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INTELLIGENT TRANSPORTATION SYSTEMS

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ABSTRACT

This paper presents a review of the state of the art on Intelligent Transportation Systems and discusses the problem of modelling and simulation. ITS involves a large number of research areas and, therefore, this paper focus on those we believe to be the most relevant.

KEY WORDS: Intelligent systems, Traffic control, Traffic information systems, Simulation and modelling.

1. INTRODUCTION

Nowadays we have a saturation of the transportation infrastructures due to the growing number of vehicles over the last five decades. This situation affects substantially our lives particularly in the urban areas, while people needs, more and more, to move rapidly between different places. The results are traffic congestion, accidents, transportation delays and larger vehicle pollution emissions. Several solutions were introduced to reduce these problems or their outcomes. Examples are the implementation safety systems, such as safety belts and airbags, and the construction of more and better roads and highways. Nevertheless, presently it is clear that building more roads to reduce traffic congestion is not the "right" solution, because is very expensive, while causing a considerable environmental impact, besides requiring a large space, which is an important limitation within an urban areas. On the other hand, it is also straightforward that the improvement of the transport infrastructure is essential for the economical development. So, a compromise solution must be implemented.

The difficulties concerned with this subject motivated the research community to center their attention in the area of ITS (Intelligent Transport Systems). This research studies the technologies and the scientific aspects with the purpose of developing new systems capable of solving some of the refered problems.

By exploiting emerging intelligent transportation systems technologies, road-vehicle systems can be safer, more efficient and more environment friendly.

ITS depend on results from research activities spread over many different areas such as electronics, control, communications, sensing, robotics, signal processing and information systems. This multidisciplinary nature increases the problem's complexity because it requires knowledge transfer and cooperation among different research areas.

Bearing these facts in mind, this paper is organized as follows. Section 2 reviews the evolution of the ITS over its different phases in Europe, U.S. and Japan. Section 3 identifies the major categories on ITS and presents several examples of real systems. Section 4 discusses the modelling and simulation of intelligent transportation systems. Finally, section 5 presents some conclusions.

2. ITS BACKGROUND

ITS is a global phenomenon, attracting worldwide interest from transportation professionals, automotive industry and political decision makers. ITS applies advanced communication, information and electronics technology to solve transportation problems such as, traffic congestion, safety, transport efficiency and environmental conservation. Therefore, we can say that the purpose of ITS is to take advantage of the appropriate technologies to create "more intelligent" roads, vehicles and users.

ITS has been around since the 30s and it has been slowly creeping into our lives. The major developments on ITS were made in Europe, U.S. and Japan, and it has gone through tree phases [1]: preparation (1930-1980), feasibility study (1980-1995) and product development (1995-present).

2.1 Preparation (1930-1980)

This is the first period of ITS development, where the technologies had not yet matured enough and constructing new roads was more attracting than developing ITS. The first ITS system, that most people considered to be "the original" ITS, was the electric traffic signals implemented in 1928. However, the ITS movement did not take root until the 60s, when appeared the first computer controlled traffic signals in US. From the late 60s up to 1970 in US was developed the ERGS (Electronic Route Guidance Systems), which used a two-way road vehicle communications to provide route guidance. During the 70s were developed the CACS (Comprehensive Automobile Traffic Control System) [2] and the ALI (Autofahrer Leit und Information System) in Japan and Germany respectively, which are dynamic route guidance systems based on real traffic conditions [3]. This decade was also important for ITS, because introduced the microprocessor and the beginning of GPS development. These technologies are now major components of ITS, but they were not associated with ITS at that time.

2.2 Feasibility study (1980-1995)

This phase is characterised by an explosion of development programs, both industry and government subsidized, in Europe, Japan and United States. Those programs were an outcome of the underlying concepts and basic technologies for ITS developed during the previous phase.

In Europe, governments, companies and universities of 19 countries established the PROMETHEUS (Program for European Traffic with Efficiency and Unprecedented Safety) project. Several ITS technologies were developed in this program between 1987 and 1994. In the 80s was demonstrated the test vehicle VaMoRs at Munich [4]. In this prototype were used two forward-looking TV cameras with the purpose of an automatic lane and road following. In the 90s, a group leaded by Daimler-Benz developed the test vehicle VITA II [5]. This vehicle incorporated 10 cameras and 60 processors with the purpose of keeping the vehicle in the center of the lane, keeping a safe distance from the car in front, changing lanes and overtaking other cars with collision avoidance. Other projects were developed in the scope of PROMETHEUS, namely the ARGO project [6], which aimed to design, develop and test of innovative solutions for the vehicles of the future. This program was followed by DRIVE for the development and test of the communication system, for drive assistance and traffic management [7].

In the United States, in the late 80s, the Mobility 2000 study team laid the groundwork for the formation of the IVHS America (Intelligent Vehicle Highway Systems) [16], which is a public-private forum for consolidating national ITS interests and promoting international cooperation in ITS. In 1994 the USDOT (United States Department of Transportation) changed the name from IVHS to ITS America (Intelligent Transportation Society of America). Several projects were developed at more than eighty places across the US [8]. A key project, AHS (Automated Highway System) was conducted by NAHSC (National Automated Highway System Consortium) formed by the US Department of Transportation, General Motors, University of California and other institutions [9]. Under this project various fully automated test vehicles were demonstrated on California highways.

In Japan, in the 80s, some projects were carried out, namely RACS (Road Automobile Communication System) [17] by the Ministry of Construction and AMTICS (Advanced Mobile Traffic Information and Communication System) [18] by the National Police Agency. In the 90s combining efforts with the Ministry of Posts and Telecommunications, and working on standardization projects, it was possible to combine those two projects into VICS (Vehicle Information and Communication System). A VICS terminal provides a locator for displaying the vehicles coordinates on the map screen, and allows the communication with the ground stations to acquire traffic conditions for route planning.

In 1996, the Ministry of Construction and twenty one major companies, namely Toyota, Nissan, Honda and Mitsubishi, formed the Advanced Cruise-Assist Highway System Research Association, and implemented various fully automated vehicles on a highway [10].

2.3 Product development (1995-present)

The previous phase focused on creating a technical foundation, with high-level functions for ITS, and this purpose was achieved successfully. Around the middle of the 90s an unified policy was adopted to deal with ITS in a consistent and harmonious manner. This lead to the present phase, dealing with the creation of feasible products. One example in Europe is the Chauffeur project, by Daimler-Benz and research institutes, having for objective a truck automatically following another one conducted by a human driver [11]. In the US, by the late 90s, the main focus of ITS programs shifted to large-scale integration and deployment.

3. MAJOR CATEGORIES OF ITS

The complete results concerning the ITS categories are too large to be totally included in this paper; therefore, in this section the global characteristics of the six ITS major categories [12] are introduced and several examples of developed systems are briefly presented [13 – 15].

3.1 Advanced Traffic Management Systems (ATMS)

ATMS are a fundamental part of intelligent transportation systems that has been used to improve traffic service quality and to reduce traffic delays. ATMS operates with a series of video and roadway loop detectors, variable message signs, network signal and ramp meter timing schedules, including roadway incident control strategies from one central location to respond to traffic conditions in real time. The information collected by ATMS is also supplied to the Advanced Travellers Information Systems discussed in the sequel.

3.2 Advanced Travellers Information Systems (ATIS)

The goal of ATIS is to supply real time traffic information to the travellers. The information about the transport systems traffic conditions influenced drivers so that they make a better use of the system, allowing the reduction of congestions, optimising the traffic flow and reducing pollution. With this system, travellers, from home, on work, or in stopping-place can decide which is the most advantageous road to reach its destination, the most favourable transportation service and the most appropriate schedule to adopt. This information can be provided through electronic panels, portable systems connected to the Internet (offering a diversity of information, such as, public transportations, alternative highways, gas station, parkings and hotels), radio systems or in-vehicles systems (displaying the map with information of its location, the state of the neighbourhood traffic, traffic delays or accidents).

In the most advanced systems there is also the possibility of advising the driver of which is the most advantageous road to choose to reach the destination.

3.3 Commercial Vehicles Operation (CVO)

CVO systems use different ITS technologies to increase safety and efficiency of commercial vehicles and fleets. CVO systems became useful for large and medium companies that have commercial fleets, because they allow the management of all the vehicles, while controlling speed and stopping-place times, besides fulfilling the destination. These systems include the technologies for travellers information, traffic management, vehicle control and management.

3.4 Advanced Public Transportations Systems (APTS)

APTS systems use electronic technologies to improve the operation and efficiency of high occupation transports, such as buses and trains. They use technologies from ATMS and ATIS to improve the mass transport service, allowing route information, travel schedules and costs, and real time information about changes in transport systems. Through an efficient traffic management is still possible to actuate on the traffic lights in order to give priority to the public transportations Through APTS one can control, plan and improve the services of a fleet, and foresee a more flexible service, efficiently, and safety to guarantee customers satisfaction, and trip control costs.

3.5 Advanced Vehicles Control Systems (AVCS)

AVCS joint sensors, computers and control systems to assist and alert drivers or to take part of vehicles driving [19]. The main purposes of these systems are to increase safety to decrease congestions on roads and highways, and to improve road systems productivity.

With in-vehicle sensors the driver can receive visual and hearing information about traffic, dangers and all vehicle situations. On the other hand, automatic control allows to react in danger situations in a faster and effective way, which is useful for aged drivers or with less practice.

3.6 Advanced Rural Transports Systems (ARTS)

ARTS are designed to solve the problems arising in rural zones (communities or areas with less then 50.000 residents) [20]. Rural areas roads have a unique set of attributes such as steep grades, blind corners, curves, few navigational signs, mix of users, and few alternative routes. Some of the referred systems used in the urban areas already begun to be implemented in rural areas, such as ATIS, ATMS and APTS.

4. MODELLING and SIMULATION

Drew, defined simulation as a dynamic representation of some part of the real world achieved by building a model and moving it through time [23]. A model of a system is an abstraction and approximation to the actual one and should simplify the analysis of the system under investigation. The purpose of modelling is to help the analysis, design, control or understanding of a system without actually having to build the system [24]. We can say that modelling is a support tool for simulation.

Computer simulation has become a common tool in the evaluation and development of intelligent transportation systems. The advantages of this tool are obvious. The simulation models can satisfy a wide range of requirements, such as: evaluating of alternative treatments, testing new designs, training personal and analyzing safety aspects.

The first research work on this subject was published in 1955 at the University of California, by D.L. Gerlough under the title "Simulation of freeway traffic on a general-purpose discrete variable computer" [25]. The car-following analysis based on GM models, is one of the oldest and most well known cases of the use of simulation in theoretical research. In these models, the movement of each vehicle in the platoon under analysis is governed by a differential equation [26]. After almost 40 years from the first trials, car-following is still under active analysis, being one of the basic questions of traffic flow theory [27]. In the recent years simulation models have been developed to support the analysis in almost all the areas of ITS discussed previously namely in Advanced Traveller Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS).

In this section, we will try to give an overall view of the development of simulation models in road traffic planning and research, which is considered as the most prevalent in the transportation community. However, it should be noted that there are many other simulation models available for use in aviation, railroad and maritime transportation [21-22].

The traffic simulation models can be classified according to various criteria, namely, the scale of independent variables, the representation of the processes and levels of detail [28]. The scale of independent variables can be related to one or all the independent variables associated with traffic, that is, actual position/velocity, desired/position/velocity, and time. However, since almost all traffic simulation models describe dynamic systems, where the time is always the fundamental independent variable, the time-scale classification is the most natural. There can be distinguished two time scales, continuous and discrete. The continuous model describes the way the traffic system's change versus time, as a response to continuous stimuli. On the other hand, the discrete model considers that the state changes occur discontinuously at discrete time instants over the time.

The representation of the process can be done through deterministic or stochastic models. In the former all the entities represented in the model are defined by exact relationships (mathematical, statistical or logical). The stochastic models incorporate processes, which include random variables, or probability functions.

The classification according to the level of detail with which the traffic system is represented by the model can be divided in Microscopic, Mesoscopic and Macroscopic. The Microscopic simulation model describes both, the space-time behaviour of the system's entities (*i.e.* vehicles and drives) as well as their interactions at a high level of detail (individually). The Mesoscopic model represents most entities at a high level of detail, but describes their activities and interaction at a lower level of detail. The Macroscopic model represents entities and describes their activities and interactions at a low level of detail. These models describe traffic at a high level of aggregation as a flow without distinguishing its constituent parts.

In Table 1 it can be observed some of the most relevant traffic simulation models, are classified according to the criteria described in the previous paragraph.

Table 1 – Traffic Simulation Models

Detail Level	Model Name	Continuos /Discrete	Deter./ Stoch.
Micro	INTEGRATION	D	D
	NETSIM	D	S
	CORSIM	D	S
	TRANSIMS	D	S
	Cellular Automaton	D	S
Meso	DYNASMART	D	D
	Multilane Gas-Kinetic	C	D
	Improved Gas-Kinetic	C	D
Macro	FREFLO	D	D
	Helbing Type Models	C	D
	Cell Transmission	D	D

Presently, most traffic system simulation applications are microscopic in nature and based on the simulation of vehicle-vehicle interactions [29]. One of the few areas where macroscopic simulation has also been in use is the traffic flow analysis. In macroscopic flow models the traffic stream is represented in an aggregated manner using some characteristics such as, flow-rate, density and velocity. Individual vehicle maneuvers, like lane changes are usually not explicitly represented. Most of the well known macroscopic applications in this area originates from the late 60s or the early 70s. One example of macroscopic simulation of highway traffic is the cell-transmission model. In a cell-transmission scheme one partitions a highway into small sections (cells) and keeps track of the cell contents (number of vehicles) as time passes. The record is updated at closely spaced instants (clock ticks) by calculating the number of vehicles that cross the boundary separating each pair of adjoining cells during the corresponding clock interval. This average flow is the result of a comparison between the maximum number of vehicles that can be "sent" by the cell directly upstream of the boundary and those that can be "received" by the downstream cell [30]. A macroscopic model of mixed-lane freeway traffic is an example of Helbing type models. This model is derived from a gas-kinetic level of description, including effects of vehicular space requirements and velocity correlations between successive vehicles [31].

A mesoscopic model does not distinguish (nor traces) individual vehicles, but specifies the behaviour of individuals in probabilistic terms. Some mesoscopic models are derived in analogy to gas-kinetic theory. With a gas-kinetic model one can describe velocity distributions at specific locations and time instants. The dynamics of these distributions are generally governed by some processes that caracterize the individual driver's behaviour (e.g. acceleration, interaction between vehicles, lane-changing) [32]. Multi-lane gas kinetic model and improved gas-kinetic model have a similar approach, although the former explicitly consider lane-changing. DYNASMART is a traffic simulation model designed as a research tool for the study of ATIS/ATMS scenarios at the network level, including the evaluation of strategies for providing traveler information, traffic control measures and rules for route assignment. DYNASMART is a mesoscopic model, which uses macroscopic flow models and simultaneously captures the movements of individual vehicles. Seven different driver (or behaviour) classes can be specified as a function of vehicle type, information availability and network restrictions. These classes allow modeling of user behavior in response to ATIS information [33]. The model can simulate traffic signals, ramp meters and incidents. DYNASMART calculates optimal travel paths based on the simulated travel times and simulates the movements and routing decisions by individual drivers equipped with in-vehicle information systems [34].

Microscopic traffic simulators are simulation tools that emulate realistically the flow of vehicles on a road network. Micro-simulation is used for evaluation prior to, or in parallel with, on-street operation. The main modelling components of a microscopic traffic simulation model are: an accurate representation of the road network geometry, a detailed modelling of individual vehicles behavior and an explicit reproduction of traffic control plans [35]. With these components it is possible to deal with ITS systems, like adaptive traffic control systems, automatic incident detection systems, dynamic vehicle guidance systems and advanced traffic management systems. The recent evolution of the microscopic simulators has taken advantages of the state-of-the-art in the development of object-oriented simulators and graphical user interfaces [36]. Also, the adaptation to traffic modelling requirements of the new trends in software design and the available tools to support it, was an important factor for the evolution of the microscopic simulators. A proper achievement of the basic requirements of a microscopic simulator implies building models as close to the reality as possible. There is a considerable number of developed microscopic simulation models. The SMARTEST project identified 58 of these models of which 32 are listed on Table 2 [37].

Table 2 – Types of models

Urban	Motorway	Combined	Other
CASIMIR	AUTOBAHN	AIMSUN2	ANATOLL
DRACULA	FREEVU	CORSIM	PHAROS
HUTSIM	FRESIM	FLEXSYT II	SHIVA
MICSTRAN	MIXIC	INTEGRATION	SIMDAC
NEMIS	SISTM	MELROSE	
NETSIM		MICROSIM	
PADSIM		MITSIM	
SIGSIM		PARAMICS	
SIMNET		PLANSIM-T	
SITRA-B+		TRANSIMS	
SITRAS		VISSIM	
THOREAU			

The main purpose of micro-simulation models is, from the model designers point of view, to quantify the benefits of Intelligent Transportation Systems (ITS), primarily Advanced Traveler Information Systems (ATIS) and Advanced Traffic Management Systems (ATMS). All the models listed classified as urban, motorway and combined types, address such objectives. The models classified as type "other" have been designed with specific objectives like modelling of the tactical level of driving and testing of intelligent vehicle algorithms, they provide a detailed roadway environment for a simulated robot-driving vehicle, to evaluate the safety and comfort conditions of a line of cars on a single lane or to simulate strategies. We will give an overview of some of the micro simulation tools listed on the table 2.

SMARTEST is one simulation modelling project that covers the different areas of ATMS. It is applied to road transport European scheme tests and is the result of European Union research project. This project uses mathematical simulation modelling for dynamic traffic management problems. AIMSUN2 (Advanced Interactive Microscopic Simulator for Urban and Non-urban Networks) is one of the SMARTEST's software tool based on a microscopic simulation approach, which reproduces real traffic conditions in an urban network. It provides a detailed modelling of the traffic network, distinguishing between different types of vehicles and drivers, modelling incidents and conflicting manoeuvres. The main types of input data to the simulator are the network description, the traffic signal control plans and the traffic conditions. The outputs consist in an animated graphical representation of the traffic network, printouts of statistical data and the data gathered by the detectors.

The CORSIM traffic simulation program is a microscopic stochastic model. It combines a simulation model of urban traffic, named NETSIM, and a simulation model of motorway traffic, called FRESIM. Because it microscopic nature, CORSIM models each vehicle as a separate entity in the network. The behaviour of each one is represented in the model by the interaction with its surrounding environment, including traffic control and network geometry. CORSIM models also some traffic control systems, such as intersection controllers and ramp-metering devices [38].

INTEGRATION is a simulation model, completely microscopic, that tracks the lateral and the longitudinal movements of individual vehicles to the resolution of a deci-second. The algorithm for the car following is a kinematics model that calculates the individual vehicle speeds based on the macroscopic parameters of jam density, speed at capacity and free-flow speed. INTEGRATION also allows the demonstration of the dispersion of a platoon as it traverses the link, through the continuous variation of the density of traffic along a link. It uses up to five different driver/vehicle types to represent distinct routing behavior or access privileges to real-time traffic conditions. Assessment of the effectiveness of route guidance systems and the modeling of incidents are included in the model features.

TRANSIMS models are used to create a virtual metropolitan region by the complete representation of the region's individuals, their activities, and the transportation infrastructure. The trips are planned to satisfy the activity patterns. After that, TRANSIMS simulates the movement of individuals across the transportation network, including their use of vehicles on a second-by-second basis. So a virtual world of travelers is created, which mimics the traveling and driving behavior of real people in the region. TRANSIMS attempts to capture every interaction considered important between travel subsystems, like the individual's activity plans and congestion on the transportation system. The Transportation Analysis and SIMulation System (TRANSIMS) allow the creation of an integrated regional transportation systems environment, through the employment of advanced computational and analytical techniques. The models "simple car-following" and "lane changing logic" are based on cellular automaton technique. This technique is based on a discrete approach where the road and street network is build from elements that can accommodate only one vehicle at a time unit. In this cellular automaton approach the vehicles move by jumping from the actual element to a new one according to rules describing the driver behaviour while maintaining the basic laws of physics present in vehicle movements [39].

4.1 Driver behaviour, traffic safety and nanosimulation

An important issue is the modelling and simulation of the driver steering behaviour. Due to the development of vehicles incorporating new technological devices, a deeper knowledge about the interaction between the vehicle and the driver becomes of great usefulness for the vehicle design. Some projects are undergoing focusing on this particular aspect. One of these projects consists on the development of a driver's model, representing his real behaviour, based on issues like surveillance and steering expertise. For example, the model considers the driver's control actions tacking into account the point where he fixes his attention. In fact, traffic safety simulation related questions have been quite a hard problem for simulation. Usually, in simulation programs, the drivers are programmed to avoid collisions, so they do not exist. Although some trials for analysis of conflict situations have been made [40], a general approach to this problem is still missing. Traffic safety simulation is sometimes classified as nanosimulation, belonging to the field of human centered simulation where the perception-reaction system of drivers and all its characteristics are described.

5. CONCLUSION

In conclusion, ITS involves a large number of areas. In this paper we referred some of the most relevant focusing on modeling and simulation. The development and refinement of models of roads, vehicles and humans is an important issue so that one can simulate and plan ITS systems. One of the most important proceedings of mathematical simulation and modelling is the translation of real contexts and objects into parameters that can be represented numerically. This is the point at which many of the inaccuracies and errors are introduced. Therefore, further research on ITS dynamic models and parameter identification is still needed.

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