Abstract.— The application of information and communication technologies to the field of transport has facilitated the development of intelligent transport systems that require powerful information systems. Geographic information systems are a highly suitable means of technology for processing information. This article examines the different areas in which GIS-T are used, from planning and management, to fleet control and logistics. New communication networks are emerging somewhere between GIS and ITS, which facilitate travel information, traffic control or assisted navigation, amongst other possible applications.

Key words.— Communication networks - Databases - Geographic information systems (GIS) - Transport (planning and management of)

Résumé.— L’application des technologies de l’information et de la communication au domaine des transports a facilité le développement de systèmes intelligents de transport (qui nécessitent des moyens informatiques et de télécommunications puissants. Cet article examine différents domaines d’application des technologies Systèmes d’informations Géographiques (SIG) : aménagement, gestion, logistique par exemple. De nouveaux réseaux de communication émergent qui facilitent l’acquisition d’informations en matière de transport (contrôle de trafic, navigation assistée, etc.).

Mots clés — Bases de données - Communication - Réseaux - Systèmes d’informations géographiques (SIG) - Transport (organisation et gestion du)

INTRODUCTION

The interest in creating intelligent transport systems as a means of achieving satisfactory safety levels is dependent on the need for powerful databases able to
manage the data. In the words of L. Downey, Deputy Secretary for Transportation: “We see Geographical Information Systems as a real opportunity to unify transport planning with the vast data processing capabilities inherent in today’s technology”. (http://www.fta.dot.gov/research/fleet/its/gis.htm). And this is not all. As Xu (2000) indicates, telematic products and services for individual means of transport are based on the integration of digital maps and RDS/TMC (radio data systems/ traffic message channels) for the transmission of traffic data, GPS (Global Positioning Systems) and GSM (the Global System for Mobile Communications) for the transmission of travel data, and mobile telephone communications and other additional sensors needed to gather travel information in real time.

This is why the role of GIS (geographic information systems) is fundamental in the development of ITS (intelligent transport systems).

1. GEOGRAPHIC INFORMATION TECHNOLOGIES AND TERRITORIAL DATA

Since their emergence, three decades ago, geographic information systems (GIS) have been a form of technology that is closely associated with the territorial analysis of transport systems. “A GIS is best described as a system which uses a spatial database to provide answers to queries of a geographic nature. The generic GIS can be viewed as a number of specialised spatial routines laid over a standard relational database management system” (Goodchild, 1987). GIS are computer systems for the storage and integrated analysis of geographic information. They give particular emphasis to the analysis of geographic information, in contrast with other graphic or management systems more directed at the representation of geographic data (computer-assisted design) or its storage (data base management systems) (Cowen, 1988).

Transport networks are built on territorial areas and these networks are used for the movement of people, goods and energy. The form, capacity and efficiency of these networks make a considerable impact on our quality of life and they affect our perception of the world. When GIS are applied to transport, this is more than just a sphere of application of their generic functionality (Thill, 2000). Given the importance that their different applications to this particular field have acquired, in the Anglo-Saxon world a specific term has been coined called GIS-T (GIS for transport), integrating modelling, handling and data analysis processes that are not always included in conventional GIS.

As Moreno indicates (1998), the extended use of geographic information (GI) is an inherent feature of present day society. One example of this phenomenon is the fact that cities and regions decide to commercialise their territory for the tourism market or for business. Geographic information technologies (GIT) are becoming used in activities as a support for territorial decision-making, planning and, more particularly, in management tasks. From this perspective, GIT are a strategic resource for geography as a discipline and for society as a whole.
Any number of names have been coined to refer to computer systems that use geographic information. This is particularly evident in the Anglo-Saxon world with names like: Geobase Information Systems, Geo-Data Systems, Spatial Information Systems, Geographic Data Systems, Land Information Systems, Natural Resource Information Systems, Multipurpose Cadastres, Multipurpose Land Information Systems, Highway Information Systems, Geographic Information Systems etc. (Burrough, 1986).

This diverse use of terminology is easy to explain. Numerous different disciplines use information technology to process geographic information (remote sensing, geography, civil engineering, cartography, topography, geodesy, photogrammetry, ecology, architecture, computer science etc.) and each one has gradually adopted different names to refer to the computer system that manages and analyses geographic information.

Behind this group of systems and technologies is a new science known as geographic information science: a discipline that is becoming more and more widespread which in recent years, in the Anglo-Saxon academic world, has come to achieve the category of a branch of scientific knowledge. It is a multidisciplinary science involving a multitude of disciplines: cartography, geodesy, photogrammetry, spatial statistics, psychology etc.

GIS are primarily regarded as technology for geographic information sciences. Indeed GIS have evolved as a tool to become a form of technology and finally they have received recognition as a scientific domain (Goodchild, 1992).

Given data’s multidimensional nature, creating a database is a very complex business. Databases orientated towards transport management and planning are no exception.

The most widely used data model is the relational one and it has been adopted by 90% of all database management systems (DBMS) (De Miguel, Piatini, Marcos, 1999). GIS tend to keep geographic data and related thematic data separate. Indeed the thematic data is usually managed by external DBMS, separate from the GIS’ own software.

When creating geographic databases in GIS-T, it is necessary to incorporate in-depth details, in the form of metadata, on the information being stored. This metadata documents database information that facilitates the identification of the data stored there. Metadata means comprehensive, systematic, deductive information on the contents, structure, relations, representation and context of the data stored in a database. As also occurs in other fields of application, with GIS-T, the project stage that involves the greatest financial cost and time is the actual creation of databases.

Importing existing digital data for use in geographic databases is becoming the main source of data for GIS. Originally, most data was incorporated into the databases by digitalizing analog maps or by introducing the data directly. Today, a substantial amount of information is distributed in digital format, and so digital

In this respect, the Internet has become one of the main ways in which private and state organizations and agencies can distribute geographic data. The web page of the US Federal Geographic Data Committee (http://www.fgdc.gov) contains the well-known US National Geospatial Data Clearinghouse, with details of hundreds of organizations that keep and supply GIS information on the subject of the United States and the world. Data can also be found that is published by GIS software distribution companies. One example is the web page of ESRI http://www.esri.com.

The United States Geological Survey (USGS) was one of the first agencies to undertake the task of developing data formats to meet its own requirements and also to offer users. For some years now many European countries have been developing and introducing their own formats and transfer standards. Some of the best known are the British National Transfer Format (NTF) and the Digital Geographic Information Exchange Standard (DIGEST) developed by the armed forces for civilian and military uses in Europe and America.

In the field of GIS-T, importing data is also considered one of the main sources of information for the creation of geographic databases. To this effect, big efforts have been made to establish geographic information standards for this particular field. The GDF (Geographic Data Files) format is a European standard used to describe and transfer information on road networks and on any associated data. It is much more than a generic GIS standard, because GDF give rules on how to capture the data, the type of features to store and the attributes and relations that must be defined. GDF was developed thanks to a technological research and development project known as EDRM (European Digital Road Map). Its initial use has been directed at vehicle navigation systems, with the participation of firms like Bosch, Philips and Volvo. Its applications are also well suited to ITS (fleet management, traffic analysis, route control etc.). Numerous firms (EGT, Bosch, ETAK, TeleAtlas etc.) and public bodies (the European Union) promote the use of the GDF format.

On an international level there are other geographical data formats for the field of transport: the North-American Spatial Data Transfer Standard (SDTS) or the Japanese Data Standard (JDS).

During the last few years, the application of information technologies to the field of transport has led to the emergence of the well-known Intelligent Transport Systems. ITS use DBMS and GIS as instruments for the creation, management and analysis of their geographic databases and they have greatly
extended the requirements needed of DBMS and GIS. ITS require efficient, accurate linear reference systems able to represent the elements involved in a transport network. With ITS, the temporal component of geographic information also needs to be included in spatial databases so that applications can be carried out in real time.

These requirements call for the development of new conceptual GIS data models adapted to suit the specific characteristics and functionalities of ITS (Chapleau, Trepanier, 1997a; Gottsegen, Goodchild, Church, 1994). With intelligent vehicle highway systems (IVHS) and other technologies included in ITS, something known as a navigable database is used. This is a geographic database that facilitates access to and the retrieval, analysis and representation of a high volume of information in real time. It must also be a distributed database that facilitates remote access to data.

Creating geographic databases for GIS-T is one of the most costly tasks, financially and from the perspective of time. Firstly, topographic bases have to be created for the transport infrastructure. Secondly, thematic attributes are compiled, providing information on the transport infrastructure and on the traffic flows carried by the latter. An extremely large amount of data is needed because information is required on a relatively large scale and the attributes vary continuously over the course of time.

GIS-T have different sources of information: conventional ones, remote sensors, topography, GPS, aerial photos and data imported from other sources.

Using information technologies for the simultaneous processing of geographical information's three components (the locational component, i.e. the position of the data within a geographic space; the thematic component, which specifies the type of geographic attributes to be found in a certain place; and the temporal component, which indicates the thematic aspect of a location at a given time) has always been a highly complex matter, leading to a certain delay in its development. In fact, at present, efficient systems have still not been achieved for the joint management, analysis and representation of all three aspects of geographic information.

As with other fields of application, GIS-T facilitate inventory-related tasks and the management, analysis and representation of data of a geographic nature. Although GIS have always been applied to transport management and planning, the development of ITS has made a decisive contribution to their diffusion, as well as providing them with new functionalities.

One of the main problem areas that geographic information technologies allow us to solve, and one which is closely linked with transport analysis, is the geolocalization of entities or events, by identifying the position of geographic entities. In the last few years, geolocalization processes have been greatly transformed by the sudden emergence of information technologies. With the incorporation of GPS (Global Positioning Systems), videologging, remote sensors, signal
communication systems, and cellular telephones (GSM, VHF) into GIS, geolocalization techniques are undergoing a big revolution (Farrell, Barth, 1999).

Global positioning systems (GPS) are particularly useful in referencing linear events due to their great accuracy, their capacity to capture both positional and thematic data, their ability to transform geographic references into linear reference systems, their financial suitability and the possibility that they offer for integrating information gathered from other databases. Differential type GPS, i.e. those that use a reference station with a known position, provide extraordinarily accurate resolutions of objects and they are revolutionizing geopositioning systems in the field of transport. Three levels of precision can be distinguished in differential type GPS: local area networks with a precision of 1-10 metres, wide area networks with a precision of 0.5 metres (the most widely used by GIS-T), and interferometers with a subcentimetric degree of accuracy.

Thanks to GPS technology, geolocalization systems are steadily incorporating the temporal component of geographic information. This is being integrated into GIS’ geographic databases, thus facilitating the development of applications that until now had been impossible to imagine. Traffic control systems, fleet control and assisted navigation are just some examples of how this new technological application can be used.

2. GIS AND TRANSPORT-RELATED FIELDS OF APPLICATION (GIS-T)

The transport-related fields of application of GIS (GIS-T) are very varied and every day new fields of development and applications appear.

Three generic fields in which GIS have been applied to transport can be distinguished: transport planning, the management of infrastructure and fleet and logistical management. The first two areas are traditional fields for GIS technology and they have been continuously developed since the initial emergence of GIS. The third area, fleet and logistics management, is the most recent and it is associated with the sudden emergence on the scene of ITS.

2.1. Transport Planning.

The application of GIS to transport planning is an extensive field of development, facilitating long and mid-term decision-making.

a. Accessibility studies.— We should highlight the use of GIS in studies to calculate accessibility (Gutiérrez, Monzón, Piñero 1988b; Gutierrez Urbano, 1996; Gutiérrez, González, Gómez, 1996; Environmental Systems Research Institute 1991a; Ding, Fotheringham, 1992), aimed at improving network efficiency when planning transport infrastructure.

b. Multimodal Transport Analyses.— GIS prototypes have been developed to design balanced networks for the transport demand (Feng, Wei, Lee, 1999), thus highlighting their capacity to offer a realistic representation of multimodal traffic.
GIS ensure the integrity of geographic databases, incorporating information on different modes of transport. Thanks to their use in this field, it will be possible to develop complex financial models able to estimate the cost of the combined use of different types of transport. One example is the estimation of the additional cost of combined transport in Europe using three modes of transport: rail, road and cargo ships (Jourquin, Beuthe, 1996b).

The Wisconsin Department of Transport in the USA has developed what is known as the Commodity Information Management System (CIMS) to model the state’s transport. The CIMS makes it possible to simulate transport scenarios based on the route, type of transport and vehicle characteristics, together with an analysis of these scenarios and the generation of maps and reports (Yarborough, Hartz, Marcos, 1997).

c. Integral Transport Planning.— In 1993, there was a pioneering United States initiative in the field of GIS for transport management and planning in a multi-jurisdictional, multimodal environment. This was the GIS-T/ISTEA project (United States Intermodal Surface Transportation Efficiency Act), integrating 41 US states, the provincial transport departments of the district of Columbia in Canada and nine private companies. (Fletcher, Henderson, Espinoza, 1995b). The project proposed the development of a GIS-T architecture that could be adapted for the planning and management of transport infrastructure including pavement and bridge management, safety and traffic congestion control, public transport management, intermodal management, traffic management and the control of atmospheric pollution.

d. Assessing the Environmental Impact of New Infrastructure or Policies.— Another important area of development is the use of GIS in transport planning and in assessing the potential environmental repercussions of certain action (Arias, Feijoo, Otero). In this field, by combining GIS with virtual reality techniques, an evaluation can be made of the potential impact on the landscape that road infrastructure will have (Bjurström, Tornberg, 2000). With these technologies, geographic databases can be used to create virtual worlds. This means that a detailed analysis can be made of proposed infrastructure’s potential effects on the land, so that the impact on the landscape can be assessed.

e. Pollution Control.— Different United States transport departments, together with local operators and private companies, are working on the development of a GIS-based congestion management system. Based on statistical optimisation techniques, transport models and atmospheric pollution models, it proposes an integrated model of environmental protection.

f. Risk Planning and Management: Transporting Dangerous Goods.— Another area of development is the application of GIS to route planning for heavy goods vehicles and vehicles transporting dangerous materials. At the University of Texas-El Paso an application has been designed for the Texas Department of Transport to automate the generation of routes for heavy goods vehicles, choosing
the best route depending on the resistance of bridges that the vehicles must cross and the characteristics of all highways to be used (Melchor-Lucero, Osegueda, 2000).

g. *The Construction of New Roads.*—GIS are being used as a support in decisions regarding the construction of new roads. They make it possible to analyse the effects of the new infrastructure on area’s accessibility, optimising the paths they take and minimizing the environmental and visual impact that the new roads might have.

2.2. Infrastructure and Services Management

The tasks involved in the management of transport infrastructure require highly detailed information on the said infrastructure, i.e. on road networks, street layouts, railway networks, river transport systems, airports, airlines etc. In fact GIS applications for this particular field of activity need detailed representations of the networks’ geometry and their connections, together with knowledge of the numerous attributes associated with them. Management applications are more directed at the maintenance of geographic databases, map production and the generation of quality control reports than at data analysis. This type of application facilitates mid-term decisions on the planning of infrastructure.

a. *Road and Motorway Management.*—Transport bodies use GIS to look after and maintain the transport infrastructure under their control and to keep it in good condition (Souleyrette, 2000). GIS are being increasingly used to manage and plan urban transport networks. In San Diego (Abouna, 2000), for example, they make it easier to keep an inventory of the city’s transport networks and they facilitate the development of models to improve vehicle traffic.

b. *Railway Network Management.*—Railway transport is a sphere of application where GIS have a great deal of potential. There are many examples of ways in which they have been applied, both for the management of infrastructure and for planning and operational control studies carried out in real time. As a result of initiatives by the World Bank and a team of Indian railway officers, the Long-Range Decision Support System (LRDSS) was created. The aim of the LRDSS is to develop a GIS for the planning of India’s railway transport system (www.gisdevelopment.net/application/utility/transport/utilitytr002pf.htm).

c. *Airport Management.*—GIS are also being used to manage airport infrastructure, particularly for the management of certain areas of the airport and for communication networks. They are also used to prevent aircraft noise and its effect on areas close by airports. Likewise they are used to coordinate vehicle arrivals at the airport and to provide them with adequate parking facilities.

2.3. Fleet and Logistics Control: Intelligent Transport Systems

This includes operational control applications characterized by their ability to manage information on transport infrastructure in real time. Their objective is to
facilitate short-term decision-making. Included in this section is the application of GIS to ITS.

In a short space of time ITS have incorporated geographic information technologies (TIG) as basic methodological instruments. The incorporation of GIS and ITS represents one of the greatest opportunities for industry and for professionals working with GIS. ITS give priority to the use of real-time systems, involving the acquisition of data by means of remote on-line sensors, interactive communications, processing and distributed computing. GIS can be applied to all ITS applications.

Much of the information processed by ITS is spatially-referenced dynamic information (e.g. the volume of traffic, congestion, incidents etc), but information is also needed to indicate the location of facilities and infrastructure. More specifically, geographic databases are needed that assist in navigation, i.e. with basic data on the layout of the infrastructure and its characteristics. With this as a base, using different types of sensors it is then possible to manage and optimise vehicle flows and the movement of fleets, passengers or merchandise.

The visualization of real-time geographic data via the Internet hugely increases the potential of GIS and ITS, not only from the perspective of being able to communicate a certain subject to millions more users but also by making this communication process much easier. Internet and geomatics are playing an increasing role in information technologies. The development of Internet-based distributed computing techniques facilitates access to geographic databases, whilst also offering remote access to GIS functionalities.

In ITS-based fleet control and management, GIS make many different applications possible, including route planning, vehicle navigation systems, meteorological hazard control, vehicle fleet control, emergency management, tourist information systems, passenger assistance systems etc. (Chapter 3 analyses the specific development of ITS one by one).

a. Route Planning.— One of the most widely used applications in the field of GIS-T is route planning. GIS make it possible to plan journeys and find the best route by road, rail, air, bicycle and public or private transport (Claramunt, Jiang, Bargiela, 2000) (White, Thompson, 2000; Fletcher, Henderson, Espinoza, 1995a). They even make it possible to plan routes that combine different means of transport or that make optimum use of different criteria, such as the journey time, financial cost, and cultural or ecological value of the route etc. Optimum routes are found in cities, regions, countries, continents or on a global level. Even in countries with badly defined road networks and cities with complex urban structures, optimum route models are proposed on different regional and urban scales (Siangsuebchart, Winyoopradist, 2000).

Real-time route planning is one application that is beginning to be introduced by public and commercial transport companies (Smith, Durvasula, Demestsky, 1998) in order to minimize costs and maximize the service given to citizens.
b. *Car Navigation Systems.*— Using GIS in conjunction with GPS not only offers a spatial vision of journeys but it also includes the time variable (Quiroga, Bullock, 1998). GIS define queries and tables of attributes, and they draw up digital maps with data relating to the journey time along motorways. The joint use of GPS, with direct, real-time information on the speed and direction of vehicles, and GIS-administered databases creates an efficient system for monitoring the vehicle, as indicated by Zito, D’Este, Taylor (1995) of the Australian Transport Systems Centre.

In all cases, this type of system needs digital maps as a base on which moving vehicles can be plotted. With this in mind, the EU NextMAP project was created to define, design a prototype and assess the contents of digital maps required by vehicles with ITS applications, particularly Advanced Driver Assistance Systems (ADAS).

c. *Meteorological Hazard Control.*— Meteorological conditions play a very important role in transport planning, management and control. By using GIS, this type of information can be included in route planning. One example is the model introduced in the United States by the Union Pacific Railroad (Suxia, Kam, 2000b), which supplies real-time information on the meteorological conditions of areas where rail transport will pass. These systems incorporate warning mechanisms to prevent catastrophes and avoid unnecessary fuel costs.

d. *Traffic Control.*— To control the traffic GIS databases must include the temporal component of geographic data (Jobes, Papayannoulis).

An important area being developed by the Department of Urban Studies & Planning of the Massachusetts Institute of Technology is the use of multimedia techniques and GIS to improve the interfaces of transport applications. Worthy of mention is the work carried out by Michael J. Shiffer (1999) to develop prototypes for traffic control systems.

The National Transit Geographic Information System (GIS), created by the North-American Federal Transit Administration, includes an active inventory of transit operations on the country’s public transport routes. The information helps to rationalize decision-making in transport policies and planning. This work is being carried out in collaboration with Bridgewater State College’s Geographic Laboratory via the digitalisation of public bus routes (http://www.fta.dot.gov/research/fleet/its/gis.htm).

As Lyons, McFonalnd, Bunford (1998) indicate, one big field of research, with applied examples, is the incorporation of travel information onto the Internet, transforming it into intelligent travel data for users and planners. Kraak and Brown (2001) emphasize that travel information is dynamic and interactive, and having this information makes it possible to improve the traffic conditions in cities. Also, in the near future, it will help drivers to select the best route before beginning a journey.
The Hampton Roads Traffic Information system, for example, assigns different colours to different road sections depending on the fluidity of the traffic or its congestion (http://www.vdot.state.va.us/roads/tunnel.html). Likewise, traffic conditions can be combined with tourist information, as occurs at the Real Time Traffic Disneyland Area website (http://www.anaheim.net/dept).

Some systems are interactive, like the Athens Real-Time Traffic Congestion Map (http://transport.ntua.gr/map/). Other more advanced modalities integrate Internet into the driving process, like the Internet Car concept. The car integrates a mobile communications system and a computer that connects it to the Internet via a server (Fuchs, Jameel, Stuempfle, 1997).

e. **Passenger Assistance Systems.**— There are several examples. The Metropolitan Transport Agency (*Agence Métropolitaine de Transport* (AMT) and the Montreal Urban Community’s Transportation Corporation in Quebec, Canada (*Société de Transport de la Communauté Urbaine de Montreal* (STCUM) offer users interactive map representations.

The mission of the first (http://www.amt.qc.ca/) is to improve traveller efficiency by promoting the use of collective means of transport in the Montreal region. It offers useful information on timetables, routes, fares, the location of stations, the capacity of car parks where parking is encouraged, their location etc. All this information is backed up by a map representation of the area, with an interactive navigation system. You can even register a chosen route by public transport and receive information if there are possible changes to timetables (LESSARD, 2000).

The second allows you to find out information about all the possible forms of collective transport inside Montreal’s Urban Community (http://www.stcum.qc.ca/), with timetables, fares, routes and even maps of journeys that can be downloaded via PDF files. This website has an automatic route calculator where the user can specify the parameters of his/her journey and the calculator shows a detailed version of the itinerary, in table version, indicating the public transport routes involved and the arrival time at all the changeover points (Lessard, 2000).

f. **Vehicle Fleet Control.**— The system introduced by the Capital District Transit Authority (CDTA) for the integrated control of buses combines the use of GIS, GPS and automatic passenger counters (APC) so as to optimise public bus routes (Guggisberg, 1998).

g. **Emergency Management.**— Since their original appearance, GIS have been used to facilitate the duties of the emergency services: the police, ambulance service, fire brigade etc. However, the emergence of GPS geopositioning techniques and mobile telephones and their connection to GIS have led to an extraordinary development.

There are any number of examples of how GIS can be used to facilitate the calculation of optimum routes for the emergency services (Barret, 1996). Another important field of application is associated with emergency assistance in connection
with the evacuation of cities and regions as a result of environmental or technological catastrophes (Cova et al., 1997).

3.- THE DEVELOPMENT OF GIS USE IN THE FIELD OF TRANSPORT

Current GIS applications for transport purposes clearly reflect the interest of researchers and professionals from the transport sector in this new emerging technology. Some trends echo the development of GIS per se, but others are technologically motivated or form part of specific research areas in this field.

Interoperability and Improved Techniques for Obtaining Spatial Data

One field of development is directed at improving systems designed to capture and integrate data from different sources of geographic information (in situ capture, GPS, remote sensing etc.). Efforts are being made to establish standards for the capture of transport-related information (geoids, datums, linear reference systems, positional precision, classification systems, metainformation etc.).

In this respect, a special mention should be made of the initiatives of the United States National Research Council Mapping Science Committee (1995), which has been working on the creation of foundational spatial databases (National Spatial Data Infrastructure (NSDI)). Three foundational bases are proposed: geodesy, digital terrain models and orthorectified images. Thematic data will be superimposed on these bases, including transport information.

Techniques for integrating/fusing data from different sources (conflation) also require further efforts. In strategies for integrating data from different sources and systems, what is needed is the creation of standards and automatic data correction techniques, so that the quality of the data can be guaranteed and it can be integrated into the databases. Data calibration systems need improving (in situ/in situ, in situ/base maps, vector/base maps, images/base maps, images/images).

To this effect, work is being carried out on the development and creation of data standards. Worthy of mention are a number of standardization agencies. In the United States, there is the Federal Geographic Data Committee (FGDC), which supervises the development of the National Spatial Data Infrastructure (NSDI). The University for Geographic Information Science (UGIS) works in parallel with the FGDC for the establishment of standards (FGDC, 1997). In Europe we should highlight the Open GIS Consortium, which works with public and private agencies in the development of interoperability standards.

One of the most important GIS-T fields of study is research into new linear referencing methods for data. A study that should be highlighted is the “Adaptation of Geographic Information Systems for Transportation” (Vonderohe, Travis, and Tsai, 1993), based on a project funded by the National Cooperative Highway Research Program (NCHRP) called Project 20-27 “Systems and Applications Architecture for GIS-T”. This provides an adapted version of GIS for the management
and integration of transport systems. The NCHRP also funded another project entitled the “Generic Linear Referencing Data Model”, aimed at establishing a conceptual data model for linear referencing systems.

Transport data is held by different public and private bodies. Each source of data has its own structure and degree of precision, depending on the capturing and storage methods used. This leads to incompatible, redundant formats. An important area of GIS development focuses on putting a stop to possible mistaken data sources as well as standardizing the quality of exchanged data. Work is being done to create detailed digital databases of urban and road maps in order to integrate them into vehicle navigation systems, emergency systems and vehicle fleet management systems (Goodchild, Egenhofer, 1999). In this way the information can be integrated into ITS, providing quality information on the position of vehicles.

3.2. Improvements to Data Management Systems

As indicated before, transport bodies and departments are responsible for keeping inventories of transport infrastructure. As a result of the efforts made to create inventories, multiple types of information are compiled (on pavements, accidents, management, photographs, projects etc) that are usually managed by specific computer systems. In the next few years GIS-T will play a fundamental role in the integration of information and in the standardization of data models, representation systems and access to data. In this sense, as indicated by Fletcher (1995b), GIS-T can be used as excellent physical and logical integrators of types of transport data, and so they have become an indispensable component of organizations.

In this particular field of research, new database management techniques must be applied. Above all, these must incorporate alternative methods of representing the temporal component and of identifying temporal aspects that cannot be represented by current DBMS.

Improvements must also be made in the application of data minimization techniques and knowledge discovery (KDD) to big databases generated as part of GIS-T.

There is clearly a need for the conceptual evolution of GIS data models (Jourquin, Beuthe, 1996a) to adapt them so that they can present data in real time. At present GIS and traffic control systems have not really been properly integrated. Despite recent progress in the use of temporal information, GIS have still not been adapted to cope with the management of dynamic geographic phenomena due to a lack of real-time interoperability with computers.

The incorporation of GIS into ITS requires improved storage, management and real-time mass data analysis systems. For this reason, geographic information systems’ access to geographic data, spatial integration techniques and data processing systems are all in the process of being updated. Data representation techniques used in GIS are more orientated towards smaller amounts of data with static information.
In this sense, considerable attempts are being made to integrate information’s temporal facet into GIS so as to create spatial/temporal GIS. (SU Xia, KAM 2000a; PALACIOS MORERA 1995; MILLER, SHAW 2001). Likewise, mechanisms are being studied to improve the analytical functionalities of GIS for interrogating, analysing and visualizing sociotemporal data.

3.3. The Development of Distributed Computing Techniques

Digital technology is focusing new efforts at development on distributed computing. It is now possible for a database to be stored and kept in different locations. This makes work much easier for users, due to the fact that they have easy, reasonably-priced remote access to specialist material, and also decision-making in collaborative contexts is facilitated. Client-server architectures are being developed via Web editors and distributed databases.

The connectivity provided by Internet technology has transformed relations between hardware, software, data and users. Computing is seen as a mobile, distributed concept. GIS on-line applications are becoming increasingly common and, in the near future, GIS software packages will be transformed into collections of progressively interoperable modules. An open flow of data between modules will be possible thanks to the interoperability of geographic data (www.ogis.org). These modules will either coexist in one system or be distributed on a network and assembled only when necessary, with the minimum of intervention by users.

Access to computing is also a mobile option and it can be done from any kind of vehicle: cars, planes, trains or on foot. All the computing elements are distributed: the data, software and hardware: but users have open access to them.

This facilitates access to real-time data (optimum routes in relation to the traffic situation, information about accidents or traffic jams etc). There are numerous projects being carried out in this field (Ziliaskopoulos, Waller, 2000a).

Interrelated multimedia systems and GIS in distributed environments are making a considerable contribution to the different types of information available to transport planners, managers and users, with data on interfaces that are increasingly user-friendly, facilitating decision making and helping to achieve a better quality of life for citizens (Shiffer, 1999; 1992).

4. CONCLUSIONS

GIS are theoretical and methodological instruments that have been traditionally used in geography for a long time. Their extensive development and applications to the field of transport have given rise to a specific category, called GIS-T. In recent years GIS’ interrelation with intelligent transport systems has considerably increased their potential for two main reasons: firstly because it has facilitated their extensive use and secondly, given the need to work with data in
real time, because of the inevitable search for a way to incorporate the time variable into models.

As information technologies have gradually made it possible to handle increasing amounts of information, whilst also making this data easier to access as each day passes, there has been an increase in the use of territorial data. The technological development of the transport sector itself and the incorporation of fixed and mobile communication systems mean that both fixed and mobile infrastructure is more efficient, secure and more in consonance with levels of environmental sustainability (ITS).

By integrating GIS into ITS, improved territorial representation is possible in a highly legible way. Their combined use facilitates better land management and improvements in the planning of new infrastructure. It also improves real-time fleet control, in both the private and public transport sectors, whilst offering assistance to passengers in selecting optimum routes. Likewise, it facilitates intermodality and integral traffic control. Finally, it contributes enormously to the management of incidents and emergencies and to the prevention of weather-related incidents.

As highlighted during the course of this paper, current fields of GIS-T development include improvements in techniques for the acquisition and management of data, interoperability, and the challenge of finding a real-time solution to potential problems when posed.

**BIBLIOGRAPHY**


