Implementation and evaluation of a simulation platform for C-ITS applications

Alessio Ciavarella
alessio.ciavarella@studenti.polito.it

Instituto Superior Técnico, Lisboa, Portugal

March 2018

Abstract

In the last few years the transport sector is having remarkable changes. A wave of technological innovation and disruptive business models has led to a growing demand for new mobility services. At the same time, the sector is trying to respond to the pressing need of making transport safer, more efficient and sustainable. In this scenario, Cooperative Intelligent Transport Systems (C-ITS) has the potential to play a significant role in responding to these needs.

However, the realisation of real and working C-ITS applications is an activity that requires many resources in terms of time and investments. Moreover, since those systems are concerned with road safety and human lives, it is not acceptable that the testing is done in a real environment. To overcome these issues a series of developing and testing methodologies have been defined, among which there is the use of well-suited simulation tools.

In this dissertation a new simulation platform able to simulate several important use cases of future intelligent roads is presented. The goal is to build a support tool for computer and civil engineering students interested in deepening the study of C-ITS systems. The work starts firstly focusing on relevant C-ITS standards like SAE and ETSI. Then the characterization of a set of use cases based on real road situations is done. Finally, the set up of the simulation platform with the implementation of some C-ITS applications is performed.

Keywords: transport sector, C-ITS, road safety, SAE, ETSI

1. Introduction

The main role of the transport sector is to provide access between spatially separated locations for the business and household sectors, for both commodity (freight) and person movements.

However, despite its constant evolution throughout the past decades it is still characterized by weak points such as safety, efficiency and environmental sustainability. According to one of the latest NHTSA[1] road accidents reports [3], in 2015 in the USA, there were an estimated 6,296,000 police-reported traffic crashes, in which 35,092 people were killed, and an estimated 2,443,000 injured people.

Furthermore, analysing the economic impact of motor vehicle accidents happened in the 2010 in the United States, property damage costs for all crash types (fatal, injury, and property damage only) totalled $76.1 billion, representing 31% of all economic costs [2]. Considering instead, the environmental point of view, the transport sector is also one of the main sources of pollution. As stated in the Inventory of U.S. Greenhouse Gas Emissions (GHG) and Sinks 1990-2015, with a share of 27%, this sector is the second leading source of GHG emissions in the United States, just behind electricity [10].

In this scenario, Cooperative Intelligent Transport Systems (C-ITS) may have a significant role in the future evolution of this sector entailing the reduction of losses of lives, costs and pollution.
A C-ITS system connects vehicles and the infrastructure through the use of Information and Communication Technologies (ICT) in a way that road users and traffic managers share and use information to coordinate their actions. This cooperative element is expected to significantly improve road safety, traffic efficiency and comfort of driving, by helping the driver to take the right decisions and adapt to the traffic situation [1].

[1] National Highway Traffic Safety Administration (NHTSA)

1.1. C-ITS issues and challenges

Normally, any kind of application, before being delivered to customers in a real working environment, needs to pass a testing phase whose goal is to ensure that it fulfils the starting requirements and that there are no bugs in the implemented features. This is even more important for C-ITS applications because many of them are safety-related, in the sense that possible system faults and misbehaviours may cause fatalities with dangerous effects for the involved people. For this reason, it is not possible to test such applications on real roads, at lest until they get a well defined level of reliability.

Another problem related to real road testing is that a C-ITS system has a relatively complex architecture involving not only the infrastructure of connected RSUs, but also vehicles equipped with proper on-board units, hence its realisation requires a remarkable amount of resources in terms of time and investments. All this leads to the necessity of implementing and testing applications in an environment that guarantees, at the same time, safety and reasonable costs.

1.2. Objectives

The Departamento de Engenharia Informtica (DEI) of the Instituto Superior Técnico, in Lisbon, is aiming at building a reduced scale prototype of a basic C-ITS system able to provide an environment where it is possible realise a first implementation, and relative testing, of those types of applications. Besides that, another goal is to have a possible teaching support tool to help students learning the organization of C-ITS systems.

The thesis work is mainly concerned with the implementation and evaluation of a simulation platform able to simulate several important use cases of future intelligent roads, laying the foundations for its realisation. Besides that, the development activity focused had two others objectives. The former was the characterisation of a set of use cases to be implemented in the simulator. Those use cases have been defined considering both standard and hazardous road scenarios, for example: intersections with or without traffic light, pedestrian crossing, level crossing, hazardous road conditions (e.g. icy road). The latter was the definition of a set of messages that applications use to exchange information. Those messages have been defined starting from the current ETSI[2] technical specifications regarding C-ITS applications.

2. State of the art

The state-of-the-art analysis is focused mainly on the study of current issued standards and the methodologies used by academic community and other stakeholders (e.g. car manufacturers and IT companies) to develop and test future C-ITS applications.

The first part is an analysis of the C-ITS standards that have been issued by two important American and European organizations, respectively the Society of Automotive Engineers (SAE) and the European Telecommunications Standards Institute (ETSI). In particular, since our work is mainly related to application development we will focus on protocols defining message formats and applications architecture.

The second part, instead, analyses what are the current methodologies, tools and facilities used by the academic community and other stakeholders to develop and test future C-ITS applications in a way that guarantee accuracy, reliability and safety. In particular there is a survey of current test site installations and simulation platforms used to validate the developed systems.

2.1. Standard message set

Due to their nature, C-ITS systems are characterized by the cooperative element. This means that all the components of those system, namely vehicles, RSUs and control unit, must be able to interact in an effective way. Besides that, due to the wide extension of cooperative ITS systems, there are many competing stakeholders among which there are car makers, IT companies, telecom operators as well as road infrastructure managers and owners.

To speed up the C-ITS development, the main standardization organizations have issued a series of standards. The two main protocol communication architectures are the DSRC and C-ITS both defining a complete protocol stack based on the ISO OSI reference model.

As stated in [7], with the exception of some services, such as multimedia or common Web access, many C-ITS services have common communication requirements:

Periodic status exchange: C-ITS services typically need to know about the status of vehicle or roadside terminals. This implies the periodic exchange of data packets with information about location, speed, identifier, etc.

Asynchronous notifications: this kind of messages are used to inform about a specific service event. In contrast to the previous status messages.

In order to support these two types of communication requirements, both the SAE and ETSI have defined some standards describing message format.

The SAE standard has not been deeply surveyed because it is not freely available on the Internet. Although this limitation, a complete study has been

[2]European Telecommunications Standard Institute (ETSI)

possible because of free available ETSI standards. In fact, both specifications are perfectly compliant covering the standardization of the very same aspects, namely communication stack architecture, message set definition and so on and so forth.

The ETSI standard includes the definition of two type of messages:

CAM messages exchanged among ITS entities to create and maintain awareness of each other and to support cooperative performance of vehicles. A CAM contains status and attribute information of the originating entity (e.g. location).

DENM an event-triggered message used by ITS applications to alert road users of a hazardous event using ITS communication technologies. The DENM contains all the information related to the detected event (type, location, etc.).

2.2. Development and testing methodologies

Surveying the current literature and some European funded projects it has been possible to understand that there are three main way of developing and testing applications. These methodologies are: real road testing, the use of dedicated testing facilities and simulations performed on well-suited tools.

The first approach consists in performing tests on real roads. On one side, this solution is characterized by the fact that tests are carried out in real traffic, weather and road status conditions. On the other side, it may expose both testers and others standard road users to potential harm caused by possible system issues and misbehaviours. An example of a real execution of this type of testing is the Drive C2X[3] initiative, an European funded project involving many car makers such as Volvo, Ford and BMW, components suppliers as BOSCH and Continental, communication equipment vendor like NEC and others research and government organizations. The tests have been carried out in a total of seven national test sites across Europe. Those test sites encompass both common used roads and specific testing site closed to normal traffic.

The second approach, instead, makes use of specific built road infrastructure that are closed to normal traffic, where it is possible to simulate various real road scenarios as well as particular hazardous situations. In this way it is possible to have a more controllable and safer environment with less exposure to possible harm, but with still a good level of accuracy. For instance, at the Swedish Test site in Gothenburg, Sweden, Stahlmann et al. [8] in collaboration with AUDI AG have performed Field Operational Test (FOT) for evaluate a GLOSA[4] system.

However, the realisation of field tests both on real road or testing sites is rather complex and expensive. For this reason, simulations are essential to prepare the tests in real world situations and reduce their costs [5]. Nevertheless, it is necessary that those simulation tools are enough accurate in order to model realistic traffic scenarios and communication amongst the participating entities. Examples of tools developed by academic institutions with the collaborations of car makers are: VEINS, VSimRTI and MSIECV. Examples of research works based have been performed by Katsaros et al. [4] to monitor the impacts of GLOSA system on fuel and traffic efficiency used an integrated simulation tool based on the Fraunhofer VSimRTI. Instead, Szczurek et al. [9] through the MITSIM software, a microscopic traffic simulator, performed an investigation for analysing the relevance of the Emergency Electronic Brake Light (EEBL) application.

3. Future road scenarios

This section gives a description of future intelligent road scenarios. It presents a more in-depth description of what are the equipment needed to implement the road infrastructure and an overview of some scenarios where C-ITS technologies may be involved to improve safety and efficiency. Those scenarios have been taken from current literature and standards.

3.1. Roadside units

One of the main components of a C-ITS system is the RSU, a device installed along the road able to communicate with vehicles and the central unit.

Studies show that in areas of low vehicle density, important safety broadcasts messages can take more than 100 seconds to reach all nearby cars [6]. The installation of milestone RSUs, at a constant distance along the road track, may avoid the fragmentation problem guaranteeing a seamless connectivity. This may also permit to further broadcast warning messages (e.g. road accident) and have better control over road status (e.g. ice presence, fog, etc.) and traffic congestion.

Those RSUs may carry on also a further function, the Active Road Sign. Nowadays, road signs are just passive entities made of a pole and a signpost laying on the side of the road. On the contrary, the Active Road Sign is an RSU that mimics a traditional signpost with the difference that it is able to communicate with the approaching vehicles and send to them the necessary information (e.g. the speed limit value).

3.2. Intersections

Intersections are road situations where the cooperative element of C-ITS is of paramount importance.

[3] Drive C2X project - http://www.drive-c2x.eu/project

[4] GLOSA - Green Light Optimal Speed Advisory

Indeed all the users that are involved in those cases must to cooperate among themselves in order to circulate safely. A set of different situations have been analysed.

Pedestrian and bicyclist crossing meeting point of different road users. Providing it with proper devices and communication functionalities may help road users to locate each other preventing accidents.

Level crossing intersection where roads and railway meet together. Providing it with well-suited communication equipment it may interact with approaching cars informing them about the train arrival.

Intersection with or without traffic light crossing where the priority is established by either stop/give way signals or traffic light. Traditional road signs and traffic lights may be substituted by roadside units able to communicate with drivers and send warning information, if necessary.

Slip Road a road entering or leaving a motorway or dual carriageway. In this situation, vehicles merging into the normal traffic flow must take care of cars present on the main road. These manoeuvres may be supported and improved by a specific C-ITS application supporting drivers actions.

3.3. Road hazards

Road hazards might be encountered while driving along roads, for instance obstacles (rocks, animals, etc.) or bad road surface conditions (ice, mud, oil). When these situations occur the vehicles that are involved can warn the others vehicles that are moving towards the same place in order to let them take the appropriate countermeasures (e.g. slow down or change path).

Another possible road hazard is represented by stationary vehicle on the roadside or accident. These situations may be notified to driver thanks to proper message exchanging among the involved vehicles.

Some of the described scenarios have been implemented in the simulation platform.

4. Simulation platform description

This simulation platform provides the possibility of reproducing a simplified city environment made of a road network with intersections, curves, pedestrian crossings and traffic lights. In addition, there is also a railway track that, in the points where it crosses the road network, is provided with level crossings.

To give a better representation of the possible situations that can be encountered on real roads, the tool includes also the possibility to simulate different dangerous situations like icy road. Besides the road and railway tracks, there is also a C-ITS infrastructure that includes a basic set of components, like roadside units and sign posts. Considering instead the road users, the simulator is provided with cars and pedestrians able to move throughout the city environment.

In addition to its basic features this tool allows also the definition of custom scenarios as well as the modification of the existing ones.

4.1. The agent-based modelling and the Anylogic platform

The simulation platform has been developed through the creation of an Agent-Based Model (ABM). The principle of this modelling method is to observe the whole system by characterizing the behaviour of the agents, of the system and the environment in which they interact and move. Then the system is modelled as a collection of autonomous decision-making entities called agents. An agent has a set of possible actions, rules of behaviour and variables that give an indication of its internal state.

The simulation platform has been developed thanks to the the Anylogic simulator is a software that allows the modelling and execution of a complex system.

4.2. Simulation model architecture

The model organization reflects the C-ITS architecture taking into account both components and their interconnections. The first analysis allowed the identification of the various entities. These entities have been then modelled as agents, and are as follows:

- Car
- RSU
- Pedestrian crossing
- Level crossing
- Icy road

4.3. Inter-agent communication

A particular consideration merits the modelling of inter-agent communications in order to get the best representation of the real C-ITS communication system. For this reason has been done an analysis of all the possible interconnections established among the various C-ITS entities. Those interconnections are characterized by three common aspects: the communication protocol, the communication range and the exchanged messages.

Taking into account all those aspects and the limitation of the model representation, the inter-agent communication has been modelled as a simple connection between agents without the implementation of a specific communication protocol and with limited distance in a way that it can be established only if two agents are within a certain distance.

The inter-agent message exchange is done by custom CAM and DENM messages. In our specific application, the usage of standards ETSI messages is not completely suitable for two main reasons. The first reason is that since we are building a simplified representation of a C-ITS system it is not possible to represent all the information. The other reason is that it has been necessary to add some other information to the CAM message in order to be able to represent information about active road signs. In fact, the standard does not provide any representation for this data.

5. Implementation

After the description of the simulation platform characteristics and the definition of all the preliminary aspects, the real implementation work has been done. The creation phase has been divided in two different activities. Firstly, the creation of each agent model defining their functionalities. Secondly, the creation of the city environment, implementing some previously described scenarios and the agents movements.

5.1. Agents implementation

Each agent is characterized by a state chart that defines its operations and a set of parameters that represent its state. The implemented functionalities and details of each agents are as follows:

Car agent models a car able to move along the road path and interact with other agents. In particular, managing various CAM and DENM messages may adapt his speed to the external conditions, and if necessary, stop. Besides that, it is also capable of detecting ice on the road and broadcast warning messages.

RSU agent represents the various RSUs that can be installed along the road track. It can carry on different functions according to the configured parameters. Possible types are: milestone RSU, and two type of active road signs, i.e. speed limit and curve warning. It is able to communicate with nearby vehicles and, when configured, with another RSU.

Pedestrian crossing represents a generic pedestrian crossing. It is made of two stop lines where cars stop in case there are pedestrians crossing. With a pedestrian detector able to discover approaching pedestrians it can inform the vehicles about the warning by means of DENM messages.

Level crossing models a level crossing. It is made of two stop lines where cars stop in case of a train passage.With a car/train detector it may notify cars about the tram approaching in order to let them stop.

Icy road an agent mimicking an icy road hazard. It is characterized by a functionality that detects a car and sends to it a message. The exchanged message aims at letting know the car about the hazard.

5.2. City scenario implementation

The modelling phase included also the creation of a city scenario represented by a map made of roads, intersections, pedestrian and level crossings. In addition, throughout the represented track are placed a set of different RSUs and road hazards (e.g. icy road). Inside this city scenarios vehicles move along the roads dynamically establishing connections with other nearby agents. An example of implemented scenario is depicted in figure 1.

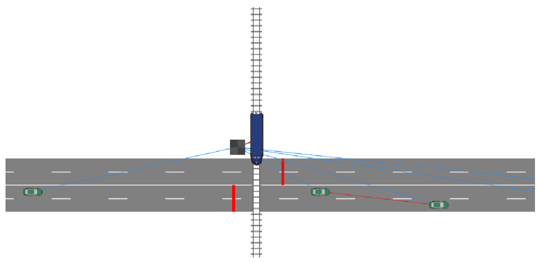

Figure 1: Level crossing scenario

Once the city scenario has been defined, then the definition of cars, trains and pedestrians paths has been done. All these activity required two different steps. The first one is the definition, for each agent type, of the agent population. An agent population is simply a set containing agents of the same type that are present in the simulation during the execution.

The second activity is the definition of the agent path. This path has been established by means of Anylogic functional blocks connected in a waterfall fashion. An example of car path definition is depicted in figure 2.

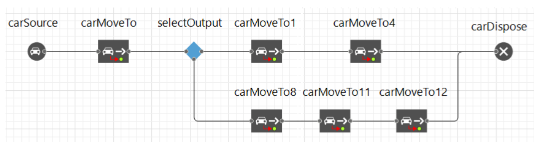

Figure 2: Car path definition

6. Evaluation

In this section we present the evaluation results of the developed simulation platform with the analysis of the Anylogic capabilities and the developed use cases as well as a focus on the performance aspect.

The evaluation phase has been mainly a qualitative process that has been performed throughout the whole thesis work. The results have been obtained comparing the main functionalities and characteristics of future road scenarios with the functionalities that where possible to implement into the simulation platform. Instead, the performance evaluation has been done through the usage some monitoring tools.

In the last part of this section, taking into account the obtained results, there is the description of a possible solution able to overcome some of the encountered development problems.

6.1. Anylogic simulator evaluation

This analysis is focused on the evaluation of the functionalities that were needed by the simulator. The first analysis focused on the possibility of creating a city scenarios with intersections, pedestrian crossing, etc. in order to have a simulation environment that mimics real road situations. Since it was of a paramount importance having the possibility of creating a C-ITS infrastructure, the possibility of establishing V2X communications and proper message exchanging has been evaluated. They have been successfully obtained through inter-agent communication.

Finally, in order to have a sort of positioning system (e.g. GPS) it has been evaluated the Anylogic positioning mechanism and verified if it was compatible with our initial requirements. Also this evaluation has been positive, indeed it is possible, through dedicated API, to get the current position of each agent moving along the road track.

6.2. Agents evaluation

Each developed agent have been evaluated comparing the initial requirements with the functionalities that have been possible to implement.

Car the first analysis is focused on which are the accessible and modifiable parameters of the vehicle, proving that position, speed, and acceleration values are available. Then it has been considered the possibility of defining a track along which the car can move and the possibility of connecting the vehicle to other agents. Both aspects have been proven. Furthermore, the possibility of executing parallel actions has been evaluated resulting that this is not achievable because of the Anylogic limitations. Finally, has been tried the possibility of changing the car path in consequence of a specific situation or event (e.g. icy road). Also in this case the expected result has not been obtained.

RSU the agent analysis is focused on three main aspects: the possibility of placing it anywhere along the road track, the possibility of communicating with cars and connected RSUs and the possibility of implementing different type of applications. The first aspects has been easily verified and successfully obtained thanks to the drag-and-drop functionalities provided by Anylogic.

The second aspect evaluation aimed at testing two type of communications: the first one between cars and RSU and the second one between two different RSUs. These result have been completely obtained establishing an inter-agent communication between RSUs.

The last aspect, instead, has been partially obtained. In fact, besides the fact that it is possible to deploy both milestone RSU and Active Road sign, it has not possible to run these functions concurrently.

Pedestrian crossing the analysis aimed at evaluating the possibility of creating an entity that could be put along a road track and where pedestrians could cross the road. The first evaluated aspect has been the possibility of interconnecting this entity with both cars and pedestrians. Exploiting these interconnections it has been verified the possibility of detecting those agents and to establish a proper message exchange between the pedestrian crossing and the cars in order to stop them in case pedestrians are occupying the carriageway. All these aspects have been successfully evaluated and demonstrated by simulation execution.

Level crossing The level crossing analysis aimed at evaluating the possibility of creating an entity that could be put along a road track where there is the intersection with a railway track. The first analysis focused on the capability of detecting approaching cars and trains and to establish inter-agent communication. Once that those aspects have been successfully proven, then has been tested the possibility of notify approaching cars about the level crossing status both in case there is or not a train passage, obtaining a positive result.

Icy road the analysis is focused on different aspects. First of all, like the RSU agent, it has been evaluated the possibility of placing the hazard on whatever part of the road track. This first result has been successfully achieved. The second phase of the evaluation is focused on the interaction between car and icy road agent. This functionality has been completely achieved thanks to the inter-agent communication.

6.3. Performance evaluation

Besides the qualitative evaluation of the Anylogic platform and developed agents a performance evaluation has been performed as well. The evaluation has been done using the built-in Anylogic tools and the Windows Task Manager. The tests have been conducted in an unloaded system running only the operating system and the Anylogic simulator.

The considered simulation has been executed with the full city road topology with the following characteristics:

- 13 roads
- 3 car entry points
- 7 intersections
- 4 curves
- 1 railway track
- average of 600 car agents per hour
- average of 2 trains per hour
- average of 80 pedestrians per hour
- 2 pedestrian crossing agents
- 13 RSU agents (including active road signs and milestone RSUs)
- 3 level crossings agents
- 2 icy road agents

From the Windows Task Manager evaluation it has been possible to observe that there is not heavy system usage both from a CPU and RAM point of view. Moreover, from the built-in Anylogic memory usage indicator, besides a model allocated memory of 2048 MB, only 132 MB are being used, meaning that it is used only a share of 6.45%. In light of these results it is possible to evince that the simulator is quite frugal on the system resources usage.

6.4. Architecture proposal for future applications

Observing the way in which the agents logic has been defined, it is possible to notice that it is based on a state chart definition. Those state charts are characterized by a set of states and transitions among them as well a set of possible asynchronous events.

This solution is characterized by a series of issues. It is not possible to define different control flow that run concurrently and the code development cannot be organized in a modular fashion.

For these reasons a possible solution has been designed and proposed.

The solution consists in the realisation of a standalone Java application that is able to communicate with the Anylogic tool via a proper interconnection. The general system architecture is depicted in figure 3, where on the left side there is the Anylogic tool with the implemented model, on the right side there is the standalone application and finally, in the middle of these two entities, there is their interconnection represented by a TCP connection.

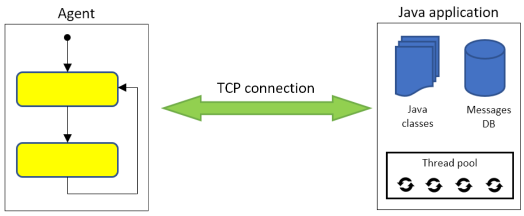

Figure 3: Architecture of the proposed solution

Concerning the Anylogic tool and its model, the proposed solution is based on the fact that the agents logic is characterized by a simple state chart with simple operations mainly devoted to the management of inter-agent communication and the interaction with the external Java application.

Considering instead the standalone application, it is characterized by a set of applications running on multiple threads and a database of messages. Each application corresponds to the agent inside the Anylogic simulator. Such application implements the real agent logic.

The messages that pass over these TCP connections are meant to keep the application and its relative Anylogic agent status synchronized. Moreover it is used by the Application to send specific control messages to the agent or receive CAM/DENM messages collected by the agent.

Regarding the database of messages, this can be considered as a possible support utility (e.g. message log) that may help in debugging and analysis phases.

In figure 4 is depicted the possible organization of two type of applications running two different agents logic. The considered agents are the car and the RSU. The applications architecture has been defined in a layered fashion. The composing layers are the facility layer and the application layer.

The facility layer is characterized by different modules, that differs accordingly to the specific controlled agent. It is meant to provide a set of API, through which the entities in the upper layer can request services. Example of services are the CAM and DENM messages that prove the functionality of sending or broadcasting the messages.

The application layer, instead, contains all the possible applications that may run on a specific agent. An axample is the Icy Road Warning System able to detect ice on the road, and in case, broadcast a DENM message.

The proposed solution, since it is a standard Java application, may benefit of all the Java features (e.g. inheritance, modularity, etc.) by solving the problem encountered with the definition of agent logic through state charts. Furthermore, because of the full availability of Java standard libraries, it is possible to enable concurrency by means of the definition of multiple threads.

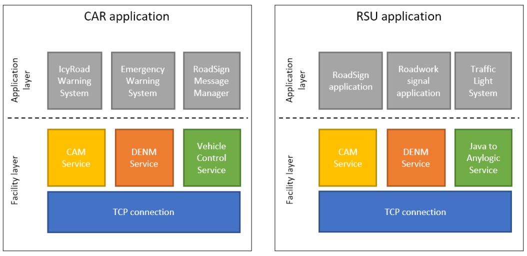

Figure 4: Possible application architecture

7. Conclusions

The thesis work started with the study of the C-ITS state-of-the-art, mainly focusing on current standards, development methodologies and testing techniques.

Then, as a preparatory activity for the realisation of the simulation platform, an analysis of possible road situations has been done. Starting from these scenarios a simplified city environment and a basic set of C-ITS infrastructure and applications have been created. Along with this activity the definition of a set of messages exchanged by vehicles and roadside units have been done.

The developed solution demonstrates the feasibility of developing future C-ITS applications that can be applied in different road scenarios. Because of that, it may represent an alternative solution for the study, development and testing of initial prototypes of future C-ITS systems and applications without the necessity of having expensive testing site facilities. Some examples are the realisation of the milestone RSU and the Active Road Sign systems.

Furthermore, this solution may represent a good teaching support tool for lectures or laboratory activities giving students a better understanding of C-ITS systems. The interested users may be not only to professors, but also IT and civil engineering students interested in deepening their knowledge about C-ITS systems.

7.1. Future works

Since this thesis work is the initial step for the realisation of the simulation platform there is a series of future works that could introduce new functionalities or even improve the current solution.

The set of defined use cases is not yet complete leaving aside a number of possible situations and scenarios. Therefore, a possible future work could be a deeper analysis of the literature related to the study of particular scenarios and then implement them into the simulation platform.

The defined functionalities stated at the beginning of the thesis work has not been completely implemented yet. In fact, from the evaluation phase it has been possible to notice that due to the lack of some Anylogic functional blocks, some desired features were not possible to implement. To overcome these limitations a future work may aim at exploring the possibility of defining custom blocks implementing custom functionalities (e.g. adaptive re-routing).

Lastly, another future work is the implementation of the solution proposed in section 6.4 that introduced a possible architecture for future application development. Indeed, currently, the agent logic definition has been done through a set of state charts that does not allow to run different control flow at the same time (.i.e. multi-threading or multiprocessing).

References

[1] European Commission. A european strategy on cooperative intelligent transport systems, a milestone towards cooperative, connected and automated mobility, November 2016.

[2] National Highway Traffic Safety Administration. *The Economic and Societal Impact Of Motor Vehicle Crashes (Revised)*, 2010.

[3] National Highway Traffic Safety Administration, Washington, DC. *Summary of motor vehicle crashes (Final edition): 2015 data*, October 2017.

[4] T. Queck, B. Schnemann, I. Radusch, and C. Meinel. Realistic simulation of v2x communication scenarios. In *2008 IEEE Asia-Pacific Services Computing Conference*, pages 1623–1627, Dec 2008.

[5] T. Queck, B. Schünemann, I. Radusch, and C. Meinel. Realistic simulation of v2x communication scenarios. pages 1623–1627, 2008.

[6] A. B. Reis, S. Sargento, and O. K. Tonguz. Parked cars are excellent roadside units. *IEEE Transactions on Intelligent Transportation Systems*, 18(9):2490–2502, Sept 2017.

[7] J. Santa, F. P. níguez, A. Moragón, and A. F. Skarmeta. Vehicle-to-infrastructure messaging proposal based on cam/denm specifications. 2013.

[8] R. Stahlmann, M. Möller, A. Brauer, R. German, and D. Eckhoff. Technical evaluation of glosa systems and results from the field. In *2016 IEEE Vehicular Networking Conference (VNC)*, pages 1–8, Dec 2016.

[9] P. Szczurek, B. Xu, O. Wolfson, and J. Lin. Estimating relevance for the emergency electronic brake light application. *IEEE Transactions on Intelligent Transportation Systems*, 13(4):1638–1656, Dec 2012.

[10] United States Environmental Protection Agency. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2015*, 2017.