Real-Time Geographical Information Systems for ITS

C. Claramunt¹, S. Fournier¹, X. Li¹², and E. Peytchev³
¹Naval Academy Research Institute, BP 600, 29240 Brest Naval
E-mail: claramunt@ecole-navale.fr
²Joint Laboratory for Geographical Information Science,
The Chinese University of Honk Kong
E-mail: li.xiang.china@gmail.com
³School of Computing and Informatics
The Nottingham Trent University, Nottingham NG1 4BU, UK
E-mail: evtim.peytchev@ntu.ac.uk

Abstract: Combined research in the fields of Geographical Information Systems (GIS), transportation modelling and traffic systems has in fact finally reached the point where paths should overlap and continue in better unison between these different domains. This paper introduces methodological and experimental results of several integrated projects that include traffic monitoring systems, GIS and several specialised remote applications in the field of aerial, terrestrial and maritime transportation that supports real-time monitoring of traffic conditions, traffic simulation and several end-user functions to serve engineers, decision-makers and final end users.

Keywords: GIS, ITS, real-time systems, traffic systems

1. INTRODUCTION

Despite earlier development of GIS and transportation systems [6], recent advances in telecommunication systems, positioning systems, client-server and three-tier architectures and mobile devices offer new perspectives and challenges to GIS and transportation-related research [15][11]. There is still a need to design new data communication and data management protocols, graphic and exploration interfaces that support real-time exchange of traffic data and GIS. Such systems will be of great interest for many terrestrial, maritime and aerial applications related to the monitoring and analysis of traffic phenomena in which represented vehicles, ships and planes and the underlying network properties are changing in a fast and almost continuous mode.

However, current GIS software and interfaces do not yet provide the set of models and functions to make this technology compatible with transportation and traffic systems used for monitoring, analysis and simulation purposes. First, the integration of GIS, transportation and traffic systems is likely to be a challenging and worthwhile objective for user communities whose needs are not satisfied by a loosely connected set of existing systems. This poor level of integration is often the result of the different paradigm used within GIS and real-time modeling systems and the fact that many integrated solutions in between transportation and information systems often imply the re-design of existing software solutions. Secondly, despite continuous progress in the development of temporal GISs, these systems are still not adapted to the management of very dynamic geographical phenomena due to the lack of modeling and processing interoperability with real-time computing facilities. Moreover, the development of GIS applications, characterized by a high frequency of changes, implies a reconsideration of the storage, modeling, manipulation, analysis and visualization functions because handled data come from very dynamic phenomena, whereas current GIS models and architectures have not been preliminarily designed to handle the properties of such phenomena.

This paper introduces several experiments developed in different fields of transportation systems where the common ground is the integration of transportation and traffic information within GIS. Through the presentation of applications in urban transportation, maritime and aerial navigation, respectively, we will illustrate the potential of GIS for Intelligent Transportation Systems (ITS) and some of the avenues of research still opened for the research communities in GIS and ITS. The first application presented in Section 2 illustrates the potential of GIS and an integrated computing architecture for the analysis and visualization of urban traffic patterns. Section 3 introduces a multi-level maritime navigation application whose objective is to provide an integrated view of a maritime system, simulation facilities and mobile access to navigation services for small ships in coastal navigation. In section 4, we describe the principles and objectives of a debriefing prototype developed for flight training in aerial navigation. Finally, section 5 draws the conclusions and some perspectives.
2. URBAN TRANSPORTATION

We briefly introduce a supervisory traffic decision support system with GIS support developed in conjunction with the real-time traffic control implemented and developed at the Nottingham Trent University over the past years [12][7][2][10]. The system architecture is based on a Distributed Memory Environment (DIME) harness, which provides communication facilities for external modules and programs to distribute real-time traffic data [9].

The GIS system supports integration of traffic data within urban management and planning studies, and the development of visualisations and analyses of urban traffic conditions. The prototype developed incorporates a pre-processor module that calculates averages and maximums of traffic conditions such as queue lengths, node saturation, occupancy values at a stop line, on a half an hour basis. It acts as a client for DIME and as a server for the GIS application. The GIS can receive incoming traffic data in either continuous or discrete mode. Aggregated values are sent through the network to the GIS database. If the GIS application is not connected, the pre-processor temporarily stores calculated data until the next connection. The database design of GIS module is based on a traffic database realised using an object-oriented model [4].

The resulting database represents the characteristics of traffic data flows within given urban system. It integrates the temporal and spatial dimensions of a traffic system using an integrated database representation. Within the scope of this prototype, different visualisation and animation techniques have been implemented:

- Map animations that present the variation of traffic properties located in the network, using different spatial (lane, road segment or node) and temporal aggregation mechanisms. Figure 1 presents an example of spatial animation that simulates traffic behaviors on the levels of either road segment or node levels. The animation can be controlled through a GUI with an interaction box that is user-controlled.

- Animated graphs that describe the variation of traffic properties, using different spatial (i.e. lane, road segment or node) and temporal aggregation levels (different temporal granules). Figure 2 presents a user-controlled example of thematic animation that simulates the variation of traffic queue values along the time line.

- Charts that present the temporal evolution of a traffic parameter for a user-defined route or a set of road elements (i.e. lane, road segment or node). Figure 3 presents an example of variation of traffic queue values along the time line for a set of traffic network nodes.

- Animations that present the evolution of the distribution of a traffic parameter for a user-defined set of temporal components (i.e. lane, road segment or node). Figure 4 presents an animation that illustrates the distribution of traffic values for a set of traffic network nodes.

The aim of the visualisation tools developed is to complete spatial and dynamic views by temporal and statistical charts that provide complementary perspectives at different levels of abstraction. These techniques reflect the dynamic properties of the generated database. Animations allow users to browse through temporal traffic states of selected and aggregated traffic values within a considered period of time. Such functions enrich user perception of traffic data through time and act as an exploration tool that can
be used to identify traffic incidents and patterns in space and time. For example, these visualisations can be used to detect the impact of an accident on the network, to identify critical nodes, or for analysis of traffic patterns within a road network.

Figure 4: Temporal-based distribution of traffic values

A second related approach stores all historical traffic data in the GIS database, whose parameters reflect the history of the changes in the pattern of the data. Therefore, similar analyses can be derived on demand. In both cases, the route travel time estimation module can use this data in establishing route travel times and subsequently ensure delivery of accurate route travel time information to end users.

Ongoing collaboration between Nottingham Trent University and the British Telecom research arm has led to the extension of DIME framework into the field of wireless communications through the government funded “Traffimatics” project. The project concentrates on the use of 2.5G, 3G and 4G communication devices in public transport for delivering real-time traffic and travel information and Nottingham has been chosen as a test site for demonstration of the project outcome’s benefits. The telematics platform has the following functionality:

- Acquisition of the internal vehicle state including state of vehicle sub-components and the vehicle location. This involved development of standard interfaces for reporting states of vehicle sub-components and the integration of the GPS tracking information.

- Acquisition of the external traffic information provided by vehicle-mounted sensors, fixed road infrastructure and vehicles in the immediate proximity. This involved development of protocols that enable integration of a broad spectrum of sensors such as optical, radar, infra-red, ultra-sound and others and the efficient communication with external information sources using again a spectrum of available technologies such as WiFi, 3G and BlueTooth.

- Information reduction to distil the general traffic situation from detailed information [13][14].

3. MARITIME NAVIGATION

Automatic Identification Systems (AIS) currently used to detect and warn about possible maritime navigation collisions are a suitable solution for well equipped ships, but are unfortunately quite expensive and difficult to maintain for small ships and pleasure boats. We developed at the French Naval Academy Research Institute a Share-Loc project whose purpose is to design and implement an alternative maritime navigation system for small ships and boats [1][3].

The Share-Loc system is made of a navigation database server and mobile navigation clients. It is based on a client-server architecture that maintains a global view of a given navigation area on the server side, and a WAP-based solution that provides location-based data on the clients side. The server is a web-based program running on an Internet connected computer. Each client is a WAP-enabled mobile phone device that accesses the WEB server data through a WAP gateway program running on the server computer. Mobile clients are connected to Internet service providers according to their choice of telephone handset and mobile telephone network. Subsequently each authorised client is able to request the appropriate UML address on the server and to start the navigation-based application.

Figure 5: VTS application

On top of these navigation-based systems that have been developed over the past years, there is still a need for additional reasoning and prediction mechanisms that improve the monitoring and planning of navigation decisions. We shortly introduce the principles of the TRANS prototype, a multi-agent spatial decision support system that supports micro-simulation capabilities where ships are modeled as autonomous agents acting in their environment [5]. We developed several new modeling concepts that enhance the semantics of this meta-model. They allow an agent to be part of a group and to act according to the roles defined at the group level. Role priorities and constraints give additional flexibility to the meta-model. Simulation objectives of the TRANS prototype are to model and anticipate ship behaviors and trajectories in order to avoid collisions and running aground. The aim is to develop a realistic simulation environment that can be
used either for monitoring purposes or as educational software for training purposes. Further work concerns progressive interoperability of the TRANS prototype with simulation systems that integrate the modeling of continuous phenomena such as ship trajectories, tides, streams and winds.

Figure 6: TRANS scenario example

4. AERIAL TRANSPORTATION

Within the civil aviation industry, although a growing number of software packages are available to support professional aviation users, there is still a need for further integration of geographical data, such as flexible tools to support amateur pilots during the course of the flight and indeed to the post-flight debriefing. These systems are expected to provide cost and life savings to the aviation industry. Real-time data integrated into a computing GIS environment is able to facilitate both in-flight decision support and post-flight analysis of navigation conditions. Several levels of users may derive some benefits from the use of such a system, i.e., student pilots, flight instructors and qualified private pilots.

Whilst it is considered that the pre-flight instruction is generally well delivered and received, the benefit derived from in-flight and post-flight training may be somewhat less than maximized for both the student pilot and the instructor. The prototype described here presents an example of approach to flight training based on an integration of flight condition parameters with geographical data [8]. A retro-analysis of flight conditions is supported through a computing environment that delivers complementary analysis and visualization tools to the pilots. Such an architecture provides a real-time GIS whose components integrate flight data and geographical data.

The objective of the computing GIS solution, that include interfaces and appropriate sensors, is to provide means as realistic as possible of collecting appropriate data to describe the flight that must be provided, i.e., aeronautical chart for horizontal position, altimeter for height/altitude, attitude indicator for attitude control/axes of control, rate of climbing indicator for climb/descent rate. The collection of flight data for further use within the GIS environment is based on the following solutions and devices:

- A GPS receiver provides aircraft positional data in terms of latitude and longitude. In order to deliver sufficient accuracy in terms of elevation, a barometric pressure transducer was identified at the time of the development and GPS sources available as the most appropriate source for altitude data.

- Airspeed data is particularly useful in identifying problems in the approach and landing phases of flight where accurate control of airspeed is extremely important. Airspeed is approximated from successive positional plots over time.

- The detection and measurement of relative motion to the centre of gravity of the aircraft is based on a two-axis fluid-filled inclinometer.

The following figures illustrate some examples of the GIS prototype development. Figure 7 presents an animation of a typical circuit exercise. The 'aircraft' is in a descending right turn onto final approach. The Altimeter indicator is showing height of 800 ft (and decreasing). The Attitude indicator shows a 15 degrees roll to the right, and a pitch down attitude of 10 degrees. The Rate of climb indicator shows a 500 ft/minute rate of descent. The GPS menu shows the following figures: Latitude/Longitude, track over ground of 200 degrees, and ground speed 65 knots.

A second example shows the Flight Data Recorder (Figure 8). The panel on RHS shows real time data from the sensors. Aircraft position is plotted on the chart as illustrated by the red aircraft symbol. The QFE value is the actual pressure measured by the pressure sensor. These values are typical of a Cessna 152 light aircraft as popularly used for training.
The following example shows the vertical flight profile for the sample circuit above (Figure 9, the horizontal axis represents the time line). We can deduce the following facts: climb out is uneventful, the transition from climb to level flight at 1000 ft exhibits the fault described in the text where the target altitude has been 'flown through'. The subsequent recovery has been executed with rather too much enthusiasm and the 'student' has overcorrected explaining the subsequent dip. The height keeping over the downwind leg is satisfactory – although some ‘ripple’ is present on the top, this is within +/- 25 ft or so of the 1000 ft target. The 'glitch' on descent is explained below.

A last example shows the vertical profile on final approach – One can remark the plateau effect around 600 feet (Figure 10). The pilot has initially commenced descent too early to arrive at 0 feet over the runway threshold, realized the fact as he turns onto final approach and applied power to arrest the rate of descent, until he judges correctly when to recommence descent at the same rate as before. This attempts to illustrate a well executed standard adjustment of profile.

The developed prototype accelerates the learning process in essentially two ways: firstly by providing realistic animations, and secondly by the support of graphical tools which enable performance to be qualitatively reviewed and reflected upon. Flight exercise results are successively stored for the visualisation and analysis on demand for the benefits of the student pilot and instructor. The permanent record of the flight exercise assists the student in reasoning about his current level of performance and directs the agenda for the following lessons. ‘Good clear knowledge minimises flight training hours’, our prototype contributes to this knowledge by providing a recording of flight performance during post-briefing activities.

5. CONCLUSION

The development of information and telecommunication technologies brings new and often unexpected possibilities for integrating, analysing and delivering traffic data within GIS. This offers new challenges and opportunities for the ITS community at several levels. First combining conventional ITS facilities with the ones of GIS open new functionality avenues in terms of management and analysis in either real-time or long-term traffic data and information flows. Secondly, integrating ITS information architectures with GIS should improve the economical and technological benefits of transportation information by allowing the diffusion of traffic information to a larger community of decision-makers, engineers and final end-users.

Research challenges open to the ITS and GIS communities are numerous, and these at different levels. At the telecommunication level there is still a need for the development of cross-domain protocols and exchange standards for the transmission and interoperability of traffic data and of geographical information across these different fields of application in air, sea and ground. Conventional statistical,
geographical data analysis and visualisation methods should also be adapted to the specific nature of traffic information often associated with large volumes of data. At the implementation level, there is a need for the development of GIS-based distributed computing environment, computational and processing capabilities as traffic data and applications are usually physically allocated in different geographical locations and expensive in terms of the data volumes generated.

The diversity of projects presented in this paper illustrates the range of opportunities of the integration of GIS and ITS for terrestrial, navigation and aerial traffic information. We believe that all these application domains should benefit for this information integration, and those methodological findings should be shared and cross-fertilised amongst the research communities active in these fields.

REFERENCES


