Modeling & Simulation for Intelligent Transportation Systems

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***Abstract*— In the era of Intelligent Transportation Systems (ITS), the technologies supporting Communications, Sensing & Surveillance mechanisms, and Information & Control systems are spread through the road infrastructure, the vehicles and the users. Their critical mission is the endorsement of efficient, safety and environmental-friendly transport networks that promote the citizens' quality of life. This complex and multidisciplinary challenge requires a conceptual framework to guide the operations and to integrate systems, processes, tools, personnel, and data. In addition, a modular platform with proper modeling, simulating, and visualization capabilities is critical to understand the system-in-analysis, to support well-informed decisions, and to involve the general public in the traffic & environment issue. This work describes the main features of contemporary ITS, emphasizing the Portuguese case, and describes the fundamental modeling & simulation tools that are considered critical to support the daily operation of the urban transportation system.**

***Index Terms*—Geographical Information Systems, Intelligent Transportation Systems, modelling, traffic microsimulation.**

I. The Modern Transportation Systems

The transportation activity is part of our everyday lives. Each one of us has already experienced some transportation activity, as a car driver, as a bus user, as a train passenger, or as a two wheel biker, and it is quite improbable to imagine our days without people or goods' movement from one location to another. These movements have the purpose of meeting demands for services and activities [1]. The transportation system is the set of means and equipment necessary to satisfy these demands at minimum cost. This cost includes direct costs such as road tolls and maintenance, and indirect costs like discomfort, pollution, and accidents.

The expansion of the existing road infrastructure, in order to accommodate the increasing flows, is prohibitively expensive either by territorial, financial or environmental constraints [2]. Consequently, the contemporary challenge of the urban traffic system is more related with the "green" management of the available network and constituent entities, and with a qualitative improvement based on timely information, personalized travel related services, and high quality guidance provided to the entities moving on those roads. This shift from "quantity of roads" to "quality of roads" is being characterized by the development of a comprehensive information network (parallel to the physical network) and by the fostering of a safe environment. As [3] states, "transportation systems are networks, and much of the value of a network is contained in its information". This information platform will impel the emergence of a host of new products and services for modern transportation.

Sussman [4] considers the transportation systems as a Complex, Large, Interconnected, Open, and Socio technical (CLIOS) system. Is complex because it is a collection of several interrelated subsystems, strongly tied through feedback loops, with different time scales and some uncertainty associated to their relationships. Is large because its impacts are large in scale, are of long duration and of large geographical coverage. It is interconnected with other subsystems like the environmental one. Is open because interacts explicitly with other critical societal systems like the social, the political, the economic and the environmental ones, and is socio technical because has complex associated technology and important social impacts.

This new complex and multidisciplinary scenery requires more comprehensive quantitative models, more technologically advanced methods to deal with operations and control in real time and on all geographic scales, and more qualitative analysis' frameworks to cope with more complex and sensitive institutional realities. Thus, an inclusive modeling & simulation platform that enables the comprehension of this multifaceted reality through some kind of abstraction and imitation is imperative.

Typically, as in other systems, we are unable to experiment on the real urban traffic system and we need to develop models (analytic, simulations, prototypes, 3D visualizations, etc.) to gain a better understanding of the system behavior (the actual process of building the model provides awareness of the real system). With these models we can estimate measures of performance, we can evaluate alternatives, we can decide what is the best alternative (according to given criteria), we can evaluate the impact of measures, and we can communicate/negotiate with different stakeholders.

II. Intelligent Transportation Systems

The discipline of Intelligent Transportation Systems (ITS) provides a set of innovative strategies for addressing the challenges of safety (to diminish the crash rates, the traffic conflicts, and the traffic law violations in order to create a secure network for the coexistence of motorized vehicles, bicycles, and pedestrians), mobility (to enable savings in travel time, delays, travel time budgets, and on time performance), congestion (to reduce congestion by the

Manuscript received April 7, 2012; revised May 12, 2012.

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efficient management of the existing road network), environment (to reduce the negative impacts of traffic on environment such as the fuel consumption and the pollutant emissions), and customer satisfaction (to increase the LoS of the road facility).

A stated by [5], “ITS encompass a broad range of wireless and wire line communications based information, control and electronics technologies embedded in the system’s infrastructure and in vehicles to relieve congestion, improve safety and enhance productivity, saving lives, time and money”. The ITS are taken as the means to achieve sustainable and environmental friendly transportation systems for the 21st Century. Through the integrated application of modern computer, communications, surveillance and traffic control techniques the traveller will be informed and safer, the vehicles and the infrastructure will become more “intelligent” and efficient, the road operations will be smarter, and the environment will be grateful. The emphasis is putted on the utilization of the new technologies to efficiently manage and control the urban traffic system in real time.

In the last few years, the location, communication, information, and sensors & control technologies that characterize the ITS have pervade the roads, the vehicles, and the users, offering a promising approach to maximize the operational performance of the network, with particular concern with the congestion, safety, user comfort, and environmental aspects. These current developments of ITS can be generally categorized into traffic flow management & control activities, and the provision of traffic information to drivers and users (with traffic information services). It is expected that the following advances will underline the decision and operation assistance to drivers for safe driving, possibly with fully automated cruising.

The ITS largely depend on information and communication technologies (ICTs) and derived knowledge based applications such as traveler information services, traffic monitoring & management services, and navigation. According to [6] this information/knowledge society will evolve towards a ubiquitous information society that will highlight the micro scale end user level. The transport system will be based on mobile, flexible and personalized ICT services relying on real-time and transparent information/knowledge. The mentioned authors point out that the transportation system will be, by 2025 2050, a global system or a grid that “functions and constantly communicates at every level: man to man, man to machine and machine to machine”.

A. Applications and Technologies

Typically, the ITS are characterized along two dimensions: the functional categories and the user services. The general ITS subsystems or functional categories, based on the primary functional intent or application, include the ATMS (Advanced Traffic Management Systems), the ATIS (Advanced Traveller Information Systems), the AVCSS (Advanced Vehicle Control and Safety Systems), the APTS (Advanced Public Transportation Systems), the CVO (Commercial Vehicle Operations), the EMS (Emergency Management Systems), and the EPS & ETC (Electronic Payment Systems & Electronic Toll Collection). Each of these categories, defined by ITS America, ERTICO (European Road Transport Telematics Implementation Coordination Organization) and ITS Japan, and standardized by the ISO [7], includes a collection of user services like, for example, adaptive traffic signal control, ramp metering, incident detection and management (in ATMS), trip planning, location and guidance, delay estimates (in ATIS), intelligent speed adaptation, vision enhancement, collision warning (in AVCSS), automatic vehicle location, smart cards, demand responsive transportation (in APTS), route planning, weight in motion, driver condition monitoring (in CVO), incident detection, emergency notification (in EMS), and electronic toll collection, variable parking fees, and electronic road pricing (in EPS & ETC).

The technologies associated with these applications and user services are diverse and at constant evolution and constitute the other typical dimension employed to characterize the ITS. In fact, the technologies can be considered as the basis of ITS providing intelligence (the “I”) to the transport system. The range of technologies for ITS is quite extensive but, in general, they can be accommodated into three major categories namely, i) Sensing/Surveillance, ii) Communications, and iii) Information/Control. As can been confirmed by the applications, the emphasis on the technologies that provide real time services is particularly relevant. The integrated utilization of the Telecommunications and Information/Computer technologies to convey information over networks is usually known as telematics. The term is markedly used in the ITS field.

The i) Sensing/Surveillance technologies are mainly used to detect and locate vehicles, to sense a group of given conditions in board or out board, and to monitor a given point or area in the network. These technologies are typically associated with the vehicle or with the road infrastructure. The most important technologies in this cluster include, for instance, the GPS, the Automatic Vehicle Location, the probe vehicles and devices, the inductive loop detectors, and the closed circuit TV cameras.

The ii) Communications technologies are mainly used to convey data, voice and video information from one point in the system to another one. These technologies are usually divided in Wireline and Wireless being the last group the most significant one in the ITS field: The wireline technology, such as coaxial cables or fiber optics, are mainly used to fixed point to fixed point communications. The wireless communications enable the transfer of data between different fixed or mobile points (at short or at long distance) without the use of physical wires. The communication is deployed via radio frequency, microwaves or infrared. The most well known categories/applications of wireless in the field include the Dedicated Short Range Communications (DSRC), the wireless networks, the Bluetooth and Wi Fi connectivity, the mobile telephony technology, and the digital broadcasting.

The iii) Information/Control technologies serve to collect, to analyze, and to display information in order to manage and control the traffic related data and the traffic system. The most remarkable technologies for intelligent transportation comprise the Internet, the Geographical Information Systems

(GIS), the Computer Aided Dispatching systems, the Automatic Passenger Counter, the ramp meters, the computer controlled traffic signal systems, the license plate recognition systems, and the electronic payment cards.

The integration and interoperability of systems, technologies, equipments and procedures is of critical importance to enforce the potential benefits of ITS at large scale. The need to integrate the diverse intelligent “building blocks” that have been developed during years, the need to ensure compatibility of information and equipment thus impelling open markets and economies of scale, the need to create synergies across the different applications, and the need to offer better services to the end users reveal the urgent necessity to adopt a holistic approach in order to “glue” the different existing pieces taking into account the complexity and multidisciplinarity of the field. This appears to be the big challenge of the future transportation that is, to deal with the network effect and the systems’ coordination.

B. Portuguese Case

The European Union has been making, since 2006, a considerable effort to create a dynamic knowledge based economy and an integrated vision for the information space (e.g. the i2010 initiative and the recent Digital Agenda programme for Europe that aim to “deliver sustainable economic and social benefits from a digital single market based on fast and ultra fast internet and interoperable applications” [8]). These efforts are also reflected in the transportation field, being the ITS one of the major applications of information and communication technologies. This vision and leadership is crucial for the development of the field but, by this time, there is still a lack of effective implementation.

The nonexistence of a comprehensive holistic approach for the urban traffic system management has been a major drawback. The majority of ITS applications that have been developed, since the 1980s, in areas such as traffic congestion, clean transport, and road safety, are stand alone systems that are neither integrated nor interoperable (like a “patchwork” of applications and services). Furthermore, the urban dimension asymmetries within European countries call for appropriate ITS solutions integrated in an overall framework but compatible with the city size.

In Portugal, the ITS initiatives follow the same patchwork pattern that has been observed in the rest of Europe with an obvious lack of institutional interest in the field. The newborn organization ITS Portugal has been founded in 2007 and, as his president states “We have a lot of work to do to stimulate ITS within Government and to try to promote ITS to politicians. We feel that companies are pushing ITS but without an umbrella organization” [9]. Its main objective is to serve as a platform for Portuguese ITS development while promoting telematics in transportation, and safety and sustainable procedures.

In April of 2010 the IMTT (the central administration body responsible for the coordination of inland transport with jurisdiction over the national territory) had recognized the absence of a coherent conceptual and operational framework devoted to these set of initiatives and announced the Mobility Package which is a national strategy for mobility. This proposed Mobility Package is now (July, 2010) under broad consultation and discussion.

At the municipal level, the CIVITAS PLUS Projects (co financed by the EU, from 2008 to 2012) are by now in intense activity. This group includes different target projects where are included some Portuguese cities: i) the CIVITAS ELAN project is devoted to mobilize the citizens to develop clean urban mobility solutions and the partner city of Oporto is developing projects such as the conception of a light weight hybrid bus shuttle within Asprela area; ii) the CIVITAS MIMOSA project is committed with the development of innovative concepts for urban mobility and sustainable actions and the partner city of Funchal is working on aspects such as the introduction of local clean vehicles, the implementation of a Green Line with low emission buses, the creation of Dial a ride services, and the settlement of a Urban Mobility Control and Monitoring Centre; iii) the CIVITAS MODERN project is determined to ensure political commitment, encourage stakeholder engagement and pursue performance orientation to improve the urban quality of life, and the partner city of Coimbra is developing projects related to the utilization of alternative fuels by private and public transport operators, and the production of Renewable Energies for Trolleybus Lines.

A brief overview of the Portuguese medium size municipalities’ websites reveals that only some of them (mainly the district capitals) display a section dedicated to Mobility describing the different sustainable mobility projects that each municipality is promoting (mainly devoted to bicycle projects). They also display insipient GIS services that enable the interactive search of geo referenced information mostly related with road infrastructures and parking areas. These websites are considerably different and puzzled with a lack of clear and relevant information concerning the mobility issues. The ITS aspect is not even clearly mentioned. It should be an effort of these municipalities in order to align their interfaces and in order to create attractive and unambiguous information for the public. It is our conviction that this absence of (clear and appealing) information can have a negative impact on the development of intelligent urban sustainable mobility plans.

In terms of education and R&D, the country has been significantly active with the several research projects that have been approved by the Foundation for Science and Technology (FCT), with the post graduate courses in ITS offered by the MIT Portugal Program, and by the research projects being developed in this conjoint Program. The ongoing projects SCUSSE and CityMotion are emblematic examples of these intense cooperative research activities.

The ITS deployments like advanced traffic monitoring systems, highway management systems, electronic fee collection systems, intermodal traveler information, and demand responsive transport systems are, for the Portuguese case, relatively scarce and limited to major urban centers. The medium size cities, which cover a considerable part of the territory, are at the moment implementing some piecewise intelligent solutions, yet with a clear lack of integrated guidance and support.

This fragmented pattern reflects, at some degree, the multifaceted problem of the Portuguese jurisdiction associated to a lack of guidance strategies and coordinated policies. According to [10], the European and national integrative guidance, strategic framework, and support are vital to the development of sustainable urban mobility solutions but, it is the municipality that has to develop its own mobility strategies and plans and then engage the regional and national authorities in that tailored plans.

III. MODELLING & SIMULATION: THE KEY TOOLS

As already mentioned, modelling is a fundamental activity to understand and simplify reality through abstraction. From our perspective, the holistic approach needed to integrate and manage ITS solutions requires a base platform (Modeling & Simulation Platform in Fig. 1.) that must include two key tools: a Geographical Information Systems for Transportation (GIS T), able to cope with the spatial dimension, and a traffic microsimulation tool, able to handle the temporal dimension.

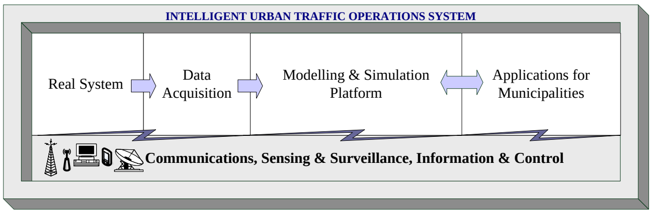

Fig. 1. Modelling & Simulation platform for intelligent urban traffic operations.

The Intelligent Urban Traffic Operations System, depicted in Figure 1, aims to be a comprehensive, integrated, modular and action oriented framework to aid the municipalities to implement integrated ITS solutions. Further information on this system can be found at [11].

The core piece of the framework is the Modelling & Simulation Platform that must complete the following requirements: i) to support a broad digital Traffic & Environment database, and allow a deep knowledge of the real system through the integration of efficient data acquisition tools and the calculation of appropriate key performance indicators, ii) to act as a decision support system by means of modelling, analysis and simulation capabilities that enable the comparison of different strategies, and iii) to provide tools to inform and involve the public via intelligible, user friendly and realistic visualizations. From our perspective, these requirements can be accomplished through the integration of two decisive tools namely, a GIS T and a traffic microsimulation tool. The platform must be able to include other modelling tools (e.g., environmental impact models, travel demand models) as needed by the municipalities.

A. Geographical Information System for Transportation

The transportation data is mainly characterized by static and dynamic spatial attributes so, this geographic nature makes the transportation system naturally tailored to be modelled by a GIS. The GIS, that enables the proper digital mapping, storage, management, analysis, and display of geographical data, adds to the traditional Database Management Systems (DBMS) a spatial referencing mechanism (geo referencing) which enables powerful analytical and geo visualization capabilities [12].

The application of geographic information systems in transportation, usually designated by GIS T, dates from 1960 [13] but this research area has come out with major advances and dedicated bibliography just in the last decade. The ITS context brings now new challenges to the field regarding network representation, unambiguous communications, integration of new technologies, interoperability, and analysis and dynamic modeling. The network data model underlying GIS T is the main support of most transportation analysis, and is particularly suited to deal with ITS applications like, for example, vehicle location and routing, collision warning and guidance, and advanced trip planning systems [14]. The topological representation allied to dynamic segmentation/linear referencing techniques and matrix operations provide an outstanding modelling environment for ITS solutions.

The integrative capabilities of a GIS T are also vital for the holistic approach required by ITS. The integration of information from different systems (e.g. land use system and transportation system), the integration of different themes from the same subject (e.g. road base network, road inventory, traffic operations, traffic impacts), and the integration of data from different sources and styles (e.g. databases, census files, picture files, GPS data points) at different resolutions (e.g. intersection, segment, traffic analysis zones) make this spatial modelling tool obligatory to operate the urban traffic system.

B. Traffic microsimulation

The modern context of ITS, claiming for offline short term operational management schemes evaluation and online traffic management & control, has been driving the development of dynamic traffic assignment (DTA) techniques. The DTA takes into account the dynamic and stochastic interactions between demand and supply considering the day to day (e.g., mode choice, route choice) and within day (e.g., incidents, lane closures) evolution of traffic, the traveler behavior and the network performance, in response to special events like incidents, bad weather conditions, lane closures, road works, sport events, etc. [15]. According to [16], the contemporary most popular dynamic traffic models are microsimulation models that are based on the representation of the behavior of each driver regarding car following, gap acceptance, and lane choice rules.

Fig. 2. Examples of traffic microsimulation 3D graphical animations from AIMSUN software (source: www.aimsun.com).

The traffic microsimulation enables the modeling of individual vehicle movements on a second or sub second basis for the purpose of assessing the traffic performance of urban street systems (traffic, transit, pedestrians, etc.), describing how vehicles move and interact. In addition to these detailed modeling capabilities, the microsimulation tools provide realistic graphical animated displays (Fig. 2) that are a unique and powerful way to gain the acceptance of the different stakeholders involved in ITS strategies.

These models can mimic the movements of individual vehicles around transport networks and have proven their usefulness in the analysis of complex traffic systems. Although their intensive data requirements, they have seen, in the last few years, a rapid evolution in their sophistication and a major expansion of their use in transport operations, particularly to evaluate scenarios, provide short term forecasting, and support real time decisions.

IV. Conclusion

This paper describes the modern context or the urban transportation systems and the present day aspect of Intelligent Transportation Systems, highlighting the Portuguese case. In order to adequately explore these intelligent solutions there must be a guiding integrative framework that can help the municipalities to efficiently manage their urban transport operations. This framework should embrace a core Modeling & Simulation Platform able to cope with the spatial and dynamic attributes of the urban transportation system. A Geographical Information System for Transportation and a traffic microsimulation tool are the key tools to fulfill the requirements.

This platform is being developed with the support of several medium size Portuguese cities. It was modeled based on a Model Based Systems Engineering (MBSE) approach and some prototypes are now being tested. The future work will also include the development of a 3D visualization module to disseminate attractive traffic & environment information to the general public.

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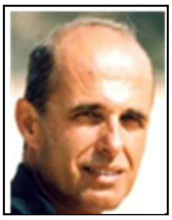

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