Towards the next-generation traffic simulation tools: a first appraisal

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Abstract— Future Urban Transport (FUT) describes all desired features that are currently being envisaged within the umbrella of Intelligent Transportation Systems. With advances in computer and communication technology, elevating thus the user to a central concern rather than favoring performance only, both the scientific community and practitioners are in search for adequate ways to model and assess new performance measures brought about by FUT’s requirements. After identifying such requirements, we’ll try to propose taxonomy on the basis of diverse criteria to assess how suitable currently available simulation packages are to assess Future Urban Transport. Some tools are compared and their ability to suit these needs is discussed, resulting in a first appraisal of suitability of existing microscopic traffic simulation tools. On the basis of the agent metaphor and the concept of multi-agent systems, we suggest ways in which to follow up this work.

Future Urban Transport, Artificial Transportation Systems, Agent-Based Simulation, Microscopic Simulation, Taxonomy.

I. INTRODUCTION

Computational simulation has the advantage of allowing the assessment of system's behaviour before it is developed or produced in real life. This technology helped man to go to the moon and, now, has a wide use on engineering in general in various sectors aiming to improve products quality, characterize system's output without any real implementation. They are based in mathematical models, which take into account responses and constraints of the system to be simulated.

This technique only achieves its optimal applicability when some conditions are observed. First, the problem cannot be easily solved using common sense, simple calculation, analytical methods, and direct experiments. The model needs to consider the system complexity that in many cases is hard to capture. If the system’s simulation is appropriate, we can then provide practical feedback to real systems, time compression or expansion, higher control, and lower costs.

Thus, one question emerges: why is it necessary to simulate traffic (road network)? In order to give an answer to this query we have to keep in mind the system's complexity. Traffic simulation is necessary because this kind of application domain is inherently complex, usually formed of diverse entities (vehicles, traffic controllers, pedestrians etc.) that present different interactions reflecting social behaviours (e.g. competition, collaboration). In such case, mathematical analyses are complex and deals with traffic as a whole, using flow equations to describe vehicles and pedestrian movements. Moreover, simulation can provide comparison studies between new infrastructures, controls without interfering in the real system neither spending resources. Concerning to the latter, it can be used as training set for real systems, because of the time compressing characteristics that condense information and create hypothetical situations, in addition to all advantages aforementioned.

Nevertheless, a new generation of mobility systems became evident with the advent of what has been coined Intelligent Transportation Systems (ITS). Embedded systems, wireless communications, and artificial intelligence are integrated to provide a new experience to the user. Not only, within the concept of Future Urban Transport systems (FUT), the notion of mobility system overcomes its limit, from a simple process of transportation of good and persons becomes more conscious in terms of environment, accessibility, equality, security, and sustainability of resources. However, long path is necessary to be traversed to accomplish this achievement. Scientific community studies how to create virtual scenarios to address such issues.

In this work we basically recall many of the different aspects involved in the FUT system and identify some requirements for a simulation platform to support it. First, we propose a taxonomy covering FUT requirements. We also select potential simulators that can fulful these features, either directly or indirectly, taking into account the accessibility to them. Therefore, all simulators were analysed by the taxonomy. Nonetheless, we identify existing characteristics and lacking features of the simulators in exam and further recognize potential application of the simulation tools in next generation transport systems. Our main goal is to evaluate the chosen simulators with respect to the FUT platform, and create interesting and challenging issues that can be discussed.

The remaining part of this work is organized as follows. In section two, we shall present a definition of FUT related
concepts and its requirements. We also present an overview of Artificial Transportation Systems (ATS) concept, the goal of which is to be the ideal platform for policy experimentation, transportation analysis and decision-making support [1]. The differences between abstraction levels used in traffic simulation, as well as an overview of all the chosen simulators are discussed in section three. Keeping all these concepts in mind, in section four we present the proposed taxonomy to compare the simulation tools, aiming to fulfil FUT requirements. Finally, in section five, we present the simulators analysis followed by some conclusions and in section six, suggestions of trends for our future work as well as issues to be further addressed, are given.

II. FUTURE URBAN TRANSPORT

During the last centuries, since the economy transformed into a trade-based economic system, the transport turned into an essential component of our society. These systems have become rather complex and extremely large, being geographically and functionally distributed, both in that respecting structure and management. Thus, first contemporary transportation revolution began with the introduction of electromagnetic communication, allowing greater integration through exchanging information more quickly and efficiently. Then, low-cost digital systems started playing an imperative role in transportation, improving efficiency of traffic control and coordination, as well as transport planning. Nevertheless, as transportation systems are becoming very large, both in terms of structure and dimension, the whole process of acquiring information from all sources, processing the essential data and providing adequate responses timely is rather a very arduous task.

Finally, the third revolution puts the user as a central aspect of transportation system, forcing architectures to become adaptable and accessible by different means so as to meet different requirements and a wide range of purposes. This novel scenario needs new technologies, methodologies, and paradigms that practitioners and the scientific community are hardly working on. On the other hand, discussions are still fostered by current ambitions to the Future Urban Transport systems, even more conscious in terms of environment, accessibility, equality, security, and sustainability of resources. Some of the main features are as follows [2]: Automated computation, Flexibility and Freedom, Accuracy, Intelligent Infrastructures, New communication technologies, and Distributed architecture.

By observing all FUT requirements, a question comes to our mind: How are we going to evaluate FUT systems? With the emergence of new paradigms, it is also needed to define new ways to measure if and how these requirements are being fulfilled. Current metrics, such as flow, time spent, storage utilization, and others, are not enough to totally evaluate these systems. Thus, as this new concept is user-centred, metrics also have to reflect user satisfaction (e.g. services availability, flexibility, and scalability). Additionally, many of the current measurements will be interpreted in a correlated form to extract system's nuances. The question spontaneously arises is, are the existing traditional traffic simulation models/tools able to interpret and fulfil the FUT features and requirements?

Artificial transportation systems according to Wang et al [2]: “is a generalization of the traffic simulation, which integrates the transportation system with other urban systems, such as logistic systems, social and economic systems, etc., to behave as a coordinate tool for transportation analysis, evaluation, decision-making and training.” Due to the high complexity and uncertainty of the transportation systems, traditional traffic simulation is not able to capture the dynamics that characterize them. Travellers can choose whether to travel or not, can change in any moment their planned routes, their choice can be affected by social or economic or environmental phenomena. Current transportation solutions are achieving high degree of autonomy and starts interacting with the user in a different dimension, as their peers. This turns the society into a system formed by multiple heterogeneous components with their own idiosyncrasy.

Simulation is a key component in this new step of mobility systems, due to the increased complexity in the test and validation task, which is especially more byzantine due to real-time constraints and the presence of heterogeneous participating entities (vehicles, urban infrastructures, traffic infrastructures, pedestrians etc.). In our view the new platform must support, natively or by extension, distributed and autonomous decision-making capabilities, that is the Multi-Agent System (MAS) paradigm, different types of communication techniques, it should simulate various types of heterogeneous entities providing as realistic as possible easy results and last should offer on-line simulation visualization, in order the user can extract the desired information.

III. SIMULATION OF TRAFFIC AND TRANSPORTATION SYSTEMS

The section bellow will give a small introduction to traffic simulation, starting with a description of different level of abstraction that can exist on it. In sequence, a brief overview of all simulators is presented so the reader can understand the tool's focus and functionalities.

A. Traffic Simulation Approaches

Traffic simulation is largely studied and can be classified in four types: macroscopic, mesoscopic, microscopic and nanoscopic. Macroscopic simulation models the flow of traffic using high-level mathematical models often derived from fluid dynamics, thus it is continuous simulations. This type of simulation handles every vehicle in the same way and as group. It uses aggregate input and output variables such as speed, flow and density. Macroscopic simulators are most useful for the simulation of wide-area traffic systems, which do not require detailed modelling, such as motorway networks and interregional road networks. This approach is not very
realistic because in real life there are many different types of vehicle driven by different individuals who have their own styles and behaviours. However, it is fast and accurate but is not well suited to urban models in general.

Microscopic simulators model individual entities (e.g. vehicle, driver etc.) separately at a high level of detail, and are classified as discrete simulations. Here, interactions are usually governed by the car-following and lane-changing logics. Thus, traffic flow details, usually associated with macroscopic simulation are the emergent properties of the microscopic simulation. These simulators can model traffic flow more realistically than macroscopic simulators do, due to the extra details added in modelling the simulated entities individually. Microscopic simulators are widely used to evaluate new traffic control and management technologies as well as performing analysis of existing traffic operations.

On the other hand, mesoscopic simulators fill the gap between macro and micro simulators. They normally describe traffic entities at a higher level of detail, than macroscopic models but their behaviours and interactions are in a lower level of detail. In mesoscopic model, vehicles can be grouped in packets, which are routed throughout the network and are treated as one entity. Other paradigm is that of individual vehicles that are grouped into cells to control their behaviour. The cells traverse the link and vehicles can enter and leave cells when needed, but not overtake.

A new trend of traffic simulation is the nano microscopic model that extends the vehicle vision, dividing it in parts. It is mostly used in autonomous driving and is in a strict relationship with automated robotic, because of the need to simulate sensors. Figueiredo et al [4] observed a great potential use of robotic simulators in the autonomous driving field, motivating an information exchange among robotic and traffic study groups.

B. Simulators Overview
In this paper we concentrate our attention to the microscopic type of simulation. There is a huge amount of traffic simulators available nowadays, with different features and choosing a certain tool depends very much on the project's requirements. In our study these are the FUT requirement, so we would like to find simulators that can support these characteristics. A preliminary study was done to filter and avoid lost of work. Thus, as first step, we try to improve the simulators list presented in Algers et al [5] and we select seven possible options most used by practitioners and researcher, cited below.

**VISSIM**

VISSIM [6] is developed by PTV in Germany. Its application ranges from traffic engineering, public transport, urban planning over fire protection to 3D visualization. Further, VISSIM uses a microscopic flux model of discrete, stochastic, and based on time step traffic. This simulator considers as one the pair vehicle/driver, also content a psychophysical model to car-following and lane changing based on rules. The package has two programs to form a traffic simulator: flux model for microscopic traffic and state generator (e.g. based on small time steps to get data directly from the simulator). These parts interact in a 1 second frequency.

**PARAMICS**

PARAMICS [7] is a microscopic traffic tool developed by SIAS Ltd and Quadstone Ltd of Scotland and is designed for a wide range of applications where traffic congestion is a predominant feature. Its modules combine together to improve usability, integration and productivity allowing users and clients to get added value from the modelling process. It is produced by Quadstone and has a package for software models to be used with a microscopic simulation as simple as an intersection, or complex traffic networks. The toolkit for developers provides access to data from infrastructure, control, communication, and other application, also create and improve behavioural models, independent of its complexity.

**AIMSUN**

AIMSUN [7] is developed and commercialized by TSS. It is used to improve road infrastructure, reduce emissions, cut congestion and design urban environments for vehicles and pedestrians. Three simulation types are present in this tool: the traffic distribution and allocation, a mesoscopic and microscopic simulator. The microscopic model is based in car-following, lane changing and gap acceptance algorithms. Thus, mesoscopic offers an additional option to model big nets and is less restrict in terms of calibration than the microscopic.

**MITSIM**

MITSIM [8] is a simulation tool that was developed for evaluating the impacts of alternative traffic management system designs at the operational level and assisting in subsequent design refinement. Examples of systems that can be evaluated with MITSIM include advanced traffic management systems (ATMS) and route guidance systems. MITSIM was developed at MIT's Intelligent Transportation Systems Program. MITSIM is a synthesis of a number of different models and has the following characteristics: represents a wide range of traffic management system designs; models the response of drivers to real-time traffic information and controls; and incorporates the dynamic interaction between the traffic management system and the drivers on the network.

**SUMO**

“Simulation of Urban Mobility” (SUMO) [9] is an open source, highly portable, microscopic road traffic simulation package designed to handle large road networks. The simulator is developed in the Institute of Transportation Systems at the German Aerospace Center. It is licensed under the GPL. Its features include: collision free vehicle movement, multi-lane streets with lane changing, fast execution speed, dynamic user assignment, and other.

**MAS-T2erLab**
MAS-T2er Lab [10], a tool developed by MAS-T2er Lab Group in the Artificial Intelligence and Computer Science Laboratory (LIACC), is an integrated multi-agent system that applies a methodological approach that allows for the assessment of today's intelligent transportation solutions through the metaphor of agents. So, the application domain is conceptualized in terms of agents and three basic subsystems are identified, namely the real world, the virtual domain, and the control strategies inductor.

**ITSUMO**

ITSUMO [11] was developed by MASLAB TRAFFIC from Universidade Federal do Rio Grande do Sul (UFRGS) in Brazil. It can use both off-line and on-line information (e.g., traffic flow). The information regarding the network is stored in a XML file. In addition to the cellular-automata approach, one can also define other driver decision-making procedures via a special, optional, module. A visualization module retrieves data originated from the microscopic simulation and exhibits a graphical representation of the traffic simulation. Four distinct modules thus compose the ITSUMO system: the data module, the simulation kernel, the driver definition module, and the visualization module.

**IV. CRITERIA FOR THE PROPOSED TAXONOMY**

Many other comparative studies have preceded this work. It is worthy to mention among others, Ratrout et al. [13] where the authors review the features of various microscopic simulators, Xiao et al. [14] where a methodology framework for selecting a microscopic simulator is proposed. In Panwai et al [15] the effectiveness of the agent-based models over the traditional approaches is shown. Last, Chen [16] provides a review of agent-based applications in traffic and transportation systems.

As stated previously, the goal of this study is to identify the ideal structure of a microscopic simulator that can be applied (or at least be adapted) to fulfil the FUT requirements. Based on Section 2.1 we create a new taxonomy to compare the chosen tools, cited above. First, the simulator should be extensible so we can create our own scenario, techniques, and entities. Parallelism/distribution is a recommended feature for large computational enforcement ad realistic scenarios. The supported simulated entities (e.g., vehicles, pedestrian, traffic and urban infrastructure among others) and the simulation approaches are, also, basic points to observe as well. In that case, agent-orientation is a main feature; Multi-Agent System (MAS) can simulate very closely behaviour of comprehensive heterogeneous systems where another approach of simulation fails. Microscopic traffic simulators based on MAS can model traffic system in realistic manner. Finally, it is important the simulation tool to be user-friendly. Accounting for these basic criteria, the taxonomy suggested in this work is formed by the following six items, as described below.

**Extension** - How extension is made? Which strategy? How deep can be the modifications? - A simulator is composed by a kernel and aggregated modules. We want to see in this item if the number of modules is extensible and, also, which properties of the kernel can be changed.

**Parallelism/Distribution** - Does the simulator use parallel and/or distributed techniques? - To simulate large scenarios, the tool can take maximum advantage of the computer performance. In this item, we want to observe the used technique by the simulator to perform complex analysis in short time.

**Simulated Entities** - Which are the simulated entities? Is it extensible? - Different actors must be considered in a simulation depending in the constraints. All entities must be enumerated in this item, including infrastructure (because in FUT it has to be intelligent), and if the user can add his/her entity.

**Agent-oriented** - Can the simulator support agents? How this can be done? - Agent paradigm can support FUT distributed characteristics. To provide that a platform have to deals with local information and be able to acts locally. These features will be analysed in this item

**Simulation type** - What is the simulation type performed by it? - As explained early, transportation can be simulated in different levels to accomplish different goals. FUT platform, ideally, has to be able to work with all levels, and in this item we enumerate the support abstraction levels.

**Visualization** - How can we visualize the simulation and its results? Is the visualization tool integrated in the simulator core or a different application? - Albeit this item seems to be dispensable, it is not because we need to analyse and see result, not only simulate the system. We see the type of visualization and if the visualization module is or not integrated with the simulator's kernel, to provide remote access.

We believe the aforementioned criteria are relevant and imperative for us to decide whether a simulation tool is adequate and enough to assess the new performance measures brought about by FUT's requirements. Of course many other criteria might be pointed out. However, we have fixed the above ones for this first appraisal, leaving further assessments as future work following up this paper.

**V. SIMULATOR'S ANALYSIS**

Starting with extension VISSIM, it uses COM port to communicate with external components, providing full control over some parts, such as the network topology, signal control, path flows, vehicle behaviour, and evaluation data. It allows one to program large applications using Visual Basic, Visual C++ or other applications' macro and script languages (e.g. MS EXCEL).

PARAMICS counts on a powerful tool named PARAMICS Software Development Kit (SDK), which allows users to augment tool engine with new functions that can override or replace simulator's model. The access is total to the simulator's model. The access is total to the simulator's core, existing two types of functions: call-back (used for providing information about the attributes of vehicles and their environment), and control (as the name say, can control entities).

A collection of tools is offered by AIMSUM, called AIMSUN NG. It is composed by three programming possibilities. The
AIMSUM API user can code extensions using C++ or Python, modifying the current simulation by changing, for instance, driver parameters, control timing, implementing powerful traffic management actions. Other option is Scripting, mainly used to quick, and not so deep, extension on simulator core. For last, Software Development Kit, aimed to C++ programmers, offers access both the Kernel and the Graphical User Interface allowing the inclusion of new functionalities at both levels, adding new models, new graphical elements, new editors and dialogues.

On the other hand, MITSIM does not provide any extension functionality or interface. Nonetheless, accounting for the fact it is an open-source project, the users can arguably modify its core and extend it. Another open-source project name SUMO uses the TraCI layer to control it through TCP connections. However, it has limited functions to control the simulation process and requires that information from the simulator be gathered though sensors spread out over the network. MAST2er Lab uses UDP connection to provide extension and user cannot access internals algorithms and vehicle states. Not enough information has been found about the ITSUMO package, although its extension seems to be limited to the creation of driver and semaphore controller agents by the user.

To compare simulators with respect to the second item, first we must establish the differences between parallel and distributed systems. To implement these two techniques, multiple processors are needed, further the distinction is the memory used. Parallel systems have shared memory among all CPUs, albeit in that regarding distributed systems, there exists a local memory per CPU that communicates data between processes. So, VISSIM, AIMSUN, MITSIM, MAST2er Lab, and ITSUMO are just parallel. SUMO due to its simplicity is neither distributed nor is parallel and just PARAMICS distributed.

In Table 1, we can see that commercial simulators can support most the types of entities. MAST2er Lab and ITSUMO are small academic projects and have a small set of entities. SUMO and MITSIM implements cars, buses, and trucks to emulate basic traffic situations. All of them, except MAST2er Lab, have sensors to gather information and signalling to act in the system.

<table>
<thead>
<tr>
<th>Car</th>
<th>Bus</th>
<th>Truck</th>
<th>Train</th>
<th>Bicycle</th>
<th>Pedestrian</th>
<th>Vehicles</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>VISSIM</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>TL, PCL, Detectors</td>
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<tr>
<td>PARAMICS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>TL, PCL, Detectors</td>
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<tr>
<td>AIMSUN</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>TL, Detectors</td>
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<tr>
<td>MITSIM</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
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<tr>
<td>SUMO</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>TL</td>
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<tr>
<td>MAST2er Lab</td>
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<td>No</td>
<td>No</td>
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<td>No</td>
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<td>TL</td>
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<tr>
<td>ITSUMO</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>TL, Detectors</td>
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</table>

Further, generally commercial simulators have more functionality than open source ones and do not exist a complete agent-oriented simulator. Most of simulators focus on traffic management, but nowadays are moving its focus to MAS paradigm. From this initial study, AIMSUN seems to be the best to work given our requirements, however a commercial license is required to use, even so the implementation from scratch the hardest and best choice.

**VI. CONCLUSION AND FUTURE WORK**

Traffic systems have been focus of much improvement and commuters have in general witnessed a revolution in the way a trip is planned and actually carried out in urban networks. Computer technologies as well as communication capabilities have put intelligent transportation solutions in the same level as users, as they now feature some degree of autonomy and intelligence as well, sometimes even deliberating with end users the best alternative to improve system's performance. In such a contemporary scenario, ITS-based solutions and users are peers and present a rather social interaction, which brings about new performance measures that must be assessed somehow. Furthermore, as user is central now, traditional traffic simulation packages fail to model and represent all aspects of human behaviour in a detailed way.

In this work we carry out a first attempt at evaluating current available simulation environments an their ability to model and simulate future urban transport. We have started by idealising a transport system featuring all desired process from the simulator, but can be seen as a part of the simulator core.

Each simulator has advanced features, for instance, VISSIM has parameters and function flexibility, PARAMICS adapts to use all the distributed machine resource available, AIMSUN provides different forms to extend it, MITSIM has various types of controllers available for use, SUMO architecture flexibility, and MAST2er Lab and ITSUMO are originally agent-oriented.
characteristics FUT, where not only performance is essential but also the user entity is a key aspect playing an imperative whole in all social interactions taking place in such a complex domain. Basically, we must take into consideration that current transportation systems are now able to explicitly interact with end users, allowing them to be rather greener, accessible, cheaper, more efficient (both in terms of resource consumption and performance), and environment friendly. Moreover, privacy and safety are other important issues that must be addressed at first hand.

Having identified those characteristics, we have devised a taxonomy that was used to assess currently available traffic simulation packages. Our taxonomy includes criteria such as extension capabilities, computational processing approach (parallel/distributed), entities simulated, agent-orientation, simulation approach, and visualisation capabilities. As for the assessment carried out, we can conclude that with respect to the proposed taxonomy, the item extension was difficult to define for each simulator because it demanded much user's knowledge, so deeply depends on who is analysing. Furthermore, parallelism/distribution and simulated entities require some work due to the lack in the tool's documentation (in the case of parallelism/distribution some tests needed to be realized). Finally, all items left were easy to define and compare, especially to define the integration level between GUI and simulator's core in visualization item.

In general, most simulators follow a microscopic approach as an attempt to improve the representation of human behaviour. However, a very few arguably implement the concept of agents, although some authors claim their representation are based on the agent metaphor. Even so, entities present a very basic behaviour, being only able to perform car-following and lane-changing interactions. As for deliberation and other more cognitive characteristics of the decision-process performed by humans, they are basically ignored in most packages. Nonetheless, extensibility in some tools are quite promising, allowing the user, with good programming skills to implement the desired features to support FUT assessment.

There are basically four extensions that could follow up the present work. Firstly, we intend to increase the number of analysed simulators, i.e., we have restricted the number of tools based on the microscopic modelling approach. However, different types of abstraction level will be needed in the FUT simulation platform. Second, as seen in Chen et al. [16], there are many platforms that are claimed to be agent-oriented from scratch, meaning they have been devised and implemented with the agent metaphor in mind from the very beginning of their conceptualisation. Thus, our taxonomy will certainly need be adjusted to contemplate specific characteristic of agents, such as which social behaviours they implement, which level of cognition agents are able to perform (are they just reactive or are they cognitive?) and so forth.

Last, another important aspect to have in mind is the necessity to enlarge the set of criteria. For example, the extension of communication abilities of entities could be taken into exam, so that new standards being currently applied in transportation such as Vehicle-to-Vehicle, Vehicle-to-Infrastructure can be tested and evaluated accordingly. As for the simulated entities, this aspect must be improved in order to allow us to consider new users' devices and intelligent infrastructures (mixed realities). Finally, after having a proper and complete appraisal of those features, the very next step is to devise and specify an artificial transportation platform on the basis of the agent-oriented paradigm, which we believe is the right way to support FUT's modelling and assessment in all levels.

**REFERENCES**


