An Integrated GPS/PDA/GIS Telegeoprocessing System for Traffic & Environment

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ABSTRACT

The development of sustainable urban transport networks is a present priority for world leaders, national governors and local authorities. The challenge is to increase mobility reducing the adverse impacts of transport. The potential of Intelligent Transportation Systems (ITS) to provide solutions for the 21st century sustainable urban transport system has already been demonstrated in several piecewise applications. An integrated framework that addresses the needs of municipal authorities, that integrates the data spread through different sources, that supports the intelligent traffic & environment operations, and that provides information to the citizens steering their involvement and commitment is of critical importance and can be the enabler towards the creation of more efficient, safety, and environmental-friendly transport networks that promote the citizens' quality of life.

This work describes an integrated GPS (Global Positioning System) / PDA (Personal Digital Assistant) / GIS (Geographical Information System) system which is part of the mentioned framework. The system includes prototypes for mobile urban traffic data acquisition, with a GPS -equipped vehicle, a PDA application and wireless communications, and for a geodatabase with a related Web application for urban traffic & environment. Their integrated operation is exemplified for a real urban transport system.

Keywords: Urban traffic, Intelligent Transportation Systems, Telegeoprocessing, GPS, PDA, wireless communications, GIS-T.

1. SUSTAINABLE URBAN TRAFFIC NETWORKS

The - traffic & environment – thematic is a relevant contemporary issue being "at the agenda" of world leaders, national governors, local authorities, research agencies, and academia. The challenge - the development of sustainable transport systems - is complex, multidisciplinary, and involves a large number of interrelated subsystems.

The sustainable development concept has been discussed since the seventies. One of the most well-known definitions is the one stated in the Brundtland report or the World Commission on Environment and Development report of 1987: "development which meets the present needs without compromising the ability of future generations to achieve their own needs and aspirations". The concept has been developed for different sectors including the transportation one. There are several definitions for sustainable transport system but the one proposed by the Council of Transport Ministers of the European Union and the Centre for Sustainable Transportation in Toronto is widely recognized [1]. The definition encompasses the social and economical dimensions, and reinforces the need to minimize the environmental negative impacts of transport networks "…limits emissions and waste within the planet's ability to absorb them, uses renewable resources at or below their rates of generation, and uses non-renewable resources at or below the rates of development of renewable substitutes while minimizing the impact on land and the generation of noise".

The growing mobility needs of modern-days allied to a significant utilization of private vehicles are causing notable congestion problems concentrated in and around cities. Besides the social and the economical costs of this urban traffic congestion, the environmental damages represent perhaps the most dramatic impact [2].

The traffic related environmental adversities are reflected on:

i) air pollution and climate change - the traffic is the dominant anthropogenic source of air pollution in urban contexts [3] being the emissions of CO, PM and NO_2 particularly preoccupant since their daily limit values are exceeded frequently; despite the recent advances in car technology, the "stop and go" nature of urban driving is a major cause of concentrated gas releases;

ii) energy consumption - the transport related energy market is almost 100% dependent on oil, and 75% belongs to road flows; the dependency on fossil fuels impels the GHG emissions to grow nearly corresponding to energy consumption and contributes to the exhaustion of oil sources [4];

iii) noise and vibration - it is estimated that more than 20% of Europeans are exposed to unacceptable levels of urban road traffic noise that is, above 65 dB(A), leading to hearing damage, disturbed sleep, annoyance, impaired school and work performance;

iv) land take and urban sprawl - the physical limitations of the existing and congested road infrastructure at urban centres are forcing the expansion of the city frontiers that are assaulting the quite surrounding villages and inciting additional problems to connect the city with public transports, hence more private cars utilization [5];

v) road accidents - poor road design, bad driving, alcoholised drivers, and excessive speeds allied to traffic congestion problems are well-known recurrent causes of road accidents.

The cooperation between all the stakeholders of the urban transport environment system like national, regional and local authorities, citizens and users, collective transport organizations, employers and employees associations, environmental agencies, urban transport and car industries is decisive to achieve the goals of sustainability [6]. This multifaceted problem requires an integrated framework designed to assist the governors with major responsibilities in urban transport management – the local authorities - and to guide the operations of this sustainable development.

2. THE IUTEO FRAMEWORK

The Intelligent Urban Traffic & Environment Operations (IUTEO) framework, proposed by the authors of this paper [7] and depicted in Figure 1, embraces the management of urban traffic operations, in the short and real time, in order to mitigate the environmental side-effects like air pollution, energy consumption, noise, and accidents. It also reinforces the dissemination of information to the citizens in order to get their involvement and commitment into the urban traffic & environment system. The backdrop of the framework are the ITS which encompass a broad range of wireless communications-based information, control and electronics technologies embedded in the system's infrastructure and in vehicles to relieve congestion, improve safety and enhance productivity, saving lives, time and money [8].

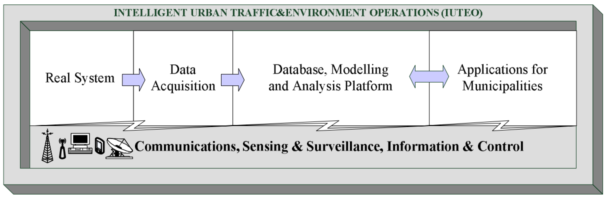


Figure 1. IUTEO framework

The framework's conceptual modelling is being accomplished through an innovative Domain Specific Modelling Language for Systems Engineering, the OMG SysML™ , The Systems Modeling Language [9], an object-oriented modelling language especially designed to model complex systems made of Systems of Systems. The main objective of Object-Oriented Modelling (OOM) is the development of models based on real-world concepts. By applying OOM to systems development we can achieve characteristics like modularity (ability to see real world entities as objects with their own identity, encapsulating sate and behaviour, and that can be arranged in separate modules serving a specific purpose but communicating with each other to produce the system's overall behaviour), reusability (ability to reuse a module/component in new models) and extendibility (ability to extend a model when system functions are expanded) and consequently, we can get a modular, adaptable and maintainable framework. The widely adopted *de facto* modelling language for OOM is the general purpose language UML (The Unified Modeling Language) [10], a software-centric language adopted by the OMG (Object Management Group), in 1997, as the standard language for object-oriented analysis and design. Since engineering systems are made of hardware, software, data, personnel, facilities and processes, the SysML language overcomes some UML limitations and is more appropriated to tackle this modelling task. Furthermore, it is a relatively "new" language (adopted by the OMG in 2006 with a first version available in 2007) and its application to this system will be innovative. Being a flexible language with extension capabilities (via stereotypes and profiles), it is also planned to add some extensions and customize SysML to cope with some particular features of the domain like, for example, geographical data.

The SysML diagrams are being developed with the Artisan Studio® tool. The Figure 2 depicts one of those diagrams (a package diagram) that shows the IUTEO framework's high-level architecture comprising a set of subsystem packages that represent its main modules. The dashed arrows correspond to dependency relations.

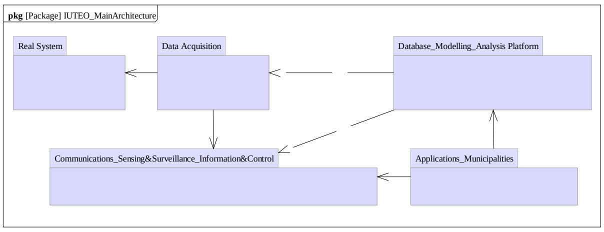


Figure 2. SysML package diagram for the IUTEO framework

The framework encloses five main subsystems (corresponding to the packages depicted in Figure 2), namely:

i) *Real System* - the actual urban transport network, its related traffic operations and environmental impacts;

ii) *Data Acquisition* - the means to attain data from the different sources of the real system in order to feed the database, modelling and analysis platform; includes three modules: Online (a critical module for ITS operations and responsible to gather the data needed in real-time like incidents, traffic volumes, road works, weather conditions; this data will be collected mainly via mobile sensors), Offline (collects data not required in real-time such as digital maps, Census statistics, network inventories) and Feedback (collects the information provided by the citizens);

iii) *Database, Modeling and Analysis Platform* - the core piece of the framework including a Geographical Information System for Transportation (GIS-T), a traffic microsimulation tool and a set of environmental impact models; other tools can be added as needed;

iv) *Applications for Municipalities* - a set of applications for local governors to achieve IUTEO, including three modules: Knowledge (gives information to the authorities about the network's infrastructure and assets, and traffic & environment key performance indicators), Action (provides tools to manage the network and to simulate different schemes, evaluating their environmental performance) and Public (displays information to the citizens through the web and provides support for their involvement in the municipality decisions);

v) *Communications, Sensing & Surveillance, Information & Control* - a traversal subsystem that represents the physical support of ITS and includes, for example, GPS, sensors, wireless communications, mobile devices.

The integrated telegeoprocessing system described in this work is one of the parts belonging to the IUTEO framework and traverses all of its subsystems, acquiring traffic & environment data from the real system, storing it in a GIS-T to appropriate analysis and decision-making, and disseminating the information to the public through a WebGIS application. The ITS support, that is the communications, the sensing & surveillance mechanisms, and the information & control systems are spread throughout the framework's applications.

3. GPS/GIS INTEGRATION

The urban transportation system is mainly characterized by static and dynamic spatial attributes like, for example, traffic signals for a given intersection, type of pavement for a given road section, traffic counts from a specific road segment or travel delays from a particular route, which cannot be adequately explored by conventional databases [11]. In a GIS environment, the geographic data can be properly stored, managed, analyzed, and displayed. The GIS adds to the traditional Database Management Systems (DBMS) a spatial referencing mechanism (geo referencing) which enables powerful analytical and geo-visualization capabilities [12]. Furthermore, its integrative capabilities are notable ranging from the integration of information from different systems (e.g. land-use system and transportation system) to the integration of different themes from the same subject (e.g. road base-network, road inventory, traffic operations), passing by the integration of data from different sources and styles (e.g. databases, census files, picture files, GPS data points) at different resolutions (e.g. intersection, segment, traffic analysis zones).

The application of GIS in transportation problems dates from the 1960s and is typically referred by the acronym GIS-T [13]. The network data model underlying GIS-T is the main support of most transportation analysis, and is particularly suited to deal with ITS applications like, for example, vehicle location and routing, collision warning and guidance, and advanced trip planning systems [14]. Nevertheless, and as [13] states, ITS bring new challenges to GIS-T regarding network representation, unambiguous communications, integration of new technologies, interoperability, analysis and dynamic modelling.

The spatial data acquisition and integration has been one of the topics with intense research in the last few years. The major advances in GPS and wireless communications technologies and the growing need of real-time information for intelligent traffic impel the continuous developments in this area. The mobile computing devices like PDAs and the Web-based GIS applications are examples of modern tools (Internet-enabled) which illustrate the contemporary global connectivity and the potential of distributed computing to facilitate data acquisition and information access [12].

The integration of GPS and GIS has been discussed and reported in several recent studies as, for example, [11], [15], [16], and [17]. The association of remote sensing, spatial databases (GIS), GPS and telecommunication systems, in order to support real-time decision-making, form a new discipline known as *telegeoprocessing* [16]. Its application in the ITS field is very promising and has already been demonstrated through several piecewise applications, mainly for location and routing, and for congestion, travel time and speed management studies.

The use of GPS to collect traffic data is being typically used in vehicle techniques which are not infrastructure dependent, have higher levels of coverage, resolution and accuracy, and are less expensive to install and maintain [15], as opposed to roadside techniques, like loop detectors, infrared sensors or closed-circuit television cameras. The satellites that orbit the Earth available to broadcast signals to GPS receivers are now thirty one [17]. The GPS/GIS integrated system procedure is generally the same for all the cases. A GPS-equipped vehicle (probe vehicle) driven in a traffic stream "gets" data from road and traffic conditions, as well as vehicle performance parameters, the data is telecommunicated (online or offline) to a Traffic Control Center where it is transformed with map-matching, data reduction and data processing procedures, and is reported.

The data that can be collected by a probe vehicle is broad and diverse. Besides time-tagged positioning data (latitude and longitude pairs), speed and direction of travel (provided by differential GPS), the vehicle can supply on-board engine data like, for example, fuel consumption, engine revolutions, and gear, and when equipped with appropriate mobile devices (and related applications) the probe can be used to carry out road inventories and to transmit network occurrences. These data is the base to derive several traffic performance measures like travel time, delay and congestion index [11]. Furthermore, the vehicle pollutant emissions can be estimated or can also be measured in order to compute traffic-related environmental impacts. This new research area of instantaneous traffic emissions modeling [18] can take significant gains from this mobile data acquisition approach.

The main advantages of GPS/GIS integration include the capacity to collect, every second and from anywhere in the urban network, positional and other traffic data which can be stored automatically and used in real-time operations, and the ability to display this spatial data in a GIS environment for ease analysis, and integration with other relevant data [11]. The main disadvantages, which tend to be overcome in the next few years with the recurrent advances in computing and telecommunications technologies, consist of enormous amount of data to process, data transaction costs (for real-time observations), and data bias [17].

Although the widespread use of these technologies, the vehicle probe technology and its integration with GIS is still an emerging research field, calling for comprehensive studies and real-world applications which can prove its adequacy and usefulness. In addition, there are relatively few studies showing the integrative utilization of the traffic & environment data from the GPS-equipped vehicle to the final user (the public), passing through the GIS. The utilization of mobile computing devices like PDAs to enhance the traffic & environment data acquisition systems has not also been reported in many studies. Thompson documents well one of these cases [19] but her system is not able to respond in real-time.

In this context, this work aims to contribute to the development of Telegeoprocessing providing prototypes for GPS/GIS integration with a PDA application, in order to enhance real-time data acquisition and diffusion. This integrated system is a "piece" of the IUTEO framework and is being developed and tested with some interested stakeholders (municipalities and general public) to be used in real-world environments. The system also aims to contribute to the development of ITS by improving Advanced Traffic Management Systems (ATMS) and Advanced Traveller Information Systems (ATIS), through real-time data acquisition methods, as well as the integration of that data in a GIS environment, enabling well-informed traffic & environment decision-making and the dissemination of relevant and attractive information to the public. As an ultimate goal, the work aspires to give some contributions to the global and complex challenge of sustainable urban traffic networks, providing essential information to analyze the environmental impacts of traffic and a set of fundamental tools to support scenarios evaluation and decision-making.

4. THE INTEGRATED TELEGEOPROCESSING GPS/PDA/GIS SYSTEM

The integrated telegeoprocessing system's prototypes, as well as the corresponding IUTEO framework subsystems, are depicted in Figure 3.

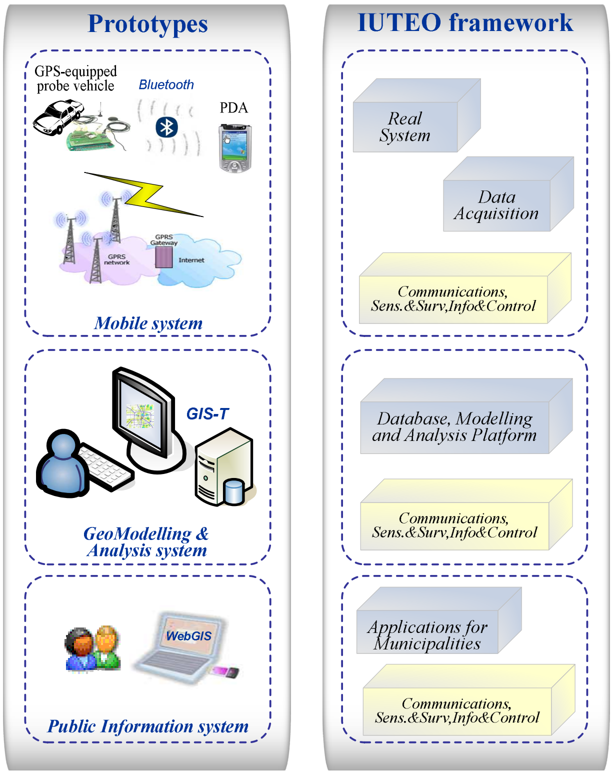


Figure 3. GPS/PDA/GIS Prototypes for IUTEO

The integrated system includes a "Mobile system" prototype for traffic data acquisition, a "GeoModelling & Analysis system" prototype to store and manipulate the collected data in a GIS-T environment, and a "Public Information system" prototype to disseminate information to the public through a WebGIS application. The first prototype is used to get data from the real system and to telecommunicate the data, in real-time, to the Traffic Management Center. These functions fit in the *Real System* and *Data Acquisition* subsystems from the IUTEO framework. The second prototype consists of a geodatabase, in a GIS-T environment, to store, analyze and display the data obtained from the mobile system. This GIS-T is part of the IUTEO *Database, Modelling and Analysis Platform*, along with a traffic microsimulation tool and a set of environmental impact models. This platform is the central part of the framework being the elected tool to perform scenarios analysis, a fundamental issue on policy decision-making.

The third one is a WebGIS application designed to display occurrences on the traffic network, in real-time. It belongs to the *Public* module of the *Applications for Municipalities* subsystem. This module is in charge of engaging the public into the traffic & environment urban life. This can be accomplished through the dissemination of intelligible and attractive information, appropriate treatment of suggestions and comments, and active participation in the decision processes. All the prototypes use and share elements from the *Communications, Sensing & Surveillance, Information & Control* subsystem, a traversal component which materializes the "intelligent part" of ITS, encompassing the technologies, the devices, the hardware components, and the software applications which support the integrated prototypes.

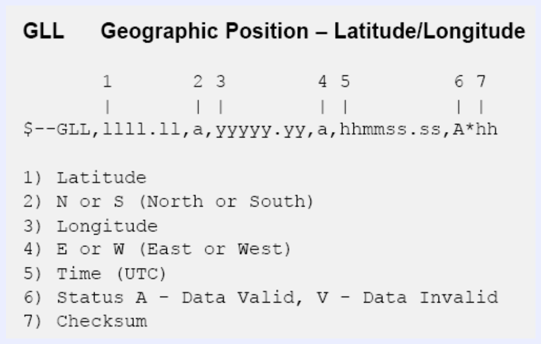
The prototypes are part of the IUTEO framework's modelling process, and they provide a contextual framework to focus the discussion, acting as "working models" to demonstrate concepts, try out design options, corroborate and explore systems requirements, and to communicate with the different stakeholders. According to [20], these prototypes can be classified as evolutionary since they are being iteratively refined with end-users until the final solution is achieved.

The Mobile System Prototype

The "Mobile system" prototype is dedicated to collect data from the urban road network and to telecommunicate it, in real-time, to the traffic centre. The prototype involves the following main components: i) a GPS-equipped vehicle, ii) a Global System for Mobile Communication (GSM)/General Packet Radio Service (GPRS) wireless system, iii) a PDA with an application for road inventory and occurrences registry, and iv) a PC application to receive the PDA messages. It requires, at least, two persons to operate the system (one for the probe vehicle and another for the traffic centre).

The GPS-equipped vehicle and the communications: The hardware of the probe vehicle used to collect data includes a HP$^{\circledR}$ iPAQ PDA and the XF55 *Tri-Band* GSM/GPRS & 12 *Channel* GPS *Receiver*, from Falcom$^{\circledR}$, connected to the vehicle's engine. This device incorporates a GPS receiver module and a GSM/GPRS module. The connectivity is made through a board-to-board connector, enabling the interaction with the PDA. The communication between the XF55 equipment (master) and the PDA (slave) is formalized by the Bluetooth wireless protocol. Bluetooth makes low cost and low power consumption in the communication between devices possible, within a range of approximately 100 meters.

The XF55 "System Start" process is characterized by the registry on the GSM network, the initialization of the GPRS operation mode, and the registry on the Internet through the GPRS Gateway, getting an IP connection (stack TCP/IP). Furthermore, it initializes the Alarm Handler and the Threads responsible for the information exchange between the equipment, the PDA, and the server, and the Thread in charge of the reception of the GPS coordinates, transmitting the data through the NMEA (National Marine Electronics Association) protocol. The type of message used was the GLL (Geographic Position - Latitude/Longitude) (Figure 4). It were also developed several NMEA non standard proprietary messages to accommodate the needs of the PDA application.



```
GLL    Geographic Position – Latitude/Longitude

         1        2 3          4 5            6 7
         |        | |          | |            | |
$--GLL,llll.ll,a,yyyyy.yy,a,hhmmss.ss,A*hh

1) Latitude
2) N or S (North or South)
3) Longitude
4) E or W (East or West)
5) Time (UTC)
6) Status A - Data Valid, V - Data Invalid
7) Checksum
```

Figure 4. GLL message from NMEA protocol

Presently, the equipment only collects time-tagged positioning data but, the prototype is being developed to enclose on-board engine data like, for example, speed, fuel consumption, engine temperature, gear, pollutant emissions. This information will be valuable to compute and evaluate traffic-related environmental impacts.

The PDA application: The application for the PDA, equipped with the Windows Mobile 6 operating system, was developed using the .NET Compact Framework and Microsoft® Visual Studio 2005, enabling the development of applications for mobile devices using existent Application Programming Interfaces. It was also used the Microsoft® SQL Server 2005 Mobile Edition to develop the database for this application (a table to store the GPS data from the GLL messages and a table related with the messages sent to the PC application).

The PDA application intends to be used by the municipal technician, in the probe vehicle, to collect road inventories and network occurrences. The road inventory data is no needed in real-time so, this data is loaded during the day through the application and downloaded to the PC, at the final of the working period, to be further processed in the GIS. The real-time data (network occurrences) like accidents, congestion, road works, pavement conditions, is of critical importance for ITS operations, and can be loaded through the application and transmitted in real-time to the traffic centre, via GSM/GPRS. The Figure 5 depicts a SysML use case diagram with the use cases for the main menu of the PDA application. In the right side of the same figure are shown the interfaces implemented in the device.

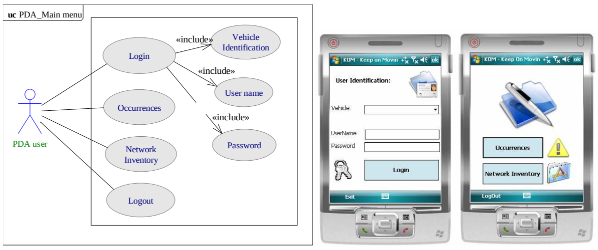


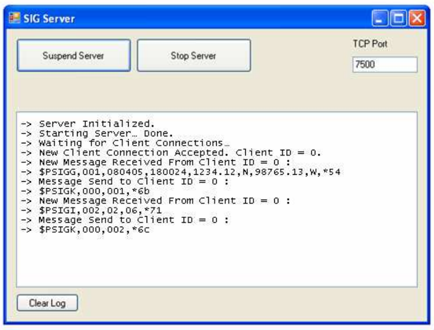
Figure 5. PC application (running mode)

The application is easy to use and depicts intuitive and attractive interfaces (Figure 6), taking into account Human Computer Interaction and interface design principles to achieve fundamental usability requirements.

Figure 6. PDA Application Interfaces (examples)

This application displays predefined lists, in fields with selection option, to facilitate the reporting task. Furthermore, it interacts with the user giving feedback information on missing data or submission status. It is also possible to take pictures of some occurrences to enrich the database. This application is being further developed to accommodate the insertion of assets and occurrences through a map of the corresponding area.

The PC application: The PC application manages the connection between the mobile system (XF55 and PDA) and the traffic centre, receiving and sending messages, and storing the received information in a SQL database (Microsoft SQL Server 2005). The application, developed with .NET and Visual Studio, is used to select a TCP/IP Port, and to start, stop, stand by, and restart the NMEA messages' reception. It also verifies the message's validity, sending a confirmation to the client, and translates the received messages to the appropriate fields of the database. The information stored in the SQL database is directly mapped into the geodatabase. Being an application with little interaction with the user, its design is very simple and minimalist (Figure 7).



TCP Port: 7500

```
-> Server Initialized.
-> Starting Server… Done.
-> Waiting for Client Connections…
-> New Client Connection Accepted. Client ID = 0.
-> New Message Received From Client ID = 0 :
-> $PSIGG,001,080405,180024,1234.12,N,98765.13,W,*54
-> Message Send to Client ID = 0 :
-> $PSIGK,000,001,*6b
-> New Message Received From Client ID = 0 :
-> $PSIGI,002,02,06,*71
-> Message Send to Client ID = 0 :
-> $PSIGK,000,002,*6c
```

Figure 7. PC application (running mode)

This mobile data acquisition system intends to be a relatively low-priced solution, with low-cost components and constantly cut-price wireless communications.

The GIS Geodatabase Schema Prototype

The central part of the IUTEO framework is a GIS-T. Its base structure is a relational geodatabase, including tables, fields, and relationships between tables. The geodatabase schema is being implemented in ArcGIS® 9.2, from ESRI. Its development was object-oriented (OO) and was formalized through the UML (the OO model can be exported to the ArcGIS relational format). The geographical data, in raster or vector format, is organized in a set of overlaid thematic layers which correspond to different characteristics of a given geographical area.

The prototype for the geodatabase schema, implemented in ArcCatalog (the tool to manage data and create metadata), is depicted in the left side of the Figure 8. The layers considered are the following: reference map, linear referencing, socioeconomic and land-use, road infrastructure and assets, traffic operations, and environmental impacts. There are additional tables to accommodate the real-time occurrences.

The software enables the creation of thematic maps, in ArcMap, where a digital map of the road network is used to display the relevant data for a given subject (right side of Figure 8).

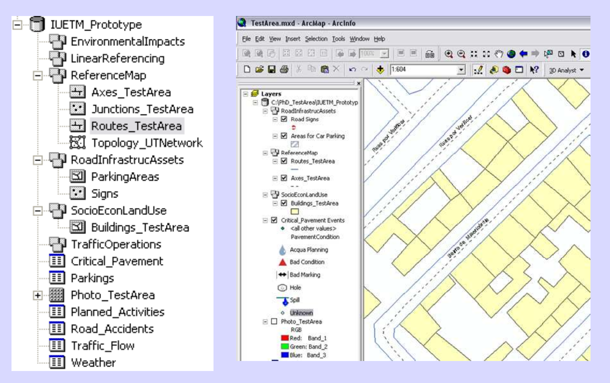


Figure 8. Geodatabase schema and a map

A GIS-T is the perfect tool to store, analyze, visualize, and integrate spatial and non-spatial data, allowing the identification of critical geographical patterns and relationships for road network analysis and decision-making.

The WebGIS Application Prototype

The WebGIS application, developed with Visual Studio and ArcGIS (ArcMap, ArcCatalog and ArcGIS Server), is used to display real-time information on traffic & environment via thematic maps on the web.

The application, still in an early stage of development, uses adequate symbols to depict the occurrences, reported by the PDA and stored at the GIS, on the corresponding location at the urban road network. The application enables the selection of the visible information, offers common navigational tools like pan, zoom in/out, return to previous map selection, permits the measurement of distances between points, and allows the visualization of additional information about a given point or event.

The integrated utilization of the described prototypes is being already tested in real urban scenarios. The Figure 9 shows one of these tests, illustrating the report of a delay (yellow symbol), by the PDA operator, in a given road section. The left side of the window exhibits the "Map Contents" tree where is possible to select the visible layers and saw the corresponding legend. The current visible layers include the occurrences reported by the PDA. In the future, this WebGIS application will enclose more relevant traffic information and traffic-related environmental impacts for a selected area, like air pollution, energy consumption, and noise levels.

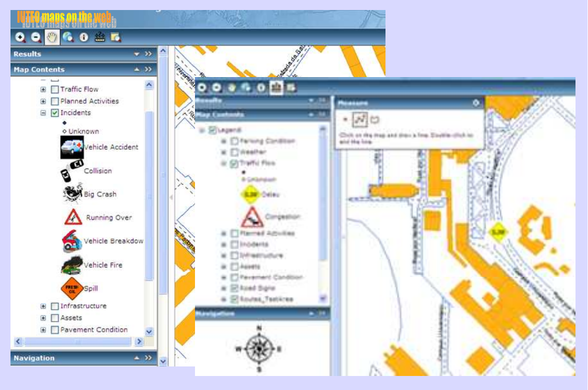


Figure 9. WebGIS application menus and maps

This application characterizes the total integration of the prototypes, displaying in real-time, and to everyone with an Internet connection, the information collected with the GPS/PDA system and stored at the GIS.

5. CONCLUSIONS

This paper described an integrated GPS/PDA/GIS telegeoprocessing system for Intelligent Urban Traffic & Environment Operations. This Telegeoprocessing system enables the real-time acquisition of traffic data and its diffusion through a WebGIS application. The real-time data acquisition, the storage of all relevant information in a GIS, the utilization of appropriate modelling and analysis tools, and the public information and involvement, are elements of vital importance to successful ITS operations.

The proposed system offers the opportunity to cost-effectively expand traffic & environment data collection coverage, being a promising tool to medium-size municipalities, usually characterized by severe budget constraints.

The prototypes are being refined and tested in real-world contexts. Some further research issues include the integration of traffic simulation models and environmental impact models, to add analysis capabilities to the system and to provide more relevant information to the citizens. It is also planned to expand the potentialities of the WebGIS application to accommodate the placing of public suggestions and to facilitate collaborative decision-making processes.

The GPS/GIS integration is one of the most prominent areas of research in the ITS field.

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