maps. Authors in (Bieker et al., 2015) developed real traffic simulation scenarios with *Simulation of Urban MObility* (SUMO) for the city of Bologna. They modeled the road networks, traffic lights and also additional traffic infrastructure. Moreover, traffic simulator is very important to evaluate other communication issues such as protocol and multimedia data dissemination avoiding resources wastages as shown in (Kurmis et al., 2015; Kurmis et al., 2017; Fazio et al., 2017). Vehicular simulators permit to test massive mobility scenarios where both traffic and network issues are analyzed for finding suitable solutions. In the VANET environment there are several problems to take under consideration. One of the most important is represented by interferences. In (Fazio et al., 2011; Fazio et al., 2012) works author propose a mechanism for disseminate data tackling interferences issues. In (Waraich et al., 2015), a new microscopic approach to traffic simulation is proposed in which a multi-agent platform is used and several ways to improve overall performance are presented. Authors of (Zhou et al., 2015) propose a mesoscopic dynamic traffic simulator with the introduction of consumption evaluation to evaluate vehicle emission/fuel consumption impact. A study on how cumulative accelerations can have a considerable impact on consumption and consecutively on emissions si carried out in (Hemmerle et al., 2016). In this work the authors show how synchronized flow patterns have a great impact on the overall emissions inside cities. A deep investigation of the different phases of traffic models has been carried out in (Knospe et al., 2000). Authors focused on how model free-flow, synchronized, and stop-and-go situations that are present in real traffic. In (Maia et al., 2011) the authors propose an electric vehicle simulator based on SUMO to better investigate the issue of energy consumption of EV. They extended the classical two-dimensional simulator modeling the altitude of the streets and transforming in this way SUMO into a three-dimensional simulator. A description of the development and modules of SUMO is present in (Krajzewicz et al., 2012). In this paper authors describe the packages composing the simulator as well as the major applications categorized by research topic and by example. Authors of (Olascuaga et al., 2015) explored like us the impact of this new alternative technology on users' driving patterns and on the energy consumption of vehicles. They did not take into account the influence of street gradient and regenerative braking on batteries duration. In (Bedogni et al., 2014) authors developed and algorithm to plan the route of an EV taking into account the overhead to reach the charging stations along the way towards the destination. However their algorithm do not consider the status of traffic flows inside the moving area and consequently neither the energy consumed due to other vehicle interactions

3 SIMULATOR

Nowadays models used in simulators are very precise and accurate in describing urban scenarios of moving vehicles. Mobility models are able to describe in a realistic way how vehicles move inside the city. Unfortunately these models do not take into account some key factors that can influence considerably EV. These factors can heavily influence the battery lifetime of this kind of vehicles. The energy consumption of an electric engine changes depending on a multitude of factors. One of the most important is the gradient of the street in which vehicles move. The slope factor also influence the consumption of fuel engines but affect in a really particular way the energy consumption of batteries of moving vehicles. For these reasons, to improve the performances of these kinds of vehicle some countermeasures needs to be developed to tackle an excessive energy consumption. One of the most used technique, derived also from motor racing, is the regenerative braking. Using this technique the kinetic energy of braking is partially transformed in electrical energy to refill the engine battery. The possibility to evaluate novel solutions in a simulated and controlled environment may help to reduce troubles in applying new solution in the real world. In next sections the overall architecture of the simulator will be presented as well as a description of the innovative modules that have been introduced.

3.1 Architecture

The proposed simulator framework is based on *Discrete Event Simulation* (DES) principles and it is composed of several modules which are herein summarized:

- Scheduler/Dispatcher
- Map module
- Mobility module
- Consumption Module
- Slope Module
- Vehicular Module

3.1.1 Scheduler

The scheduler is the heart of the simulator and has the task to elaborate the events in chronological order. Each created event is pushed into the buffer of the scheduler in a time-sorted way. The events extracted from the queue are then analyzed and passed with Java reflection to the recipient. Every recipient has a method to manage the message

3.1.2 Map Module

The map module takes care of building a map where vehicles move. The map is represented by an oriented graph that derives directly from the representations of real maps that can be found on *Open Street Map* (OSM) (osm, 2018). For this purpose an *eXtensible Markup Language* (XML) parser has been developed that parse the structure of the file and build the graph representation used inside the simulations. Information about streets slope is derived instead from the Google Maps API.

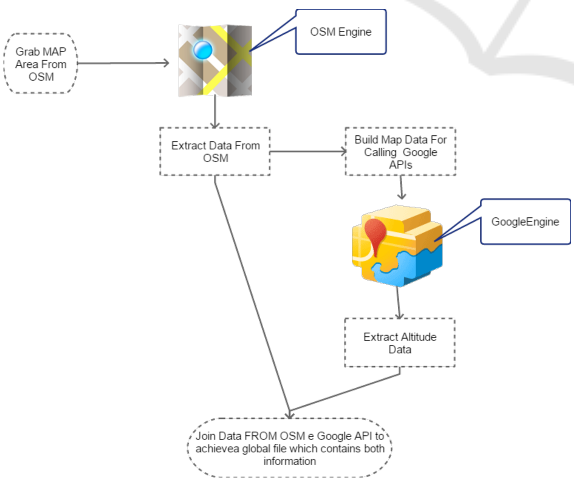

Figure 1: Framework integration for Map modules.

This information is encapsulated inside the map graph as a property of the edges. The map is also divided in zones with an altitude coefficient. This coefficient is used for consumption estimation. In Figure 1 the procedures needed for building the map area used in the simulation are shown. OSM allows users to download an XML file representing all the interesting features of a chosen area. The XML extracts the topology of the map building a representative map graph of the interested area. For each node a call to the Google Maps API is carried out in order to collect the altitude of each node. The slope is evaluated and stored as attribute of the edge that connect two adjacent nodes. Figure 2 shows the map area as result of the whole process started from the acquisition of OSM data related to a San Francisco sub-area.

3.1.3 Slope Module

One of the most important simulator enhancement is the introduction of the slope factor achieve by the parsing of altitude information. In order to gather information about street height a software interface with Google Maps API web services (map, 2018) has been developed. Due to the limitations use of the Google Maps Api we had to minimize the number of requests through altimetry data caching. To collect these information it is necessary to make a RESTful request to the serve specifying latitude and longitude coordinates of the point of interest. In addition to node height also an *Altimetric Coefficient* (AC) has been introduced. This coefficient measure the slope factor of an area given the slope of the segments that are inside it. The AC of an area is calculated:

$$AC = \sum_{i=1}^{n} (segment\_length_i / total\_length) * slope_i \tag{1}$$

Where n is the number of area segments. Using this coefficient it is possible to divide areas in three different classes:

- low class: areas with AC between 0 and 2
- medium class: areas with AC between 2 and 5
- high class: areas with AC more than 5

3.1.4 Energy Consumption

In order to explain how we introduced inside the simulator the regenerative braking module we need to show how we manage the energy consumption of vehicles. Energy consumption into our simulator takes into account:

- vehicle instantaneous speed
- vehicle instantaneous acceleration (a)
- street gradient angle coming from AC
- battery energy load expressed in kWh

Regarding vehicles' movement we take into account three forms of energy depletion:

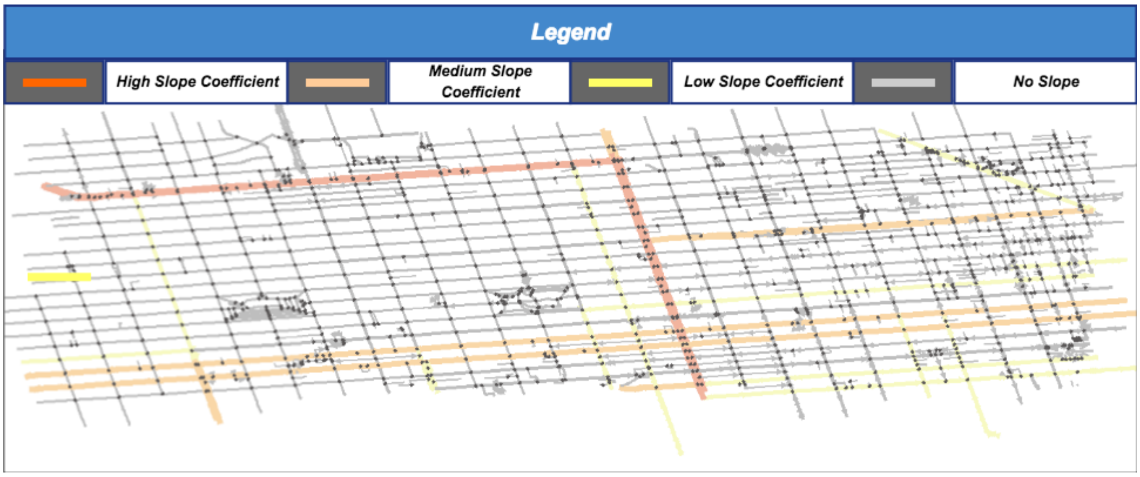

Figure 2: San Francisco graph representation.

- W_v is the work necessary to move the vehicle
- W_t is the work necessary to overcome tires friction
- W_a is the work necessary to overcome air friction

Taking in consideration

$$m * a = F - m * g * sin\varphi \tag{2}$$

The necessary force to move the vehicle taking into account the street gradient is

$$F = m * (a + g * sin\varphi) \tag{3}$$

and its work is

$$W_v = \frac{1}{Efficiency_v} * \Delta t * F * \frac{V + V_{old}}{2} \tag{4}$$

The mass vehicle m is known as well as its efficiency. The work necessary to withstand tires friction is:

$$W_t = \frac{1}{Efficiency_v} * \Delta t * (m * g * cos\alpha * cRoll) * \frac{V + V_{old}}{2} \tag{5}$$

Where $cRoll$ is the friction coefficient of tires. The work necessary to withstand air friction is :

$$W_a = \frac{1}{Efficiency_v} * \Delta t * \frac{\rho * cDrag}{2} * \frac{V + V_{old}}{2} \tag{6}$$

The model used is shown in 3.

And so energy depletion model can be expressed like:

$$E_d = \frac{W_v + W_t + W_a}{3600000} \tag{7}$$

that is subctracted to the energy inside vehicle battery.

3.1.5 Energy Recovery Brake

Part of the energy that is dissipated through air heating below the brakes can be recovered through a particular device that very often is used in EV environment called KERS. To add this device effect to the

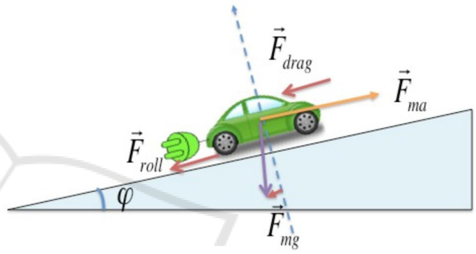

Figure 3: energy depletion model.

Table 1: Table of Symbols.

Symbol Name	Description
W_v	Work for moving vehicle
W_t	Work to withstand tires friction
W_a	Work to withstand air friction
$Efficiency_v$	Vehicle (v) Efficiency
V	Current vehicle speed
V_{old}	Last measured speed
φ	Slope angle
m	vehicle mass
F	Force to move vehicle
a	Vehicle acceleration
$cRoll$	Friction Coefficient
$cDrag$	air Friction Coefficient
Δ_t	Observation Time Window
ρ	Density air coefficient
η_{reg}	recoverable energy in percentage

model we considered the kinetic energy produced by the negative acceleration expressed in Joule (J). This energy is defined as :

$$E_{kin} = \frac{1}{2} * m * (V^2 - V_{old}^2) * \eta_{reg} \tag{8}$$

where η_{reg} is the recoverable energy percentage. This coefficient depends on the brake device efficiency that has a theoretical limit of 30%

Table 2: Consumption conversion.

1 kg of anthracite	36 MJ	10 kWh
1 kg coal	37 MJ	10.3 kWh
1 mˆ3 of natural gas	39 MJ	10.8 kWh
1 litre of gasoline	34MJ	9.4 kWh
i litre of diesel fuel	40 MJ	11.1 kWh
1 litre of gas oil	41 MJ	11.4 kWh
1 litre of fuel oil	44 MJ	12.2 kWh

3.1.6 Combustion Vehicle Consumption

Regarding combustion vehicles, the consumption we used data presented in (Packer, 2011) which converts energy consumed by vehicles from kWh to fuel liters. Just like for electrical vehicles we considered an average efficiency of 30%. Data used during simulations are displayed in Table 2

3.1.7 Mobility Model

The mobility model used in our simulation is a $carfollowing$ model based on the idea that each vehicle travels along a road just following the previous vehicle. The basic assumption is that vehicle dynamic is influenced only by the just ahead vehicle. Particularly, the model used in our simulation is customized Gipps model (Gipps, 1981).The Gipps model is a behavioral car-following model which describes how one car reacts to the behavior of the preceding vehicle. This kind of model is used mainly to analyze the effects on the traffic flow when something changes on the road network. Before the Gipps model the most part of approaches were based on the acceleration variation. The constraints that need to be respected in the Gipps model are :

- Vehicle n will not exceed its drivers desired speed
- Its free acceleration must be adequate to the speed change
- Consider the reaction time of a typical driver. If the preceding vehicle brakes the following one must have enough space and time to slow down in safety

In this way this model allow us to simulate vehicle dynamic. Gipps model is one of the most used microscopic model in vehicular environment simulation. In this work, in case of multiple lanes on a given road, the possibility of lane change to overtake another vehicle is also been considered. A vehicle can overtake another one if the current speed of vehicle and the free space allow the overtake. Moreover, the mobility model takes into account different users that may have a own drive style. Each vehicle is modeled with a specific drive style that influence accelerations and decelerations. The available driver style are BN (Below Normal), N (Normal), A (Aggressive) and VA (Very Aggressive). In this way a vehicle target speed is chosen depending on the type of street that the vehicle is traveling on and driver behavior. In this simulator we considered four type of roads Urban, Secondary extra-urban, Primary extra-urban and Highway.

Every time a vehicle needs to compute its new mobility parameters as acceleration, speed and traveled distance the new target speed is chosen using table 3

Table 3: Table of speeds .

Road type	BN	N	A	VA
Urban	15.0	25.0	45.0	60.0
Extra Urban sec	20.0	50.0	80.0	100.0
Extra Urban pr	20.0	60.0	100.0	120.0
Highway	50.0	80.0	120.0	140.0

3.1.8 Vehicular Module

The simulator allows the user to configure vehicle characteristics in a simple way through an XML file. Moreover, it is possible to specify the main feature for both combustion and electric vehicles. Once specified their features it is also possible to choose the number of combustion or electrical vehicles spawned in the simulation and their spawning rate. Table 4 presents the vehicles features, which are easy to configure, and their meaning.

Table 4: Vehicle features.

Vehicle Type	Combustion, Electric
Brand	Manufacturer
Model	Car model
Consumption	Consumption factor $[Km/l]$
Battery	Battery Capacity $[kWh]$
Charging Time	Charging time $[min]$
Efficiency	Engine efficiency
Mass	Vehicle Mass $[Kg]$
Cda	Aerodynamic Drag
Speed	Max speed $[m/s]$
Acceleration	Max acceleration $[m/s]$
Deceleration	Max deceleration $[m/s]$

Each class of vehicle can be utilized into simulation. In fact it is possible to specify a random class or a specific class for a certain spawn point. Once the main characteristics of the vehicle are chosen the vehicle is instantiated and it starts its activity by sending a self message of *”start engine”*. Once received this message represents the first event that will start each activity of the vehicle entity. First of all, vehicle starts to move by calling gipps and map module for moving in the space. Gipps module gives us mobility information, instead map module permits to move along the roads. This module is also responsible to keep data about the position of vehicles in the map area.

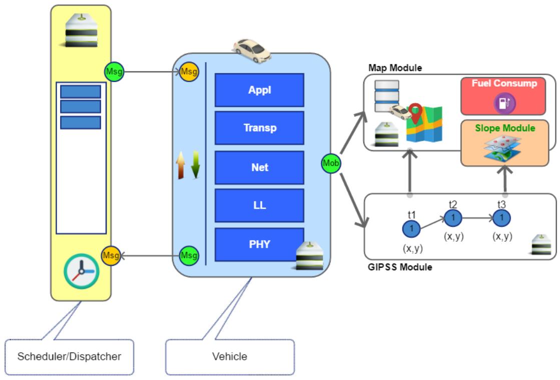

Figure 4: Simulator Modules integration.

3.2 Module Interfaces

Each vehicle is an entity which is able to communicate with other entities in a bidirectional way. Moreover, it is a composed module in which other entities that allow to implement algorithm and protocol mechanisms take place. In Figure.4 an abstract representation of the main modules that compose simulator is proposed. The scheduler/dispatcher module is the recipient of the events and it has the main goal to guarantee the timing order. Dispatcher exploits module interface to trigger handler methods in the vehicle.

Every time that a *position update* message is delivered to a vehicle, it evaluates its new position exploiting the mobility model in terms of speed, acceleration and traveled distance and map modules to know its position in terms of 3D coordinates. These data are then used to query the consumption module. In this way it is possible to updated inner variables which are related to energy/fuel consumption, position and mobility data such as speed, acceleration and so on. The consumption module uses the slope module to tune the effective consumption according to the street gradient. It is important to recall that the mobility model is obtained by a customization of Gipps model because of the introduction of the third map dimension that give us the possibility to carry out slope factor.

A simplified schema of the call sequence diagram of the simulator is shown in figures 5. Every time the position update message reaches a vehicle handler it queries the mobility module which interface map module and slope module as well as consumption module. Once the mobility model returns data about speed, acceleration and traveled distance they are used by the vehicle to calculate the new coordinates on the map through the map module. They are also used to compute the consumption step by step querying the consumption module. The consumption module takes into account the gradient of the street requesting for slope coefficient. The obtained energy from regenerative braking system in case of deceleration is also been taken into consideration.

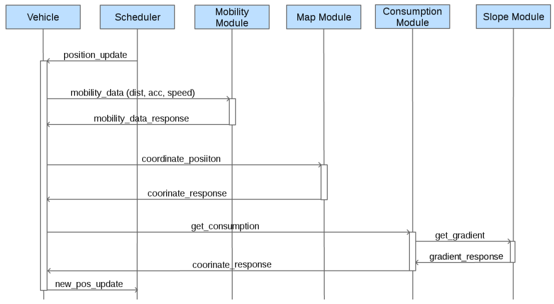

Figure 5: Sequence of calls.

3.3 Module Integration

Each module is completely configurable and extensible. The main idea is to realize compound modules in which their behavior can be easy customizable by changing inner module that may overcast the standard module. In this way it is possible to extend simulation framework by adding details for improving the analysis of some particular issue. The global integration between modules in Figure.4 is shown. Finally the simulation framework is ready to be instantiated with an ad-hoc module able to recall configuration module and initialize data structure. Simulator dashboard is depicted in Figure 6.

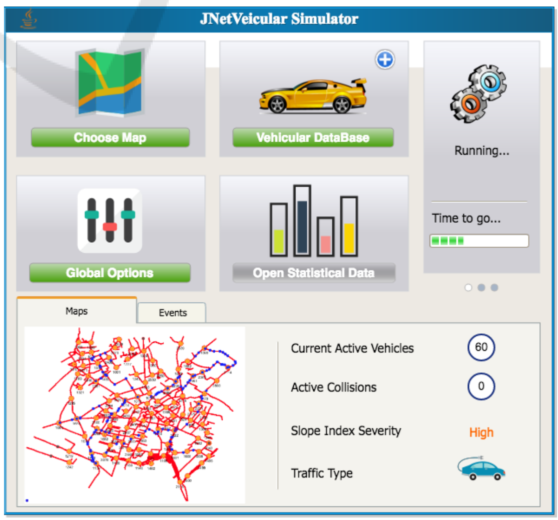

Figure 6: The main dashboard of simulator framework.

4 SIMULATION & RESULTS

In this section we introduce the achieved results by using the proposed simulation model. Here we investigate how the slope coefficient can affect overall results in different scenarios. Moreover, hybrid traffic composed of EVs and classic vehicles have been considered in the scenario. In the first campaign we evaluated the distribution of consumptions by considering the following scenario. An urban map area has been considered where roads measure different slope coefficient. For better understand how the slope can influence the results we report the altimetric path of a vehicle which is interested to travel through the map area. This path is reported in Figure 7.

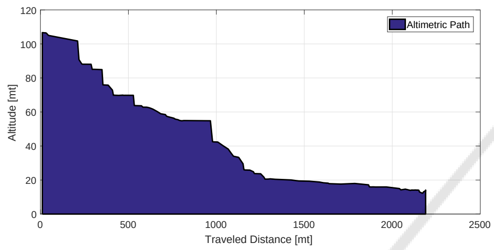

Figure 7: Altimetric Path along the map area.

The *Probability Density Function* (PDF) of the consumption trend is shown in Figure 8. In this scenario, higher consumptions for the model that consider slope coefficients of roads are measured. The differences between the consumption of vehicles concerning the altitude coefficient and the driver behavior is presented in Figure 9. In particular, we evaluated the energy consumption of vehicles by changing the considered map area. Each map presents a different average slope coefficient which are summarized in table 5. Moreover, we evaluate the consumption by considering different driver style as shown in table 3. Thus, each point of the line represents results about average consumption per Km of vehicle with a specific altitude coefficient and a driver behavior. As expected when the altitude coefficient of the map raises also the average vehicle consumption increases. The same happens regarding the driver behavior: gradually the more the behavior becomes aggressive the more consumption raises.

Table 5: Slope Coefficients.

Map Name	Avg. Slope Coeff.	Area Size
Map Area 1	4.50	15.6 Km^2
Map Area 2	3.07	9.5 Km^2
Map Area 3	1.35	10.6 Km^2

The slope coefficient is also important to evaluate energy consumption of vehicles during their travel along roads. For this reason we perform a dedicated simulation campaign to evaluate the impact of slope coefficient for different vehicle class. The vehicle differentiate between them because of mass. Considered vehicles are reported in Table 6. In Figure 10 the trend of Energy consumption versus vehicle class is reported. Here it is possible to note how the slope coefficient influences the overall performances of the EVs. Moreover, it is possible to note how the mass of vehicle is related to the overall consumption. This demonstrates the importance of the slope coefficient that must be considered in the simulation environment to achieve a more realistic scenarios.

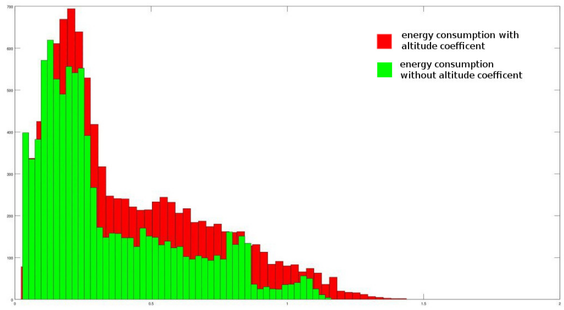

Figure 8: Comparison of PDF trend considering map area with altitude coefficient and not.

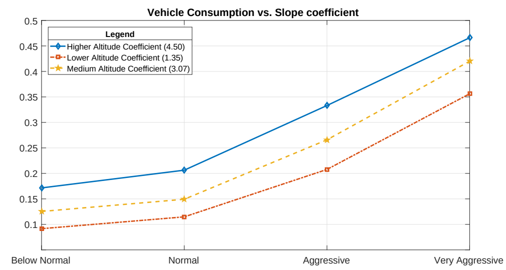

Figure 9: Average Energy consumption per Km of vehicles versus drivers' behaviors.

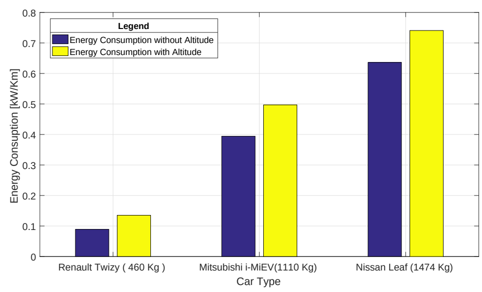

Figure 10: Average Energy consumption related to vehicle class.

Table 6: Table of vehicles.

Model	**Brand**	**Mass**	**CdA**	**Efficiency**
Twizy	Renault	460	0.40	0.8
i-MiEV	Mitsubishi	1110	0.75	0.8
Leaf	Nissan	1474	0.57	0.8

5 CONCLUSIONS

In this work we propose a new simulation framework in which simulation environment is much closer to the real world conditions. Here in the simulation scenario it is possible to consider the altitude and related roads' slope coefficient as well as classic parameters in the modeling of the EVs. Moreover, it has been proved that the altitude heavily influences the results and in particular the Energy Consumption model. Therefore, for considering EV simulation environment and to evaluate overall behavior it is important to include the road slope coefficient during the EV journey. In order to achieve more detailed simulation results, in this work we propose a driver classification by introducing four driver classes. In fact, drivers may influences performances in terms of traveling time, road congestion and collisions because of their behaviors. Moreover, in this work the model was extending to classic vehicles for better monitoring energy consumption and emissions. In this way will be possible to extend this work to design and the develop of *Intelligent Transportation System* (ITS) policies in a further work.

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