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Towards the Development of Intelligent Transportation Systems

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***Abstract*--This paper presents a review of the state of the art on Intelligent Transportation Systems. ITS involves a large number of research areas and, therefore, this paper focus on those we believe to be the most relevant. The main purpose is to study the achievements attained in the last years and to give an overview of possible directions towards future research.**

***Index Terms*--Intelligent systems, Road vehicle location, Traffic control, Traffic information systems, Simulation and Modelling.**

I. 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 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 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 develloping 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. While conventional road-vehicle systems depend almost entirely on human drivers, the modern road-vehicle systems will incorporate some intelligent systems technology to assist human operators.

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.

In this work we give an historical perspective and an overview of the state of the art on ITS. To fulfill that objective the 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. Finally, section 4 discusses some of the possible directions towards future developments of ITS.

II. ITS BACKGROUND

Intelligent Transportation Systems 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, as represented in fig. 1.

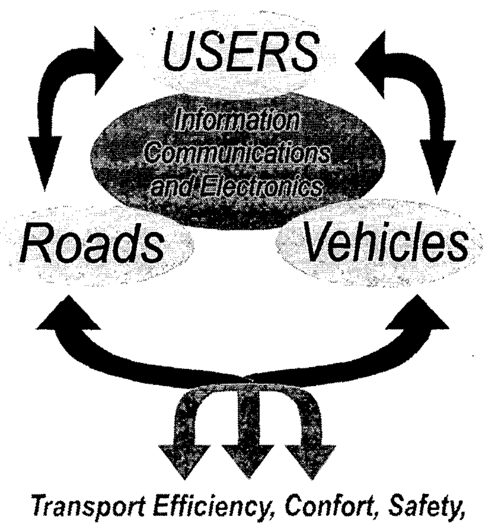

Fig. 1 ITS Conceptual Model.

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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) as represented in fig. 2.

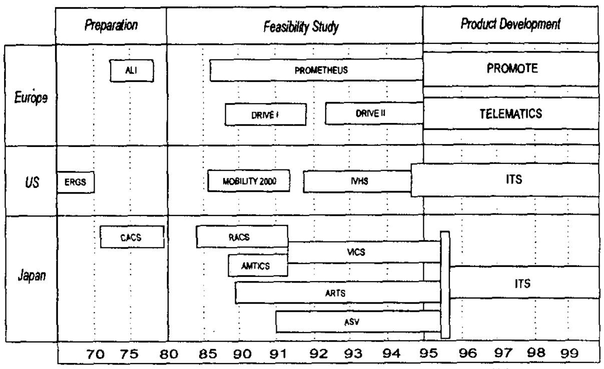

Fig. 2. ITS Development Chronology in Europe, US and Japan [2]

A. 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. Later on, at the GM pavilion of the 1939 world fair in New York it was presented a concept for Automated Highway Systems (AHS). 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) [30] 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 many ITS systems; nevertheless they were not associated with ITS at that time.

B. 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 (Dedicated Road Infrastructure for Vehicle Safety in Europe) for the development and test of the communication system, for drive assistance and traffic management [7]. The public-private sector organization ERTICO (European Road Transport Telematics Implementation Coordination Organization) was set up to provide support for refining and implementing the Europe's Transport Telematics Project.

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) [29], 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 [8]. 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) [27] by the Ministry of Construction and AMTICS (Advanced Mobile Traffic Information and Communication System) [28] 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 vehicle's coordinates on the map screen, and allows the communication with the ground stations to acquire traffic conditions for route planning. Examples of other developed projects are ARTS (Advanced Road Transportation Systems), by the Ministry of Construction, for the advance of road traffic through integration of roads and vehicles considering ASV (Advanced Safety Vehicle) intended for the promotion of research and development of vehicle safety technologies. Representatives of academia and industry organized the VERTIS (Vehicle, Road and Traffic Intelligent Society). That conducts a variety of ITS related activities, namely information exchanges with its European and American homonymous, ERTICO and ITS America.

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].

C. *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. Several projects were or are being developed. 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.

III. 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] [14] [15].

A. *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 three main ATMS elements are:

- *Collection data team* – monitor traffic conditions;
- *Support systems* – cameras, sensors, semaphores and electronic displays. Help system operators to manage and control real time traffic;
- *Real time traffic control systems* – these systems use the information provided by the two previous elements they can change semaphores, send messages to electronic displays and control highway access,

The information collected by ATMS is also supplied to the Advanced Travellers Information Systems discussed in the sequel.

For example, a ATMS technology has been in use for several years at some metropolitan areas is Ramp Metering. Ramp meters are red-green stoplights placed at the head of on-ramps for highways. These lights can be timed for certain periods of the day or controlled by a detector placed upstream on the highway. By metering one car at a time, this type of control limits the input flow at certain roads eliminating highway congestion and maintaining smooth traffic conditions. Fig. 3 shows a general layout of traffic ramp metering system.

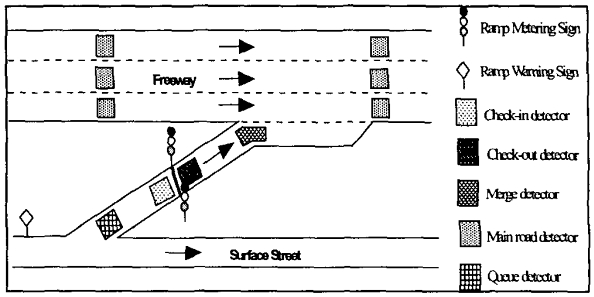

Fig. 3. Ramp metering layout [16]

One of the frustrating things on a rush-hour flow on a highway is that in the opposite direction the traffic is usually light. This situation originated the creation of a machine that actually moves the concrete jersey barriers dividing many highway flows the width of one lane in either direction. Using such a machine, traffic into and out of urban areas can be more efficiently handled through the creation of an extra lane in the direction of heavy travel. This process is illustrated in fig. 4.

Fig. 4. Moving the concrete jersey barriers dividing the highway [17]

B. *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 destiny, 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. In fig. 5 we can see a map with a traffic display from the WEBFLOW32 system. This system is used to obtain real time information about the traffic conditions on Seattle, U.S. and is available on Internet [18].

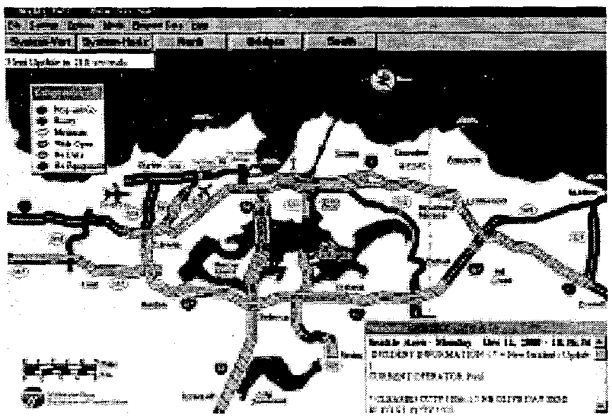

Fig. 5. WEBFLOW32 Seattle Area Traffic Display

C. 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.

Moreover, the ITS technologies increase the speed of goods delivery, patient transport and reduction of costs operation. Automatic weighing systems can also be implemented, with a high level of safety and efficiency. In fig. 6 is depicted a Centre for Commercial Management using GPS (Global Positioning System) and GSM (Global System for Mobile Communications) technologies.

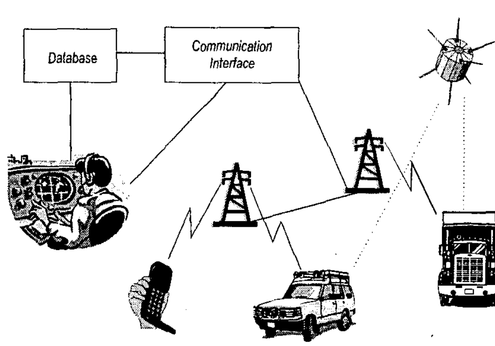

Fig. 6. Commercial Management Center

These systems include the technologies for travellers information, traffic management, vehicle control, management, such as:

- Automatic Vehicles Identification
- Automatic Vehicles Classification
- Automatic Vehicles Location
- Pedestrian Movement Detection
- Board Computers
- Real Time Traffic Transmissions

D. 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, with efficiency and safety, to guarantee customers satisfaction and trip control costs.

For example, fig. 7 represents the user interface of a bus location system BUSVIEW [19], where we can find the real time information of the buses location.

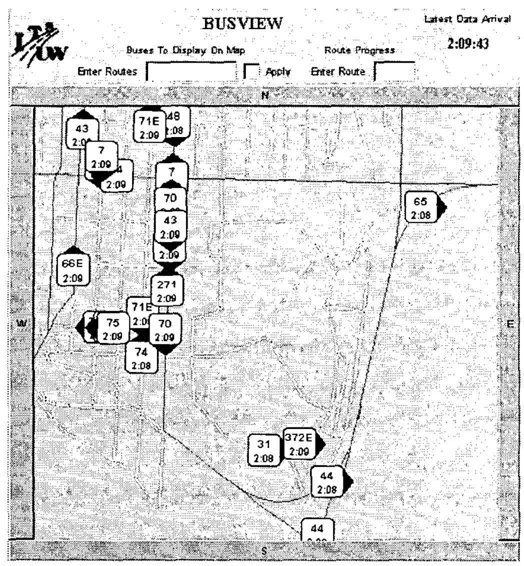

Fig. 7. BUSVIEW Map Area

In APTS are also included the automatic payment systems, through the use of multiple usage smart cards which provide functions such as stored credit or automatic capture of passenger information and journey profile. To increase safety, are included systems with cameras (inside and outside of the public transportations), which allow driver and central information to detect and react to any suspicious activity.

E. Advanced Vehicles Control Systems (AVCS)

AVCS joint sensors, computers and control systems to assist and alert drivers or to take part of vehicles driving [20]. 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, like actuate in the braking or acceleration systems, which is useful for aged drivers or drivers with less practice.

An example of this kind of vehicle is the automatic vehicle developed at the Ohio State University Centre for Intelligent Transportation Research (CITR). This vehicle demonstrated advanced cruise control, automated steering control for line keeping and autonomous behaviour, including automated stopping and lane changes in reaction to other vehicles. Fig. 8 shows the equipment of this automatic vehicle consisting on throttle, steering, brake actuator, video camera, laser rangefinder and radar RF components. This car is also equipped with an image processing computer, graphical status display computer, vehicle control computer, angular rate gyro, radar signal processing components, and interface electronics.

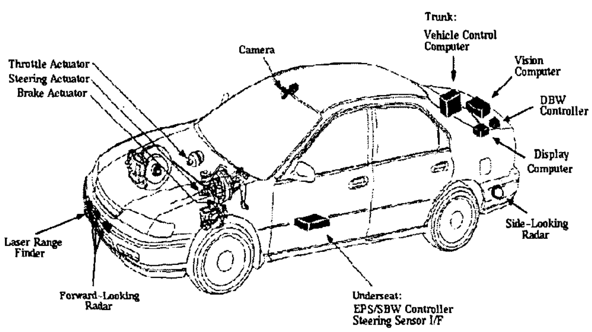

Fig. 8. OSU Autonomous Vehicle [21]

F. *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) [22]. 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.

IV. PROMISING DIRECTIONS OF FUTURE RESEARCH

Some of the projects in ITS consist on laboratory prototypes used to explore ideas and particular aspects of this area. The objective is the development of completely autonomous systems, which is a complex task requiring high economical resources and a large variety of technologies encompassing different research areas.

A. *Simulation and Modelling*

One important research area is the simulation and modelling. Through these tools we can identify, quantify and analyse the phenomena revealed by an ITS deployment proposal [32]. With mathematical models, one can simulate real-life situations, opening the possibility for an analysis that was only available through real systems. Therefore, we have the ability to create, evaluate and modify designs without the need to actually implement them. To resume one can say that in the ITS context, simulation models can be very attractive, as many of the products and services intended for deployment are relatively new and we need a detailed understanding of the likely impacts and effects. In the recent years have been developed simulation models to support the analysis in almost all the areas of ITS discussed previously. We focus three of those areas, namely traveller information, traffic management (section 3) and driver steering behaviour by giving examples of the corresponding simulation systems [23] [24].

1) *Traveller Information*

The simulation of traveller information requires the modelling of human behaviour, namely the reaction to information that represents the choice between different alternatives. In many cases, the behaviour is represented by a cost function that determines the cost associated with each alternative. This cost function is usually developed based on a survey work.

2) *Traffic management*

With a simulation model representing both the vehicles and the road networks it is possible to analyse the effects of changing the network, the vehicles and the driver behaviour. In these systems the road network is typically represented as a series of nodes and links. A link represents a length of a road, with basic characteristics such as total width and number of length, and a node is the jointing of two or more links. The vehicles are classified by their type, namely, private cars, buses and trucks. Each type is characterised by its acceleration, maximum speed and amount of road space required.

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 dynamic models and parameter identification is still needed.

SMARTEST [16] is one simulation modelling 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) [31] 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 simulated detectors.

3) Driver steering behaviour

Another 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 [33]. 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. Foe example the model considers the driver's control actions tacking into account the point where he fixes his attention [25].

B. Fully automated systems

So far we referred simulation and modelling as an important area for future research, but we think that another promising research direction is the development of a new form of public transportation [26] consisting on the concept of "car-sharing", by offering individual cars for public use.

In the most advanced form, this means that a car can be picked up by a customer at one location and dropped at another one. At the moment, there are several experiments going on in different parts of the world but complete conclusions are not yet available.

V. Conclusions

ITS involve a large number of areas and in this paper we focused on those we believe to be the most relevant. As a conclusion of this review we can say that there are several future directions to follow. A first one is the continuous improvement of road-vehicle systems (navigation systems, board computers, real time traffic transmissions). A second direction is the introduction of fully automated systems (like the "car-sharing" concept) for limited applications in an early phase and gradually increases the variety of the applications. A third possibility consists on the development and refinement of models of roads, vehicles and humans so that we can simulate and plan more efficient ITS systems.

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